Techniques of Water Conservation & Rainwater Harvesting for Drought Management

(SAARC Training Program)

Editors
Prasanta K Mishra, M Osman, Satendra
and
B Venkateswarlu

Central Research Institute for Dryland Agriculture
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Soil and Water Conservation Measures for Checking Land Degradation in India

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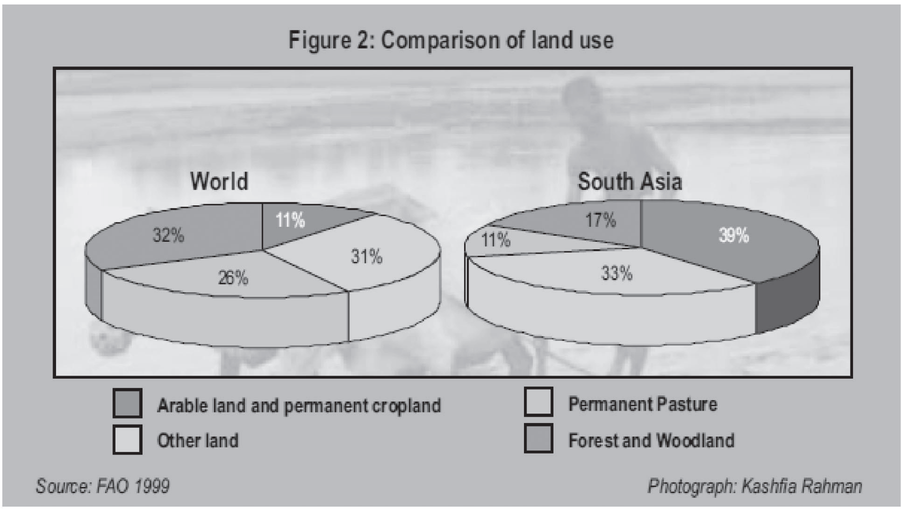
South Asia is home to one of the oldest civilizations of the world. The sub-region includes the countries with Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka. It has a 1.5 billion strong population growing at the rate of 1.8% per annum but has only 4.8 per cent of the world's total land area. South Asia's topography includes an amazing variety of mountains, plateaus, dry regions, intervening structural basins and beaches. It varies from world's highest point, Mount Everest to the world's lowest, the sea beach. The entire coastline runs to about 10, 000 km from Pakistan to Bangladesh, with wetlands occupying an area of 1,34,161 sq km. The region is characterized by a tropical monsoon climate. Two monsoon systems operate in the region: the southwest or summer monsoon (June-September) and the northeast or winter monsoon (December-April). This region also features large year-to-year variations in the rainfall frequently causing severe floods/droughts over large areas. Some of the world's largest river systems are in the South Asia. The River Indus originates in China and flows to Pakistan. The Ganga-Brahmaputtra river systems originate partly in Bhutan, China and Nepal and flow to Bangladesh and India. The Indus is one of the world's greatest river systems, measuring 3,180 km, from its source to the sea. The Ganga stretches for about 2,525 km and the Brahmaputtra – the third great Himalayan River, stretches for about 2,900 km flowing through Tibet, India and Bangladesh. Soil and water are the principlal natural resources of South Asian region and ultimate source of people's livelihood. However, sustainability of these resources is a major concern due to land degradation in general and soil erosion in particular. Irrespective of slopes, the soils are used intensively, and severe erosion is common on hill slopes cultivated for upland crops. The soil erosion and landslides are considered as the most critical environmental hazards in the region.

Land and Land Use

South Asian economies are mainly based on agriculture and, therefore, land constitutes an important resource. The region displays an extraordinary diversity of landforms due to climatic regimes, latitudes, altitudes and topography. Land, in South Asia, is under immense pressure as agriculture, urban areas and industrial areas all compete for the same resource. The demand for land has increased, along with the intensity of land use, causing widespread environmental damage and the degradation of land quality. Land degradation is a major problem in all South Asian countries especially due to water erosion resulting from steep topography coupled with high intensity rainfall. Modern methods of agriculture have further contributed to land degradation, with practices such as overuse of fertilizers and pesticides, excessive irrigation of saline lands and shifting cultivation.

Due to high density of population compared to available land resources, large proportion of total land resource is under agricultural use. Over 22% of the world's agricultural population lives on just under 5% of its land area; whilst about 50% of the total land area is under agricultural use, a far higher proportion than for the world as a whole. India occupies 46% of the land area of the region but supports 71% of its population. High agricultural population densities result in lower availability of per capita land. The availability of per capita crop land is 0.31 ha, 0.13 ha of pasture land or a total of 0.44 ha of agricultural land. With the possible exception of Bhutan, for which data are uncertain, Bangladesh has the highest agricultural population density, with 0.12 ha of per capita agricultural land. A comparative picture of land use of the World vis-a-vis the South Asia is presented in **Fig. 1.**



Source: UNEP, 2009

Fig.1. Major land utilization patterns in the World and South Asia

Land Degradation

Land degradation and soil erosion in the region are largely attributed to faulty land use practices, rapid rates of deforestation, poor irrigation and drainage practices, inadequate soil conservation measures, steep slopes and excessive grazing. Estimates indicate that in South Asia, 42 per cent of the land is affected by one or the other forms of land degradation. Half the region's dry lands face the threat of desertification, with as much as 63 million hectares of rainfed cropland and 16 million hectares of irrigated land having been lost due to it, especially in India and Pakistan; with higher land degradation in India. Other countries have also been badly affected. It is estimated that nearly one-third of the land in Sri Lanka has been subjected to soil erosion. One-fourth of Pakistan's total land area is facing serious threats of water and wind erosion. In parts of Bangladesh and northern India, soils have become acidified and salinized. The steep terrain of Nepal is susceptible to soil erosion and landslides. As per Global Assessment of Soil Degradation (GLASOD) estimates, six per cent of Afghanistan's land is very severely affected and ten per cent is severely affected due to anthropogenic activities. An area of about 75 per cent is affected by loss of top soil due to both water and wind, the former being more serious. Extensive erosion of riverbanks, leading to siltation and the loss of valuable farmland, is also increasing due to the loss of tree roots that hold the soil in place.

According to the GLASOD assessment, a total of 83 M ha is affected by water erosion in the region, of which 25 % area is under crops and pastures. It comprises of 33 M ha of land with light erosion, 36 M ha with moderate erosion and 13 M ha with strong erosion. The dry zone is most affected with 39% of the area under crops and pastures, compared to 18% in the humid zone. The countries most seriously affected are India and Iran in absolute area and Iran, Sri Lanka and Nepal relative to crops and pastures. Examples where erosion has reached a severe degree, leading to abandonment of land, include parts of the hill areas of Sri Lanka (Stocking, 1992; Sri Lanka, Natural Resources, Energy and Science Authority, 1991, p.120), and the Pothwar Plateau of the Punjab region of Pakistan (Nizami and Shafiq, 1990). For current erosion under inappropriate land use, there are many estimates in excess of 100 t/ha per year, including parts of India, Nepal and Sri Lanka (Das et al., 1991; Stocking, 1992). Most affected are the populated mountain regions of the Himalaya-Hindu Kush, the mountainous rim of Iran, and the areas under predominantly rainfed agriculture of the Deccan of India (with the Western Ghats most seriously affected) and Sri Lanka. Also affected are strips where the Gangetic river system has cut into terraces, whilst ravines are widespread along the rivers Yamuna and Chambal. **Table 1** shows major land degradation problems in South Asian countries. For India, the earlier estimates are in the range of 69-127 M ha, which is 2-4 times the GLASOD estimate. The Figure of 4 M ha under gullies or ravines has frequently been quoted, and is one third of the GLASOD value for strong degradation. The estimates of Sehgal and Abrol (1992) are based on the criteria and guidelines of the GLASOD methodology. The value is over twice the original GLASOD estimate.

Table 1 : Major land degradation problems in South Asia

Country	Land degradation problems
Bangladesh	Soil erosion, salinity, acidity of soils, river bank erosion, waterlogging, decreasing soil fertility.
Bhutan	Soil erosion, river bank erosion.
India	Soil erosion particularly sheet and gully erosion, waterlogging, soil salinity, alkalinity, decreasing soil fertility, spread of weeds, chemical degradation due to pesticides and fertilizers not assessed, land subsidence, mine spoils debris dumps and loss of land due to mining.
Maldives	Salinity due to salt water intrusion, coastal erosion.
Nepal	Soil erosion, deterioration of soil quality, waterlogging along canal systems, quarrying has led to denudation of hill slopes, excessive erosion and debris accumulation in rivers.
Pakistan	Soil salinity, waterlogging, soil erosion.
Sri Lanka	Soil erosion, waterlogging, pesticide accumulation in the soil, groundwater and surface water bodies, land degradation due to extraction of raw materials for the ceramic and cement industry, industrial pollutants discharged onto agricultural land, gemming, sand mining, brick and tile clay extraction.

Land Degradation and Soil Erosion in India

The land degradation results from natural hazards, direct causes and underlying causes. Natural degradation hazards are the environmental conditions which lead to high susceptibility to erosion such as steep slopes, high intensity rains, high speed winds etc. The direct causes include deforestation, overcutting of vegetation, shifting cultivation, overgrazing, non-adoption of soil conservation measures, extension of cultivation into fragile or marginal lands, improper crop rotation and faulty management practices which lead to unsuitable land use management practices. Underlying causes are the basic reasons resulting into land degradation due to direct causes such as land shortage, land tenure and open access to sources, economic pressure, poverty and population increase.

The land degradation has both on-site and off-site effects. On-site effects are the lowering of productive capacity of the land mainly due to loss of nutrients, causing either reduced outputs or need for increased inputs. Off-site effects of water erosion occur through changes in the water regime include decline in water quality, sedimentation of river bodies and reservoirs, loss of biodiversity and natural disasters like floods and droughts.

Harmonization of Databases of Land Degradation

Harmonized data base on wastelands/land degradation indicated that 120.72 M ha in the country is affected by various forms of land degradation **(Fig.2).** Out of 120.72 M ha degraded area, water erosion alone accounts for 68.4% (82.57 M ha) followed by chemical degradation (24.68 Mha), wind erosion (12.40 Mha) and physical degradation (1.07 Mha) (Maji, 2007). The area under physical degradation only accounts for waterlogging due to permanent surface inundation (0.88 M ha) and does not include sub-surface waterlogging. Similarly, barren rocky/stony wastes (6.46 Mha) which are the sources for runoff water and building materials and snow covered/ice caps which are the best sources of water were not considered as wastelands/degraded lands. For acid soils on arable lands (10.81 Mha), areas under paddy growing and plantation crops were also included.

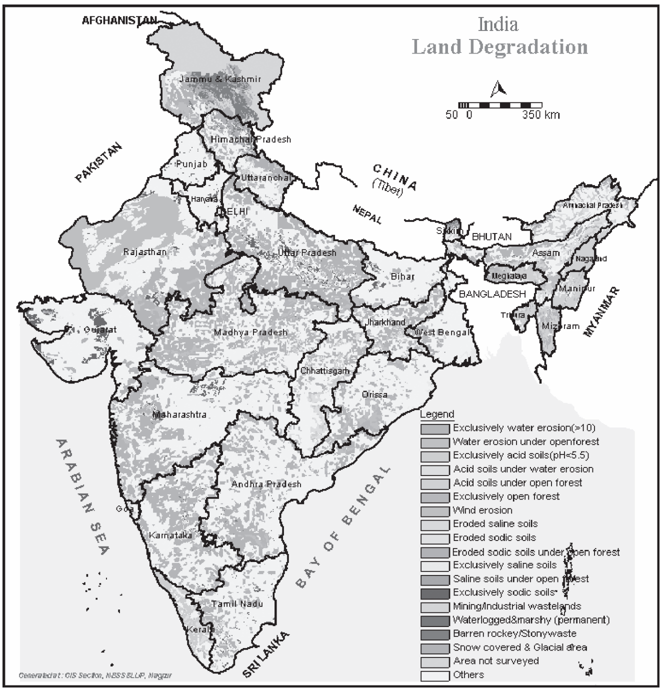


Fig. 2. Wastelands/land degradation map of India

Estimation of Soil Erosion and Potential Erosion Rates

It is estimated that about 5334 million tonnes of soil is lost annually which works out to 16.35 tonnes/ha (Dhruva Narayana and Ram Babu, 1983)**,** of which 29% is lost permanently into the sea, 10% gets deposited in the reservoirs decreasing their capacity by 1-2% every year and the remaining 61% is displaced from one place to another or re-distributed. Among different land resource regions, highest erosion rate occurs in the Black soil region (23.7–112.5 t/ha) followed by Shiwalik region (80 t/ha), North-Eastern region with Shifting Cultivation (27-40 t/ha) and the least in North Himalayan Forest region (2.1 t/ha). The CSWCRTI, Dehradun in collaboration with NBSS&LUP, Nagpur estimated potential soil erosion rates for different States of the country using 10 x 10 km grid size data for the parameters of Universal Soil Loss Equation. Permissible soil loss in India varies from 2.5 to 12.5 t $ha^{-1}yr^{-1}$ depending upon soil quality and depth (Mandal et al., 2009). Since about 70% of land area has soil loss tolerance limit of 10 t $ha^{-1}yr^{-1}$, it has been used for computation of degraded lands in the country covering 120.72 m ha. The analysis has revealed that about 39% area in the country is having erosion rates of more than permissible rate of 10 t/ha/yr, thereby resulting in reduced agricultural productivity. About 11% area in the country falls in very severe category with erosion rates of more than 40 t/ha/yr. Some of the States in the North-West and North-East Himalayas are worst affected with more than 1/3rd of their geographical area falling in very severe (> 40 t/ha/yr) category.

Loss of Crop Productivity

Studies in the lower Himalayan region revealed that removal of 1 cm top soil reduced 76 kg/ha of maize grain yield and 236 kg/ha of maize straw yield (Khybri et al., 1988). Maize grain yield, on an average, decreased from 37 q/ha to 13 q/ha with 30 cm removal of top soil (65% reduction over control). Similarly, in the Shiwalik region of Punjab, grain yield reduction of 103 kg/ha has been recorded in maize crop with every cm removal of top soil (Sur et al., 1998). Vittal et al. (1990) reported that in Alfisols, yield losses were 138, 84 and 51 kg/ha/cm of top soil removal for sorghum, pearlmillet and casterbean, respectively. Yadav et al. (1993) observed that loss in crop productivity on soils having different degrees of erosion by water (slight, moderate and strong) is within 10, 10-35 and 60-75% from the model yields, respectively. Further, sorghum suffered the most followed by soybean and pigeonpea with cotton being least affected.

An effort to systematically assess the impact of water erosion on productivity was made recently by CSWCRTI, Dehradun (Sharda *et al.,* 2010). Their analysis reveals that at national level, water erosion resulted in an annual production loss of 13.4 Mt in cereal, oilseed and pulse crops equivalent to approximately $ 162 billion considering MSP of 2008-2009. Crop-wise losses are depicted in **Fig. 3**. Degree of severity of water erosion is very much linked to the loss of agricultural productivity. The trend analysis on the basis of very limited data available on loss of productivity/crop yields vis-à-vis the erosion class indicated that the productivity may decline by 5-50% under major soil groups of the country (Sehgal and Abrol, 1994). The effect on loss of productivity is more pronounced in red soils followed by black soils and alluvium derived soils.

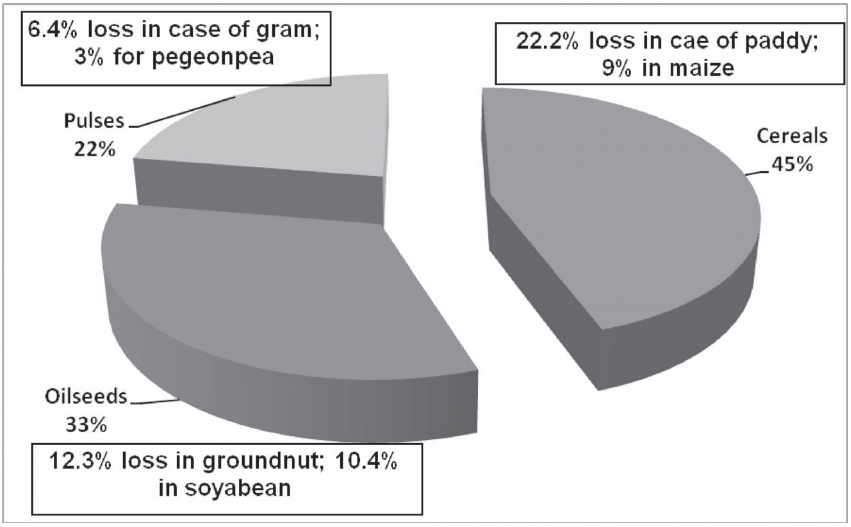


Fig.3. Losses for cereal, oilseed and pulse crops due to water erosion

Strategies for Combating Land Degradation

Broadly, two-pronged strategy is needed to prevent land degradation and bring erosion by water and wind within permissible limits for sustained productivity. Firstly, there is a need to properly assess the degree, type, extent and severity of soil erosion and its effect on production and nutrient losses. Secondly, to check and reverse the process of land degradation, appropriate technologies and conservation measures should be evolved through strong research support.

The research efforts in the past 4-5 decades have identified a number of resource conservation techniques which reduce the risk of soil degradation, preserve the productive potential, decrease the level of inputs required and sustain agricultural productivity in the long run. These measures include land shaping or mechanical measures, agronomic manipulations, vegetative barriers, alternate land use systems and run-off harvesting and recycling techniques. The agronomical measures are generally recommended on mildly sloping lands with the objective of maximizing *in-situ* rainwater conservation to ensure protection against erosion and achieve higher productivity. They include contour farming, intercropping, strip cropping, mixed cropping, cover management, mulching, crop geometry, tillage practices and diversified cropping systems. Mechanical measures are adopted to support the agronomical measures on steeper slopes or where the run-off is high by reducing the length and/or degree of slope to dissipate the energy of flowing water. They include land levelling, bunding, terracing, conservation bench terracing and contour trenching. These measures increase the time of concentration and thereby provide enhanced opportunity for infiltration of rainwater. The performance of different conservation measures were evaluated at 2-8% slopes in Doon Valley region of India

(Table 2). It is evident from the table that contour bunding was found economical and efficient in controlling 50-60% runoff and soil loss. Compared to contour farming, graded bund reduced runoff by 52-56 and soil loss by 65-72% while bench terracing reduced runoff by 85-92% and soil loss by 90-92%.

Table 2 : Runoff (mm), soil loss (t/ha) and crop yields (kg/ha) on different slopes and conservation measures in Doon Valley

Land shaping measures	**2 % slope**		**4 % slope**		**8 % slope**	
	Runoff	**Soil loss**	**Runoff**	**Soil loss**	**Runoff**	**Soil loss**
Contour cultivation	63.9	16.18	144.3	25.75	327.2	54.67
Graded bunding	27.8	4.28	67.9	7.24	156.1	19.40
Contour bunding	15.8	2.87	39.8	4.56	89.6	10.02
Bench terracing	9.3	1.53	16.2	2.15	27.2	3.01
	Maize	Wheat	Maize	Wheat	Maize	Wheat
Contour cultivation	2185	2165	2218	2070	1758	1750
Graded bunding	2007	2060	1936	2010	1576	1875
Contour bunding	1850	2350	1781	2335	1361	2085
Bench terracing	1528	2680	1594	2590	1432	2315

Effect of Tillage and Crop Residue

Tillage is a conservation practice which makes the soil surface more permeable to increase infiltration of rain water into the soil and conserve runoff, soil and nutrients resulting in higher crop yields. Soil erosion can be controlled to a great extent by adopting conservation tillage, which refers to any tillage practice that reduces loss of soil and water relative to conventional tillage. Singh et al. (2006) reported that minimum tillage along with crop residue as mulch conserved rain water by 40% and 11% and soil by 69% and 28% over cultivated fallow and conventional tillage, respectively in maize at 4% slope. The highest net return of Rs. 8350 per hectare and B:C ratio of 1.48 was obtained with minimum tillage + crop residue treatment **(Table 3).**

Table 3 : Effect of tillage and crop residue on erosion losses and yield of crops (mean of 8 years)

Treatments	Runoff (% of rainfall)	Soil loss (t/ha/yr)	Grain yield (kg/ha)		Net return (Rs./ha)	B:C ratio
			Maize	Toria		
T_1 -Conventional tillage	23.3	19.83	2407	667	7194	1.40
T_2- T_1+ crop residue	20.0	16.30	2704	772	8108	1.43
T_3- Minimum tillage	24.2	15.46	2279	631	8030	1.52
T_4- T_3+crop residue	20.6	14.32	2593	730	9350	1.57
T_5- Cultivated fallow	35.7	45.50	-	-	-	-

Agroforestry: Growing multipurpose trees or shrubs in agricultural fields not only satisfies fuel and fodder needs of the farmer, but also has a great potential for erosion control through the tree canopy, litter and root effects. Tree rows may also act as a barrier to surface flow. The plantation of Leucaena and Eucalyptus in maize field in paired rows at 4.5 x 1.5 m spacing reduced soil loss by more than 70% (Narain et al, 1988). Eucalyptus rows were more effective than Leucaena when both are managed as trees **(Table 4).** Although trees had adverse effect on the crop yields but tree products compensated the loss thus making the system economically viable.

Table 4 : Runoff and soil loss under agroforestry systems

Landuse	Runoff (%)	Soil loss (t/ha)	% reduction in	
			Runoff	Soil loss
Maize	18.3	17.7	-	-
Maize+*Subabul*	8.9	5.0	51.9	71.8
Maize+*Eucalyptus*	3.6	0.91	80.3	94.9
Chrysopogon fulvus	1.6	0.33	91.3	98.8
Grass+*Subabul*	0.6	0.13	96.7	99.3
Subabul	0.4	0.04	97.8	99.8
Grass+*Eucalyptus*	0.1	0.02	99.5	99.9
Eucalyptus	0.1	0.01	99.5	99.9

Conservation Bench Terrace (CBT) System

The CBT system consists of a terrace ridge to impound run-off water on a level bench and a donor watershed which is left in its natural slope and produces run-off which spreads on the level bench. The contributing area is either kept fallow or under a drainage loving crop like maize, whereas the lower reaches of the field are levelled to grow crops like rice in high rainfall regions. The CBT system has been successfully demonstrated in arid, semi-arid and sub-humid regions in India on mildly sloping lands for erosion control, water conservation and improvement of crop productivity. In India, at Dehradun, the CBT system constructed at 2 % slope with 3:1 ratio of donor area to recipient area and 20 cm depth of impoundment at the end, significantly reduced run-off and soil loss by over 80 and 90%, respectively, compared to the conventional system of maize-wheat rotation. Similarly, in the north-eastern hill region, the CBT on 55% slope with ¼ upper area under maize, and ¾ lower area under rice on bench terraces, resulted in maximum reduction in run-off and soil loss, and produced optimum yields of both the crops. Thus CBT system provides a viable alternative to conventional system for conserving in-situ rainwater, minimizing soil erosion and enhancing crop productivity.

Grasses: Grasses are perhaps the best friends of soil conservation. Low and evenly distributed canopy and fibrous root systems with high soil binding capacity make grasses highly effective in controlling soil *erosion*. Chrysopogon grass alone could reduce the runoff and soil loss by 91.3 and 98.1 percent, respectively (Narain et al 1988), but when grown with trees reduced the runoff and soil loss completely **(Table 4).**

At 9 to 11 percent slopes at Dehradun, efficacy of various grasses for erosion control was more than 98% (Narain et al 1994) hence their selection shall be based on the production potential of these grasses under given edaphic conditions and local preferences. *Pueraria hirsuta* and *Chrysopogon fulvus* have shown the highest production at Dehradun **(Table 5).**

Table 5 : Runoff and soil loss under different grass species

Land Slope	Conservation measure	Runoff (%)	Soil loss (t/ha)	% reduction in		Yield (kg/ha)
				Runoff	Soil loss	
9%	Bare & ploughed	59.6	155.95	-	-	-
	Bare fallow	71.1	92.42	19.3	40.75	-
	Cynodon dectylon	27.1	2.10	54.5	98.70	4355
	Natural grasses	21.2	1.02	64.4	99.3	-
11%	Cultivated fallow	16.2	18.45	-	-	-
	Pueraria hirsuta	1.80	0.11	88.89	99.40	15950
	Dicahthium annulatum	1.90	0.23	88.27	98.75	12870
	Chrysopogon fulvus	2.50	0.30	84.57	98.40	19170
	Eulaliopsis binata	5.20	0.29	67.1	98.43	11290

Grasses as Vegetative Barriers: Vegetative barriers include contour rows of perennial grasses, hedges, wind breaks and shelter belts etc. As a live bund of perennial grasses, use of Guatamala grass (*Tripsicum lamms*) on lateritic soils of Ootacamund was an excellent example for formation of Puertoricon or California type terraces through vegetative barriers. *Khus* (*Vetveria zizaniodes*) has been recommended widely by the World Bank in India and South East Asian countries for growing as live bunds. In Doon Valley on 4% slope Bhardwaj (1991) reported that live bunds of Guenia grass, bhaba*r* grass and *khus* grass reduced the runoff by more than 18% and soil loss by more than 78% compared to cultivated fallow which produced 52 per cent of rainfall as runoff and 45 t/ha soil loss. The suitability of vegetative barriers in different agro-ecological regions of India is presented in **Table 6** (Sharda and Juyal, 2009).

Table 6 : Vegetative barriers reported superior at different locations in India

Location	**Crop**	**Barrier**
Dehradun	Corn	*Panicum maximum*
Akola	Sorghum, Cotton	*Leucaena and Vetiver, Leucaena*
Anantapur	Groundnut	*Vetiver* on account
Bijapur	Safflower	Rubble check and *Leucaena*
Indore	Soybean	*Cymbopogon margini**
Bengaluru	Finger millet	*Combination of graded bund and Vetiver*
Hyderabad	Sorghum/Castor	*Cenchrus ciliaris**
Bellary (Karnataka)	Sorghum	*Agave sislana* and *Vetiver* plus *Bhabar*
Ballowal (Hoshiarpur)	Maize	*Saccarum munja*
Sirsa (Ambala)	Black gram	Mixed barrier of *Vetiver* plus *Bhabar*
Boli (Yamunanagar)	*Bajra* and Wheat	Mixed barrier of *Vetiver* plus *Bhabar*
Bhawanipatnam (Orissa)	*Paddy*	Vetiver*
Bhubaneshwar (Orissa)	Cowpea (green pod)	*Cynodon dactylon**
Udhagamandalam (Tamil Nadu)	Potato	*Napier* grass

*Barriers with small bund of cross-section – 0.1 sq m

Slopping Agricultural Land Technology (SALT): SALT is basically a method of growing crops between rows of shrubs and trees such as *Gliricidia* and *Leucanea.* The three-tier system developed by the ICAR Research Complex for NEH region for sloppy hills (lower 1/3rd bench terraced for agriculture, middle 1/3rd for horti-pasture with grasses on contour bunds and remaining 1/3rd for agroforestry with contour bunds) with flexibility according to specific needs. The short-term fallow periods (3-5 years) of weedy species are not only resulting in poor soil fertility build up but also posing a major threat to the cropping phase due to build up of weed seed pool accompanied by low yield of crops taken. Rapid restoration and maintenance of soil productivity can be achieved by improved fallow with woody and herbaceous legumes with primary purpose of fixing N as a part of short fallow (2-3 years) to increase the accumulation of large quantities of N and to provide a residual effect on two or three subsequent crops. The main legumes of the genus *Sesbania, Tephrosia, Leucaena, Mucuna, Centrosema, Pueraria, Crotolaria, Cajanus, Indigofera* and *Mimosa* can be successfully used for the short fallow to rejuvenate the soil fertility lost during cropping.

Impacts of Integrated Watershed Management Programs in India

Over the past three decades, India has addressed the challenges of land degradation and enhancing productivity of rainfed areas head-on and has made major investments in the area of watershed management through an appropriate combination of technical innovations, participatory approaches and an enabling policy environment. There is ample evidence of positive impacts of watershed programs in terms of reduction in soil and water losses and improved agricultural productivity in normal rainfall years in regions that were bypassed in the conventional green-revolution era. Several reviews on the performance of watershed development projects (Hanumantha Rao, 2000; Joshi *et. al.,* 2000, 2004; Kerr *et al.,* 2000, 2004; Palanisami *et al.,* 2002; Joy *et al.,* 2005) in India have diagnosed various limitations of watershed programs. Participatory integrated watershed management (IWSM) approach being adopted in the recent past has shown encouraging results over the previously adopted commodity based or sectoral approaches. Operational Research Project on Watershed Management at Fakot in outer Himalayas which was implemented by Central Soil & Water Conservation Research and Training Institute (CSWCRTI) during 1975-86 is a successful example of this participatory approach. Similar trends in production increase and environmental benefits have been observed in other watersheds developed under NWDPRA, DPAP, RVP and other bilateral projects implemented during 1990s.

The IWSM programs were quite effective in conserving natural resources of land, water and vegetation for sustained productivity. Run-off reduction in the range of 1.5 to 2.5 and soil loss in the range of 1.2 to 4.8 times was realized in the experimental watersheds **(Table 7).**

Table 7 : Impact of integrated watershed management practices on runoff and soil loss

Watershed (State)	Runoff as % of rainfall		Soil loss (t ha^{-1})	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Fakot (Uttarakhand)	42.0	14.2	11.9	2.5
Behdala (Himachal Pradesh)	30.0	15.0	12.0	8.0
Una (Himachal Pradesh)	30.0	20.0	12.0	10.0
G.R. Halli (Karnataka)	14.0	1.3	3.5	1.0
Joladarasi (Karnataka)	20.0	7.0	12.0	2.3

Generally, the impact of integrated watershed management (IWSM) projects is analyzed through tangible benefits accrued out of the program in terms of productivity components. The environmental externalities and intangible benefits are rarely accounted for. Even by considering tangible benefits, IWSM programmes were found to be economically sound with benefit: cost ratio varying from 1.10:1 to 2.94:1. Data in **Table 8** presents benefit-cost ratio of some of the projects in western Himalayan and Shiwalik region.

Table 8 : Economic evaluation of watershed management programmes in Western Himalayas and Shiwaliks region

Watershed	Benefit-cost ratio	Project life (years)	Discount rate (%)
Fakot	1.92	25	10
Relmajra	1.20	20	12
Sukhomajri	2.06	25	12
Nada	1.07	30	15
Bunga	2.05	30	12
Maili	1.10	50	15
Chohal	1.12	50	15

Integrated Watershed Management Programmes are being implemented all over the country on a massive scale since 1991 after the tremendous success of model watershed projects developed by CSWCRTI, Dehradun and other organizations. The programme is funded by Ministries of Rural Development, Agriculture, Environment and Forests besides many externally aided projects from foreign agencies. A review of more than 300 integrated watershed management projects indicated that in majority of the watersheds, total crop production increased by 50 to 123 percent with some of them registering up to 5 fold increase (Joshi et al., 2004). Water harvesting technologies increased the irrigated area by 50 to 156 percent and consequently cropping intensity increased by 64 percent on an average. Apart from increasing production, IWSM projects were quite beneficial in generating employment opportunities varying from 11 to 960 mandays. A spectacular increase in ground water level varying from 0.2 to 2 m has been reported in the watersheds successfully implemented by CSWCRTI, Dehradun and ICRISAT, Hyderabad. **Table 9** presents the area covered and the expenditure incurred to develop degraded lands under various watershed development programmes since inception up to Tenth Five Year Plan (Sharda et al., 2008). Up to March, 2007, an area of 56.54 million ha has been treated at a cost of about Rs. 19,471 crores under various Central and State sponsored schemes. Perusal of progress of Watershed Development Programmes in each state indicates that some of the States have accomplished more than 80% of the targets while many are still lagging behind which needs to be expedited.

Table 9 : Degraded lands developed under various watershed development programs since inception up to the Tenth Five Year Plan (March, 2007)

(Area in Lakh ha and expenditure in Rs. Crore)

Sl. No.	Ministry/Scheme and Year of start	Area	Expenditure
(A)	**Ministry of Agriculture (Deptt. of Agri. & Cooperation)**		
	NWDPRA (1990-91)	88.46*	2787.43
	RVP and FPR (1962 and 1981)	59.92	2050.31
	WDPSCA (1974-75)	3.92	294.15
	RAS (1985-86)	7.36	118.51
	WDF (1999-2000)	0.98	46.13
	EAPs	14.58	2244.11
	Sub-Total	**175.22**	**7540.64**
(B)	**Ministry of Rural Development (Deptt. of Land Resources)**		
	DPAP (1973-74)	137.19	2443.01
	DDP (1977-78)	78.73	1837.79
	IWDP (1988-89)	107.22	2268.53
	EAPs	5.82	846.10
	Sub-Total	**328.96**	**7395.43**
(C)	**Ministry of Environment and Forests**		
	NAEP (1989-90)	**9.59**	**2031.42**

Sl. No.	Ministry/Scheme and Year of start	Area	Expenditure
(D)	**Planning Commission**		
	HADP (1974-75)	0.29	127.74
	WGDP (1974-75)	8.06	503.49
	Sub-Total	**8.35**	**631.23**
(E)	**Other Watershed Schemes Operating in Different States**	43.28	1871.84
	Total (A+B+C+D+E)	**522.12**	**19470.57**

Source: Sharda et al. (2008)

GOVERNMENT INITIATIVES FOR LAND MANAGEMENT

National Level Mechanisms

For effective coordination and management of land resources of the country, a National Land Use and Wasteland Development Council (NLWDC) was constituted under the Chairmanship of Prime Minister in 1985-86 with its Secretariat located in the Department of Land Resources, Ministry of Rural Development. For effective coordination, the following Boards/Authority have been constituted:

(i) National Land Use and Conservation Board (NLCB): It is located in the Ministry of Agriculture, Deptt. of Agriculture and Cooperation, to serve as policy planning, coordinating and monitoring agency at national level for issues concerning health and management of land resources.

(ii) National Rainfed Area Authority (NRAA): This authority was created in November, 2006. It is a multi-disciplinary organization of renowned professionals. Formulation and advocacy of policies, perspective planning, capacity building, monitoring, evaluation etc. are the major mandates

(iii) National Wastelands Development Board (NWDB): It is located in the Department of Land Resources, Ministry of Rural Development for addressing matters related to wastelands in the country.

(iv) National Afforestation and Eco-development Board (NAEB): It is located in the Ministry of Environment and Forests to take care of the matters related to the land belonging to forests.

Under India's Federal structure, land is a state subject and there is so far no National legislation. The NLCB is considering the enactment of a composite Land Resources Management Act encompassing various aspects of land use. National Land Use Policy outlines have already been prepared which take into account environmental, social, demographic, economic and legal issues. The policy has been circulated to all concerned for its adoption and implementation. For effective management of forest resources, the Central Government has brought the subject under concurrent list and enacted the Forest (Conservation) Act (1980), in which all cases of diversion of forest lands are required to be approved by the Central Government.

State Level Mechanisms

The State Land Use Boards (SLUBs) were established in 1970's to implement the policies and guidelines issued by the NLCB and to ensure that scarce land resources are put to optimal use. Since land is a state subject, all states are required to enact suitable laws and prepare a policy for land use. However, only few states, namely, UP and Kerala have prepared Draft Land Use Policy so far. SLUBs are not functioning properly in most of the states and need to be revitalized for effective land use planning. A holistic approach to understand the livelihoods of rural people especially in marginal agro-climatic zones can provide the basis for sustainable rural poverty alleviation and natural resources management simultaneously. The strategy of Land Use Policy should cover elements of food security, rural development, viability of rural areas, environmental and social aspects.

Local Level Mechanisms

At the local level, Panchayats, Watershed Committees, Self Help Groups, User Groups, NGOs, State Implementing agencies etc. are fully involved in decision-making for planning, implementation, post care maintenance activities etc. of land resources. In the Common Guidelines for Watershed Development Projects implemented by Govt. of India for all Ministries/Departments since April, 2008, institutional arrangements required at project level and at village level have been duly emphasized with active participation of the local community.

At the district level, the concerned development departments take decision on land management issues in consultation with people's representatives. The role of women has been fully recognized in integrated planning and management of land resources.

Conclusion

Four countries of the humid zone - Bangladesh, Nepal, Sri Lanka and the greater part of India are severely affected by water erosion on their rainfed lands, soil fertility decline, and deforestation. In parts of the hill and mountain areas of Nepal, deforestation and water erosion have reached an alarming proportion. Bhutan, because of its lower population density, has not yet suffered from severe land degradation, but deforestation, often the initial cause of degradation, is taking place. Institutional structures to combat land degradation exist in all countries of the region. These offer much potential, both for research and implementation of appropriate measures. Some countries possess an unduly complex structure, sometimes with poorly defined or overlapping responsibilities. There is a need to recognize land resources, productivity and degradation as a distinctive field, and clarify responsibilities for research, survey, monitoring and implementation. Many of the proposed actions will initially require discussion on a regional, and in some cases international basis in order to secure uniformity of methods. They will subsequently require modifications in detail to meet the needs and conditions of different countries. If integrated action is not taken, to combat both the direct and indirect causes of land degradation: resources will be destroyed, in some cases irreversibly; there will be further considerable economic losses at the national level; and the people, mainly the poor, will suffer. A pre-requisite for effective action is recognition, by national governments, of the severity of land degradation and its effects upon the people and the national economies. It is not sufficient to pay lip service to ‘environment’ nor to write reports. There must be allocation of staff, budget and resources. Some of the issues which need to be addressed to check land degradation and as a policy framework are summarised below:

Clarify institutional responsibilities: It may be necessary to establish a high-level advisory committee on land degradation policy. This body should then seek, through collaboration with the Ministries and Departments concerned, to clarify responsibilities in areas of research, planning and implementation. It is desirable that countries should identify one nodal institution for land degradation affairs as a whole, together with others with defined responsibilities for particular types of degradation and aspects of research, planning and implementation.

Identify priorities: In all countries there are critical aspects, where land degradation and its consequences have already reached serious proportions or threaten to do so. In some cases these will be specific land regional areas, such as those with particularly severe erosion or salinization. In others, a priority may arise in the existence of a problem of moderate degree but occurring over a large area, such as soil fertility decline.

Plan and implement national programs: It is at this point that the international, regional and national activities will be put into practice.

Implementation of measures to combat the direct causes of degradation: Much activity of this nature is already being undertaken, but the scale of activity needs to be expanded. Increased funding will be required. Measures of this type include: watershed management and soil conservation projects and extension work; methods for improving soil organic matter status; application of integrated plant nutrition systems; salinity control and reclamation projects; reafforestation; further development of agroforestry, including applications for soil conservation; and control of desertification, including sand dune fixation and improved rangeland management.

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Rainwater Conservation and Management in High Rainfall Region for Increasing Land and Water Productivity

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The eastern region of the India is bestowed with plenty of rainfall. The mean annual rainfall varies from 1008 mm in Eastern Uttar Pradesh to 3126 mm in Sub-Himalayan West Bengal. Bulk of this rain (about 80%) occurs during monsoon. During this period, about 50% of the annual rainfall comes from few intense storms (Pisharoty, 1990). Water received from such intense storms is subjected to high runoff losses (Pal *et al.,* 1994). Added to this, is the erratic nature of the onset, distribution and the withdrawal of rains, which increases the probability of water stress at various crop growth stages of rice (Bhuiyan and Goonasekera, 1988). The spatial heterogeneity and temporal variability of rainfall create a situation where enormous amount of water causes surface flooding at one point of time and scarcity of water during dry spells. High runoff also erodes the topsoil and nutrients, thereby threatening sustainability of agriculture. Further, poor water resource development to provide assured irrigation to crops during dry season has restricted the cropping intensity of the region around 143%. About half of the rice acreage in eastern region is under rain-fed system, whose productivity is significantly lower than that of the irrigated system. The region is prone to frequent occurrence of natural calamities such as flood, drought and cyclone, which repeatedly damages the crop and weakens the financial backbone of the farming community. These are the main bane in achieving the production potential. Thus, conservation of rainwater at various plausible sites to create a better water regime in the cropped field through its efficient utilization can improve the overall productivity of the rain-fed ecosystem.

Rain water conservation/harvesting is an age old technique being practiced by our ancestors since ages. This practice of rainwater harvesting can be felt from the existence of farm ponds in every village of our country. The importance of rainwater harvesting has increased very much with ever increasing demand of water from different competing sectors like agriculture, domestic and industry. Further, the importance of rainwater harvesting is gaining importance as in certain pockets there is depletion of groundwater level due to its over-exploitation. Significant amount of rainfall is lost as surface runoff during monsoon causing substantial loss of soil. Due to this, sedimentation of reservoirs is taking place at a faster rate. Rainwater harvesting not only reduces runoff and soil loss but also facilitates groundwater recharge. It also prevents early sedimentation of the reservoirs. The rainwater harvesting and groundwater recharge enables the farmers to provide supplementary irrigation to crops grown during monsoon season and also to go for the second crop during dry season. Therefore, it is desirable to harvest as much of rainwater to avoid irrigation water scarcity.

In-situ and *ex-situ* Rain Water Conservation

Runoff collection is generally distinguished as *in-situ* management, when the water is collected within the area of harvesting, and *ex-situ* when it is diverted outside of the harvesting area. The storage is of crucial importance. In case of *in-situ* rainwater conservation the soil acts as the storage, whereas for *ex-situ* rainwater conservation the reservoir can be natural or artificial, where natural generally means groundwater recharge, and artificial means surface/subsurface tanks and small dams. The differentiation between the two is often minor, as water collection structures are generally placed in a systematic relation with each other; hence, the runoff from certain structures may be a source of recharge for others.

Components of Rain Water Harvesting System

A rain water harvesting system has three components

- The catchments;
- The collection system; and
- The utilization system.

Research Undertaken at WTCER/ DWM

Over the years, several methods have been developed for conservation of rainwater. Some of the important methods of rainwater conservation in the high rainfall region on which research has been carried out at WTCER/ DWM in the recent past and which have made significant impact in the field are as follows:

1. *In-situ* rainwater conservation in the rice field
2. Two-stage rainwater conservation in the rice field
3. Tank cum well system in the plateau region

Some of the features of the above mentioned techniques are described below :

In-Situ Rainwater Conservation in the Rice Field

One of the important techniques of *in-situ* conservation of rainwater in the bunded rice field is through strengthening of field bunds. In spite of heavy rainfall in rainy season, the rain-fed rice suffers from water deficit during the dry spells. This warrants for strengthening of bund height around the rice field. When the level of water in the rice plots exceeds the level of its weir, spilling of excess water takes place and is termed as runoff or rainfall excess. Little systematic information is available on rainfall excess values from rice fields with various weir heights in the high rainfall region.

An experimental study was conducted at WTCER, Bhubaneswar for three consecutive years to determine the optimum weir height around the rice fields in the rain-fed flat lands of medium textured soil **(Plate 1).** The amount of runoff obtained from the experimental study (rice plots with various weir heights) as well as from the water balance simulation model (Mishra *et al*., 1998 and Mishra, 1999) is presented in **Table 1**. The data show that much as 57% and 99.5% of the rainwater can be stored in plots with a weir height of 6 cm and 30 cm respectively. An exponential relationship between the observed runoff values and weir height is obtained:

$$RO = 121.75\ e^{-0.181H},\ R2=0.967 \qquad \ldots(1)$$

Where, RO is the runoff as a percentage of rainfall and H is the weir height in centimeters. By differentiating Eq. (1) with respect to H, we obtain the slope of the curve at different points:

$$d(RO)/dH = 122.04\ e^{-0.181H} \qquad \ldots(2)$$

The slope of the curve, i.e. d(RO)/dH at weir heights of 6, 10, 14, 18, 22, 26 and 30 cm were obtained as –7.44, -3.61, -1.75, -0.85, -0.41, -0.2 and –0.1% cm^{-1} respectively. The d(RO)/dH achieves –1., -0.5 and –0.25% cm^{-1} values at 17.1, 20.9 and 24.7 cm weir heights respectively. Thus, up to 17.1 cm weir heights, the rate of change of runoff with regard to weir height is found to be less than the –1.0% cm^{-1}. In other words at up to 17.1

Plate 1 : Experimental plot for determining optimum weir height for *in-situ* rainwater conservation

cm, for each 1 cm increase in weir height there was a more than 1% reduction in runoff. Therefore, the zone up to the weir height of 17 cm is more conservative than the zone above that height. Hence, 17 cm weir height may be considered as a critical lower limit. For maximum conservation of rainwater resources one may take $d(RO)/dH \geq -0.25$ % cm^{-1}. Hence, a weir height of 24.75 or say 25 cm may be considered a more appropriate height for conservation of natural resources, for at this weir height about 98.68% of the rainwater is retained in the field itself.

It is observed that about 55% of the rainfall was stored in the 6 cm weir height plots, 97% in 22 cm weir height plots and 99.5% in 30 cm weir height plots. Hence, 30 cm weir height plots conserve almost all the rainfall.

Table 1 : Observed and computed amount of rainfall conserved in rice fields with various weir heights

Weir height (cm)	Amount of rainfall conserved as percentage of total seasonal rainfall (%)	
	Three years of experimental study	Water balance model simulation using 32 years climatic data
6	56.75	54.90
10	72.07	74.74
14	93.87	87.03
18	95.07	93.69
22	98.38	97.25
26	98.59	99.05
30	99.43	99.52

Temporal Distribution of Runoff

Fortnightly distribution of model computed runoff (mean of 32 years) is shown in **Table 2,** when the irrigation application depth was kept at 6 cm. The mean values of runoff indicate that these are the expected runoff values at a 50% probability level. The figures in parentheses represent the percentage of total seasonal runoff which is expected to occur during that specific fortnight. About 50-60% of the runoff takes place during the second half of July and the month of August. The distribution during the first three fortnights is more or less the same, i.e. about 20% of the total seasonal runoff. Thereafter, a gradual reduction in runoff is noticed. The least runoff occurs in the month of November. At higher weir height plots (26 cm and 30 cm weir heights), negligible amount of runoff has been observed (Mishra, 1999).

Table 2 : Temporal distribution of runoff in mm (mean of 32 years)

Weir height (cm)	Runoff distribution							
	July 2nd half	August 1st half	August 2nd half	Sept. 1st half	Sept. 2nd half	October 1st half	October 2nd half	Nov. 1st half
6	87 (21.12)	84 (20.39)	71 (17.23)	56 (13.59)	44 (10.68)	30 (7.28)	28 (6.80)	12 (2.91)
10	46 (20.54)	47 (20.98)	40 (17.86)	33 (14.73)	21 (9.37)	15 (6.70)	15 (7.14)	6 (2.68)
14	24 (21.05)	22 (19.30)	24 (21.05)	18 (15.79)	11 (9.65)	4 (3.51)	8 (7.02)	3 (2.63)
18	12 (21.05)	9 (15.79)	13 (22.81)	10 (17.54)	6 (10.53)	1 (1.75)	4 (7.01)	2 (3.51)
22	6 (24.00)	3 (12.00)	4 (16.00)	6 (24.00)	2 (8.00)	0 (0.00)	3 (12.00)	1 (4.00)
26	3 (37.50)	3 (0.00)	0 (0.00)	3 (37.50)	0 (0.00)	0 (0.00)	2 (25.00)	0 (0.00)
30	2 (50.00)	0 (0.00)	0 (0.00)	2 (50.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)

Note : Figures in parenthesis show the percentage of total runoff during rainy season

Loss of Sediments in Runoff Water

In the experimental fields, loss of sediments in runoff water was monitored by collecting samples of runoff water for each spilling of rainwater. As much as 347.78 kg/ha of sediment was lost from rice plots with 6 cm weir heights and 3.31 kg/ha was lost from rice plots with 30 cm weir heights. Therefore, the amount of sediment which was lost in one cropping season from 6 cm weir height plots would take almost 106 cropping seasons from 30 cm weir height plots. Hence, this analysis emphasizes that the determination of optimum weir height should be based on both the rainwater conservation and soil conservation. Sediment loss, when plotted against weir height, yielded an exponential relationship, which is as follows (Mishra *et al.*, 1998) :

$$S = 810.7\ e^{-0.166H},\ R^2 = 0.945 \qquad \ldots(3)$$

Where, S is loss of sediments (kg/ha) and H is weir height (cm).

Loss of Nutrient in Runoff Water

Loss of nutrient such as total Kjeldahl Nitrogen (TKN) and available K were monitored in the runoff water. Chemical fertilizers N(60):P(30):K(30) kg/ha were applied to the crop at three split doses. As much as 4.23 kg TKN and 2.20 kg of available K were found to be lost through runoff water from 6 cm weir height plots in one cropping season. A very negligible amount of TKN and K was lost from 30 cm weir height plots.

TKN was lost 33-fold more from 6 cm weir plots than from 22 cm weir height plots. Similarly for K, the amount lost from 6 cm weir height plots, was 50-fold more the amount lost from 30 cm weir height plots. A decreasing trend of these losses is observed with the increase in weir height. However, it is expected that with the increase in weir height ponding depth, the loss of TKN and K will increase in leaching water. Loss of nutrient in the leaching water was beyond the scope of the present investigation and hence was not studied.

Like sediment loss, loss of nutrient in runoff water correlated with weir heights according to the following exponential relationships (Mishra *et al*., 1998):

$$TKN = 25.25\, e^{-0.23H},\ R^2 = 0.904 \qquad \ldots(4)$$

$$K = 4.81\, e^{-0.168H},\ R^2 = 0.904 \qquad \ldots(5)$$

Where, TKN is total Kjeldahl nitrogen loss in kg/ha, K is available K loss in kg/ha, and H is weir height in cm.

Supplemental Irrigation Requirement

In the experimental plots, supplemental irrigations were given during dry spells and depth of irrigation in each application was kept at 6 cm. On an average, four irrigations were applied for 6 cm weir height plots. Three irrigations were required for 10 and 14 cm weir height plots. Weir height plots of 18 cm and higher required only two irrigations per crop growth period. Computed values from the simulation model revealed that 6 cm weir height plots required four irrigations and higher weir height plots required three irrigations per crop growth period.

The model computed irrigation water requirements (average of 32 years) for 6 cm, 10 cm, 14 cm, 18 cm, 22 cm, 26 cm and 30 cm weir height plots were 27.7, 22.8, 21.1, 20.5, 20.4, 20.1 and 20.1 cm, respectively. Practically, no difference in irrigation water requirement was seen for 18-30 cm weir height plots.

Inference

In the rain-fed agro-ecosystem, provision of surplus weir **(Plate 2)** at a height of about 25-cm is recommended optimum for *in-situ* conservation of rainwater in leveled rice land in medium textured soil of the study region. This height is sufficient to conserve about 98% of rainwater, thereby minimizing significant loss of nutrients and sediment in runoff water. Further, this reduces the supplemental irrigation requirement of rice crop during dry spells. Large scale adoption of this measure will reduce the problems of water-logging in low lying tracts by increasing groundwater recharge.

Plate 2 : Brick masonry weir in the downstream side of the rice plot

Two-Stage Rainwater Conservation in Rice Field

In order to increase the productivity from unit volume of rainwater, a two-stage rainwater conservation technique was conceptualized and tested, in which part of the rainwater was conserved in rice field up to the weir crest level and the remaining in a refuge for rearing of fish. The research effort was focused here on conservation of rainwater and adoption of integrated rice-based farming system in medium lands. The rainwater immediately falling over the rice field is conserved through strengthening of bund height around rice field and providing a surplus weir at the down stream bund of the rice field at an optimal height. The excess rainwater spilling over the weir is further harvested through provision of a small farm pond constructed in the rice field at its downstream portion. The harvested water in the farm pond is utilized for providing supplemental irrigation in dry spells to monsoon rice, rearing of a short duration fish culture of about four to six months, cultivation of a light duty crops in winter season and growing of horticultural crops on the embankment of the farm pond.

The results of the study presented here was carried out in five farmers' fields, located in the medium lands at Sadeiberini village of Dhenkanal district, Orissa (Lat. 20°58′ N and Long. 83°51′ E) for three consecutive years (2001-02 to 2003-04) after successful testing of the technology in the research farm. In the medium lands, each rice plot was provided with a brick masonry broad-crested rectangular weir at the partition dike between the on-farm refuge and the rice field. The length of the weir was kept at about 1 to 1.5 m. Three weir heights of 15 cm, 20 cm and 25 cm were considered as treatments with two replications each (total six plots) for *in-situ* conservation of rainwater in the rice fields. In this process a portion of rainwater was conserved in the rice field up to the weir crest level (weir height). The excess rainwater above the crest level was allowed to spill over the weir for further conservation in the farm pond **(Plate 3).** Though the design area of the farm pond was kept as 10% area of the rice field, farmers initially did not spare much

Plate 3 : Two-stage rainwater conservation in the rice field

area for farm pond. Therefore, at the downstream end of each plot, farm pond was constructed, approximately occupying 5-8% of the individual plot size to harvest the excess rainwater during heavy downpour. The average depth of the farm pond was kept at 1.75 m with a side slope of 1:1. The top width of the embankment of the farm pond was kept as 1m. The excess water from the farm pond was drained out through a hume pipe (fixed at weir crest level) with fine-meshed net to prevent escape of fish (Mishra *et al.,* 2003). Schematic diagram of the farm pond with rice field and surplus weir is shown in **Fig. 1.**

During the rainy season, 'Saruchinamali' (farmer's choice, a traditional local variety), 'Jagannath' and 'Moti' (high yielding) cultivars of rice were grown. Transplanting of the rice was carried out during 3rd to 4th week of July with a spacing of 20 x 10 cm. Chemical fertilizer @ 80:40:40 (N: P: K) kg/ha was applied in three split doses along with bio-fertilizer (*Azosprillum*). On the embankment of farm pond, horticultural crops such as Banana, Papaya, Drumstick, French bean etc. were grown **(Plate 4).** During winter season farmers grew crops such as winter rice ('Lalat' and 'MW-10'), ladies finger (*Hibiscus esculentus* L.), greengram (*Phaseolus radiatus* L.), blackgram (*P. mungo* L) and water

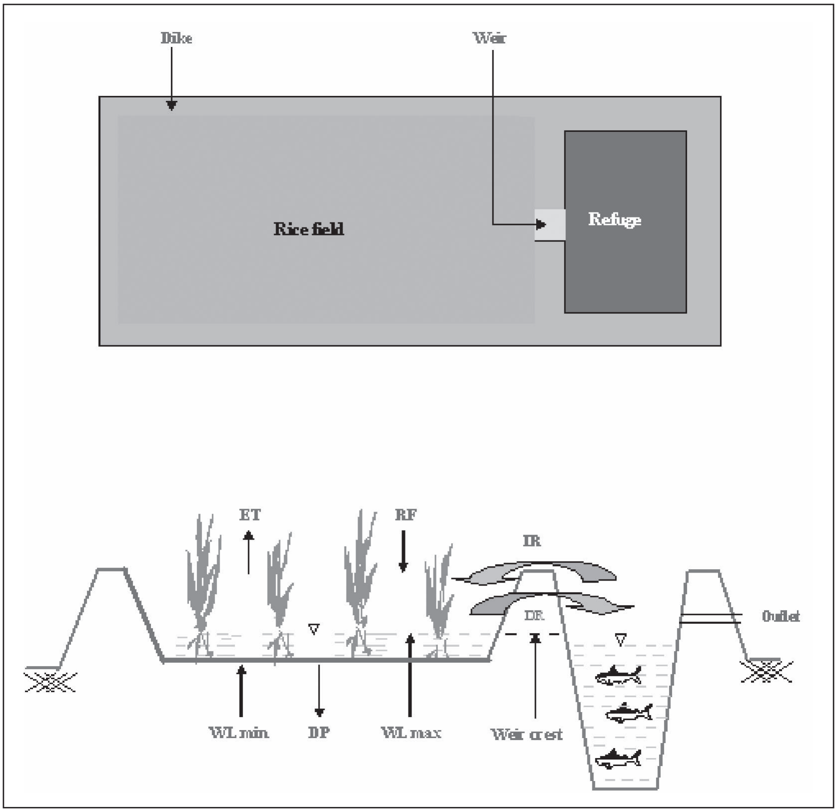

Fig. 1 : Schematic diagram of two-stage rainwater conservation through on-farm refuge and surplus weir in the rice field of rain-fed medium lands

Plate 4 : Horticultural crops grown on the embankment of the farm pond

melon etc. using the harvested rainwater from farm ponds. Fish and prawn were reared in the farm ponds seven days after first manuring and fertilization. Early fingerlings (<1.5 gm size) of *Catla catla, Labeo rohita, Cirrhinus mrigala* and *Cyprinus carpio* were stocked with a species composition of 30:30:20:20, respectively. Stocking density of 20,000 fingerlings/ha was maintained in all the treatments and rearing continued for about 180 days (3rd week of August – 3rd week of February).

Rainwater Conservation and Management

In 2001, rainfall of 1535 mm and 1420 mm were received during the entire year and rainy season, respectively. In this year, an unusual rainfall during July amounting to 719 mm (2.2 times more than that of 20 years average value) had occurred. In spite of heavy rainfall during July and subsequent scanty rainfall during August and September, water levels in the farm ponds were observed to be sufficiently high till end of February 2002 (**Table 3**). In the year 2002, rainfall of 728 mm and 543 mm was received during the entire year and rainy season, respectively. Similarly, in 2003 rainfall of 1572.5 mm and 1451.5 mm was received during the entire year and rainy season, respectively. Twenty years average annual rainfall and rainy season's rainfall are 1415 and 1226 mm, respectively. Thus, the first and third years experiment were excess rainfall years and the second year was a drought year. Amongst these two excess rainfall years, the monsoon rain was well distributed in 2003 and was poorly distributed in 2001. However, in all these extreme cases, the water levels in the farm ponds were observed to be good enough (>1 m most of the period) till end of February. This enabled the farmers to successfully

Table 3 : Average depth of standing water (m) in the farm ponds in different years

Weir height, cm	Year	August	September	October	November	December	January	February
15	2001-02	1.70	1.70	1.71	1.69	1.66	1.62	1.63
	2002-03	1.10	1.08	1.07	1.05	1.02	1.03	1.02
	2003-04	1.21	1.20	1.20	1.19	1.16	1.17	1.15
	Average	1.34	1.33	1.33	1.31	1.28	1.27	1.27
20	2001-02	1.58	1.43	1.45	1.31	1.24	1.17	1.18
	2002-03	1.28	1.24	1.09	0.89	0.79	0.74	0.65
	2003-04	1.62	1.57	1.54	1.53	1.43	1.40	1.36
	Average	1.49	1.41	1.36	1.24	1.15	1.10	1.06
25	2001-02	1.62	1.61	1.59	1.54	1.47	1.39	1.38
	2002-03	1.22	1.16	1.05	0.93	0.87	0.81	0.74
	2003-04	1.60	1.59	1.58	1.56	1.48	1.40	1.38
	Average	1.48	1.45	1.41	1.34	1.27	1.20	1.17

rear the fish for a period of about six months. After the harvest of fish in February, about one meter depth of water was available in the farm pond (farm ponds occupying 5 to 8% area of each field) which provided about 7 cm depth of irrigation water to rest of the area for winter crops. Out of the three experimental years, 2002-03 was a drought year. In this drought year farmers could grow paddy during monsoon using the stored water from the farm ponds as life saving irrigations. They could also successfully carryout fish culture in the farm ponds. The stored water depths in all the farm ponds were lower in comparison to other two experimental years.

Crop Growth and Yield in Monsoon Season

Treatment wise and variety-wise average yield and yield attributes of rainy season's rice crop is presented in **Table 4**. Highest grain yield of 5.3 t/ha was obtained in 20 cm weir height plots. Highest panicle/m^2 was observed in 15 cm weir height plots followed by 20 cm weir height. Similarly, highest filled grains per panicle were obtained in 25 cm weir height followed by 20 cm. The variation of both the yield attributes at different weir heights were found to be statistically not significant. Perusal of individual years yield data infers that due to sufficient rainfall in first and third years of experiment, maximum yield of rice was recorded in 20 cm weir height plot. However, in the second year (drought year) highest yield was recorded in 25 cm weir height plot. This clearly indicates the effect of *in-situ* conservation of rainwater as a function of weir height on crop growth and yield. Among varieties, Jagannath recorded the highest grain yield (5.91 t/ha) followed by Moti (4.7 t/ha) and Saruchinamali (4.12 t/ha). This was primarily due to highest number panicles/m^2 and filled grains/panicle. Thus, from highest grain yield point of view, 20 cm weir height may be considered as the optimum height for the study site to have two-stage rainwater conservation.

Table 4 : Average yield attributes & yield of monsoon season rice (2001-02 to 2003-04)

Weir height (treatment)	Panicles/m^2	No of filled grains/panicle	Grain yield (t/ha)
15 cm	272.1	140.8	4.59
20 cm	267.6	143.9	5.30
25 cm	257.9	150.3	4.83
CD (0.05)	NS	NS	0.556
Rice variety			
Saruchinamali	238.4	131.2	4.12
Moti	272.3	147.4	4.7
Jagannath	286.8	156.4	5.91
CD (0.05)	NS	NS	0.382

Crops in the Winter Season

In the first year (2001-02 winter) two rice varieties i.e. MW-10 and Lalat were grown and recorded yield of 2.34 t/ha and 2.70 t/ha, respectively. Ladies finger was also grown in the same year which resulted in productivity of 1.85 t/ha. In the second year rice variety MW-10 recorded 3.5 t/ha grain yield. In this year, ratooning was practiced in Savitri and Durga varieties of rice. Savitri resulted in good productivity (2.73 t/ha). Pulses such as black gram and green gram were cultivated in second year, which registered pod yield of 0.34 t/ha and 0.45 t/ha respectively. In the third year rice varieties MW-10 and Lalat yielded of 1.23 t/ha and 1.3 t/ha respectively. Black gram and green gram were also grown in the third year which resulted in better yield compared to that of previous year.

Horticulture on the Embankment

On the embankment of the farm ponds, dwarf variety of papaya, banana and drumstick were grown at a spacing of 1 to 1.5 m. Irrigation to these plants was given using the harvested rainwater from the farm ponds. Among these three horticultural plants, banana performed the best in terms of yield and survival. These plants (specifically drumstick) were subjected to severe damage by cattle grazing in winter and summer because of adjacent fallow fields of other farmers in that locality. The yield of banana and papaya was recorded as 1600 kg/ha and 200 bunch/ha respectively.

Cropping Intensity

Before intervention, monsoon season's rice was the only crop grown in the study site. The harvested rainwater from the farm pond was utilized for growing a second crop which has resulted in increasing the cropping intensity of the site from 100% to 131%, 176% and 200% in the 1st, 2nd and 3rd year of experiment, respectively. In the very first year of experiment, the farmers were not much interested to go for a second crop. Benefits accrued from the second crop gradually developed interest among the farmers to bring more area under cultivation during winter. That is how, in the third year of the experiment the entire area was brought under second crop.

Growth Performance and Yield of Fish

Irrespective of stocking density, faster growth rate was recorded for *C. carpio* followed by *Catla catla* and *C. mrigala* during 180 days of culture. Average daily growth rate decreased with increase in weir height that reduces water availability in the farm pond. Overall survival rate (inclusive of all species) was high in farm ponds with 15 cm weir height, while species-wise, no such trend was marked among the treatments. Fish catch of 1693.6 kg/ha/180 days was obtained in 15 cm weir height farm ponds which was significantly higher ($p<0.05$) than the yield of 20 cm and 25 cm weir height farm ponds. However, there was no significant variation between yields of farm ponds of 20 cm (1265.3 kg/ha/180 days) and 25 cm weir height (1279.4 kg/ha/180 days) **(Table 5).**

Table 5 : Fish Catch (kg/ha) from farm ponds in different years

Weir height	1st year	2nd year	3rd year	Pooled
15 cm	1232.40	1988.80	1859.60	1693.60
20 cm	1004.8	1553.00	1238.10	1265.30
25 cm	1109.90	1478.35	1250.00	1279.40

Rice Equivalent Yield

For the base year 2004, considering the sale price of rice as Rs. 4.00/kg and fish as Rs. 40.00/kg, the rice equivalent yield (REY) for all three treatments was calculated **(Table 6)**. The highest rice equivalent yield was recorded in 20 cm weir height plots (5.74 t/ha) followed by 25 cm weir height plots (5.44 t/ha). The bench mark survey of study site revealed that before interventions the average yield of rice was 1.8 t/ha. Thus, there is a 3.2 fold increase in the land productivity due to efficient and multiple uses of conserved rainwater and scientific crop management practices.

Table 6 : Rice equivalent yield

Weir height	Rice area (m^2)	Farm pond area (m^2)	Total area (m^2)	Rice yield (t/ha)	Fish catch (kg/ha)	REY, (t/ha)
15 cm	3202.4	171	3373.4	4.6	1694	5.23
20 cm	4595.2	294	4889.2	5.3	1265	5.74
25 cm	2217.2	184	2401.2	4.83	1279	5.44

Water Productivity

The total water utilized per hectare (average of three treatments) was estimated at 8204.5 m^3. Considering the selling price of rice, fish, banana, papaya, black gram, green gram and ladies finger as Rs. 4, 40, 50/bunch, 4, 15, 15 and 7/kg, respectively (in the base year 2004), the net return from mono-crop rice, rice + fish, rice + fish + embankment horticulture and rice + fish + embankment horticulture + winter crop was calculated. The economic index of gross water productivity was computed as 2.76, 2.94, 4.94 and 5.87 Rs/m^3 for mono-crop rice, rice + fish, rice + fish + embankment horticulture, and rice + fish + embankment horticulture + winter crops, respectively. Similarly, the economic index of net water productivity for different farming systems was computed as 2.06, 2.17, 3.07, and 3.76 Rs/m^3 for mono-crop rice, rice + fish, rice + fish + embankment horticulture and rice + fish + embankment horticulture + winter crops, respectively. The percentage increase in net water productivity for rice + fish, rice + fish + embankment horticulture and rice + fish + embankment horticulture + winter crop over mono-cropped rice was 5.34%, 49.03% and 82.52%, respectively. Thus, the highest water productivity in rice + fish + embankment horticulture + winter crop combination indicates the most efficient and multiple use of conserved rainwater which has almost doubled water productivity over mono-cropped rice.

Economics

The highest gross returns of Rs. 46,238.00 and net returns of Rs. 29,617.00 were recorded with 20 cm weir height followed by 25 cm weir height **(Table 7)**. The highest benefit-cost ratio of 2.78 was obtained with 20 cm weir height followed by 2.70 with 25 cm weir height. The cost difference between different weir heights was not significant; hence it was not taken into consideration. The gross returns were calculated by adding the returns generated from monsoon season's rice, fish and winter crops. The returns from banana and papaya were also included.

Table 7 : Benefit-cost ratio of the farming system (three year's average)

Weir height	Gross returns (Rs./ha)	Cost of cultivation (Rs./ha)	Net returns (Rs./ha)	B:C ratio
15 cm	43,992	16,621	27,371	2.65
20 cm	46,238	16,621	29,617	2.78
25 cm	44,829	16,621	28,208	2.70

Lessons Learnt

In the rain-fed medium land, *in-situ* and *ex-situ* conservation of rainwater through provision of optimum weir height and farm pond respectively observed to be a viable solution in harvesting the rainwater in diked rice fields. Individual farmers can have this intervention constructed in their own field with very little training. This is suitable for small and marginal farmers. Efficient and multiple use management of harvested water have been successfully demonstrated in the farmers' field. Supplemental irrigation to monsoon rice during dry spells, short-duration pisciculture in the farm ponds, horticulture on the farm pond embankment and cultivation of a light duty winter crops have been successfully tried in the farmers field. This has resulted in significant increase in crop yield, cropping intensity and net return. The dual production system (rice and fish) in monsoon, perennial horticulture and light duty winter crops generated additional income, employment opportunity and nutritional security. In addition, this also minimizes the risks due to natural calamities. The system is eco-friendly and promotes synergism between different components.

The technology can be successfully implemented in large areas. Selection of the appropriate area (medium and shallow low land) for its implementation is extremely important. Sporadic application of this technology will lead to problems like cattle grazing in winter season and poaching of fish from farm ponds. Hence it is recommended to adopt this technology in relatively large patches to avoid these problems. Further, if high duty crops are to be grown in winter, then more area needs to be put under farm pond.

Strategies for Upscaling

Individual farmers can implement this technique of rainwater harvesting in their own field. In the state of Orissa, this technology has been given to the Watershed mission, Govt. of Orissa which is implementing it in large scale through various watershed development schemes. This has become one of the very popular water conservation measures in the watershed development schemes. Other states having similar areas can implement it through various watershed development schemes also.

Tank-cum Well System in the Plateau Region

Rainwater harvesting in high rainfall areas of eastern India has got great potential of creating water resource for supplemental irrigation during rainy season and irrigation to light duty crops during dry season. Considering the topography of plateau region, tank cum well system has been designed and developed at Water Technology Centre for Eastern Region, Bhubaneswar (Srivastava *et. al*., 2003). In this system, a series of tanks and wells are constructed in a watershed **(Fig.2).** The tanks are constructed primarily to store runoff water **(Plate 5)**. The tanks aim at providing supplemental irrigation to transplanted rice in rainy season and irrigation to low duty crops grown in winter in the entire command or heavy duty winter crops grown in part of the command. The seepage loss from this tank as well as percolation loss from the paddy fields can be reharvested through the open dugwell located at down stream of the tank **(Plate 6)**. The well provides water for nursery raising in June and irrigates crops during rainy, winter as well as summer. This system has been found very effective in providing reliable irrigation. Considering the financial condition of the farmers situated in these areas, it is not possible that individual farmers will construct this system on their own and therefore government need to take initiative and construct this system under various watershed development programmes.

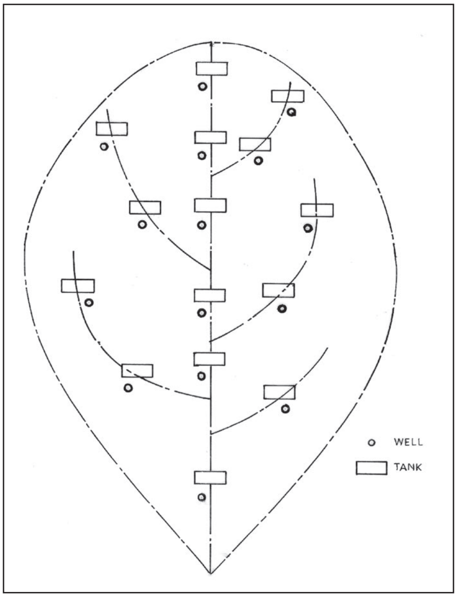

Fig. 2 : Schematic diagram of a series of tanks and wells in a watershed

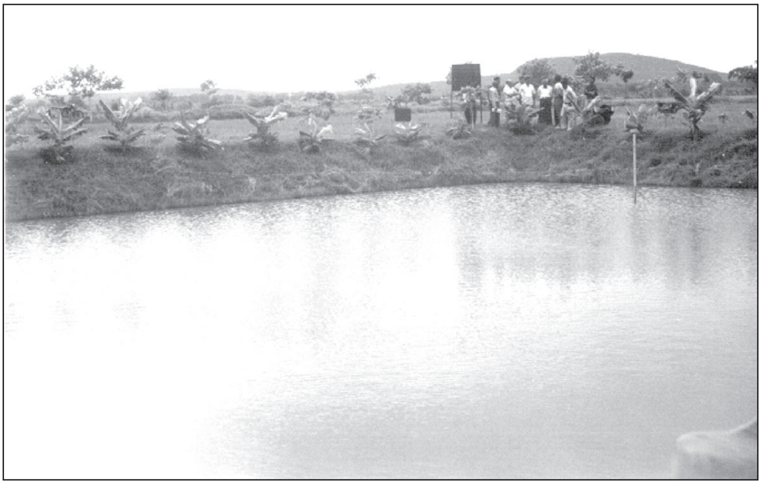

Plate 5 : A tank with horticultural crops in the plateau region

Plate 6 : A well serving as source of irrigation water for growing winter vegetables

Site Selection

This system is suitable for undulating topography with slope varying between 2 to 10%. The area should have a well defined valley where the runoff flows either as overland flow or channel flow. As far as possible, severely gullied area should be avoided. Normally, the water harvesting tanks are constructed in patches and thus, the irrigated areas are isolated plots of land. As majority of the area is rain-fed, the cattle menace becomes a major deterrent for growing second crop in patches. The care of such isolated areas is very difficult and whole purpose of construction of the water harvesting systems is lost. Therefore in this system, it is essential to have tanks and wells in series (Srivastava and Verma, 2003).

Design Considerations

The tank size is a function of the seepage rate of the site. The design parameters will depend upon seepage rates. To estimate seepage rate, a pit of 1 x 1 x 2m should be excavated. The rough estimate of rate of seepage loss can be made by feeling of bottom soil. If soil is clayey, the seepage loss can be expected to be less than 6 mm per day else it will be more than 6 mm per day. If it is very sandy the seepage loss will be more than 10 mm per day. If seepage loss is more than 10 mm per day, the lining of the tank is essential. However before deciding for lined tank, the possibility of alternative sites needs to be explored. One or two inlet pipes are required to be put on the sides of the tanks from where the water inflow is expected. Hume pipes of 30-45 cm diameter are cheaper and can be fabricated on the site itself for this purpose. The construction of spillway may or may not be necessary as per the site conditions. If the pond has to be constructed on a waterway, then spillway is essential else the excess water will flow through fields at its earlier course after attaining full storage level. The tanks are inverted trapezoid in shape. The side slopes should be minimum 1:1. The depth of the tank may vary between 2.5 to 3.5 m. Shallow tanks should be avoided as it entails high evaporation losses. The individual tank capacity should be sufficiently large with minimum being 2000 m^3. Excessive berm should not be left. The embankment should be turfed with grass to avoid erosion. There should be top width of the tank of 1-2 m so that some horticultural crops can be taken up using the harvested water.

Dug wells have been found suitable for this purpose. The open dug wells should be located in the drainage line downstream of the tank where seepage from the tank, percolation loss from paddy fields and seepage from sloping lands on both sides of the drainage line concentrate. In no case, compromise should be made in case of the site of the well. The wells should be placed about 150 to 300 m down stream of the tank for best results depending upon the slope of the site. If the tank is quite big and the recharge to the ground water is more than 15000 m^3, more than one dugwell can be constructed with a spacing of 200-300 m. By thumb rule, one well can be constructed for capturing 10000 m^3 recharge. It has been found that while pumping by a 3.5 hp pump with a discharge of 9 lps, about 80% of the water comes from stored water in the well and the remaining 20% comes from recharge during pumping period. Due to this, wells should be large and 6 m diameter. The depth of the wells may be kept around 8 m. These wells should be fortified by stone masonry against collapse. However to facilitate entry of the water, side gaps between two stones should not be filled up by mortar. The wells need to have about 75cm high parapet above the ground surface to avoid falling of cattle or children.

For irrigation purpose, underground pipelines may be laid connecting both tank and well. The feeder can be connected to the flexible delivery pipe of the pump which pumps water from tank as well as well. The feeder can be two or more depending upon the site of different tanks and wells.

Multiple Use of Harvested Rainwater

In order to increase the productivity of harvested rainwater it is recommended to have short duration fish culture in the tank. Duck rearing can also be taken up as a remunerative option. It has been observed that these two activities contribute quite significantly to the income of the farmer. Further the farmer can utilize the embankment for horticultural crops viz. papaya, vegetables or growing pulse crop like pigeon pea. The benefit from these activities compensate more than the expected returns from the piece of land where the tank is constructed. Thus, the farmer whose land will be used for tank benefiting others also will not feel deprived of but will be happy to get more returns.

Management of Water Resource

It is easy to physically create the system than to maintain and manage for its long term use. Thus, management of created water resource is extremely important. The development of water resources will require involvement of several farmers whose land will be used for construction of tanks, wells and laying of pipelines. Similarly, a group of farmers will be benefited from the created water resource. Thus, the participatory approach of stake holders is essential for proper management. The water resource user association should be formed for a group of manageable water resources and all the resources should be handed over to this body after execution. These groups need to be trained about efficient utilization of the water for irrigation and crop raising. A proper handling of this matter will ensure (i) equity both among land owners as well as landless persons, (ii) withdrawal syndromes do not affect the working of the system, (iii) equitable distribution and conflict resolution among different users as well as different usage of water like fishery and duckery.

Inference

There exists a huge potential of creating water resource through a network of tanks and wells. This potential can be utilized only if suitable interventions are devised both at research, administrative and social management levels. Research efforts are required to develop methodologies for designing the network, tillage practices, irrigation methods, cropping systems compatible to the agro-climatic conditions and socio-economic conditions. Administrative procedure needs to be fine tuned to shoulder the responsibility with a changed mindset and accountability of final outcome. Social management institutions/methodologies need to be developed for long term maintenance and management of structures.

Micro-Catchment Rainwater Harvesting

Micro-catchment water harvesting is defined as a method of collecting surface runoff from a contributing area over a flow distance of less than 100 m and storing it for consumptive use in the root zone of an adjacent infiltration basin **(Fig. 3).** The main idea

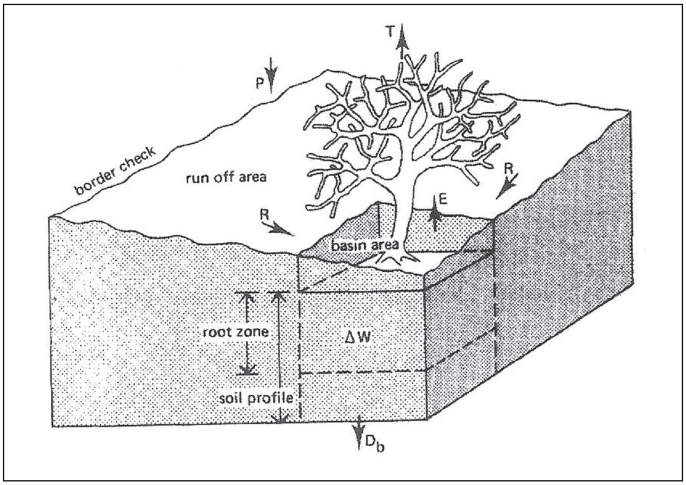

Fig. 3. Definition sketch of micro-catchment rainwater harvesting

behind micro-catchment water harvesting is that water is collected and stored in the soil during relatively wet period for use during dry period.

Micro-catchment water harvesting can be used to capture rainwater to improve soil-moisture and vegetation. After transplantation, rainwater harvesting can be used to speed up tree/crop establishment, deep root development and to reduce mortality rate. Water harvesting could increase crop productivity and diversity, decrease soil erosion and rehabilitate degraded lands. A higher runoff efficiency of micro catchments can capture a large proportion of the rainfall as run-on and concentrate this additional water for establishment of crops / trees. Deciding the micro-catchment area to cultivated area is of paramount importance. Micro-catchment area is a function of active root depth, soil water holding capacity of the soil, runoff coefficient, cultivated area, rainfall and actual evaportranspiration.

This technique of water harvesting has done considerable attention of the researchers for the arid and semi-arid region. Very little work has been done for humid and high rainfall areas where almost 75 to 80% of the rainfall occurs during monsoon season of four months duration and the crop suffers from severe water deficit problem in the remaining eight months period of the year. Thus there is an urgent need to scientifically address the micro-catchments water harvesting practice for horticultural and tree crops grown in humid and high rainfall areas. To address some of the above mentioned issues presently research is in progress on micro-catchment rainwater harvesting for horticulture crops at DWM research farm.

Conclusion

Rainwater conservation of is an age old practice. Different techniques have been developed for different climatic conditions and crops grown. As the demand for irrigation water is increasing day by day, conservation of rainwater is gaining more and more importance with effective utilization of the conserved water. The productivity of conserved rainwater can be increased through multiple uses. With the adoption of proper package of practices, the farming community can be greatly benefited through location-specific conservation measures.

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Soil and Water Conservation Measures for Management of Arid Lands

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Soil and water are two essential natural resources for sustaining life and environment. Since advent of human race on the earth these resources are being used for various purposes. The prosperity of mankind on the earth depends to a great extent on these resources and their management. In nature, soil and water resources are often in a fine balance however, with unprecedented increase in human and livestock population; demand for food and fodder have increased tremendously and these resources have been exploited indiscriminately. Though nature has its own process of resource build-up but the present rate of exploitation is much faster than the natural process of resource build-up, thus leading to imbalances in the nature. The imbalances in natural resources had resulted in reduction in productivity of land to sustain human development. Available natural resources of a region form a vital part of ecosystem.

Arid ecosystem is among the world's most fragile ecosystems made more so by periodic droughts and increasing over-exploitation of meager resources. Arid environments are extremely diverse in terms of their land forms, soils, fauna, flora, water balances and human activities. Because of this diversity, no practical definition of arid environments can be derived. However, the one binding element to all arid regions is aridity. Aridity is usually expressed as ratio of mean annual precipitation (P) to the mean annual potential evapotranspiration (EPT) where potential evapotranspiration is calculated by method of Penman, taking into account atmospheric humidity, solar radiation, and wind. UNEP (1997) has recognized four main classes of aridity: hyper-arid (P/EPT < 0.03), arid (0.03 < P/EPT < 0.20), semi-arid (0.20 < P/EPT < 0.50), and dry subhumid (0.50 < P/EPT < 0.65). The term "arid zone" is used here to collectively represent the hyper-arid, arid, semi-arid, and sub-humid zones. Of the total land area of the world, the hyper-arid zone covers 4.2 percent, the arid zone 14.6 percent, and the semi-arid zone 12.2 percent (FAO, 1989). Therefore, almost one-third of the total area of the world is arid land and is inhabited by about one billion people, a large proportion of them are being the poorest in the world (Malagnoux *et al.,* 2007).

Arid Zone Climate

The arid region of India is spread in 38.7 million hectare (M ha) area out of which 31.7 M ha is under hot arid zone and 7 M ha under cold arid zone. The hot arid region occupies major part of north-western India (28.57 M ha) between 22°30' and 32°05' N latitudes and from 68°05' to 75°45' E longitudes, covering western part of Rajasthan (19.6 m ha, 69%), north-western Gujarat (6.22 M ha, 21%) and 2.75 M ha in south-western part of Haryana and Punjab (Faroda *et al.,* 1999). The climate of Indian hot arid zone is characterized by an abundance of solar energy from cloud-less sky, high diurnal and seasonal temperature variations and annual and inter-annual irregular rainfall with long dry seasons associated with strong winds. Annual rainfall is approximately in the range 100-500 mm, with a coefficient of variation varying from 40 to 70% (Rao and Singh, 1998). The rainfall results largely from convective cloud mechanisms and is characterized by a relatively high intensity, short duration and limited aerial extent. The distribution of rainfall in space is very much influenced by the local terrain. With low ground level and little topographic relief, it is common to see rain evaporating before reaching the ground. The incoming radiation ranges from 15.12 to 26.50 MJ m^{-2} day^{-1} with very little cloud for most of the year. The annual potential evapotranspiration ranges from 1400 – 2000 mm $year^{-1}$ leading to a permanent negative water balance (Rao, 2009).

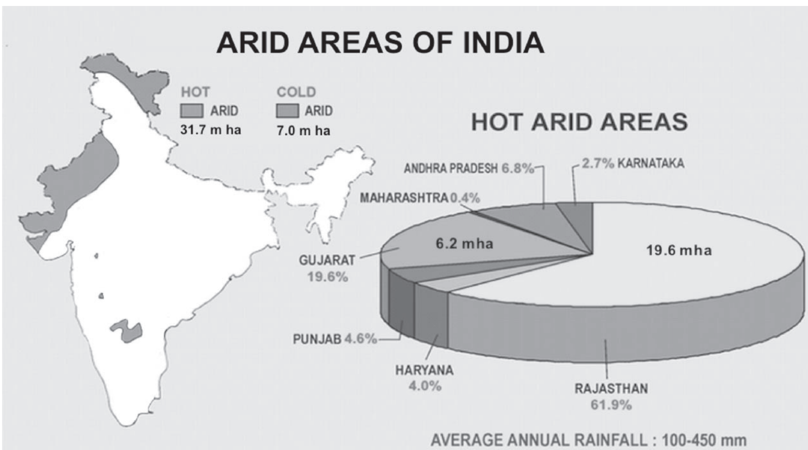

Fig. 1 : Distribution of Arid areas of India

The soils in arid regions, as a result of these climatic conditions, are characterized by large variations in soil moisture, ground-water storage and high infiltration rates. A dominant feature of these soils is their susceptibility to erosion and degradation by wind, water and human activities. There are frequent dust and sand storms. The surface water resources are meager and directly resulted from rainfall and dry up during the rainless season. Groundwater is deep and often brackish. During the twentieth century, the region has experienced agricultural drought once in three years to every alternate year in one or the other part of the region. The overall probability of drought is 47%. The weather condition, even in average years, for most part of the year remains too dry and inhospitable for successful growth of crops. Under such conditions of uncertainty, conventional cropping is risky and is essentially for sustenance only (Goyal and Vittal, 2009).

Challenges for Arid Lands

Everywhere in the world where people changes a natural ecosystem, the land degrades. The major challenge before arid lands is desertification. The UNCCD defines desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". The most commonly cited forms of unsustainable land use are over-cultivation, overgrazing, deforestation, and ill-considered irrigation practices. Soils are being mined of nutrients at an alarming rate (Smaling, 1997; Van der Pol, 1992). Periodic droughts debilitate and destabilize poor societies, and contribute to land degradation by reducing vegetative cover and water supplies, triggering a desperate exploitation of the remaining resources in order to survive. The major physical manifestation of desertification in hot arid zone of India is wind erosion/deposition, followed by water erosion, as well as water logging and salinity (Ghose *et al.,* 1977). Wind erosion is a major problem in arid sandy tract of north-western India, especially in west Rajasthan. About 76 % area of western Rajasthan is affected by wind erosion, encompassing all major land uses, followed by vegetation

Fig. 2 : Wind erosion is a severe problem in western Rajasthan

degradation (3%), water erosion (2%), salinization (2%) and about 0.10% area by mined spoiled degradation (Kar, *et al.,* 2009). Despite the present state of land degradation, Indian hot arid region supports 22 million human and 29 million livestock population over 19.6 M ha geographical area. The human: animal ratio ranges from 1:1.3 to 1:5 in hyper arid regions against a national average of 1: 0.5. (Narain and Goyal, 2009). Acute human and biotic pressure has put tremendous pressure on the fragile water and land resources of this region. Desertification, manifested in different forms of degradation has been a challenging issue to the arid zone of India.

The Central Arid Zone Research Institute, Jodhpur was established in 1959 to combat desertification and evolve sustainable land management technologies. Over five decades of research the Institute has evolved technologies of soil and water conservation for the management and sustainable development of the arid lands.

Soil and Water Conservation Measures for Management of Arid Lands

There are always strong links between measures for soil conservation and measures for water conservation, and this applies equally to arid lands. Many measures are directed primarily to one or the other, but most contain an element of both. Reduction of surface run-off by structures or by changes in land management will also help to reduce erosion. Similarly, reducing erosion will usually involve preventing splash erosion, or formation of crusts, or breakdown of structure, all of which will increase infiltration, and so help the water conservation (Hudson, 1987). Measures for soil and water conservation can be divided into two main categories i.e. physical/engineering measures and biological measures. While the physical measures are the first line of defense and are very necessary to prevent immediate damage, biological measures are the offensive attack made from a position of good defensive strength. Physical measures consist of construction of mechanical barriers across the direction of flow of water to retard/retain the runoff and thereby reduce soil and water losses. Biological measures like vegetative barrier, windbreak/shelter belt, stubble mulching is very effective for moisture conservation and controlling soil erosion due to wind and water. A proper combination of both mechanical and biological measures is prerequisite for resource conservation and sustained crop production. Conservation measures can also be classified on the basis of their utility for particular land use i.e. arable and non- arable lands. The basic objectives of any conservation measures for arid regions are;

- Increasing the time of concentration for rainwater and thereby allowing more runoff to be absorbed and held in soil profile;
- Intercepting a long slope into several short slopes so as to maintain less than a critical velocity for runoff water
- Protection against damage owing to excessive runoff and conserving moisture.

Conservation Measures for Arable Lands

Arable lands are those lands which can be used for growing crops. The arable lands include net sown area and current and other fallow lands. Land capibility classes I-IV comes under arable lands. On short term basis these lands have very little limitations for crop production, however, on long term basis these lands need some management practices for conservation of soil and water. About 63.67% area of western arid Rajasthan comes under arable land. These lands suffer from varying levels of soil depth, slope, drainage and erosion limitations, however with proper soil and water conservation measures these lands can be used for crop production on sustainable basis.

Contour Farming

Contour farming is beneficial on all slopes where line sown is adopted. All ridges and rows of plants are placed across the slope to form continual series of miniature barriers to water and offer maximum opportunity for infiltration.

Fig. 3 : Contour farming for soil and water conservation

Contour operations reduce the power of the water to erode, suspend and carry away soil particles and increase the moisture storage. Increased uniform moisture storage can boost up the yield above 10%. Contour farming alone cannot control runoff volume from higher sloppy lands which may need bunding and grass waterways in natural drainage. For small fields with uniform slopes, one contour guideline is enough and where slopes are irregular two to three guidelines may be enough for farming operation. Contour farming is most effective on moderate slopes of 2 to 7%. Contour farming is reported to reduce soil loss upto 60 % in comparison to up and down farming on 1% slope (Smith and Wischmeier, 1962).

Contour Bunding

Contour bunds are narrow base trapezoidal earthen embankment on contour, 1.5 to 2 m wide, constructed across the slope to act as barriers to runoff, to form water storage area on their upslope side and to break up a long slope into short segments. Contour bunds are recommended upto 6% slope and rainfall of upto 600 mm. Contour bunds are not suitable for shallow soils having depth less than 7.5 cm. Spacing between contour bunds is usually expressed in terms of vertical interval (VI), which is the difference in elevation between two similar points on two consecutive bunds. The principle involved in fixing the spacing between two bunds is to keep the velocity of water below critical value in order to avoid scour. Vertical interval is generally expressed as a function of percent slope (s)

$$VI = 0.305\left(\frac{s}{a} + b\right)$$

Where VI = vertical interval between consecutive bunds in m
s = land slope in percent
'a' and 'b' are constants specific to particular region

For soils having good infiltration rates value of 'a' and 'b' are 3 and 2 respectively. For soils with low infiltration rate the value of 'a' and 'b' may be taken as 4 and 2 respectively. The horizontal interval (HI) is related to vertical interval (VI) by following equation

$$HI = \left(\frac{VI}{s} x100\right)$$

Depth of impounding in calculated on the basis of maximum rainfall of 24 hours for 10 years recurrence interval as follows

$$h = \sqrt{\frac{\text{Re}\, xVI}{50}}$$

Where 'h' is height of impounding (m) Re is 24 hours maximum rainfall (cm) for 10 years recurrence interval. Total height of bund H can be found out by adding 20- 25% freeboard to height of impoundment. For light red loam and sandy loam soils, the side slope of both the sides is taken as 1.5: 1 whereas for sandy soils it is taken as 2:1. The line of seepage should not cross the bottom of the bund while deciding the other dimension of the bund. On average, contour bunds had 27 percent higher soil moisture and 14 to 181 percent higher fodder yield than flat surfaces on grasslands of western Rajasthan (Wasi-Ullah *et al.,* 1972).

Contour Vegetative Barriers

Contour vegetative barriers are hedgerows of perennial grasses or shrubs planted at a regular interval on contours for conserving soil and water in sloping lands. Suitable grass species are grown along contours at suitable vertical interval to intercept part of runoff and to control erosion in agricultural fields having flat to slight undulating topography. The contour vegetative barrier moderates the velocity of overland flow and traps silt at low cost, and augment production of food, fuel and fodder or fibre from lands by growing suitable vegetation species. In recent years, contour vegetative barriers have found acceptability among the farmers as these are cheaper than mechanical measures and are protective while being productive. Contour vegetative barriers can be easily established across a wide spectrum of soil-climatic conditions. Selection of species depends upon purpose of barrier, site-specific conditions, particularly soil and climatic variables. The spacing between plant-to-plant and row-to-row is governed by vegetation species to be planted as barrier. In general the plant-to-plant spacing of 20 to 30 cm at predetermined or 50 to 100 cm vertical interval between the barriers has been found effective for soil and water conservation. Generally, paired row of barrier planted in staggered form across the slope proves more effective.

Generally, dominant grass or shrub species of the region should be preferred for vegetative barrier. Among grasses *Cenchrus ciliaris, Cenchrus setigerus, Saccharum bengalense, Vetiveria zizanioides, Lasiurus sindicus, Panicum antidotale* and *Panicum turgidum* can be effectively used for soil and water conservation in arid areas. Shrubs like *Leptadenia pyrotechnica, Ipomoea carnea* and *Euphorbia antisyphylitica* can also provide good protection against water and wind erosion. Contour vegetative barriers of *Cymbopogan jwarancusa, Cenchrus ciliaris* and *Cenchrus setigerus* transplanted at 0.30 m apart on contours at 0.6 to 1.0 m vertical interval in sandy loam soil of Jodhpur (Rajasthan) have performed well and formed effective barriers in reducing soil erosion and increasing soil moisture storage. In a study conducted during 1992-1994 at 19 farmers fields near Jodhpur rooted slips of local eight species of perennial grasses (*Cenchrus ciliaris, Cenchrus setigerus, Cymbopogon jwarancusa, Lasiurus sindicus, Panicum antidotale, Panicum turgidum, Saccharum bengalense* and *Vetiveria zizanioides*) and seedling of six species of shrubs (*Agave americana, Aloe barbadensis, Barleria prionitis, Euphorbia antisyphylitica, Ipomoea carnea* and *Leptadenia pyrotechnica*) were transplanted at 1 m vertical interval on contours across the slope. Results indicated that perennial grass species performed the best and formed effective barrier against soil erosion. Runoff volume and specific peak discharge were reduced by 28 to 97% and 22 to 96% respectively (Sharma *et al.,* 1999; Tiwari and Kurothe, 2006). In another study conducted at Kalyanpur (Distt. Barmer) during 1998, vegetative barrier of *Lasiurus sindicus, Saccharum munja* and *Cassia angustifolia* were established at horizontal interval of 30 m. The moisture data revealed 36.5%, 72% and 54.2% higher moisture storage as compared to control in *Cassia angustifolia*, *Lasiurus sindicus* and *Saccharum munja* respectively (Gupta and Rathore, 2002).

Graded Bunds

Graded bunds are used to dispose off safely the excess water from the agricultural fields to avoid water stagnation. Graded bunds are suitable in areas where annual rainfall is 500 mm and if the soils are highly impermeable. Graded bunds usually have wide and shallow channels and earthen bund laid along a predetermined longitudinal slope. As graded bunds are essentially means for the safe disposal of excess water from cropped lands, suitable outlets are required to be constructed on graded bund. Draining of excess water from one plot to another through outlets provided in the bund requires special attention since considerable amount of soil may be lost through these outlets. Provision should be made to arrest the silt and allow only clear water to flow away. The vegetated watercourse strengthens the system. In areas with high rainfall where the volume of water to be disposed from one plot to the next lower level plot is large and the vertical interval between the plots is reasonably high, a site specific outlet design like a pipe outlet, drop structure etc. must be provided for safe disposal of the excess water. Graded bund is reported to reduce the run-off from 20 to 4.8 per cent and soil loss from 24 to 4.12 t ha^{-1} yr^{-1}. Besides other benefits intercropping on contour resulted in 48 per cent higher grain yield (Singh *et al.,* 1997).

Grass Waterways

Grass waterways are developed for safe disposal of excess water from agricultural fields. These may be natural or man made courses protected against erosion by suitable grass cover. Grass waterways are also used for channalising and regulating runoff flows for water harvesting purposes. The best location for waterways is a natural depression or along valley line. These may also be constructed along field boundaries for safe disposal of excess rainfall from agricultural fields. Vegetative waterways may be located in all classes of lands except hard rocks, where construction may be difficult. The cross section of waterways may be trapezoidal, triangular or parabolic with shallow depth and flat side slope to facilitate easy movement of man, animal and machinery. The depth of waterways may be kept within 20 to 50 cm and side slope more than 4:1. The channel should have free board of 15 cm. The channel cross-section and bed slope should be such that the computed velocity is within permissible limit (Singh *et al.,* 1990). Cost of construction of grass waterways depends upon type of soil, channel cross-section, length of channel and grass plantation technique.

Shelterbelts

In arid zones, the harsh conditions of climate and the shortage of water are intensified by the strong winds. Living conditions and agricultural production can often be improved by planting trees and shrubs in protective shelterbelts which reduce wind velocity and provide shade. Shelterbelts are barriers of trees or shrubs that are planted to reduce wind velocities and, as a result, reduce evapotranspiration and prevent wind erosion; they frequently provide direct benefits to agricultural crops, resulting in higher yields, and provide shelter to livestock, grazing lands, and farms. Shelterbelt when planted across and on the margins of agricultural fields effectively protects crops and controls sand drifting (Ganguli and Kaul, 1969). The effectiveness of shelterbelt in reducing wind velocity depends on wind velocity itself, direction, shape, width, tree height and density etc.

Trees for shelterbelt are planted at right angles to the prevailing wind direction. If the wind direction changes frequently a checkerboard pattern of plantings is required. Otherwise only parallel lines are needed. From 2-5 rows of fast growing trees of different heights should be planted to prevent any possible breaks in single rows, which would create a tunneling action with high and dangerous wind velocities. The shape of shelterbelt should be pyramidal in structure, i.e., tallest trees should be in centre followed by flank rows of medium height trees and lateral rows should be of bushy plants or shrubs. Windbreaks should be partly permeable to prevent turbulence. A permeability of 30-40% is considered the optimum. The distance between shelterbelts should be about 20 times the expected height of trees after 5-7 years of growth. No cutting for firewood should be permitted in shelterbelts. In an experiment a three rows shelterbelt in which *P. juliflora* shrubby thicket was used as outer rows with central row of *Albizzia lebbek* reduced wind speed from 12% at 10H (height) distance from shelterbelt to 33% at 2H distance during summer season (Gupta *et al*., 1984). The following trees/shrub species are recommended for shelterbelt plantation in arid areas.

Flank rows	:	*Prosopis juliflora, Zizyphus nummularia, Acacia bevinosa, calligonum polygonoides*
Lateral rows	:	*Cassia siamea, Tamarix articulata, Acacia tortilis, Parkinsonia aculeata*
Central rows	:	*Azadiranchta indica, Albizza lebbek, Acacia nilotica, Ailanthus excela, Hardwickia binnata, Eucalyptus cameldulensis*

Fig. 4 : Shelterbelt plantation for wind erosion control, CAZRI farm - Jodhpur

Conservation Measures for Non –Arable Lands

Non-arable lands are those lands, which do not fulfill their life sustaining potential. These can result from inherent / imposed disabilities such as by location, environment, chemical and physical properties of the soil or financial or management constraints. In arid zone of western Rajasthan alone, about 7 million hectares area is classified as wasteland. The area under wasteland is further increasing because of over-exploitation and improper land use, to meet increasing demand for food, fodder and fuel. Also, cultivable area is decreasing because of increasing urbanization, mining and other economic activities. So there is need to develop these wastelands appropriately for sustained and improved fodder production. The adoption of dryland conservation technologies can significantly increase productivity and profitability in these areas (Halvin and Schlegel, 1997).

Contour Furrowing

Contour furrowing is the most effective measure to reduce runoff and soil loss, increase in yield and commonly adopted in grasslands and forestlands. However, in very sandy soils or soils with heavy clay pan area, their benefit is limited. Contour furrows varying from 30-60 cm wide and 10-25 cm deep can be used. The shape varies from "V" to square, rectangular, or parabolic. The cross section and depth of furrows mainly depend on soil and equipment used for making them. Furrows spaced 8-10 m apart give a better distribution of runoff water and higher yield of fodder. The effectiveness of contour furrows to hold water depends upon the degree of slope smoothness of the surface and accuracy in following contours and its life depends upon stability of soil and water storage capacity of the furrow, which can be estimated by following equation.

$$Q = \frac{WxD}{100HI}$$

Where,
- Q = Depth of runoff water stored in cm from unit area
- W = width of furrow, (cm)
- D = depth of furrow, (cm)
- HI = horizontal spacing, (m)

Construction of contour trenches is always started from the ridge and progressively extended towards the valley. In a study conducted in arid part of Iran it is found that contour furrow and pitting has significantly helped in controlling soil erosion, increasing water penetration and soil moisture content and promoted propagation of *Hammada saliconica* species, a desirable plant species for both soil conservation and livestock grazing in the region (Jahantigh and Pessarakli, 2009).

Contour Trenches

A contour trench is a useful practice in forestry areas. This practice can be adopted in area which is unsuitable for cultivation but suitable for forestry. Normal standard size of a trench is 60 cm x 30 cm x 60 cm depth with an unexcavated portion 1.5 m after every 50-75 cm. Length spacing or vertical interval depends on the slope of land. Spacing may vary from 30-60 m. After the trenches are excavated to correct size, they are refill partially, and stocking the remaining excavated material as a small bund on the down stream side. The storage capacity of trench is estimated by the following equation.

$$Q = \frac{WxD}{100HI\left(1 + \frac{X}{L}\right)}$$

Where, Q = depth of runoff from area in cm
W = width of trench in cm
d = depth of trench in cm
HI = horizontal interval in meters
X = gap between the trenches in m
L = length of trench in m

Mane *et al.,* (2009) reported effectiveness of continuous contour trench for runoff control and recommended as best soil conservation practice on area having 7 to 8 per cent slope in Konkan region of India.

Gradonies

Gradonies are steeply inward-sloping narrow bench terraces constructed on contours. Usually, gradonies are suitable for afforestation in uniformly steep sloping lands. Based on the steepness of slope, vertical interval is kept from 1.0 to 1.5 m. The width of gradonies also varies from 1.0 to 1.5 m. The material dug from the inner side is heaped on the outer edge in order to make a berm of about 20 to 30 cm high with an inward slope of 7.5:1. In the middle of the gradonies, pits of 50 cm x 50 cm x 50 cm are made at spacing of about 3 m. On an average 1000 trees are planted within the gradonies and interspaces in one hectare area (Mahnot and Singh, 1993).

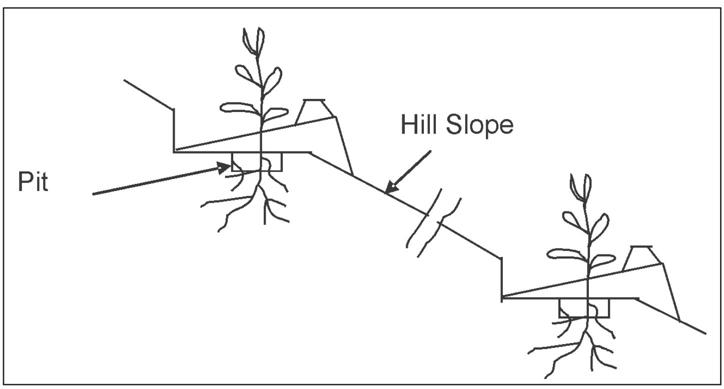

Fig - 5. Cross section of a Gradoni

Gully Control Measures

About 4 million hectares in India are affected by gullies and ravines that threaten another 4-6 million hectares of productive tablelands. On marginal farmland, gully erosion is major source of soil and associated nitrogen and phosphorous losses (Sharpley *et al.,* 1996). However, with proper management, the gullies can be utilized to store runoff for groundwater recharge and human and livestock consumption. In western countries, construction of gully control works was initiated as far back as 1900. However, in India, such works have been taken up on an extensive scale since 1960 in Gujarat, Maharashtra, Madhya Pradesh and Rajasthan.

Anicut / Check Dams

Check dams are masonry overflow barriers (weirs) constructed across seasonal streams. A check dam as such has a relatively limited storage capacity but a large volume of water can still be pumped from such storage as the stream continues to flow and the check dam serves the purpose of an ideal intake structure. A check dam, by storing the base flow, maintains a supply of water for recharge as well as for direct use beyond the monsoon period (Goyal and Narain, 2006). It creates flooding of upstream area, which requires surplusing arrangements at suitable intervals to drain water. Check dam should be avoided in isolation. The number of check dams primarily depends upon the slope of the gully and the quantity of runoff. It may not be advisable to construct check dams on bigger streams with high gradient and where runoff is very high. The bigger streams should be treated with drainage line treatment like gabionic structures and boulder checks with masonry work to curtail the runoff.

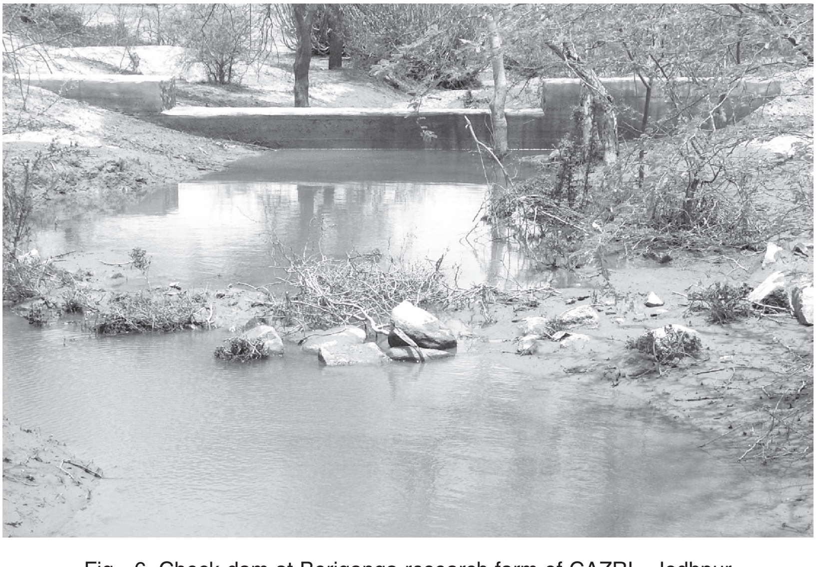

Fig - 6. Check-dam at Beriganga research farm of CAZRI - Jodhpur

Gabionic Check Dams

Gabionic check dams are useful in a locality where stones are readily available and their irregular shape makes them unsuitable for making loose stone cheek dams. If the expected water velocity is very high, gabion is recommended in place of loose rock dams. A gabion is rectangular shaped cage made of galvanized wire, which is filled with locally available boulders, rocks or stones. The gabion may be conveyed flat and are folded to shape at the construction site. Usually, gabions are 1 m wide and 0.75-12 m high with varying lengths ranging between 2-10 m. The gabionic check dams are constructed by connecting several gabions in horizontal and vertical direction. The gabionic check dams are very stable and semi-permanent in nature. These structures are flexible; they may even change shape automatically according to the streambed, even when the bed shape changes due to erosion, without losing stability.

Loose Stone/Dry Stone Masonry Check Dams (LSCD)

These structures are effective for checking runoff velocity in steep and broad gullies. These are suitable at upper reaches of the catchment. They have a relatively longer life and, usually require less maintenance. The bed of the gully is excavated to a uniform depth of about 0.3m. Stones are then hand packed from the foundation level. Flat stones of size 20-30 cm are the best for construction and laid in such a way that all the stones are

Fig - 7. A series of loose stone check-dams (LSCD) at gully in Jhanwar Watershed (Jodhpur)

keyed together. Large size stones are placed at the center of the dam and gaps between stones may be filled with small piece stones. The dam should go up to 0.3 to 0.6 meter into the stable portion of the sides of the gully to prevent end cutting. In the center of the dam, sufficient spillway is provided to allow maximum runoff to discharge. LSCD constructed at 1 m V.L. in Jhanwar watershed area on 17 gullies proved to be very effective in controlling further extension of gullies (Goyal, *et al*., 2007). Vangani *et al*., (1998) reported sediment deposition of 3.86 t ha^{-1} yr^{-1} against loose stone check dam in Osian-Bigmi watershed (Distt. Jodhpur).

Brushwood Check Dams

These check dams are constructed by using locally available brushwood and supported by wooden stakes and used in the small gully heads not deeper than 1 m. These check dams are of two types; single row post brush dam and double row post brush dam. Brushwood check dams are constructed in areas where wooden posts, brushwood etc., are available in plenty. These check dams can only be used in the small gully heads not deeper than 1m. Single row post brush dam is made of single row of wood stakes to which long branches of trees are tied length-wise along gully with their butt ends facing upstream while in double row post brush dam, the straw and brushwood are laid across the gully between two rows of wooden posts, the distance between the rows being not more than 0.9 m. The longest branches are laid at the bottom and the shorter length branches are laid above it till the required dam height (0.3 to 0.7 m) is obtained.

Rainwater Harvesting for Arid Lands

Since primary source of water in arid zone is rainwater, so for any improvement in availability of water, catchment conditions become crucial. Catchment is the base for harvesting rainwater in form of runoff. Runoff is highly dependent on catchment's shape, size, slope, and type etc. beside rainfall characteristics. Goyal and Issac (2009) has estimated runoff coefficients for different catchments characteristics for hot arid zone of India. Some general modifications can greatly help in enhancing the runoff percentage from catchments.

Techniques for Enhancing Runoff from Catchments

1. Simple earth smoothing and compaction helps increasing runoff from catchment areas. Success is generally greater on loam or clay loam soils. Care must be taken to reduce the slope and/or the length of slope to lessen runoff velocity and thereby reducing runoff.

2. Small amounts of sodium salts - particularly NaCl, $NaHCO_3$ applied to desert soils where vegetation has been removed- causes dispersion of the surface soil, reducing infiltration and increases runoff. However, this type of treatment requires a minimum amount of expanding clays in the soil.

3. Removal of stones and boulder and unproductive vegetation from catchment helps in uninterrupted flow, enhances runoff to collection site.

4. Land shaping into roads and collection of water in channels.

5. Sandy soils have low water holding capacity. Spreading of clay blanket to the soil surface reduces the infiltration and consequently accelerates runoff.

6.. Chemical treatments like wax, asphalt, bitumen and bentonite prevent downward movement of water, which augments runoff.

Rainwater Harvesting through Tanka

Tankas (small tanks) are underground tanks, found traditionally in most part of western Rajasthan. They are generally built in the main house or in the courtyard. *Tanka* is a circular hole made in the ground, lined with fine polished lime for collection of rainwater primarily from rooftop of individual house. The water collected in small *Tankas* is generally used for drinking purposes, however bigger tanka can be used for providing supplemental/ life saving irrigation to horticultural plants. During subnormal rainfall when tanka did not get adequate rainwater, water is hauled in camel/bullock cart from nearby wells/ *nadis* to fill the household *tankas*. For rainwater management, CAZRI has designed underground *tanka* of 10 m^3 to 600 m^3 capacities for different rainfall and catchment conditions. These *tankas* were successfully constructed in Jhanwar, Sar, Baorali-Bambore (Distt. Jodhpur) and Kalyanpur (Distt. Barmer) villages. Harvested water of these tankas was used to provide life saving irrigation to plants. The benefit-cost ratio of tanka ranged

Fig. 8 : Improved *tanka* of 21 m^3 capacity at Baorali village (Distt. Jodhpur)

from 1.25 to 1.40 under different uses (Goyal *et al.*, 1995, 1997; Goyal & Sharma, 2000). The improved design of tanka has provision for inlet and outlet with silttrap for control of silt inflow with runoff. The catchment of a *tanka* is made by spreading the excavated material around the structure. With a view to inducing the runoff, the catchment may be treated either with asphalt or sodium carbonate spray on soil surface. A uniform slope of 2-3 per cent towards *tanka* is provided for harvesting maximum possible runoff. The improved design of tankas have a lifespan of more than 20 years. The improved *tanka* design developed at CAZRI has wide acceptability in the region, which has been widely replicated in large numbers under Rajeev Gandhi National Drinking Water Mission.

Rainwater Harvesting through Nadi

Nadis are village ponds used to store runoff water from adjoining natural catchments during the rainy season. In arid Rajasthan *nadi* system of water harvesting is the oldest practice and still the principal source of water supplies for human and livestock consumption. Across Rajasthan, most *nadis* have a capacity of 1,200 to 15,000 m^3. Water availability in *nadi* ranged from 2-12 months after the rains. Since *nadis* received runoff from sandy and eroded rocky basins, large amounts of sediments used to deposit regularly in them, resulting in quick siltation. High evaporation and seepage losses through porous sides and bottom, heavy sedimentation due to biotic interference in the catchment and contamination are major bottlenecks. Evaporation losses ranged from 55 to 80% of the total losses in various environments. Seepage losses are greatest during the rainy season (July-September) when *nadi* is completely filled. To overcome these problems CAZRI has developed design for improved *Nadis* with LDPE lining on sides and bottom keeping surface to volume ratio 0.28 and provision of silt trap at inlet (Khan, 1989).

Fig. 9 : Improved nadi with inlet and outlet

The site selection of *nadi* is based on availability of natural catchment and its runoff potential. The location of the *nadi* had a strong bearing on its storage capacity due to catchment and runoff characteristics. *Nadis* are 1.5 to 4.0 meters deep in dune areas and those in sandy plains varied from 3 to 12 meters. In addition, planting suitable tree species around the *nadi* creates an oasis in the desert and improves the local environment.

Rainwater Harvesting through Khadin for Crop Production

Khadin is a unique practice of water harvesting, moisture conservation and utilization in hyper arid region of Rajasthan. This system was designed & developed by the Paliwal Brahmins of Jaisalmer (Rajasthan) in the 15^{th} century. This system has great similarity with the irrigation methods of the people of Iraq around 4500 BC and later of the Nabateans in the Middle East. A similar system is also reported to have been practiced 4,000 years ago in the Negev desert, and in southwestern Colorado 500 years ago. The main feature of *khadin* is a very long (100-300 m) earthen embankment built across the lower hill slopes lying below gravelly uplands. Sluices and spillways allow excess water to drain off. The *khadin* system is based on the principle of harvesting rainwater on farmland and subsequent use of this water-saturated land for crop production. The ratio of farmland and catchment areas is regulated to be about 1:10 so that a suitable moisture supply is uniformly maintained. It is suitable for deep soil surrounded by some natural rock outcrops constituting catchment area. CAZRI has developed *Khadin* of 20 ha areas in Baorali-Bambore watershed with surplussing arrangements. Before construction of *Khadin*, uncontrolled runoff from upper catchment used to wash away seeds, fertilizers, and standing crops besides loss of valuable water. After construction of Khadin, farmer could take excellent *Kharif* and *Rabi* crops (Narain and Goyal, 2005). Collecting water in a *khadin* aids the continuous recharge of groundwater aquifers. Studies of groundwater recharge through *khadins* in different morphological settings suggest that 11 to 48 per cent of the stored water contributed to groundwater in a single season. This replenishment of aquifers means that subsurface water can be extracted through bore wells dug downstream from the *khadin.* The average water-level rise in wells bored into sandstone and deep alluvium was 0.8 metres and 2.2 metres, respectively (Khan, 1996).

Fig. 10 : *Khadin* with wastewier at Baorali-Bambore watershed (Jodhpur)

Rainwater Harvesting through Micro-Catchment for Tree Establishment

Micro-catchment technique is particularly suitable for establishment of trees. In this technique a circular catchment of 1 to 1.5 meter radius is constructed around the tree. The catchment is compacted by roller or any other heavy machine. A slope of 5-10% is provided in catchment towards tree for directing flow of water. The catchment can also be lined with locally available materials such as polythene sheets, lime mortar, stone pieces, grass etc. for higher runoff generation. It is reported that the plants with micro-catchment have better chances of establishment in rainfed conditions as compared to conventional plantation technique (Ojasvi *et al.,* 1999). In another study Sharma *et al.* (1986) suggested that conversion of canopy area into runoff catchment may be just sufficient for improving its soil moisture profile.

Fig. 11 : Circular micro-catchment for tree establishment

Agronomic Practices

All operations carried out in the field, from land preparation to crop harvesting, with the aim of increasing the crop yield are included under agronomical practices. Certain simple agronomical practices like optimum tillage, administration of organic manure, suitable cropping pattern, and strip cropping have been found to be effective in retaining soil fertility as well as giving satisfactory crop yield.

Tillage Operation

Tillage (Ploughing) is the practice of breaking and working the soil to the desired depth prior to sowing. Tillage makes soil loose and hence prone to erosion. Timing and depth of tillage are the two important factors, which need special attention. Tillage should be done immediately before the crop season to take advantage of one or two early showers for land preparation. In arid region, land tilled into ridges and furrows across the wind direction has been found to reduce the effects of wind erosion during the summer months. However excessive tillage before the monsoon lowers the percentage of clods and accelerated the wind erosion (Gupta, 1993). Therefore proper tillage is very important to take advantage of moisture conservation during rain and at same time should avoid soil erosion by wind.

Crop Management

Row crops that are widely spaced are generally erosion-permitting. To reduce the erosion, the plants should be spaced in such away as to obstruct the flow of water downhill by crop itself. A proper combination of row to row and plant to plant spacing goes in long in reducing the soil erosion besides enhancement in yield. For same plant population increase in raw spacing and corresponding decrease in plant to plant spacing help in creating mini barrier to control erosion by water and wind without adversely affecting the yield. Weeds consume water at much faster rate than crop because of smaller life cycle. Elimination of weeds at proper time greatly reduces the competitions for water for the crop. Crops of moth and gaur when kept weed free till maturity produces higher seed yield where as weed infestation after 30 to 40 days of sowing, resulted significant reduction in yield (Singh, 1984). Optimum plant population is important aspect of crop production in arid areas. Higher plant density enhances evapo-transpiration losses relative to non-growth parameter of plant. Higher plant densities do not allow deep percolation of soil moisture as observed in vegetables grown under drip irrigation (Singh, 1978). In arid region, particularly rainfed condition, larger canopy growth may be disadvantageous as it may exhaust the available soil moisture from root zone during drought (Singh, 1977). So in such areas, one has to be more cautious in deciding optimal plant population and row spacing for sustainable crop production. Crop rotation is another practice to maintain the fertility of soil. Crop rotation not only helps to increase the crop productivity and soil fertility, but also improves the water and nutrients use efficiency by reducing weeds, providing conductive micro-climate for plant growth and development.

Strip Cropping

Strip cropping for wind erosion control consists of alternate plantation of erosion susceptible and erosion resistant crop against prevailing wind direction preferably across the slope. In this system soil eroded from one strip is retained by the next strip and the overall fertility of the land is maintained. Narrow strips are more effective in reducing wind erosion in lighter soils. The width of the strip varies from 6 m in sand to 30 m in sandy loam. Establishment of strips of perennials like *Lasiurus sindicus* and *Ricinus communis* at right angle to the prevailing wind direction at CAZRI Farm - Jodhpur, reduced the impact and threshold velocity of wind to the minimum and checked the erosion. Consequently, crop grown in between the protective strips recorded increased production (Mishra, 1971). Reduction in sand drift due to protective strips of grass at Bikaner and Hingoli (Jodhpur) was also reported by Singh (1989). In another study the productivity and quality of fodder was increased by strip cropping of *C. ciliaris* or *L. sindicus* with *L. purpureus* in association with *C. mopane* or *H. binata* under silivi-pastoral system in arid zone (Patidar *et al.,* 2008). Another advantage of strip cropping is that it helps in the prevention of pest attack on the crops. Since pests are mostly crop-specific, one particular strip affected by one particular pest remains confined within that strip itself and does not spread to the next strip, thus preventing the spreading of the diseases to the entire field.

Mulching

Mulching of open land surface is achieved by spreading stubble, trash or any other vegetation. The objectives of mulching are to minimize splash influence of rain drops on base surface; reduce evaporation; increase absorption of the rainfall; obstruct surface flow thereby retarding erosion and allow microbiological changes to occur at optimum temperature. Sometimes, spreading of organic residues, instead of mixing can help in reduction of soil and water loss to a considerable extent. Polythelylene mulches have also been utilized for water harvesting and control of seepage. Trash farming, in which crop remains are cut, chopped and partly mixed in ground and partly left on land surface, is also a form of mulching. Studies conducted at CAZRI have shown that use of organic mulches reduced the maximum soil temperature at 10 cm depth by 1 to 6^{o}C with suppressed weed growth and increase in soil moisture status. Similarly application of grass mulch at the rate of 6 t ha^{-1} resulted in reduced mean maximum soil temperature, reduced evapotranspiration and consequently increase of 40% yield of green gram (Gupta, 1978, 1980).

Fig. 12 : Grass mulch for evaporation control

Conclusion

Worldwide arid zones have witnessed increase in human and livestock population like any other region as a result of natural increase. The increased population pressure has stressed the limited natural resources of this fragile eco-system. Since good lands are already under intense cultivation so focus has shifted towards arid zone all over the world for the crop production. The scientific approach towards understanding the problems of arid region and adoption of proper soil and water conservation technology can greatly help in achieving the goal of meeting the aspiration of its dwellers on sustainable basis.

A successful application of any soil and water conservation measures for improving production requires an integrated approach. In arid areas, conditions vary too much soil, climate, social factors and the list is endless so no two areas are identical, and therefore proper selection of technology for area-specific is must. While designing any structure for area-specific its cost-effectiveness should be kept in mind. It is generally cheap to repair a structure rather than designing a robust costly structure for extreme events of 100 years. All the technologies discussed above are essentially site-specific and different components need to be integrated as a holistic approach to maximize production on sustainable basis. These technologies are time tested and are of proven soundness for extreme conditions such as of arid.

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Optimal Sizing of Rainwater Conservation Structure for Drought Mitigation in Rainfed Agriculture

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In the eastern region of India, supposed to be the rice bowl of the country, the reign of 'Rainfed' has extended over 67% of its net sown area. The mean annual rainfall (1500 mm) received in the region is plentiful and seems to be more than enough to harvest two crops in succession, had it been precipitated uniformly and not drained out from the crop fields unnecessarily. Onset of monsoonal rain, its withdrawal and the pattern of rainfall are quite unpredictable, irregular and erratic in nature resulting in part or complete failure of crops either due to droughts or inundation likely to occur in every alternate year. On an average, two long dry spells during the main crop season are most likely to occur every year out of which the first one coincides with transplanting or *biasi* operation and the second one during the critical stage of the crop growth (Panigrahi *et al*., 2001). Rice is the major crop in the region, grown in rainy season in all topo-sequences including uplands. The average yield of rice in the region is 1350 kg/ha while the all India average is 1746 kg/ha (Anonymous, 1998). A second crop is hardly practiced due to quick loss of residual moisture after the withdrawal of monsoon. Hence, production of oilseeds and pulses and above all, most of the food grains from the region is at par with the other regions of the country.

The major hurdle of enhancing agricultural production in the region is its vast rainfed uplands. Out of 44 Mha of total rice area in India, upland rice occupies 7 Mha. of which 75% (5.2 Mha) is from eastern India only. Rice, an unsuitable pawn in the race, is grown widely in this topo-sequence resulting in an unstable and very low yield (< 1 t ha^{-1}) as reported by Kar *et al*. (2004). Most of the land holders in upland situation are marginal and small farmers, poor in resources. They constitute 58% of the farming community where as only 21% of land area is under their occupation (Verma *et al*, 2004). The soil in this topo-sequence is mostly light textured, highly permeable and have very low water holding capacity accompanied with low nutrient status. Growing rice, a very high water requiring crop, in this ecosystem is definitely not a profitable proposition. A diversification in the existing cropping pattern in rainy season in addition to an assured provision of water for growing a second crop is required to meet the ever increasing demand for cereals, pulses, oilseeds, fibre, fodder and fuel etc. Rejuvenating degraded soil health, which becomes alarming day by day, is also another important factor for enhancing and sustaining production and productivity from the topo-sequence.

Since rice is the staple food of the people in the region, they cannot afford to replace rice completely. Though crop diversification will be a remunerative venture as compared to rice, this has not been acceptable to farmers without provision of supplemental irrigation as well as instant drainage provision. On-farm reservoir technology developed for upland ecosystem seems to be a full proof technology for enhancing production and productivity of the land by enabling the beneficiary to grow a light duty second crop in the same field after harvest of rice crop. In addition to food grains, pisciculture is also another aspect of crop diversification that can be practiced successfully in this harvested water to make the investment paid back quickly (Laxmi et al., 2005). But as the country has become self sufficient in rice production, so situations like distress sale of rice is coming up frequently. On the other hand, a rice crop at the upstream (u/s) of the water harvesting structure obstructs a large amount of runoff to maintain its ponding requirement and also requires equally enough water as supplemental irrigation during its critical growth stage (Rathore et al., 1996). This may be the reason why the reservoir lacks adequate storage before the second crop is sown. So, an assured and optimum return from a second crop from the OFR treated land becomes a chance factor. In this context, a partial crop diversification with high value non-rice crops at the u/s of a rainwater harvesting structure (OFR) and a rice crop at its downstream (d/s) with better management practices under favourable conditions of water availability during rainy season seems to be a suitable alternative to solve the production crisis of rainfed uplands in eastern India.

Objectives

- To predict the hydrological events like onset and withdrawal of monsoon, time and length of dry spells occurring in the region
- To evaluate the feasibility of rainwater harvesting structure for various cropping patterns by simulating the water harvesting potential of the crop fields in the upland situation.
- To simulate the various sizes of the OFRs under different cropping scenarios using water balance model.
- To assess the optimum size of OFR based on economic analysis of the system.
- To assess the feasibility of aquaculture in the OFR.
- To develop a Decision Support System to compute optimum OFR sizes for various land holdings, soil types and climatic conditions.

Theoritical Considerations and Methodology

Behaviour of Hydrological Events in the Region

Fore hand information about effective onset of monsoon and its withdrawal is the basic tool that helps in deciding the time of sowing of the crops, varieties to be chosen and also gives clues to the type of cropping pattern to be adopted for the region. Though it is difficult to predict the time of arrival and recession of the south-west monsoon accurately, the methods used by some researchers namely Ashok Raj (1979) and Verma and Sarma (1990) to predict the events are quite effective in arriving at some conclusion about the probability of the occurrence of the events. The method of minimum moisture content in the seeding zone required for effective germination of seeds and continuity of rainfall event in subsequent days/weeks are used to predict the date of effective onset of monsoon. In case of date of withdrawal of monsoon, the last week's rainfall amount and its pattern was taken into consideration. When the rainfall event either disappears or happens in a very less quantity ($< 2.5mm\ d^{-1}$) and the event continues for more than 10 days at a stretch it is assumed as a long dry spell for rice. When such a dry spell coincides with the period of some important field operations like biasi / transplanting or critical stage of the crop growth, the yield is affected severely. So, the arrival time and length of such dry spells need to be predicted before hand to enable the farmers to make arrangements for meeting such eventualities.

Water Harvesting Potential (WHP) of the Crop Fields

Water harvesting potential indicates the rainfall adequacy to meet the supplemental irrigation (SI) requirement of crops and also establishes the feasibility of the OFR system in the problem area.

$$WHP = SI / Runoff \quad (1)$$

WHP very less than 1 suggests the infeasibility of the OFR system in the area (Guerra et al., 1990; Oweis et al., 1999). When it is greater than 1, a green signal is indicated to go for the OFR system. When it is nearer to 1, the deficiency is met by the direct rainfall collected in the OFR.

Water balance model of the crop fields in upland situation with rice and non-rice crops is developed with the assumption that the total runoff generated from the crop field has to be diverted to an imaginary common reservoir outside the farm area and the SI requirement of the crops will be met from it. It is assumed that the OFR is of unlimited capacity that can accommodate all the runoff generated from both rice and non-rice crop fields.

Two types of models are used in the study such as (i) single layer or static model **(Fig. 1)**; (ii) double layer or dynamic model **(Fig. 2).** The static model assumes that the maximum root zone depth of the crop is a single layer. All the water balance parameters are computed accordingly. Whereas in the dynamic model the root zone is divided into two layers called active and passive layer based on the position of the root system (Hajilal et al., 1998) on the day in question. All the water balance parameters except deep percolation are assumed to occur within the active layer and deep percolation from the passive layer of the soil. Each day the active layer moves below along with the root and the day it reaches the maximum root zone depth of the crop, the passive layer vanishes and the total root zone depth is occupied by the active layer.

Static Water Balance Model for WHP

$$SMC_i = SMC_{i-1} + R_i + SI_i - SR_i - AET_i - DP_i \tag{2}$$

where, i is the time index taken as 1 day in the study (i =1 means date of sowing and so on);SMC_{i-1} is the soil moisture on the previous day; R_i is the rainfall; SI_i is the supplemental irrigation; SR_i is the surface runoff; AET_i is the actual evapotranspiration; and DP_i is the seepage and deep percolation from the root zone of the crop.

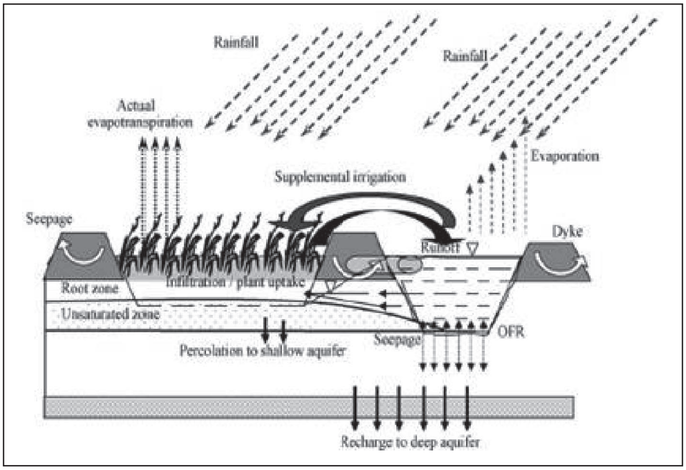

Fig.1 : Schematic presentation of water balance parameters of rice field and the OFR

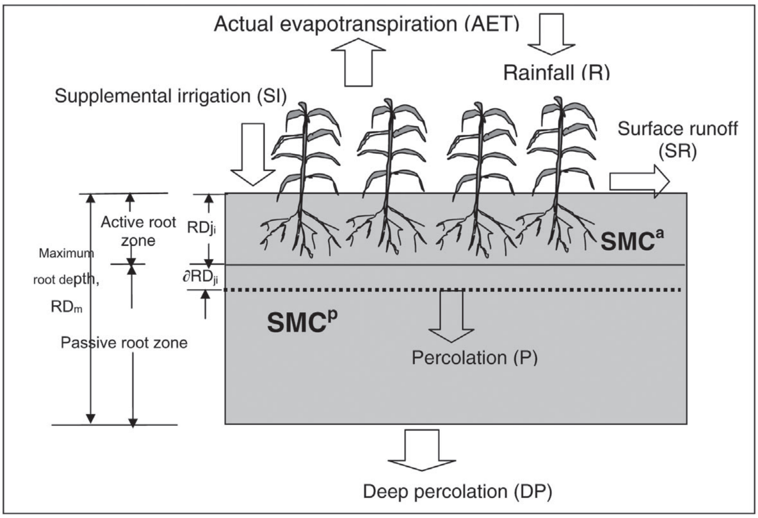

Fig. 2 : Water balance components of two layered root zone

Dynamic Water Balance Model for WHP

Active Layer

$$SMC^{a}{}_{ji}.RD_{ji} = SMC^{a}{}_{ji-1}RD_{ji-1} + R_i + SMC^{p}{}_{ji-1}.\delta RD_{ji} + SI_{ji} - AET^{a}{}_{ji} - SR_{ji} - P_{ji} \quad (3)$$

Passive Layer

$$SMC^{p}{}_{ji}\left(RD_{jm} - RD_{ji}\right) = SMC^{p}{}_{ji-1}\left(RD_{jm} - RD_{ji}\right) + P_{ji} - DP_{ji} \quad (4)$$

where, i = time index taken as 1 day in the study (i =1 means date of sowing and so on); j = type of crop; $SMC^{a}{}_{ji}$ = soil moisture content in the active layer of the crop; $SMC^{p}{}_{ji-1}$ = soil moisture content in the passive layer; RD_{ji}= Root zone depth of crop; ∂RD_{ji} = Incremental root growth of crop (cm); R_i = Rainfall; $AET^{a}{}_{ji}$ = Actual evapotranspiration from active layer of crop; SR_{ji} = Surface runoff from the crop field; SI_{ji} = supplemental irrigation to the crop; P_{ji} = percolation from the active layer to passive layer; and DP_{ji} = Deep percolation from passive layer to down.

Root Depth

Two types of root growth models are available to predict the position of the root system with time. i) Linear root growth model (Bhirud et al.1990), ii) sigmoidal root growth model (Borg and Grimes, 1986). The linear root growth model has been used in the study as the sigmoidal model lacks validity for all types of crops taken under the study.

$$RD_{ji} = RDs + \left(RD_{jm} - RDs\right)\frac{t_i}{t_{jm}} \quad (5)$$

where, RDs is the depth at which the seed is sown; RD_{jm} is the maximum depth of root zone of crop; t_{jm} is the days to attain maximum depth; and t_i = day of simulation after sowing.

Surface Runoff

The surface runoff from crop fields is computed based on SCS-CN method. Under Indian condition SR_{ji} is estimated as:

$$SR_{ji} = \left[\frac{\left(R_i - 0.3S_{ji}\right)^2}{R_i + 0.7S_{ji}}\right] \qquad \text{if } R_i > 0.3\ S_{ji} \quad (6)$$

$$= 0 \qquad \text{if } R_i \le 0.3\ S_{ji}$$

The parameter S is related to the curve number (CN) as :

$$S_{ji} = 254\left(\frac{100}{CN} - 1\right) \quad (7)$$

where, S_{ji} is the maximum storage capacity of the root zone depth of crop; CN is the curve number with respect to CN_2 for the soil cover, hydrologic soil group and crop type etc. CN_1 and CN_3 values are computed as suggested by Sharpley and Williams (1990).

A 5 cm ponding has been allowed in the rice field during 10 days after germination to 10 days before harvest and in this period the runoff will be calculated as:

$$SR_i = SMC_i + R_i - (SAT + 5) \quad \text{when } SMC_i > SAT + 5$$
$$= 0 \quad \text{if } SMC_i = SAT+5 \quad (8)$$

Actual Evapotranspiration

Reference crop evapotranspiration (ET_o) and crop coefficient are the basic parameters required for calculation of actual evapotranspiration (AET). Penman-Monteith equation (Allen et al, 1998) is accepted universally for computation of ET_o and hence the same is used in the study. But when a simulation starts from the day of sowing of the crop in rainy season to the date of sowing of the second crop in post-monsoon period, another two conditions are encountered such as germination period and turn-in period. During these periods, only evaporation from the soil is considered.

AET During Crop Growth Stage

Under crop growth stage two kinds of situations are encountered such as, i) adequate soil moisture condition and ii) deficit soil moisture condition based on management allowed depletion (MAD) level of the crop (Doorenbos and Kassam, 1979).

Adequate Soil Moisture Condition

$$AET_i = PET_i = Kc_i \times ETo_i \quad \text{when } (SMC_i - WP) = (1 - p)(FC - WP) \quad (9)$$

Deficit Soil Moisture Condition

$$AET_i = \left[\frac{(SMC_i\text{-}WP)}{(1\text{-}p)(FC\text{-}WP)} \right] PET_i = \quad \text{when } (SMC_i - WP) < (1 - p)(FC - WP) \quad (10)$$

where, PET_i is the potential Evapotranspiration; FC = SMC at field capacity; WP = SMC at wilting point; p = fraction of available soil moisture depletion; and Kc_i = crop coefficient.

Supplemental Irrigation

SI will be applied only in the critical stage of the crop growth and the event will take place at the end of the previous day.

SI for Rice Crop

$SI = 0$ if $SMC_{i-1} = 0.8$ (SAT)

$= 50$ if $SMC_{i-1} < 0.8$ (SAT) (11)

SI for Non-Rice Crop

$SI_{ji} = FC^a{}_{ji}.RD_{ji} - SMC^a{}_{ji}.RD_{ji}$ if $SMC^a_{ji}.\ RD_{ji} < WP^a_{ji}.RD_{ji} + (1\text{-}p)\ (FC^a_{ji} - WP^a_{ji})RD_{ji}$

$=0$ if $SMC^a_{ji}.\ RD_{ji} = WP^a_{ji}.RD_{ji} + (1\text{-}p)\ (FC^a_{ji} - WP^a_{ji})RD_{ji}$ (12)

Seepage and Percolation from Crop Fields

Two kinds of situations are encountered in the crop fields as far as percolation and seepage are concerned. i) Saturated condition when there is standing water in the field and ii) unsaturated condition when the SMC goes down below saturation moisture content. Percolation takes place from the field in both saturated and unsaturated conditions. When it goes down below the root zone depth of the crop, it is assumed to be deep percolation. Seepage that occurs only in ponded condition is assumed to be inseparable from percolation. In unsaturated condition the seepage loss from the field is assumed to be zero.

Percolation under Saturated/Ponded Condition

Empirical equations are developed based on field observations for computing seepage and percolation loss from the field (Panigrahi, 2001).

$$SP_i = -16.45 + 0.145\ (SMB_i) \quad (13)$$

$$SMB_i = (\text{Depth of ponding+SAT-AET}_i) \quad (14)$$

Where, SP_i is the seepage and percolation rate (mm); and SMB is the soil moisture balance in the effective root zone depth (mm).

Percolation under Unsaturated Condition

The matric suction under unsaturated condition was computed using Van Genuchten equation (Simunek et al, 1998) which is expressed as

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[\ 1 + |\alpha h|^n\ ]^m} \quad \text{when } h<0 \quad (15)$$

$$K(h)= K_s S_e^l [1-(1-S_e^{1/m})^m]^2 \quad \text{Where } m=1-1/n \text{ and } n>1 \quad (16)$$

$$S_e = \theta(h)-\theta_r / \theta_s - \theta_r \quad (17)$$

Where $\theta(h)$ is soil moisture content, θ_s is saturation moisture content, θ_r is residual moisture content, h is matric suction head, á is the parameter in water retention function, n is the exponent in the soil water retention function,l is the hydraulic conductivity function and its value is 0.5 for most soil types; and K(h) is the unsaturated hydraulic conductivity; S_e is the fraction of soil moisture with respect to saturation moisture content.

$$SPi = (h_1-h_2) / [L (1/K (h_1) + (1/K (h_2))] \qquad (18)$$

Where, $K(h_1)$ and $K(h_2)$ are unsaturated hydraulic conductivity at two points; L is the vertical distance between the two points.

Optimum Size of Lined and Unlined OFR

Optimum size of OFR is derived in two steps as suggested by Sharma and Helweg (1982).

Step I : Simulation of minimum and maximum size of OFR using water balance model through out the study period.

Step II : Economic analysis based on net return from the supplemental irrigation will decide the optimum size of OFR.

- Water yield from the fields to the OFR
- Water requirement by the crops
- Water balance model of OFR
- Crop yield with response to soil moisture status under irrigated and rainfed conditions in both rainy season and post-monsoon period.
- Economic analysis of the system

Water Balance Model for OFR

$$FV_i = FV_{i-1} + VR_i + VSRP_i - VE_i - VSP_i - VSI_i \qquad (19)$$

where, FV_i = Final volume of storage in the OFR; FV_{i-1} = volume of storage in the OFR on (i-1)th day; VR_i = Volume of rainfall on the OFR; $VSRP_i$ = Volume of surface runoff to OFR; VE_i = Volume of evaporation from OFR; VSP_i = Volume of seepage and percolation loss from OFR; and VSI_i = Volume of supplemental irrigation from OFR.

Volume of Evaporation from OFR

Evaporation from the Open OFR

Doorenbos and Pruitt (1977) suggest using pan evaporation data to estimate evaporation rate from open water bodies up to 5m depth.

$$VE_i = 0.74 \times Epan_i \times WSA_i \tag{20}$$

where, $Epan_i$ = evaporation from class A pan evaporimeter on i-th day (mm); and WSA_i = water spread area of OFR on i-th day (m^2).

Evaporation from the OFR with Polyethylene Cover

As suggested by Agrawal et al. (2004)

$$VE_i = 0.5\ (0.74 x Epan_i\ x WSA_i) \tag{21}$$

Evaporation from the OFR with Biological Shading

The evaporation from the underlying surface (soil / water) is influenced by radiation interception capacity of the canopy cover **(Fig. 3)**. As suggested by Gallardo et al. (1996) and Wardana et al., (1996)

$$VE_i = 0.74 \times Epan_i \times WSA_i \times \left(1 - \frac{RI_i}{100}\right) \tag{22}$$

Where, RI_i is the percentage of total daily radiation energy intercepted by crop canopy.

$$RI_i = 0.63 + 1.373(G_i) - 0.0039(G_i)^2 \tag{23}$$

Where, G_i is the per cent canopy cover on i^{th} day with respect to maximum ground cover of the crop.

Fig.3 : Biological cover of bottle gourd (Lagenaria sisce) over the OFR

Volume of Seepage Loss from OFR

Cross laminated polyethylene sheet of 120 gsm has been used for lining purpose in the OFRs. So, the seepage loss from lined OFR is assumed to be zero. But in case of unlined OFR, an empirical equation was developed based on field observation (NATP Project Report, 2004). The equation is expressed as:

$$SP_o = 0.135(1\text{-}exp(\text{-}0.304d) \qquad (24)$$

Where, Sp_o is the seepage and percolation loss from the OFR (m); and d is the depth of water level in the OFR (m).

Prediction of Crop Yield

Yield of the crops during simulation period are predicted with the help of regression models and dated water production functions using AET values at different growth stages of the crops grown under irrigated and rainfed situations.

Rice Crop

A multilinear regression model developed for eastern region of India by Panigrahi *et al* (2001) will be used to predict rice yield under the study.

$$Y_a = -13.06 + 0.05AET_1 + 0.07AET_2 + 0.75AET_3 + 0.45AET_4 \qquad (25)$$

where, Y_a = actual yield of rice, 1000 kg/ ha; AET_1, AET_2, AET_3 and AET_4 are actual evapotranspiration of rice crop during crop establishment (1), crop development (2), mid season (3) and late season (4) stages respectively, in cm.

Non-Rice Crops

An additive model of dated water production function is used in the study to predict the actual yield of maize, blackgram and mustard grown in rainy season and winter seasons. The equation is as:

$$\frac{Y_a}{Y_p} = 1 - \sum_{s=1}^{ns} Ky_s \left(1 - \frac{AET}{PET}\right)_s \qquad (26)$$

where, s = growth stage index of the crop; Y_a = actual yield with available moisture, kg/ ha; Y_p = potential yield that can be obtained with adequate moisture through out the crop period, (kg/ha); Ky_s = stagewise yield response factor; AET = actual evapotranspiration, (mm); PET = potential evapotranspiration, (mm); and ns = no. of growth stages

Economic Analysis of OFR System

Net present value (NPV), Benefit cost ratio (BCR), Internal Rate of Return (IRR) and Pay Back Period (PBP) economic indicator such as are used in the study to derive the economic feasibility of the OFR system in upland situation (Yuan et al, 2003; Mishra et al., 1998; and Selvarajan et al., 1984).

NPV > 0	the project is economically viable
NPV < 0	the project is not economically viable
NPV = 0	this project adds no monetary value. Decision should be based on other criteria

$$NPV = I_o + \sum_{t=1}^{n} \frac{(C_t - Co_t)(1+f)^{t-1}}{(1+r)^t} \quad (27)$$

where, I_o = Initial investment; C_t = cash inflow at time t; Co_t = cash outflow at time t; f = inflation rate (%); r = rate of interest or discount rate (%); and t = time interval assumed to be 1 year under study.

Conclusion

- At 50% probability of exceedance (PE), power transformation gives onset and withdrawal date of monsoon in the region as June 16 and October 3, respectively (Table 1). Thus the monsoon is effective in the region for 110 days. So, short duration rice of 100-110 days should be grown under rainfed farming system (Panigrahi and Panda, 2001).

- At least two long dry spells, both are of 13 days duration, are likely to occur every year in the region during rainy season out of which one comes on July, 18 and the other on August, 22 at 50% PE (NATP Project Report, 2004). Hence, the *biasi* operation in case of direct sown paddy and transplanting operation in case of transplanted rice are to be completed before July, 18 to achieve an effective physiological growth of rice crop. The second dry spell coincides with the critical growth stage of rice crop which hints upon the creation of water source to provide supplemental irrigation.

- Simulation of ponding and soil moisture status of rainfed uplands reveal that there is a need for drainage of ponded water during early crop establishment and later part of late season stage and supplemental irrigation during critical growth stage of rice crop **(Fig. 4)**. Moreover, after harvest of rice, the residual soil moisture at the time of sowing of light duty crop in the post- monsoon period is found inadequate for germination of seeds in 45% of the years and thus, requires pre-sowing irrigation (Panigrahi and Panda, 2001) **(Fig. 5)**. When the rice crop is completely substituted by maize crop in rainy season and soil moisture status is simulated, it is found that in none of the years during 1977 to 2006, the crop needs any supplemental irrigation. It indicates that a plenty of harvested water will be available to meet the full irrigation demand of winter crops.

Table 1 : Occurrence of OEM, WM and duration of CDS during the rainy season

Year	OEM	WM	Number of CDS	Occurrence and duration of CDS		
				First CDS	Second CDS	Third CDS
1969	June 11	September 30	1	June 21 (10)	-	-
1970	June 14	October 3	2	July 30 (11)	September 7 (12)	-
1971	June 1	October 22	3	June 12 (10)	June 29 (13)	September 17 (13)
1972	June 22	September 27	2	July 27 (11)	August 17 (10)	-
1973	July 6	October 17	2	August 8 (19)	September 4 (10)	-
1974	July 15	October 9	2	Aug 17 (12)	September 12 (16)	-
1975	June 18	October 8	2	July 19 (17)	September 15 (10)	-
1976	June 26	September 22	1	August 6 (10)	-	-
1977	Jun 13	September 18	0	-	-	-
1978	Jun 25	October 5	1	September 3 (11)	-	-
1979	Jun 22	September 19	1	August 9 (13)	-	—
1980	Jun 1	September 19	1	August 12 (11)	-	-
1981	Jun 13	October 1	2	June 26 (10)	August 25 (14)	-
1982	Jun 25	September 17	1	July 3 (16)	-	-
1983	Jul 25	October 12	1	September 8 (21)	-	-
1984	Jun 4	September 13	1	June 26 (12)	-	-
1985	Jun 3	October 17	3	June 18 (11)	July 18 (14)	September 12 (13)
1986	Jun 23	October 8	3	July 9 (12)	August 15 (14)	September 13 (10)
1987	May 25	September 26	2	June 10 (12)	August 5 (12)	-
1988	Jun 16	October 3	1	August 19 (10)	-	-
1989	Jun 14	September 28	2	August 5 (11)	September 2 (14)	-
1990	May 21	October 9	2	June 3 (12)	September 8 (10)	-
1991	Jun 2	October 7	3	June 14 (19)	July 24 (12)	September 15 (10)
1992	Jun 8	September 30	3	June 26 (10)	August 19 (15)	September 12 (13)
1993	Jun 17	October 20	2	July 28 (13)	September 10 (10)	-
1994	Jun 21	October 10	1	September 19 (15)	-	-
1995	Jun 19	October 15	2	July 4 (11)	September 9 (10)	-
1996	May 31	September 30	2	June 10 (11)	September 1 (15)	-
1997	Jun 10	October 2	0	-	-	-
1998	Jun 21	October 3	2	July 5 (13)	August 13 (22)	-
1999	June15	September 25	1	July 14(15)	-	-
2000	June 5	September 23	2	July 1 (9)	September 22(25)	-
2001	June 4	October 12	1	September 19(9)	-	-
Mean,μ	Jun 14	October 2	2	July 18 (13)	August 22 (13)	September 14 (12)
St.Dev., σ (days)	13	9	-	30 ((3))	21 ((3))	2 ((2))

(Source: NATP Project Report, Dept. of Agricultural and Food Engg., IIT, Kharagpur)
Note: Figures in parentheses represent duration of CDS in days.
Figures in double parentheses represent standard deviation, s of CDS in days

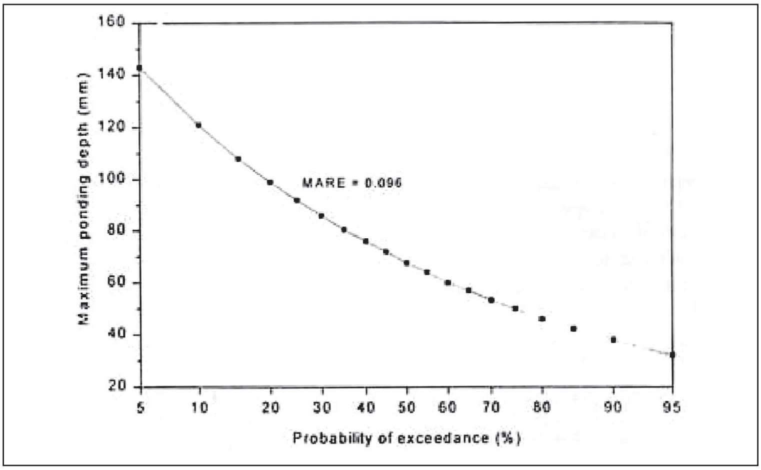

Fig. 4 : Variation of maximum ponding depth in rainfed upland rice field at various PE

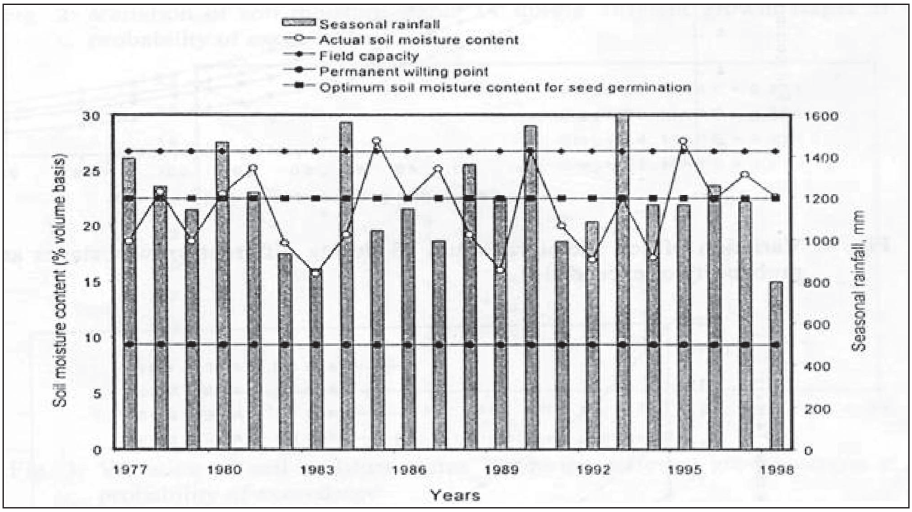

Fig. 5 : Variation of soil moisture content at the time of sowing of winter crops and seasonal rainfall in different years

- Study on water harvesting potential reveals that at 50% PE level, 95% of the supplemental irrigation requirement of rainfed upland rice during the critical growth stage can be met from the surface runoff generated from the rice lands **(Fig. 6).** The rest can be met from the direct rainfall collected in the OFR (Oweis *et al*. 1999). The average seasonal surface runoff from the rice field and irrigation requirement of rice crop is 116.51 mm and 110.38 mm, respectively (NATP Project Report, 2004) **(Fig. 7)**. So, the irrigation requirement can be supplemented by recycling the harvested runoff from the OFR and thus, there is a scope for rainwater harvesting in the OFR.

On the other hand, the water harvesting potential under partial crop substitution (Non-rice:rice::2:1) is more than 4 times the irrigation demand of rainy season crops. It widens the scope of full irrigation practice during the critical growth stage of rice crop as well as at least two irrigations to the second crop in winter season.

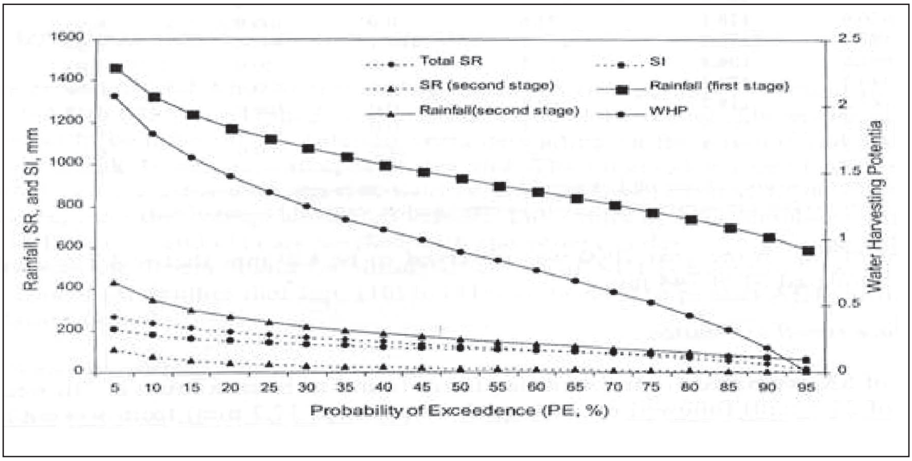

Fig. 6 : Variation of Rainfall, SR, SI and WHP at different PE levels

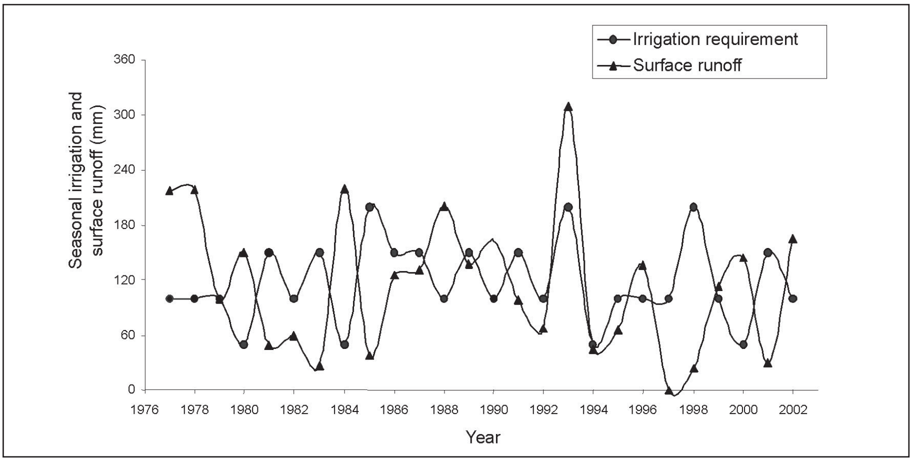

Fig. 7 : Seasonal irrigation requirement of rice and runoff generated from the rice field

- Economic analysis indicates that 12% of farm area is optimum for construction of OFR that can meet on an average 93 and 33 mm of supplemental irrigation to rice crop during the critical growth stage in wet season and pre-sowing irrigation / SI demand to mustard in post-monsoon period **(Fig. 8)**. The average increase in yield of rice grains and mustard seeds due to supplemental irrigation from the said size of OFR are found to be 29.2 and 22.3% more over the average yield of corresponding crops under rainfed condition (Panigrahi and Panda, 2003).

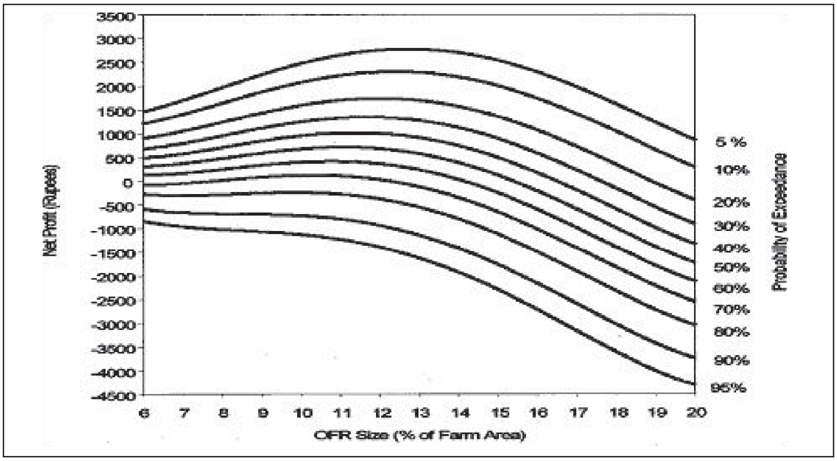

Fig. 8 : Variation of net profit from various sizes of OFR at different probability of exceedance

- The study reveals that the unlined OFR is also equally capable to meet the SI requirement of rice and pre-sowing irrigation to mustard after rice except few inadequacies like larger size, quick depletion of harvested water after recession of South-West monsoon as compared to lined OFR. Second irrigation to the second crop after rice is hardly possible in case of unlined OFR. For a 1:1 side slope, a return period of 5 years requires 15% of the farm area for unlined OFR (Pandey et al., 2006) and the size of the OFR becomes larger with increase in side slope.

- The value of the benefit-cost ratio (BCR), IRR and PBP of the optimum size (12%) of OFR were found to be 1.22, 16.1% and 13 years (Panigrahi et al., 2004). BCR value of more than 1 indicates that on every rupee investment made on OFR irrigation system gave a dividend of Rs.1.22 which is justified.

- When fish is integrated with both OFR system (lined and unlined) in rainfed uplands along with rice-mustard cropping sequence, the net return to the beneficiary increased leading to a remarkable increase in benefit-cost ratio of the system as a whole. The BCR value of lined and unlined OFRs occupying 10% of farm area becomes 1.65 and 2.70, respectively (Sethi et al., 2005). Pay back period of unlined OFR is found to be 13 years and that of lined OFR is 20 years.

- Average evaporation rate from the open and creeper cover OFR is 2.73 and 2.28 mm/day, respectively, during September to February. Percent reduction in water surface temperature and increase in relative humidity due to the presence of the creeper cover over the OFR as compared to open OFR is 9 and 5.8%, respectively. Seasonal reduction in evaporation loss due to creeper cover as compared to the open water body is 32 to 35%. Thus the canopy cover of bottle gourd is recommended as an evaporation mitigation measure for the small scale water harvesting structures in eastern region of India (Sahoo et al., 2010).

- A user friendly software using Visual Basic 6.0 programme has been developed to find out the optimal size of the OFR in terms of percentage of the farm area in rainfed farming system (Roy et al., 2009) **(Fig. 9).** Its menu driven system is flexible enough to simulate the OFR sizes for various combinations of OFR geometry, field sizes and cropping patterns. The user has to specify the crops to be grown, irrigation management practices, types of OFR (lined or unlined), side slope and depth of OFR and the farm area.

- Experimental verification of the aforementioned study both in the lined and unlined OFRs (with and without fish in the OFR) is carried out in the agricultural farm of Indian Institute of Technology, Kharagpur since 1998 under various national and international research projects **(Fig. 10 and 11)**.

- The OFR technology is rapidly disseminated to farmers' field in the States of West Bengal, Orissa and Jharkhand by NGOs and farmers themselves **(Fig. 12).**

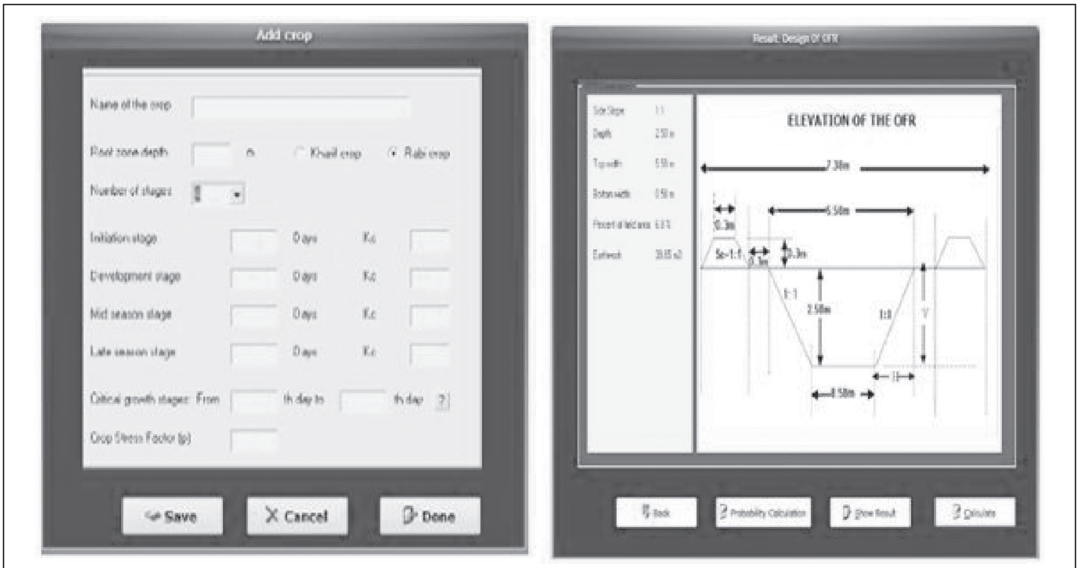

Fig. 9 : Menu Driven System for optimum size of the OFR

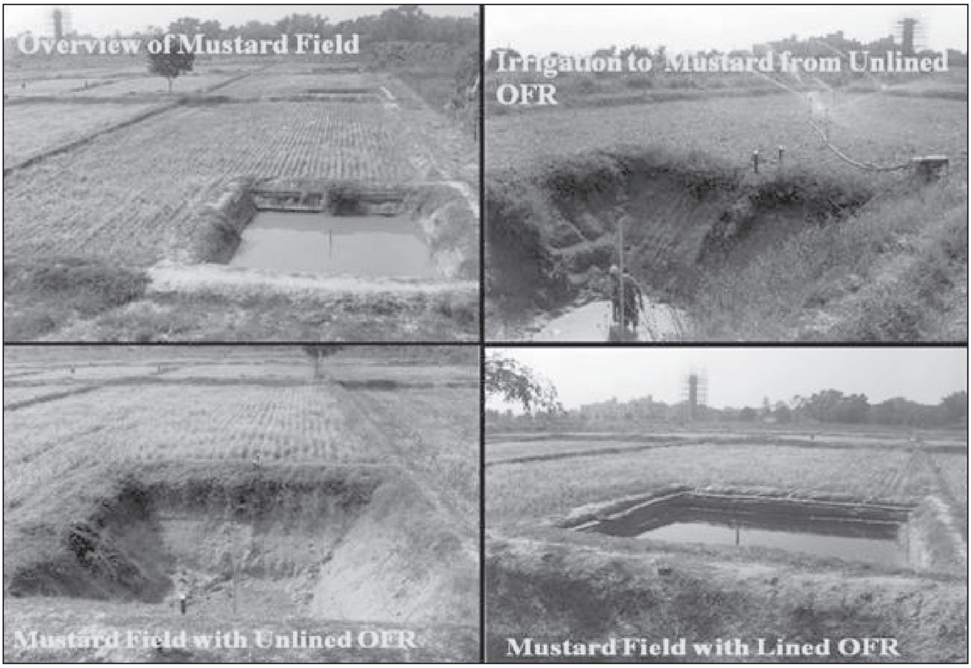

Fig. 10 : Field experimental setup for providing supplemental irrigation to Mustard from the OFR

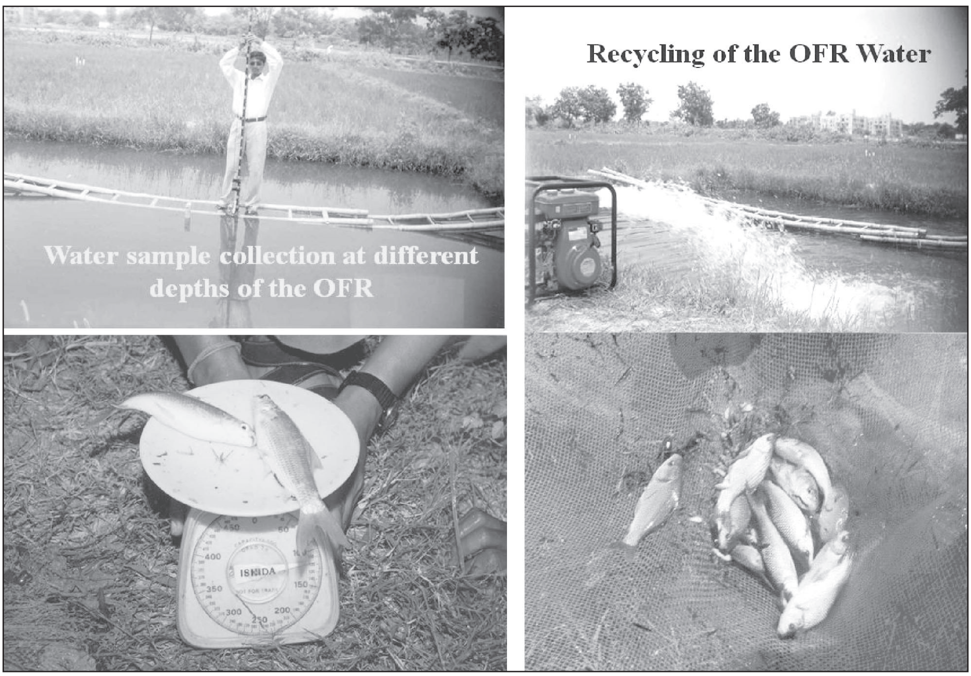

Fig. 11 : Field experimental study on fish growth in the OFR

Fig. 12 : Adoption of the OFR Technology in farmers' field
(Jetia Pahar village, Mallarpur block, Birbhum district, West Bengal)

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Machinery for Soil and Water Conservation, Land Development and Drainage

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Land development and land shaping is grading the land to a planned grade for efficient and uniform utilization of irrigation water and safe disposal of excess water within stipulated period. Land development is a skilled operation and any project should not be executed on guesswork. Land development is the costliest preparation in farming. It involves jungle clearance, soil opening with deep tillage equipment, moving soil from high to low spots, making farm roads, field bunding and levelling .etc. These operations require use of self propelled and heavy equipment such as crawler tractors with heavy duty ploughs and dozers, high horsepower tractors with dozing and hoeing attachment,. crapers, ditchers, chisel ploughs, sub-soilers, terracers, levellers etc. In India, human and animal labor, machinery and often a combination of both are used for excavation, as well as maintenance of drainage systems. Small field drains are usually constructed with the help of manual labor. However, machines are used for construction of bigger intermediate and main drains. These machines include draglines, backhoes, excavators, and dredgers. They have many advantages over manual and animal labor, as they are quick with much larger output. Machines are especially suited to drainage projects in humid areas, as these areas are generally wet, making it difficult for manual and animal labor to work in them.

In recent years availability of machinery and equipment for drainage projects has been on the increase both in India and other countries. Special machines have been developed for variety of jobs. For sub-surface drainage (SSD) system machines are now available which can excavate the trench, place drain pipes as well as filter material and backfill the trench in one pass. Grade control has been made precise with the introduction of laser-guided equipment. Special equipment is also available for coastal areas for dragging and removal of sand bars and weed control in ditches. Selection of proper equipment, its correct size and combination of various construction equipment will give maximum efficiency and economy. Factors which determine proper selection of equipment are nature of land development work, soils and topography of the area, size of the pond, time available, capacity of machine and skill of operator and availability of various earth moving equipment suitable for construction. Here soil and water conservation machinery used in context of Conservation Agriculture are discussed. Conservation Agriculture represents a practical concept to achieve improved soil health and better soil-crop-nutrient-water management leading to ecologically and economically sustainable agriculture. Interventions such as mechanical soil tillage are reduced to an absolute minimum and the use of external inputs such as agro-chemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or, disrupt, the biological process.

Criteria for Land Development

*Soil profile:*Depth of cut can only be decided by knowing topsoil, sub-soil hardpan, etc.

Land slope: Considering the land slope, field may be divided into small strips considering soil type the uniform grade of 0.05 to 0.25 % for heavy soils, 0.2 to 0.4 % for medium soil 0.25 to 0.65 % for light soil may be given. Accordingly earthwork has to be estimated.

Rainfall characteristics: It will influence the minimum and maximum grade of the field and should therefore meet the drainage requirement, which is influenced by the amount of rainfall, intensity - frequency and seasonal occurrence.

Cropping Pattern: Where high value crops are proposed to be grown, the leveling should be done with case and precision, however, for low value crop a rough leveling will work which involves low investment.

Irrigation Methods: Depending on irrigation method to be used, the amount of earth work will vary. Sprinkler and drip methods may require only removing of bumps and filling up of lower spots. Border, furrow, basin methods will have different length, strips.

Other Considerations: View of farmer without sacrificing technical feasibility.

Land Leveling Design Methods : Grid survey at 10 x 10, 15 x 15, or 30 x 30m has to be carried out and field may be prepared for land development.

Land Development Equipment/ Machinery

Various equipment are in use for land development, excavation of pond, earth moving, construction and maintenance of drainage works. These machines can be classified according to function and earth-moving action involved as shown in**Table 1**. With regard to their function, earth moving, excavation and drainage machinery may either cut and carry soil, or cut, spread and push the spoil. With regard to type of earth-moving action, it may either to be continuous or intermittent type.

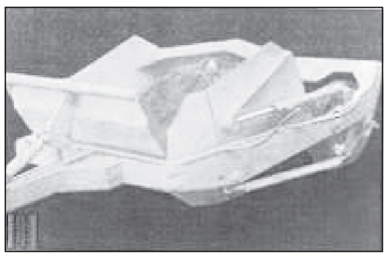
Table 1 : Classification of earth-moving equipment for construction and maintenance of drainage works.

Function	Earth-moving action	
	Continuous	Intermittent
Excavation	Wheel excavator (Trench type)	Dragline (Scraper-bucket excavator)
	Plough-type ditcher[1]	Backhoe
	Template excavator	Shovel
	Blade grader[1]	Scraper
	Elevating grader[1]	Bulldozer
	Hydraulic dredge	Pull back blade
	Rotary ditcher[1]	
Spoil spreading	Blade grader[2]	Bulldozer[2]
	Tillage machines[1]	Scraper
	Terracing machines[1]	Pull back blade[2]

[1]Continuous except for turning at the ends.
[2]Either continuous or intermittent, depending on the method of operation.
(Source: Schwab *et al* 1993)

Continuous-action machines generally have a higher output than intermittent-motion equipment. Intermittent-action machines are generally used for open channel construction. Continuous-action machines for spreading the spoil include the bulldozer and the blade grader. The bulldozer is perhaps the most widely used machine for spreading soil banks, but scrapers may be satisfactory for small channels. Such machines as the dragline, clamshell, and large back hoe, however, may deposit the spoil so that very little, if any spreading is required.

Scrapers



A bucket scraper, also called carry all scraper consists essentially of a bowl or bucket mounted rubber tyred wheels with a blade and apron across its front and of the bucket for cutting and scooping the earth to load, when the scraper is pulled, the bowl is lowered and the apron is partly lifted. In hauling position the apron is closed and the bowl is lifted clear of the ground. It is operated hydraulically. With this earth can be excavated, loaded, hauled and spread. Scrapers are not generally suited for the excavation of large open drainage channels near the water table due to marshy condition. A carryall scraper that is pulled behind a tractor. Small scrapers unit of 1.5 to 6.0 m^3 are available which can be pulled by farm tractors of

40 to 120 hp. Most larger units of 6 to 19 m^3 capacity are equipped with their own power units and operate on pneumatic tired tractors which have more speed and maneuverability than the crawler tractors. Self propelled motorized scrapers are used for large quantity of earth movement over long distances (500 to 600 m). In India, hydraulically operated scrapers in two models TW 01 and TW 02 with brand name 'Hydroscrape' of 2 to 3 cu.m. capacity are manufactured by Bora Brothers Industries, Bhopal. These scrapers can be operated with 50 to 100 HP tractors. For operation, the hydraulic scraper is attached to the tractor of 50 hp or more, hydraulic system connected and apron is raised. With the forward movement of the tractor, the blade penetrates in to the soil and fill bucket bowl gets filled. The apron is closed after the bucket is filled and the scraper is moved to the point of unloading. For unloading, the bucket is tilted hydraulically.

Dozer Crawler Tractor with Dozer Blade and Ripper

Bulldozers are primarily used for cutting hard soil, spreading spoil banks and back filling trenches. They can be either crawler or wheel machines depending upon the requirements of traction, speed, and maneuverability.For efficient operation, the movement of earth by a bulldozer should be limited to a distance of not more than 30 m. In India, various crawler tractors such as Bharat D-6, catter piller D4E and Hanomang K-7 etc. are used for excavation work, backfilling or spreading operations. Bulldozers are attached with dozing blade in the front and ripper (with shank) on the rear which are hydraulic operated. In India, Bharat Earth Movers Limited, Bangalore manufactures wheel dozers of 130, 300, 460 hp sizes.

Motor Graders and other Blade Graders (Land Planes)

A motor grader is a self-propelled, automatically controlled, pneumatically tired blade grader. It is quick, highly maneuverable, and efficient for constructing shallow surface drains, and for smoothing operations of side slopes and plain surfaces. Blade graders, also known as drag scrapers, levelers, land planes or bottomless scrapers in various forms are mainly used for land smoothing operations. The blade has little or no carrying capacity and soil movement is accomplished by scraping the high areas and dragging to the low areas. In India, Bharat Earth Movers Ltd., Bangalore is manufacturing motor grader of 145 & 280 hp.

Draglines

Draglines are best used for the excavation of loose materials that are below the grade of the machine. Draglines are probably the most common machines used to dig large drainage ditches. They are especially suited for digging beneath the water table. The machine remains on dry ground while digging. Common capacities of dragline buckets range from about 0.4 to 2.00 m^3. In India, Bharat Earth Movers Limited, Bangalore manufactures walking draglines of 23-24 m^3 capacity.

Dredgers

Dredgers can dig under-water soil and waterside banks without involving cross bunding or closure of the channels. They can dig sand, clay, gravel and material including rock. Hence, they can be used with advantages for desilting of canals, deepening of drains and maintenance of waterways in the deltas. The basic types of dredgers are mechanical (bucket) dredgers and hydraulic dredgers. Mechanical dredgers are classified as loader, grab, and dipper. Hydraulic dredgers are plain suction, drag head, and cutter suction. Although the popularly used cutter suction dredger is more versatile than other types.

Hydraulic Excavators

Hydraulic excavators of two types namely shovel and backhoes are available. Loading shovel of 1.4 to 9.5 m^3 capacity and backhoe of 1 to 8.5 m^3 capacity are manufactured in India by BEML, Bangalore. The backhoe incorporates some of the characteristics of the shovel and the dragline. Its dipper bucket, which is mounted on a rigid arm, is powered back toward the machine when digging. They are used extensively in the excavation of small to medium open drains. All modern backhoes are hydraulically powered. Backhoes are also commonly used as trenchers for subsurface drainage. Backhoes with bucket capacities of 0.3 m^3 to 3.0 m^3 are sold in India. Larger backhoes are mounted on track laying machines but backhoes with bucket capacities of up to 1 m^3 can be found mounted on wheel tractors. Best Used Tractors and John Deere are other leading manufacturers of the backhoes of 74 to 115 hp.

Front End Loaders

Front end loaders have hinged, front mounted, hydraulically operated bucket. The bucket is loaded by pushing it into the loose material to be loaded. The bucket is then hydraulically operated for elevating and for dumping. It can also be operated similar to a bulldozer for backfilling or spreading operations. Wheel type front end loaders are manufactured in a variety of sizes with bucket capacities of 1 m^3 to 4 m^3 in India by BEML, Bangalore and Escorts Construction Equipment Limited, Bhopal. The power of these machines ranges from 72 to 210 hp. Small front end loaders are commonly attached to a backhoe. These machines are called a wheel tractor loader backhoe and are very handy for a variety of jobs for the construction of small open discharge ditches.

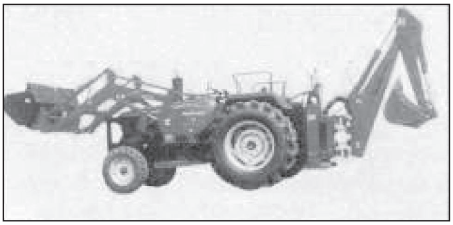
Tractor Mounted/ Drawn Land Development Equipment

The various tractor mounted and tractor drawn equipment used for land development and excavation works are briefly described in following sections:

Tractor Mounted Backhoe Dozer

Dozer is used for agricultural land levelling, making bunds in the farms and terracing of farm, for trench filling after laying cable or pipe backhoe is used for excavating soil, making trenches for pipe and cable laying, and removal of bushes and trees etc. etc. The dozer is mounted in front of the tractor and backhoe in the rear. The dozer and backhoe can be easily removed and joined to the tractor. The dozer consists of a thick curved plate and hardened strip. The dozer plate is joined to the tractor with sturdy arms and can be raised or lowered with hydraulic system of the tractor. Backhoe consists of a bucket with digging fingers, hydraulic cylinder, arms and base for attaching to the rear of the tractor. The bucket position is manipulated by hydraulic system. The Dozer blade size is 240x 900mm and cutting depth upto 190 mm.

Backhoe Loader

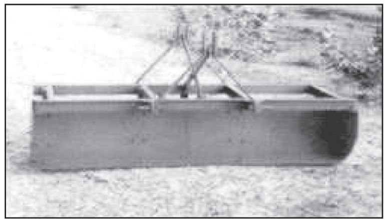


Loader is used for removal of mud and loose soil at canal worksite, for handling of clay and soil and loading it into the trucks and trailers etc. Backhoe is used for excavating soil, making of drainage channels, making trenches for pipe and cable laying, and removal of bushes and trees etc. These are attachments of tractor and are easily removable. The loader is mounted in front of the tractor and backhoe at the rear. Backhoe consists of a bucket with digging fingers, hydraulic cylinder, arms and base for attaching to the rear of the tractor. The bucket position is manipulated by hydraulic system. Loader consists of curved frame in the front, which acts as bucket, arms hinged to each other by pins, hydraulic cylinders and hydraulic system. The loader, therefore, can be maneuvered to the required position through hydraulic controls. Tractor mounted loader bucket capacity is 0.5 cu. m maximum digging depth of backhoe is 3.35m.

Equipment for Land Leveling and Land Grading

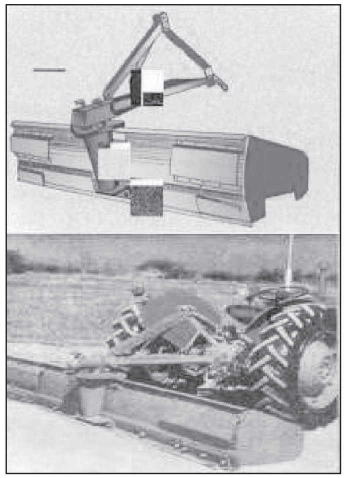
To carry out land leveling and grading, three steps procedure is adopted. First, field is roughly leveled by using dozer blade, scraper and land leveler. Secondly, field is leveled and is given a grade/ slope by using terracer blade. Finally, the field is leveled or given a grade precisely by using Laser guided land leveler. These equipment are briefly discussed below:

Tractor Drawn Leveler



It is used for leveling of fields and pulling or pushing loosened soil from one place to other. It consists of frame, 3-point linkage, cutting or scraping blade, and thick curved sheet closed from sides to form a bucket. The scraping blade is made from medium carbon steel or low alloy steel, hardened and tempered to about 42 HRC. The blade is joined to the curved sheet with fasteners and can be replaced after being worn out or becoming dull. The working depth of the implement is controlled by hydraulic system of the tractor. A tractor of 35 hp is required.

Tractor Mounted Terracer Blade



The terracer blade is used for grading, levelling of fields, filling of depressions and smoothening of field for irrigation. It is attached to the tractor with the 3-point linkage system and is hydraulically controlled. It consists of replaceable blade attached to curved steel body, side wings and indexing arrangement for tilting and angling of the blade. The blade with body is also called mould board. The mould board can be angled left or right by lifting the spring loaded latch pin and by turning the mould board. To tilt the blade for ditching or terracing the blade is tilted to the desired angle by moving the index pin. The depth of cutting is controlled by hydraulic system of the tractor. It can be reversed for back filling. For increasing the length of blade, extensions are provided. Power requirement for Terracer Blade is 35-50 hp tractor.

Laser Guided Land Leveler

The laser system consists of laser transmitter, laser receiver mounted on electric/ manual mast, control box. electric/ manual mast fitted on the leveler and external hydraulic system of leveler. The laser guided leveling system utilizes laser rays for controlling the depth of cut of the leveling blade along with hydraulic and electronic control circuitry. The laser transmitter generates a plane of laser beam above the field. This plane of laser beam provides a stable and accurate reference from which a level or graded (sloped) field is created. Some laser transmitters are designed for providing laser rays in level plane only. The laser receiver detects the laser plane generated by the transmitter and sends a signal to control unit which in turn actuates solenoid valves regulating the fluid flow by means of a double acting hydraulic cylinder. The leveler blade that is mounted relative to laser receiver actuates according to hydraulic flow direction thus controlling the depth of cut i.e. raised or lowered. The control unit has usually two options manual and auto. In manual option the operator moves the blade manually according to signals provided by the laser system i.e. raises or lowers or maintains same level of the leveling blade. In auto mode the signal received from laser system actuates the solenoid valves which inturn operates hydraulic valves and hydraulic cylinder. The operator may not worry for raising or lowering the leveling blade it is done automatically. The working principle of laser guided land leveler and connectivity of controllers are shown in **Fig. 1**. The operation of the laser guided leveler is shown in **Fig. 2.**

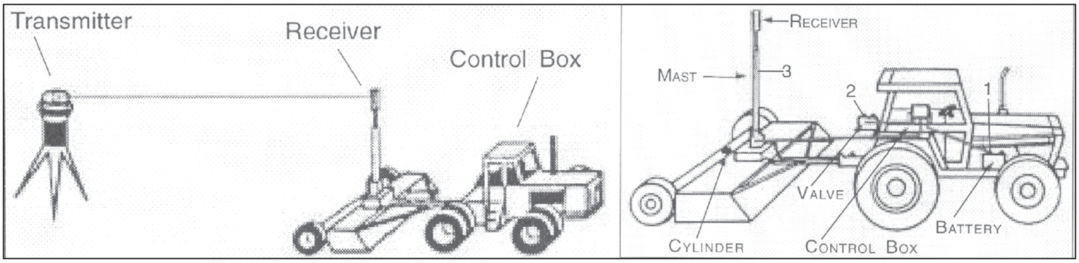


Fig. 1 : Working principle and Connectivity of controllers of laser guided land leveler

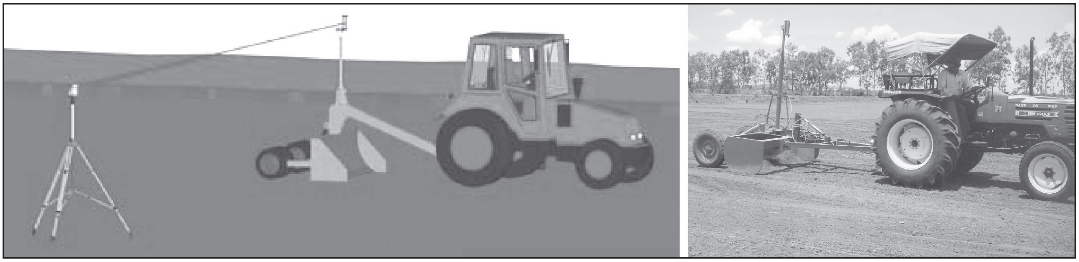


Fig 2 : Operation of a laser guided land leveler

The accuracy of land leveling in animal drawn and tractor drawn bucket and scrappers even with the best efforts is ± 4-5 cm whereas it is ± 1 cm in laser-operated bucket (**Table 2**). The operational efficiency of tillage operations of a tube well irrigated farm in western Uttar Pradesh was increased by about 23 % after precision land leveling. The comparative performance evaluation of tractor operated laser guided land leveler and land planer is given in **Table 3**. The fuel consumption of laser guided land leveler was 2.8 l/ha and the cost of grading was nearly twice of land planer and four times that of land leveler. Thus the good quality of work could be achieved by using the laser-guided land leveler with minimum emission of GHGs (Sidhu, et al. 2001). The specifications of levelers are given in **Table 4.**

Table 2 : Comparative performance of different leveling systems

S.No.	Leveling system	Work efficiency (ha/day)	Accuracy
1	Animal	0.08	± 40 - 50 mm
2	Power tiller	0.12	± 40 – 50 mm
3	Tractor operated blade scraper	0.5 – 1.0	± 40 – 50 mm
4	Tractor operated bucket scraper	0.5 – 1.0	± 40 – 50 mm
5	Tractor operated laser leveler	Up to 2	± 10 mm

Table 3 : Comparative performance evaluation of tractor operated laser guided land leveler, land planer and leveler.

S. No.	Variables	Values under		
		Laser guided land leveler	Land planer	Tractor operated blade scraper
1	Average forward speed, km/h	5.5	6.0	6.8
2	Average slope along length, %	0.324	0.075	0.24
3	Average slope along width, %	0.5	0.79	0.65
4	Field capacity, ha/h	0.09	0.13	0.20
5	Leveling index, cm	0.74	2.85	4.64
6	Fuel consumption, l/ha	2.8	4.0	2.8
7	Cost of operation, Rs/ha	4867.00	2540.00	1110.00
9	Nos. of units (2003-04)	-	798,000	1592,000

Source : Gupta et al., (2007)

Table 4 : Specifications of the laser guided tractor mounted land leveler

S.No.	Parameter	Remarks
1.	Laser transmitter	Dual slope type, accuracy 0.01%, self leveling type
2.	Tripod for mounting transmitter	3 m high
3.	Laser eye receiver	With telescopic grade rod, 4 m
4.	Laser receiver standard	Mounted on mast
5.	Manual mast	Mounted on drag scraper
6.	Control box	Auto and manual mode (LED display of raise, lower and normal)
7.	External hydraulic system	Consists of electro-hydraulic control valve, hoses and other accessories
8.	Drag Scraper	Width 2.4 m, capacity 1.6 m^3 fitted with double acting hydraulic system

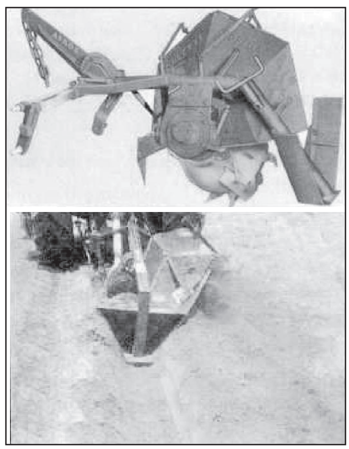
Equipment/ Machinery for Irrigation & Surface Drainage

In land forming and constructing surface ditches three types of operations namely digging, hauling, and placing are performed. Digging of drains is normally done in off-season to provide employment. Tractors with back hoe front-end loader, dragline ; excavators, ditchers, etc. are generally used for drainage construction. For open ditch construction the selection of equipment depends largely on moisture conditions and type of soil. The roughness of the terrain and the condition of the soil have the most bearing on the choice of equipment for land forming practices. Many of the machines described briefly herein are suitable for land forming practices, construction and maintenance of irrigation and drainage channels.

Tractor Drawn Ditcher

It is used for making ditches for irrigation and drainage. It consists of two curved wings with cutting blades, front cutting point, tie bars for adjusting wingspan, and hitch assembly with 3-point linkages. The ditcher is operated by tractor and controlled by hydraulic system. The ditcher penetrates in the soil due to its own weight and suction of the cutting point. Upon drawing the ditcher in the fie1d, it opens the soil in the shape of ditch with either 'V' bottom or flat bottom. The depth and width of the ditch is adjusted from the operators seat. Earthen channels because of their low cost and ease of construction are widely used for conveyance of irrigation water. For small holdings V ditcher can be used for making channels (T=40 cm & d= 25 cm). Tractor drawn V ditcher can be used (T=120 cm and d=40 cm) at faster rate. @ 1.2 km/h.

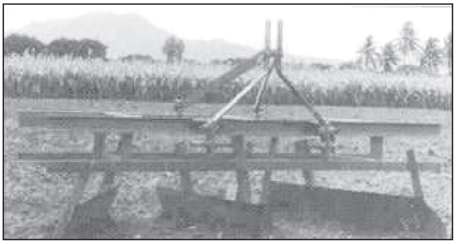
Rotary Ditcher



Rotary ditcher is used for making ditches for irrigation and drainage. It consists of a rotary cutter operated by PTO shaft of the tractor, gear box, 3-point linkage, hitch system, frame, body, deflector and ditch former. The machine is operated by tractor. Rotary cutter is main component of the ditcher and it consists of drum fitted with cutting knives or cutters. The rotary cutter excavates soil, which is uniformly distributed to one side. The deflection of the soil can be adjusted by the deflector. Ditch former, having trapezoidal shape fitted in the rear, form the ditch. The specifications are given below :

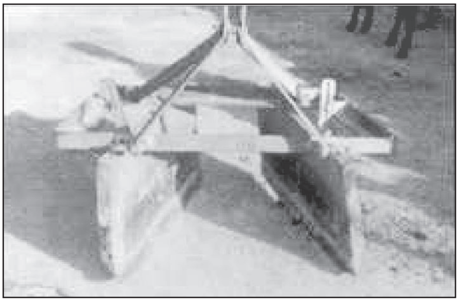
Top width of the ditch (mm)	:	740-915	Depth of the ditch (mm)	:	460-560
Base width of the ditch (mm)	:	180-250	Power requirement (hp)	:	40- 70, tractor

Tractor Drawn Channel Former



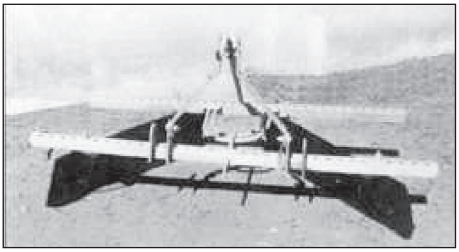
It is used for making channels and beds at regular intervals for irrigation. The channel former consists of two inner blades, two outer blades, hitch frame, mainframe and shovel. The front portions of the two inner blades are joined together and form an angle of 30^0 in between them. At the junction of these two inner blades a cultivator shovel is fixed to penetrate into the soil. The inner blades can be mounted 50 to 100 mm lower than the outer blades and form a furrow at a lower depth than the surface of the bed for the flow of irrigation water. The two outer blades are placed one on each side of the inner blades and at an angle of 60^0 to the direction of the travel. The soil collected from the furrow is formed as bund on both the sides of the irrigation furrow. The power requirement for channel former is 35-45 hp tractor and its field capacity is 1.2 - 1.4 ha/day.

Tractor Drawn Bund Former



It is used for making of bunds in the field. The bund former consists of mild steel angle iron frame; hitch system, and two blades (wings).The blades are adjusted in converging manner and has wider opening in the front in comparison at the rear end. The distance between blades can be adjusted according to size of bund required. The implement is mounted type and operated in tilled soil. The field capacity of bund former is 0.3 – 0.4 ha/h.

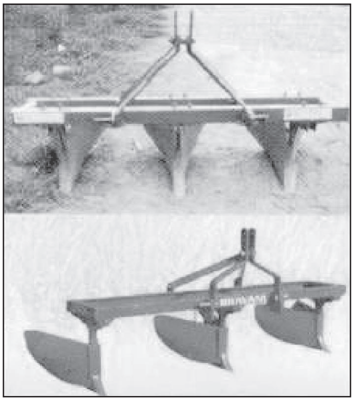
Tractor Drawn Channel cum Bund Former



It is used for making field channels to manage the irrigation water effectively and making small bunds across the slope for inter-plot rainwater harvesting under rainfed areas. It consists of inner wing, adjustable handle, frame, hitch pin and outer wing. The wings are reinforced or tensioned at, the bottom edge and are made from thick mild steel sheet. It is operated under well-prepared and pulverised soil condition and can be used under all types of soil and crop conditions. The distance between wings can be adjusted according to the size of bund. The power requirement is 20 hp tractor. The performance results are given below :

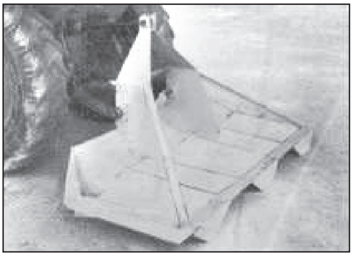
Width of coverage (mm)	:	500-1000 for bund, 1000-1300 for channel
Depth of cut (mm)	:	10-50
Operating speed (km/h)	:	2.5
Spacing (m)	:	10 crosswise
Field capacity (ha/h)	:	4 when spacing is 1.0 m crosswise
Field efficiency (per cent)	:	70
Range of bund size (mm)	:	250-1000 base width and 120-350 height
Range of channel size (mm)	:	100-450 width and up to l000 height
Labour requirement (man-h/ha)	:	0.25

Tractor Drawn Ridger



It is used for making furrows and ridges for sugarcane, cotton, potato and other row crops. It consists of rectangular frame made of mild steel angle or channel section, 3 -point hitch assembly, shanks and ridger body. The ridger body consists of two mould boards, share, point and tie bars to vary the wingspan of ridgers. The ridger is operated in tilled soil by a tractor, the share point penetrates in the soil, ridger body displaces the .soil to both sides and a furrow is created. The soil mass between furrows forms a ridge. The depth of operation is controlled by hydraulic system of the tractor. Power requirement of ridger is 35-50 hp tractor and its field capacity is about 2 ha /day.

Tractor Drawn Bed-Furrow Former



It is used for forming alternate beds and channels. The beds are suitable for planting crops like sorghum, maize, cotton. This bed and furrow system is ideal for efficient irrigation management. The tractor drawn bed-furrow former requires 35 hp tractor and consists of mild steel angle iron frame; three point linkage, lifting pin, furrow former, bed former and stiffeners. The bed and furrow formers are made of mild steel sheet and bent in required shape. The stiffeners are used to strengthen the fortners. The implement is operated in the tilled soil.

The performance results are given below :

Width of coverage (mm)	:	2250 (3-furrows at 750 mm centre distance)
Depth of cut (mm)	:	140
Operating speed (km/h)	:	3.2
Field capacity (ha/h)	:	0.75-1.00
Field efficiency (per cent)	:	43.6
Labour requirement (man-h/ha)	:	8

Machinery for Subsurface Drainage

Generally, many types of mechanical equipment are available for installing sub-surface pipe drains. These include the general groupings of (1) backhoes, (2) trenchers and (3) trenchless plows. Backhoes have been discussed earlier; other groupings are discussed in following sections. Maintaining proper grade is the single most important component of installation of a surface drainage system. Most trenching machines are equipped with features for maintaining a uniform grade and many are now fitted with automatic laser grade control systems. Trenchers were one of the first agricultural operations to use laser beam technology, which provides increased productivity while maintaining laying accuracy.

Trenching Machines

Trenching machines, which can operate continuously, are of two basic types:(1) a wheel excavator on which digging blade buckets that cut and carry the soil are attached, and (2) endless chain normally operating on a slanting boom. These trenchers are manufactured in various sizes depending upon the size of the pipe to be laid and the difficulty of excavation. Trench widths may vary from as little as 240 mm to as wide as 650 mm with maximum trenching depths 1.8 m to 5.5 m.

Wheel Trenchers

Rotating, hydraulically powered, circular digging wheel trenchers have been used extensively in America and Europe for many years for the installation of sub-surface field tile drains. In recent years many of these machines have been converted from track to pneumatic tired propulsion and adapted for laser grade control to achieve greater mobility and accuracy of excavation. The digging wheel used for trenching for agricultural purposes is about 2.5 to 3.0 m in diameter and can dig a trench to a maximum depth of 1.8 m. With wheel excavators soil is carried to the top of the wheel and then dropped onto a moving conveyor belt, which carries it to the spoil bank along the side of the trench. Wheel machines generally have a more limited depth capability than do the endless-chain types.

Chain Trenchers

The endless-chain trenchers are generally more versatile than the wheel trencher with greater depth capability and are thus used on a greater variety of agricultural, utility and civil construction projects. Chain trenchers are nearly always mounted on tracks and therefore have limited mobility but are capable of working in more difficult terrain and moisture conditions. The endless-chain type trencher may have a slanting boom (usually 60^0 boom to ground angle) as shown in **Fig 3.**

Trenchless Plows

The most recent of sub-surface drainage innovations is the development of trenchless plows which are capable of inserting continuous perforated corrugated plastic drainage title into the ground. These machines have the potential for rapid installation on large jobs and may be more economical than trenching type machines **(Fig. 4).** Trenchless machines are ideally suited for installing corrugated plastic drainage tubing and are capable of placing tubing up to 200 mm in diameter to depths of up to 2.5m . They can be used in stony soils. They have less stoppage for repairs than trenchers.

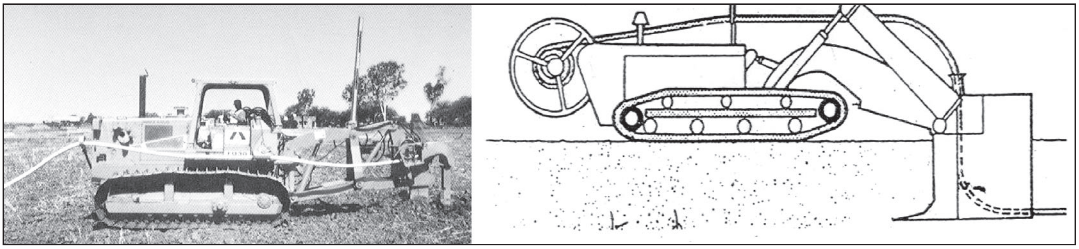


Fig. 3 : Endless- chain slanted boom trencher

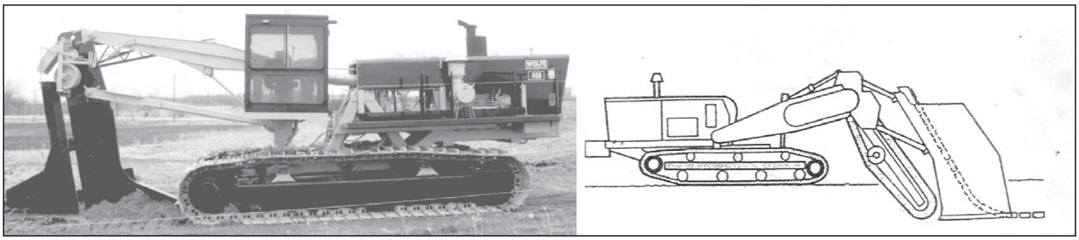


Fig. 4 : Drain tube plow - Comparison of trencher and trenchless installation

Experience in Western Europe and North America has shown that, for drain depths up to some 1.3 to 1.4 m, the cost of trenchless drain installation is lower than trencher installation, mainly because of a higher speed. In the Netherlands, with drain depths of mostly 1.0 to 1.2 m and pipe diameters of up to 0.08 m, the difference is 15 to 25%. Soil resistance is higher in fine-textured soils than in coarse-textured ones, as illustrated in **Table 5**.

Laser Beam Grade Control Equipment

Since the late 1960's, laser beam equipment for grade control has become available commercially. One system consists of a tripod command post with a 360^0 rotating low-power laser beam that can be set to give a level or sloping plane of reference. A second major component is the detector, which is placed on the trenching machine. It picks up the beam and automatically keeps the machine on the same slope as the plane produced by the laser beam. The area covered by the circle of the beam at one setup is about 70 ha. The laser beam is accurate to about 5 mm in 300 m distance. A system of electrically controlled valves and cylinders keeps the trencher automatically on grade. A grade modification device with a distance-measuring wheel mounted on the trencher, called a grade breaker, will change the drain grade from that made by the laser beam. The laser system has been adapted to many other earth-moving machines, such as the blade grader, scraper, bulldozer, drain-tube plough, etc. The maximum safe operating distance between the laser and receiver is 300 m.

Table 5 : Example of the capacity (m/h) of a trencher and a trenchless machine with a V-shaped plough for the installation of field drains (Van Zeijts and Naarding, 1990)

Soil type	Drain depth (m)	Capacity (m/h) Trencher(160kW)	Capacity (m/h) Trenchless(200kW)	Ratio Trenchless/ Trencher
Sand	1.00	700	840	1.2
	1.30	600	600	1.0
	1.60	520	430	0.8
Clay loam and clay	1.00	620	1150	1.9
	1.30	540	1050	1.9
	1.60	470	80	1.7
	1.90	420	—-	—-

Because of the high speeds, depth regulation by laser is the only practical method for trenchless machines.

Equipment FOR Subsoiling and Drainage

Mole Plough for Mole Drains

Mole drains are unlined circular soil channels, which function like pipe drains. Mole drainage is an inexpensive and effective method of drainage which is widely used in the clay soils of temperate regions such as United Kingdom, northern Europe and in New Zealand. It is generally confined to soils having clay content of about 30 – 35%. Their disadvantage is their restricted life (5 to 10 years), but at favourable benefit-cost ratios, a short life can be acceptable. Mole drains are formed with a mole plough (**Fig.5**), which comprises a cylindrical foot attached to a narrow leg, followed by a slightly larger diameter cylindrical expander. The foot and expander form the drainage channel and the leg generates the slot with associated soil fissures, which extend from the surface down into the channel. The leg fissures are vertical and formed at an angle of approximately 45^0 to the direction of travel. A Mole Plough suitable for tractors from 80 to 200 H.P. which forms a 100mm diameter drain tunnel, subsoils or lays water pipe at a depth adjustable from 300 mm to 500 mm.

Fig. 5 : Cracking and fissuring of heavy soils formed by Mole plough

The mole drain spacings range between 2.0 and 3.5 m. Common length of mole drains vary from 20 m to 100 m but can go upto 500 m long depending on the grade, which may range from nearly level to 5 per cent. Mole plough dimensions, as commonly used in the United Kingdom and New Zealand, are given below :

Common mole plough dimensions

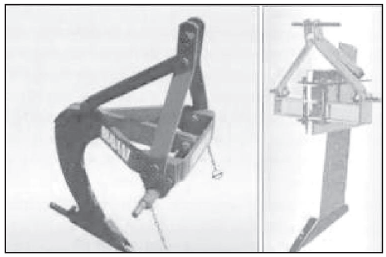
	Foot Diameter (mm)	Expander Diamater (mm)	Leg Thickness (mm)	Side length of leg (mm)
United Kingdom	75	85-100	25	200
New Zealand	50	75	16	200

The success of a mole drainage system is depends upon satisfying two requirements: achieving the desired water flow path for the particular drainage situation, and installing stable mole channels. Four basic types of mole plough are available :

- **Fully Mounted:** the plough is attached directly to the 3-point linkage of the tractor;
- **Long-Beam Scrubbing Mole Plough:** here a long beam (3 to 4 m long), carrying the mole plough leg and foot, moves along in contact with the soil surface;
- **Long-Beam Mole Plough with Front Skids:** the beam runs clear of the ground, but it is supported on front skids; the depth is controlled by angling the leg and foot assembly relative to the beam;
- **Long-Beam Floating Mole Plough:** the complete beam rides clear of the soil surface; the plough is usually attached to the tractor through a smoother device to reduce the effects of tractor pitching on the mole foot movement.

The best results with the mounted mole plough are achieved when it is used with the tractor linkage operating in 'free float', rather than in draught control mode. The depth of operation and hence channel gradient in draught control can vary greatly, even on smooth surfaces, because of changes in soil conditions. Mounted mole ploughs are only satisfactory on smooth field surfaces. The long-beam scrubbing and front-skid mole ploughs are more satisfactory than the mounted types when local surface undulations are more significant. The scrubbing long beam tends to bridge over the irregularities, minimizing movements at the foot, particularly when passing through local depressions. The long-beam floating plough always operates with minimum draught, and the foot position, and hence the mole channel itself, is least affected by surface irregularities and soil variations. This plough also allows the mole channel to be graded independently of the average surface level, without the need for sophisticated grading equipment.

Tractor Mounted Subsoiler



It is used to break hard pan of the soil, loosening of the soil and helps the water to seep into the soil for improving drainage. It consists of beam made of high carbon steel, beam supports which are flanged at upper and lower edges for rigidity, hollow steel adaptor welded to bottom end of the beam to accommodates share base having square section, share plate made from high carbon steel and shank drilled and counter bored for set board which secures the base in the adaptor. Two symmetrically located bolt holes allow reversibility of share. The working depth of the subsoiler is controlled by hydraulic system and linkage of tractor and is upto 535 mm.

Equipment Conservation Agriculture

Tractor operated agricultural equipment and machinery, which support conservation agriculture generally refer to the cultivation systems with minimum or zero tillage and *in-situ* management of crop residues. Different designs of direct drilling machines viz zero till drill, no till plant drill, strip till drill, roto till drill and rotary slit no till drill have been developed with controlled traffic measures for energy efficient and cost-effective seeding of crops without tillage. Laser guided land leveler and roto tiller helped to retain *in-situ* soil moisture longer thereby reducing the irrigation demand. Under rainfed conditions, a shift towards higher productivity, decentralized micro-irrigation system can help in saving water.

Precision Land Levelers

Land leveling is a precursor to good agronomic, soil and crop management practices and the levelness of the land surface has significant influence on all the farming operations. The benefits of precision land leveling include (i) more level & smooth surface, (ii) reduction in time & water required to irrigate the field (15-20%), (iii) more uniform distribution of water, (iv) more uniform moisture environment and (v) increased crop yields (10-20%). These equipment are briefly discussed earlier.

Conservation Tillage Machinery

Shukla, Tandon & Verma (1984) at Punjab Agricultural University, Ludhiana developed a conventional zero-till drill and tested for sowing wheat in paddy harvested field. It consisted of conventional tractor drawn seed cum fertilizer drill with disc coulters attached in front of the fixed type furrow openers. Main features of different conservation tillage and sowing machines are highlighted below and details specifications are given in Table 6.

Zero till (no till) seed cum fertilizer drill: It is 35 hp or above tractor operated sowing equipment and is used for sowing wheat, maize and other forage crops on zero- tilled or semi-tilled soils. It helps to sow the seed at a required appropriate depth thereby economise the use of inputs save time, labour, fuel and irrigation expenses as compared to traditional methods of sowing. It performs minimum tillage of the field and thus increases the yield.

Roto till drill: It is 35 hp or above tractor operated equipment and is used for sowing seeds into the soil directly opened with the help of rotavator attached with the machine, in a single operation in the stubble fields of paddy, maize and sugarcane. Cost reduction by time and energy saving and optimization of environmental health by reducing soil compaction are the main highlighted features of this machine.

Strip till drill: It is 35 hp or above tractor operated equipment and is used for sowing seeds into 50 mm strips prepared with the help of rotavator, attached with the machine, in a single operation in the stubble fields of paddy, maize and sugarcane. Cost reduction by time and energy saving and optimization of environmental health by reducing soil compaction are the main highlighted features of this machine.

Rotary no till slit drill: It is 35 hp or above tractor operated equipment and is used for sowing seeds into the slits opened with the help of rotary slit disc, attached in front of the furrow openers of machine, in a single operation in the stubble fields. The machines prepare a 20 mm slit in the soil and places

seed and fertilizer in the prepared slits in the stubble fields of soybean, maize and paddy. The machine reduced the loss moisture and draft force as compared to strip and roto till drill. The brief specifications and field performance of slit till drill as compared to zero till, strip till, roto till are given in **Table 6 and 7**. The machines were used for sowings at shallow depth (50-60 mm) under residual moisture condition (21.8-23.6%) with 100 kg/ha seed rate and fertilizer dose of N:P:K::120:50:30 kg/ha. There was net saving of Rs 2400 and Rs 2000/ha and 71% and 67 % reduction in CO_2 emission and fuel consumption per ha due to use of rotary slit no till drill and zero till drill as compared to conventional sowing of wheat crop after harvest of paddy.

Table 6 : Specifications of different types of conservation tillage seeding/planting machine

Sl. No.	Particulars	Zero till drill	Strip till drill	Roto till drill	Slit till drill
1.	Source of power	35/45 hp tractor	35/45 hp tractor	35/45 hp tractor	35/45 hp tractor
2.	Type / no. of furrow openers	Inverted 'T' type/ 09-11	Rotary blade strips and shoe type/ 09	Rotary blades and shoe type/11	Rotary cutters and shoe type/ 09
3.	Row spacing, mm	180 (Adjustable)	200 (Fixed)	180 (Adjustable)	230 (Fixed)
4.	Width, mm	1600-2000	1800	2000	1800
5.	Drive wheel	Angle lug-front mounted	Angle lug-side mounted	Star lug-rear hinged	Peg type-side mounted
6.	Weight, kg	210	300	350	300
7.	Unit price, Rs	30000	60000	70000	55000

Table 7 : Performance of different types of conservation tillage, sowing/planting machines compared to conventional tillage-sowing of wheat

Sl. No.	Particular (s)	Zero till Seeding	Strip Till Seeding	Roto till Seeding	Slit till seeding	Conv. Tillage (3 passes)- sowing
1.	Time, h/ha	3.23 (70.1)	4.17 (61.2)	3.4 (68.1)	2.50 (76.8)	10.80
2.	Fuel used, l/ha	11.50 (66.8)	17.50 (49.4)	13.80 (60.1)	10.00 (71.1)	34.60
3.	Operational energy, MJ/ha	648.96 (67.2)	1001.76 (49.3)	783.60 (60.3)	565.00 (71.4)	1976.11
4.	Cost of operation, Rs./ha	1400 (58.8)	2000 (41.2)	1800 (47.1)	1000 (70.6)	3400
5.	Saving, Rs/ha	2000	1400	1600	2400	-
6.	Command area, ha	45	30	40	50	-
7.	Benefits, Rs/year	90000	42000	64000	120000	-

Figures in paranthess show percent savings over conventional practice

Multicrop raised bed planter

It is 35 hp or above tractor operated equipment and is used for sowing bold grains like maize, peas, soybean, bengal gram etc. by changing the planting discs suitable for different crops without dismantling the seed hopper's main shaft on the two raised beds formed by ridgers. Raised bed former cum seeder/planter is suitable for making raised beds of different width and height and sowing of wheat crop simultaneously on these beds in one operation. It is suitable for any kind of soil but in light soils the results are more pronounced. This equipment prepares 2 beds of 35 - 45 cm wide and 3 furrows of 30-45 cm wide and 15-20 cm depth. The planter has 3 furrowers and bed shapers to form bed and shaping the beds. On these beds 2 or 3 lines of wheat can be sown. Also this equipment could be used to make broad bed of 80-120 cm wide and planting of 4-6 rows simultaneously. The advantages derived are saving of about 30 to 35 percent of irrigation water and increased in yield 5-10%. The field capacity of this machine is about 0.48 ha/h. The cost of this equipment is approximately Rs 80,000/-

Broad bed former cum planter

A broad bed former with planting/seeding attachments was developed by CIAE, Bhopal for forming of beds and planting of crops. The bed former design consists of a main frame and a tool bar for the adjustment of width of beds. The planting unit consists of modular inclined plate planting unit and row-to-row spacing could be adjusted as per the need. Field trials for sowing of soybean and pigeonpea on three rows and two rows of 30 cm row spacing were conducted on broad bed of 1.55-meter top width. Two furrower assemblies were fixed on front tool bar of the planter for forming of broad beds. Furrowers were found to be effective in forming of broad beds of 10-15 cm height (average 12.5 cm). Field capacity of the five-row machine was found 0.25 ha/h. Trials conduced on techno-economic evaluation of bed seeding techniques in wheat crop indicated that there was 41.5 % saving in irrigation water and 25.41 % reduction in cost of operation as compared to flat bed under sandy loamy soil condition.

Equipment for Residue Management

Crop residue management is essential for successful direct seeding. Maintaining crop residue, rather than baling, burning or tilling, offers many benefits. These include increased snow catch and water infiltration, reduced moisture evaporation, increased soil organic matter, improved soil structure and plant nutrient cycling, virtually no chance for wind erosion and much reduced potential for water erosion, and the reduction of some weed species. For managing the crop residue in the field following equipment are used.

Stubble shaver

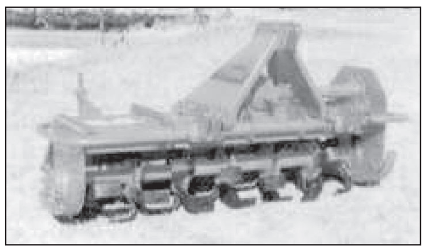
It is 35 hp or above tractor operated crop stubble chopping and spreading machine. It is used to chaff and spread the crop stubble of wheat, maize, paddy and other crops by the rotating cutter operated by PTO of the tractor. The chaffed straw can be incorporated in the soil by the use of mould board plough or rotavator or both the implements effectively.

Rotary slasher

Rotary slasher helps in performing the most versatile method of grass cutting i.e. slashing. It is powerful enough to cope with tall weeds and small bushes and provides better results by keeping scalping to minimum. The machine has a light but strong construction to suit the 35 hp or above tractors. It is one of the best machines for cutting unwanted wild grass and very cost-effective for medium size grass cutting. Slashed and spread grasses can be incorporated in to the soil by the operation of rotavators or MB Plough.

Rautaray (2003) revealed that the straw incorporated tillage showed that direct rotavation under chopped straw condition followed by drilling was 28.5% energy efficient and 23.6% cost-effective compared to the mould board plough + rotavator + drill operations. The mould board plough and rotavator operations gave almost straw free surface (Straw incorporation = 89.7% at 50-125 mm depths) for unimpaired drillings.

Rotavator



It is suitable for preparing seedbed in a single pass both in dry and wetland conditions. It is also suitable for incorporating straw and green manure in the field. It consists of a steel frame, a rotary shaft on which blades are mounted, power transmission system, and gearbox. The blades are of L-type, made from medium carbon steel or alloy steel, hardened and tempered to suitable hardness. The PTO of tractor drives the rotavator. Rotary motion of the PTO is transmitted to the shaft carrying the blades through gearbox and transmission system. A good seedbed and pulverization of the soil is achieved in a single pass of the rotavator. Tractor of 35 hp or more is required for rotavator.

Conclusion

Land development and installation of the drainage system can be done either by manual or by mechanical means. Manual construction requires mostly the simple hand tools used for digging and dressing such as shovels, spades and augars etc. A variety of machines are used for mechanized land development including land leveling and installation of the drainage system. Land development and grading require use of self propelled and heavy equipment such as crawler tractors with heavy duty ploughs and dozers, high horsepower tractors with dozing and hoeing attachment,. crapers, ditchers, chisel ploughs, sub-soilers, terracers, levellers etc. Land graders and shapers are used in surface drainage for improving the surface topography to facilitate smooth overland flow. 'V' Ditchers or motor graders can be used for making field ditches. Motor graders permit the field ditches to be constructed with much flatter side slope than is possible with 'V' ditchers. Under specific field preparation, even a plough can be used for reshaping the land to facilitate surface drainage. Machines such as backhoe, dragline etc. are used for the construction of large drainage channels. In the installation of sub-surface drainage, such machines are to be used which combine all the basic operations like , trenching, laying of flexible or rigid drain pipes, placement of filter and backfilling of the trench.

The installation can also be done partially by mechanical means and partially by manual means. This involves trenching by machines as backhoe, trencher etc. and then laying the drains manually. motor grader, dozer etc. can then be used for backfilling. Trenchless plough is to be used for fully automatic laying of flexible drain pipes . These machines operate with a laser control system to maintain uniformity in depth and grade of the drain pipes. These machines are capable of laying drain pipes at a specified depth without any appreciable deformation of the surface and without actually opening up a trench. Role of modern equipment/machinery for conservation agriculture is vital .Though the effect of direct drilling (no-tillage) has been found to be advantageous in terms of increase trafficability, decrease soil compaction in long run, reduced soil erosion due to wind and water, decreased water evaporation and increased availability of water in the soil. However, to realize the full advantage of conservation tillage, retention of crop residue especially with controlled traffic measures may further be beneficial due to reduce soil compaction and increased water infiltration and reduced soil evaporation due to residue mulch and provide more water for plant growth.

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PRA and Focussed Group Discussion as tools for participatory Natural Resources Management

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Participatory Technology Tools for decision and empowerment is a participatory development communication methodology whereby community members are able to articulate their problems, ideas and vision about optimal and productive use of water in a community so that equitable distribution of water takes place without conflicts and competition.

The people begin to see that each village is experiencing similar problems and become aware of the need for community organization. The government policies and actions are proposed to be changed, the people begin to organize, and the history of the villages is to be changed forever as far as the resources and the farming systems management in the village or community is concerned. To achieve this we practice certain tools and techniques called the RRA (Rapid Rural Appraisal) and the PRA (Participatory Rural Appraisal).

RRA is a systematic, semi structured activity conducted on site by a multi-disciplinary team with the aim of quickly and efficiently acquiring new information and hypothesis about life and resources, while PRA is enabling local people analyse their living conditions to share the outcomes and to plan their activities. PRA is defined as an approach and method of learning about rural life and conditions from, with and by rural people (Chambers1994). In otherwords, it is a growing family of approaches and methods to enable local people to share, enhance and analyse their knowledge of life and conditions to plan and act.

The purpose of Rapid Rural Appraisal (RRA) is to enable the outsiders to gain information from rural people about the rural condition in a more cost effective and timely manner. It entails outsiders obtaining information, taking it away and analyzing it. So RRA is meant for learning by the outsiders. Participatory Rural Appraisal (PRA), on the other hand, is a family of approaches and methods which enable the local people to analyze their situation to plan and act.

Differences in RRA and PRA

Criteria	RRA	PRA
Objective	Decided by the agency	Decided by the community
Time scale	Relatively rapid and is apart of the long term data gathering and planning process within the agency	Short or prolonged but a part of the long term process in the community
Key actors	Outsiders facilitated by community members	Community members facilitated by outsiders
Interpretation/use of results	By outsiders	By the community
Techniques used	Few	Many and diverse
Political correctness	Low to moderate (seen as passe)	High (no funding without it)
Developed in	1970 to 1980	1980 to 90
Key resource	Local people's knowledge	Local people's analytical ability
Main innovation	Change of behaviour and attitudes	Methods
Nature	Extractive	Facilitative
Mode of instruments	Verbal (interview, discussion)	Visual (participatory diagramming)
Ideal objectives	Learning from insiders by outsiders	Empowerment of local people
Outsiders role	Investigator	Initiator and catalyst
Insiders role	Respondent	Presenter, analyst and planner
A model for	Participatory intervention	Participatory planning and action

In contrast to these approaches, the traditionally used 'Surveys' are usually close to roadside/urban areas, users of services than non users, meeting men rather than women, elites than disadvantaged, readily accessible and articulate persons instead of timid and remotely dwelling people. The PRA and the Survey differ in their approach as the PRA emphasizes on the relevance of context, richness of data for its applicability, the Survey research emphasizes rigour and precision in data collection and verification which is useful for theory building. Collinson (1981) proposed easier way to conduct an exploratory survey to identify agricultural research priorities within a short period. These may further be validated by formal and exhaustive surveys.

PRA has emerged as a development research methodology mainly to position the partners of rural development in the right perspective and iron out the inherent problems found in the conventional research methods like survey. PRA as a development methodology has primarily been evolved to appraisal the rural resources, problems and requirements. University of Chiang Mai and Khon kaen in Thailand have tested, modified and reinvented the key concepts of RRA/ PRA. The new term PRA is being replaced by PLA. While the PRA implies only finding out and assessment, the PLA (Participatory Learning and Action) implies decentralized empowerment and local creativity.

Comparative analysis of PLA, Survey and Ethnographic Research

Item	**PLA/ PRA**	**Survey Research**	**Ethnographic Research**
Duration	Short	Long	Long
Cost	Low to medium	Medium to high	Medium
Depth	Preliminary	Exhaustive	Exhaustive
Scope	Wide	Limited	Limited
Integration	Multidisciplinary	Weak	Weak
Structure	Flexible informal	Fixed, formal	Flexible informal
Direction	Bottom up	Top down	Not applicable
Participation	High	Low	Medium to high
Methods	Basket of tools	Standardized	Basket of tools
Major research tool	Semi structured interview	Formal questionnaire	Participant observation
Sampling	Small sample size based on variation	Random sampling representative	None
Statistical analysis	Little or none	Major part	Little or none
Individual case	Important, weighed	Not important, not weighed	Important weighed
Formal questionnaires	Avoided	Major part	Avoided

Item	PLA/ PRA	Survey Research	Ethnographic Research
Organization	Non hierarchical	hierarchical	Not applicable
Qualitative descriptions	Very important	Not as important as hard data	Very important
Measurements	Qualitative or indicators used	Detailed, accurate	Detailed, accurate
Analysis/ learning	In the field and on the spot	At office	In the field and on the spot

Source: S.P.Singh 1997 Lecture delivered in training programme on "Extension Management and Communication" organized by the International Federation for women in Agriculture and Indian Agricultural Research Institute, New Delhi, India on Sept, 15 to Oct 5,1997

The principles of PRA/RRA:

1. **Offsetting biases**: Seeing the problem as it appears and not from the point of view of one's own discipline (Not being boggled upon by discipline-wise specialization).
2. **Triangulation:** Cross checking using different methods within the team and with the villagers, and all those concerned with PRA. **Ref Annexure.1**
3. **Optimizing trade off**: Searching for the best possible data and information in terms of analyzing the problems of the villagers.
4. **Optimal ignorance**: Listening carefully as an ignorant, without jumping to conclusions or providing answers and solutions for the problems of farmers.
5. **Appropriate imprecision**: Trends can provide enough insight on to the situation and pointers to solutions even when the exact statistics is not known as there is no precision data collection as the ultimate purpose is to identify the problems of farmers.
6. **Check list of items:** A check list of items to focus upon is to be made for each tool prior to setting off for PRA. **Ref Annexure2**
7. **On the spot analysis:** PRA provides for on the spot analysis of the issues and not at a later time.
8. **Bottom up approach:** The emphasis is laid on listening to problems of farmers or the user clientele for their point of view to be communicated to the top, rather than the top down approach where the decisions are taken at the top based on their understanding of the client system and carried out.
9. **Searching for difference:** A variety or diversified data from different sources is to be collected from the villagers.(key informants**- Ref Annexure 3)**

PRA becomes ***scientific*** provided, if it is formulated for research purpose, planned systematically, recorded systematically, subjected to cross checking (triangulation), and controlled on reliability and validity.

Before embarking on the PRA, ensure the appointment with the village key stakeholders such as Village Headman (Sarpanch/Pradhan), Village Accountant, Village Development Officer, Officials of other Line Development Departments posted in the village and resource poor farmers, farm women etc., by freely and frankly sharing the objectives of the exercise to gain the confidence and willing cooperation of the stakeholders. These contacts are to be used to quickly build the rapport with the villagers. The PRA can then be started using the techniques more or less in the same sequence as appear below. All the PRA outputs should essentially include the names of KI's. The KIs may be different for different tools. Wherever necessary, the direction and village boundary is to be indicated.

PRA Tools

1. **Collection of Basic Information of the Village**: This will indicate the data related to the population to area under crops, number of families, yield of animals and crops, mortality related to animals etc. The Site Coordinator's good office could be used to have this information collected and supplied in order to save time. However, whenever a PRA is done within a reasonable time frame, the PRA team has to collect basic information of the village by referring to the records available in the village panchayat office and also by interacting with the key informants (KIs). For this, official members of panchayat/ school and such organizations of the village could be ideally selected as KIs.

   Village Transect: It is also known as **General Transect**. Transect is not an imaginary line passing through the village. Transect is making a long walk inside the village and locating the various items that are found in the village like soil, crops, animals, problems, etc. Start with a transect walk, decide the route with varied features, take at least three routes, two along both the sides of village and one passing through the village, ensure participation of villagers. Discuss while conducting transect walk. Identify topography (Agro ecological niches) like upland, medium land, low land, road, residential area, field bunds, ponds, stream, hillock, marshy land, common land, forest land, orchards, arable land, non arable land etc. Write down above transect line, in local language along with translation in English. Mention one niche once only, no matter how often it occurs. General convention is that to place the highlands on left and lowlands on right. Draw pictorial representation of niches on top. Then transect matrix is to be filled up with reference to following variables in each agro-ecological niches: Soil type, water resources, crops, vegetables, animals, trees, forests, agro-forestry, forages, weeds, technological interventions, problems and opportunities. While listing the crops, also list those not available at present, but grown at other time of season.

An Illustration of a Transect of MORAPPANADU VILLAGE(TUTICORIN DIST)

Criteria	**Roadside Fields**	**Residential Area**	**Riverside Fields**	**Pond**
Soil type	Black sandy loam soil	Red sandy loam soil	Black sandy loam soil	Calcareous and sandy loam soil
Topography	Low land	Low land	Low land	-
Crops	Rice, black gram, green gram, tuber crops	Brinjal, cucurbits, turmeric, ladies finger	Rice, black gram, green gram, tuber crops	-
Livestock/ Fish	-	Cow, buffalo, goats, poultry, ducks	-	Catla, Rohu, Mrigal, Common carp, Silver carp
Tree crops	Banana, mango, coconut	Coconut	Banana, mango, coconut	-
Other vegetation	Neem, palm, prosophis	Neem, palm, prosophis, turmeric	Neem, palm, prosophis	
Water sources	Open wells, canal	Open wells, canal	Canal, river	Canal
Diseases and pests	Blast of rice, Sheath blight of rice, shoot borer of rice, Pod borer in pulses, anthracnose in green gram, Sigatoka in banana, bacterial disease	Foot and mouth disease in cattle, Ranikhet in poultry, fits in goat	Blast of rice, Sheath blight of rice, shoot borer of rice, Pod borer in pulses, anthracnose in green gram, Sigatoka in banana, bacterial disease	-

Criteria	**Roadside Fields**	**Residential Area**	**Riverside Fields**	**Pond**
Weeds	*Solanum nigrum,* Saranai, Vasambu	Grasses, Korai	*Solanum nigrum,* Saranai, Vasambu	Neerchedi, Lotus, Prosopis
Problems	Water scarcity, lodging of rice, disease and pests, weeds	Diseases in livestock	Water scarcity, lodging of rice, disease and pests, weeds	Silting, underutilization
Opportunities	Lodging resistant varieties, IPM, SRI, Medicinal plants	Mushroom production, Milk production	Lodging resistant varieties, IPM SRI, Medicinal plants	Desilting and fish production

2. **Mobility Map**: It indicates the ease of agricultural resources availability and accessibility for the villagers. The mobility map should show the direction, frequency, mode, the cost incurred and the purposes for which the villagers have to travel outside the village for agriculture. The mobility maps can be made for different user groups.

Sl. No	**To/From**	**Mode of Transport**	**Distance (Km)**	**Fare (Rs)**	**Purpose**
1.	Vallanadu	Bus/cycle/ Two wheeler	3	2.00 -3.50	- Purchase of pesticide - Purchase of seed - Purchase of fertilizer - Bank - Agricultural office - Vety. Office - School
2.	Palayam-kottai	Bus	12	4.00-5.50	- Market - Hospital - School - Entertainment - Implements purchase/ repair - Fuel

Sl. No	To/From	Mode of Transport	Distance (Km)	Fare (Rs)	Purpose
3.	Seythunga-nallur	Bus/ two wheeler	7	7.00	- Purchase of seed - Agricultural office
4.	Killikulam	Bus/cycle/ Two wheeler	4	3.50	- Training - Consultancy
5.	Tuticorin	Lorry/Bus	40	Rs10/km* 11.75	- Paddy procurement
6.	Alankulam	Lorry/Bus	50	Rs10/km* 20.00	- Paddy procurement
7.	Eeral	Lorry/Bus	35	Rs10/km* 12.00	- Paddy procurement
8.	Aathur	Lorry/Bus	50	Rs10/km* 20.00	- Paddy procurement
9.	Surandai	Lorry/Bus	45	Rs10/km*	- Paddy procurement
10.	Trichy	Bus	450	Rs 250.00	- Paddy thresher
11.	Kerala	Lorry	150-200	Rs10 /km*	- Ernakulam - Kollam - Trivandrum - Banana procurement

*** Lorry rental charge**

3. **Time Line**: This indicates the major events in agriculture remembered by the villagers. Both historical and futuristic timelines can be drawn. While the historical timelines are common for analyzing an understanding the developments or major events and interventions that had their bearing on the agriculture sphere in the past, whereas, the futuristic timelines would provide leads for planning and development trends. The KI for the historic timeline is to be chosen carefully who would be old enough and knowledgeable on the major events that affected agriculture.

Time Line

Year	Event
1945	Primary school was started in the village.
1949	Police station was constructed.
1955	Bus services started.
1959	Panchayat office was constructed
1960	Iron plough put in use.
1960	Bike introduced in the village.
1962	**Demonstration of Japanese line planting technology.**
1962	People started using herbicides.
1962	Radio was introduced.
1963	Use of pesticides started.
1970	Post office started.
1975	Electricity connection was provided.
1980	People were sensitized about over-use of pesticides.
1980	First diesel pump introduced.
1985	First tractor was introduced.
1985	First hand pump was introduced.
1988	**Sindhi cow was introduced.**
1988	**AI technique was demonstrated.**
1989	**ASD 16 and ADT were introduced.**
1990	**Jersey cow was introduced.**
1994	Agricultural Co-operative Society was started.
1994	Ottu samba rice hybrid was introduced
1995	Thrasher was introduced.
1995	Middle school was started.
1995	First TV was introduced.
1996	Biogas plant was introduced.
1998	Farmers’ education programme launched.
1998	Freshwater fishes were introduced in the village pond.
1999	Water supply from tanks started.
2002	Cable TV services started.
2003	Solar lights were introduced.
2004	**SRI technology was introduced.**
2004	Central water commission appoints a representative from here.

4. **Time Trend:** It depicts the changes in past few years/ decades indicating trends related to variables specific to the village concerned with agriculture. Time trends can be drawn on changes in cropping/ farming scenario, the area, production, productivity and price fluctuations etc.

5. Seasonal Calendar and Seasonal Analysis: Seasonal calendar depicts month-wise activities for agriculture based enterprises (crops/ animals etc.) in a year. The gender disaggregated seasonal calendars indicate the differential involvement of men/ women/children in these enterprises. The Seasonal Analysis on the other hand represents the deviations from the normal or the month-wise abnormalities regarding agriculture and animal husbandry. The pests and diseases prevalence in crops and animals, the fodder availability, the cash inflows/out flows, the labour requirements and migration, on-farm, off-farm and non-farm employment etc., can be shown in the Seasonal Analysis.

An Illustration of a Seasonal calendar of MORAPPANADU VILLAGE (TUTICORIN DIST)

Particulars	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Crop												
Paddy	N	FP	TP	W1	W2	H&T						
(Pisanam)	S				FA							
Paddy									N	TP	W	H&T
									FP		FA	
Banana						FP	PL	FUR	W1	FA1	RS	FA2
	W2		W3	H	H	H						
Black gram						S			H			
Green gram						S			H			
Livestock												
Coleus	PL	W&F	H									
Cow			SG				OG				SG	
Goats	SG				OG				SG			
Poultry						CF						

N – Nursery, S – Sowing, FP – field Preparation, TP – Transplanting, W1 – First weeding, W2 – Second weeding, FA – Fertilizer application, FUR – Furrowing, PL _ Planting, H & T – Harvesting and Threshing, FA1 – I dose fertilizer application, FA2 – II dose fertilizer application, RS – Removing side suckers, H – Harvesting, SG – Shed Grazing, OG – Open grazing and CF – controlled feeding.

An Illustration of a Seasonal analysis (problems)

Crop	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Paddy		LS	LaSh	LF,SB	EHB	RD	LaSh					
(Pisanam)												
Paddy										LS	LF,SB	EHB& RD
										LaSh	WS	LaSh
Banana	W	BW	SLF								FW	
	LaSh											
Black gram								PB	PF			
Green gram								PB	PF			
Coleus		W										
Livestock												
Cow			TD	FMD								
Goats											Fits	

LS – Leaf spot disease, LaSh - Labour shortage, LF – Leaf Folder, SB - Stem borer, EHB – Earhead bug, RD – Rat Damage, WS – Water Scarcity, FW – Fusarium wilt, W – Weed, BW – Bacterial Wilt, SLF – Sigatola leaf spot, PB – Pod Borer, PF –Pod fly, TD – Throat disease, and FMD – Foot & Mouth disease.

6. **Farm Household Map:** This map depicts the way in which the surrounding of a typical household appears without going into the details of its inside structure.

7. **Bio-resource Flow Diagram:** This indicates the extent to which a typical farm household utilizes and recycles various biological resources among different agricultural enterprises for their efficient utilization. The map also provides for indicating suggestions/ technological interventions for bettering the bio-resources utilization.

8. **Daily Routine Diagram/ Daily Activity Profile:** This daily routine diagram depicts the way in which a typical farmer (middle/old aged) or farm woman (middle/old aged) spends his or her time from morning to night. These maps can be drawn for peak and off-seasons. As these maps indicate specific involvement of farmers and farm women in different home, homestead and farm activities as well as the leisure on time dimensions, it can be effectively used to plan the extension (developmental /capacity building) interventions in the village.

Daily Routine Diagram of Chak-Nawada village

KIs: Rajeev Ranjan Kumar, Arvind Yadav, Mrs Rajni Devi

Time	Rural Men	Rural Women
04:30 A.M.	Wake-up	Wake-up
05:00A.M.		Household activities
06:00A.M.	Milking, harvesting and	
07:00A.M.	marketing of vegetable	
08:00A.M.		
09:00A.M.		Farm activities or labour
10:00A.M.	Breakfast	
11:00A.M.	Farm activities	
12:00 noon		
1:00 P.M.	Lunch	Lunch
02:00P.M.	Farm activities	Farm activities/Labour
03:00P.M.		
04:00P.M.		
05:00P.M.		Milking
06:00P.M.		Household activities
07:00P.M.		
08:00P.M.	Dinner	Dinner
09:00P.M.	Sleep	Sleep

9. **Agro-ecology Map:** Agro-ecology map will indicate the relation between agriculture and environment which includes average temperature, average rainfall, fragmentation of holdings, natural vegetation, drainage system, weeds, etc. Encourage farmers to draw this map. Identify major land marks. Identify systems (village) and sub systems (crop land, orchards, common land etc.) boundaries, show the neighboring villages or other features like river, hillocks, government land, forests etc., where the boundary of village ends. Depict crops, animals, natural resources like soil type, water resources (wells, river, channel, ponds etc.), forest, Common Property Resources (CPR), use of locally available resources or whatever stakeholders observe during the walk. Write in local language along with English translation.

10. **Resource Map:** This indicates both the natural resources and man made resources needed for development of agriculture. Ensure the participation of all stakeholders (male, female, old, young and children). Depict main crops, trees, animals, CPR, farm implements, communication items, human resources for agriculture like skilled labour, technical manpower (AO, VO) etc.

Social Map: This is a simple drawing or map drawn without scale to enable to understand and simplify location and structure of houses and other social facilities. It depicts the various social issues of the village such as social structure (neighbourhoods, housing pattern, social and religious bodies like panchayat, schools, temples, churches, mosques etc.), social stratification (based on social occupations, caste), social capital (SHGs, mahila mandals, charcha mandals, youth clubs, local self government etc), social facilities, social processes (conflicts, cooperation), value systems, leadership pattern, , taboos, beliefs, social evils etc.

11. **Indigenous Technical Know-how (ITK)**: The indigenous technological practices, the indigenous species/ breeds found in village with reference to agriculture is documented on a structured proforma indicating the rationale/ purposes for which it is being used along with the details on the users, the product/process description and the consent of the user representative to record the same.

No	Technique	Use
1	Kudhir	Paddy seed storage
2	Dry neem leaves	Grain Storage
3	Owl perches	Rat control in paddy fields at grain maturity
4	Neem, Pongam and Pugaiyan leaves	Green leaf manuring
5	*Philanthus niruri* + Milk	Treatment of Jaundice
6	Neem kernel extracts	Pest control in paddy
7	*Trianthema portulacastrum* (Saranai) leaves	To reduce general body pain and for women who have given birth to child
8	*Trianthema portulacastrum* (Saranai) roots + Pepper + Sukku	For curing cough
9	Vallarai + Cow milk	Good health
10	Vallarai dried powder + sugar	Improves memory and cures gas trouble
11	*Cissus quadrangularis* (Pirandai) whole plant	For good body health
12	Thutthuvaamadaki + child urine	Medicinal cure for *Vata*

12. **Technology Map**: The technology map will indicate the technology decision behaviour of the farmers, in terms of adoption, over-adoption, reinvention, rejection and discontinuance with reference to the agricultural technologies.

Category	**Technology**	**Technology adoption behaviour**	**Reasons**
Rice	*Arikurai, Kottam samba, Kudippam, Aanaikambu,*	Discontinued	Due to poor rice yield and disease susceptibility
	Hybrid rice (MGR)	Discontinued	As marketing was a serious problem.
	IR 20, ADT 36 and IR 50	Adopted	Due to their better disease resistance and yield
	SRI technology	Adopted	Reduced water consumption, better yield, good departmental assistance
	CO 43	Replaced by ADT 43	Due to better disease resistance
	ASD 16	Over -adoption	There is no match for the variety in terms of yield, marketability and tillering capacity.
Black gram	T9 and ADT 3	Adopted	Good yield, less disease incidence
Banana	*Kozhikoodu* and *Sakkai*	Replaced by *poovan* and *kathali*	Owing to better production characteristics and marketing.
	Eththan	Passively rejected	Extremely susceptible to diseases.
Other crops	Mushroom and medicinal plants technologies	Passively rejected	Owing to lack of interest and perceived fear of poor economic returns.
	Oil palm	Actively rejected	Due to poor economic viability and marketability.
Machinery	Tractor (HM)	Adopted	Convenient to use; help to enhance work efficiency of the farmer operations.
	Thrasher (Assembled)	Adopted	As above.
	Power tiller (Mitsubishi)	Adopted	As above.
	Power sprayer	Adopted	As above.
	Rotary weeder (TNAU)+C7	Adopted	As above.
Livestock	Local breeds (N.D.) and cross bred cows	Adopted	High milk yield, low cost, resistant to diseases, etc
	Murrah	Discontinued	Reduction in grazing lands
	Poultry and goats (N.D.)	Adopted	Alertative source of income
	A.I. Technology	Adopted	Increased productivity

13. **Matrix Ranking**: Matrix ranking will indicate the reasons for technology decision behaviour of the farmers.

Types of Ranking: Ranking methods include:

- Preference Ranking
- Pair wise Ranking
- Direct Matrix ranking .
- Wealth Ranking (already covered)

Preference Ranking

Adopt the exercise to local conditions and choose a topic preferably one which is related to the fieldwork. For example, what are the main problems affecting the growth and development of crop husbandry / animal husbandry / fishery / horticulture ~ farm mechanisation / fisheries / agro-forestry in your area?

Preference ranking allows the PRA team to determine quickly the main problems of preferences of individual villagers and enables the priorities of different individuals to be easily compared.

It has logical steps to be followed:

1. Decide upon a set of problems or preferences to be explored.
2. Interact with the person and know his / her favoured items in order of priority .
3. Repeat this exercise with a good number of people .
4. Tabulate the responses.

Pair- wise Ranking

Steps:

1. Identify a set of problems, or preferences, to be prioritised. For example, farming problems, preference for tree species, preference for cattle breed, preference for poultry breed etc.
2. Identify six or less types of trees (in case of tree species preference). .Note down each one of the six trees on a separate card.
3. Place two of these in front of the farmer and ask him to choose most preferred one with reasons for choice. Mark the response in the appropriate box in the priority ranking matrix.
4. Follow the procedure for rest of the species. Each time the criteria should be noted.
5. Present a different pair and repeat the comparison
6. Repeat until all possible combinations have been considered.
7. List the problems / preferences in the order
8. Repeat the pair-wise ranking exercise for a number of individuals and tabulate their responses.

Prepare a pair- wise comparison table as below:

Technology	T1	T2	T3	Total (Rank)
T1	-	T2	T3	0(III)
T2	T2	-	T3	1(II)
T3	T3	T3	-	2(I)
Total (Rank)	0 (III)	1 (II)	2 (I)	

Scoring and ranking, especially using matrices, for systematic comparison of technologies according to locally generated criteria. Various matrix rankings and scoring are used to understand farmers' decision-making processes, comparing preferences for different technological options between individuals and between different groups and eliciting decision criteria. Specific criterion or reason related a specific behavioural decision like adoption, discontinuance, over-adoption, rejection, passive rejection, disenchantment, discontinuance etc., is also called Direct Matrix Ranking.

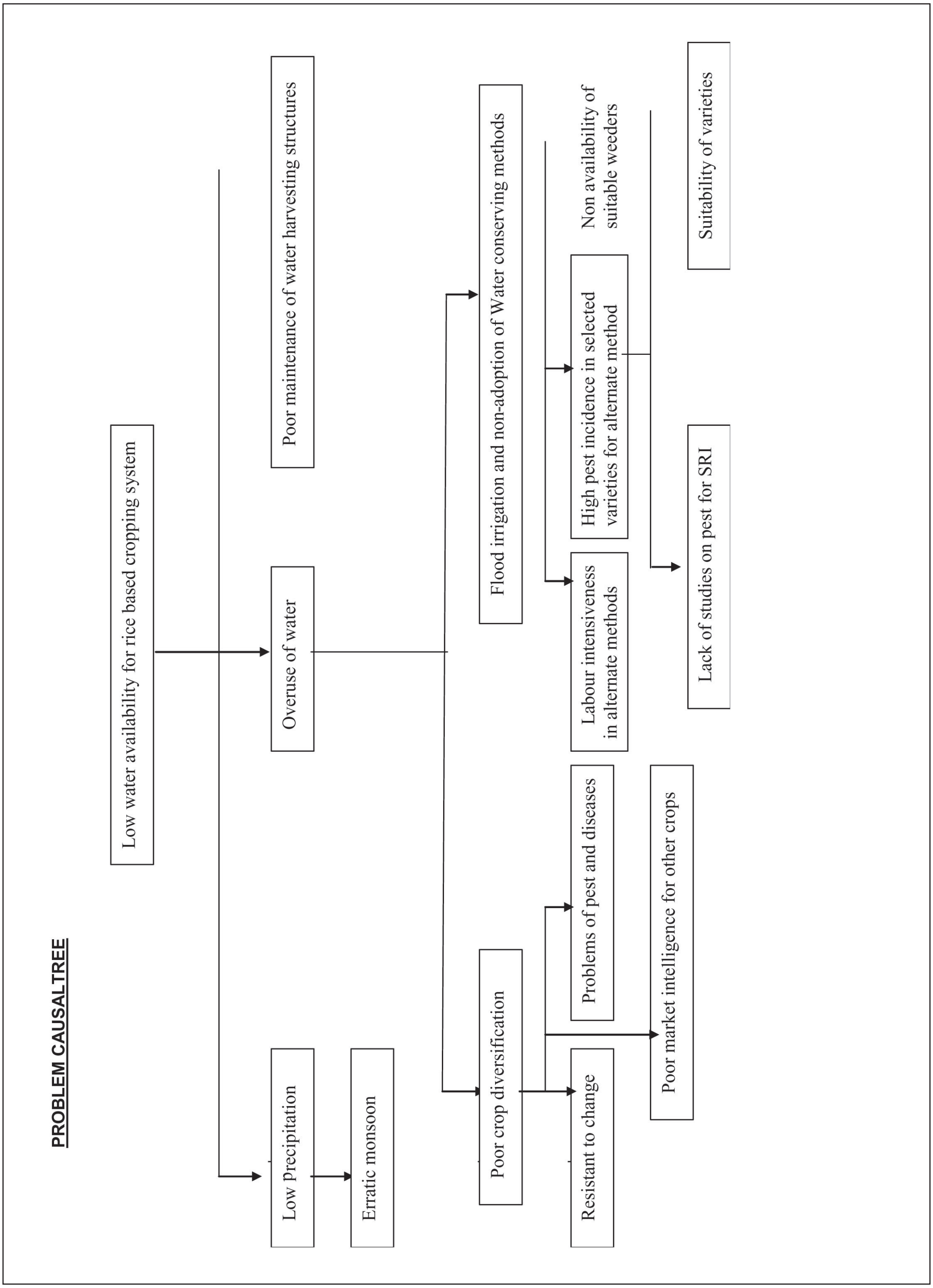
Matrix Ranking for Different Rice Varieties Adopted in the Village

Parameters	KIs	ASD 16		ADT 31		1R 20		CO 43		TKM 9	
		Rank	Points	Rank	Points	Rank	Points	Rank	Points	Rank	Points
Yield	KI - 1	A	5	B	4	E	1	C	3	D	2
	KI -2	A	5	B	4	C	3	E	1	D	2
	KI -3	A	5	B	4	C	3	E	1	D	2
	KI -4	A	5	B	4	D	2	C	3	E	1
	Total		**20**		**16**		**9**		**8**		**7**
Disease resistance	KI - 1	A	5	B	4	C	3	D	2	E	1
	KI -2	A	5	B	4	C	3	D	2	E	1
	KI -3	A	5	B	4	D	2	C	3	E	1
	KI -4	A	5	B	4	D	2	C	3	E	1
	Total		**20**		**16**		**10**		**10**		**4**
Straw yield	KI - 1	A	5	B	4	C	3	D	2	E	1
	KI -2	B	4	A	5	C	3	E	1	D	2
	KI -3	A	5	B	4	C	3	D	2	E	1
	KI -4	A	5	B	4	D	2	C	3	E	1
	Total		**19**		**17**		**11**		**8**		**5**
Tillering capacity	KI - 1	E	1	B	4	D	2	A	5	C	3
	KI -2	A	5	B	4	C	3	D	2	E	1
	KI -3	B	5	B	4	D	2	C	3	E	1
	KI -4	C	3	B	4	E	1	A	5	D	2
	Total		**14**		**16**		**8**		**15**		**7**

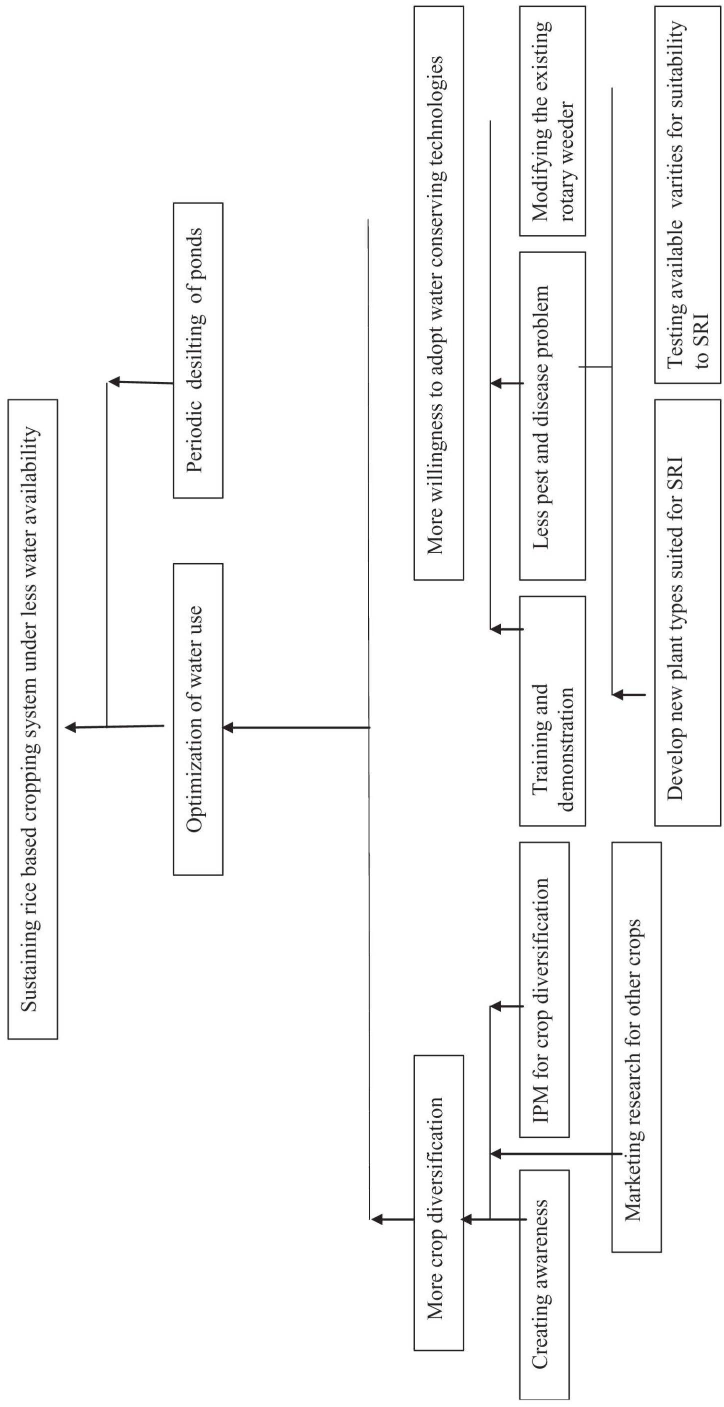
Parameters	KIs	ASD 16		ADT 31		1R 20		CO 43		TKM 9	
		Rank	Points	Rank	Points	Rank	Points	Rank	Points	Rank	Points
Profit	KI - 1	A	5	B	4	E	5	C	3	E	1
	KI -2	A	5	B	4	C	3	D	2	E	1
	KI -3	A	5	B	4	C	3	E	1	D	2
	KI -4	A	5	B	4	E	1	C	3	D	2
	Total		**20**		**16**		**12**		**9**		**6**
Shattering of grains in field	KI - 1	A	5	D	2	C	3	B	2	E	1
	KI -2	A	5	B	4	C	3	D	2	E	1
	KI -3	A	5	E	1	B	2	C	1	D	2
	KI -4	A	5	B	4	D	2	C	3	E	1
	Total		**20**		**11**		**10**		**8**		**5**
Quality of rice / taste	KI - 1	A	5	C	3	E	5	B	2	D	2
	KI -2	C	3	B	4	A	5	E	1	D	2
	KI -3	D	2	B	4	C	3	E	1	A	5
	KI -4	C	3	B	4	E	1	A	5	D	2
	Total		**13**		**15**		**14**		**9**		**11**
Final Score			126		107		74		67		45
Final Rank			1		2		3		4		5

14. **Preference Ranking:** This is to find out the perception of farmers regarding the magnitude of the problems of agriculture found in the village.

15. **Problem Tree**: The problem tree will indicate various resources responsible for the specific problem related to agriculture. This will also indicate the intervention for the various causes which will help in problem identification related to a discipline. An Illustration of Problem Solution Tree in Morappanadu Village (Tuticorin Dist) is presented below


PROBLEM CAUSALTREE
Low water availability for rice based cropping system
Low Precipitation
Erratic monsoon
Overuse of water
Poor maintenance of water harvesting structures
Poor crop diversification
Flood irrigation and non-adoption of Water conserving methods
Resistant to change
Problems of pest and diseases
Poor market intelligence for other crops
Labour intensiveness in alternate methods
High pest incidence in selected varieties for alternate method
Non availability of suitable weeders
Lack of studies on pest for SRI
Suitability of varieties

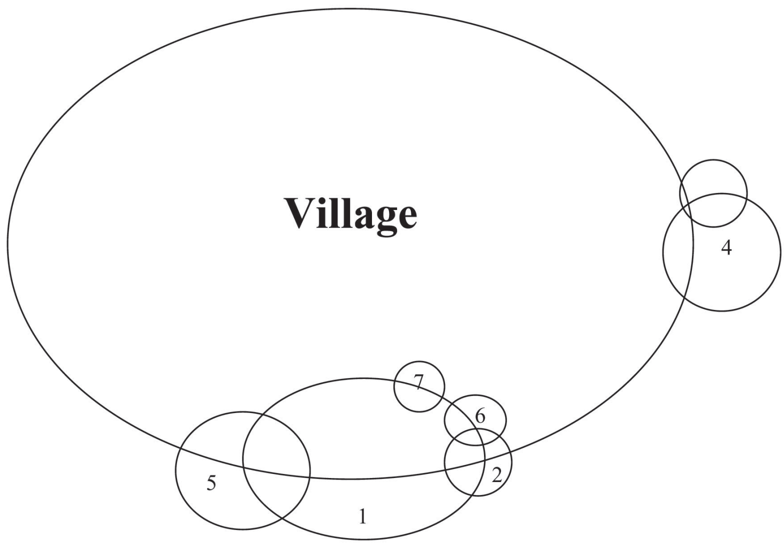
SOLUTION TREE



16. Solution Tree: It is a modification of the problem tree, wherein for each level of problem cause, solutions are indicated to solve that particular problem.

17. Venn Diagram: This indicates the importance of the various individuals and the institutions in and outside the village with regard to a phenomenon related to agriculture. The importance of various organizations/ individuals for a phenomenon is indicated in terms of size of the circles and the interaction among these is represented by the overlapping of the circles.

VENN DIAGRAM FOR SRI TECHNOLOGY IN MORAPPANADU VILLAGE



1. Agriculture College, Killikulam
2. Valarum velanami (Developing Agriculture)- (TNAU)
3. Vivasaya vigyana malar (Agricultural Science)- (FTC)
4. Farmers training centre
5. Department of Agriculture
6. Farmer- Kandasami
7. Farmer- Perumal

18. Wealth Ranking: It is an analytical exercise carried out by local KIs based on their own criteria such as income, assets, employment status and other local measures of well being for the purpose of investigating perceptions of wealth differences and inequalities in community, discovering local indicators and criteria of wealth and establishing relative position of households in community. For this technique, the representative KIs are to be selected from different socio- economic strata for offsetting the biases. The wealth ranking technique is basically an enumerative technique involving all the farm households in a village.

1 Rice ear head bug
2 Banana sigatoka leaf spot
3 Lodging in Rice
4 Fits in Goats
5 Foot and mouth disease in cattle
6 Rice green leaf hopper
7 Rice stem borer
8 Green gram spotted pod borer
9 Poultry coccideiosis
10 Rat menace in rice
11 Water scarcity for rice based cropping system
12 Rice blast

19. Problem Identification and Prioritization: The data collected from various PRA tools indicate the problems faced by the farming community. These can be cross checked by ranking the problems faced by a cross section of farmers/ farmwomen representing different socio-economic strata using snow ball technique or by using paired comparison method. The Value Based Index (VBI) could be worked out wherever quantification of the losses is possible to logically prioritize the problems at the village level across the enterprises, based on economic criteria. The formula for the RBQ is given below

Rank Based Quotient:

$$RBQ = \frac{\Sigma f_i(n+1-i) \times 100}{N \times n}$$

Where, i = Concerned ranks (1 to 5) N = Total numbers of farmers (30)
n = Numbers of rank
f_i = Frequency (Number of farmers reporting that particular problem)

Once the RBQ are found out for each problem, the top most researchable issue in the village is identified by calculating the value based index for each RBQ.

Value Based Index:

VBI = RBQ x Average loss experienced x area of crops/animals

The problem with the maximum value based index is identified as the top most researchable problem.

The table given below shows that water scarcity in rice based cropping system is having the maximum VBI and hence identified as the most important researchable issue.

20. Action Plan: Planning to meet the problems of farmers on problems identified is called an action plan. The plan of work should include the problem, goals to be achieved, the work to be done, who is to participate in carrying out the plan. A calendar of work showing the approximate amount of time to be devoted for each major activity and distribution of major activities. It answers the questions, What, Who, Where, When, How, an activity will be done and the cost involved and the outcome expected out of the action plan.

Problem Identified based on ranks

Sl No	Identified problem	RBQ	Avg % Loss	Area (acre/animals)	VBI
1	Rice ear head bug	94.00	30	150	3383000
2	Banana sigatoka leaf spot	24.67	10	75	1110150
3	Lodging in Rice	28.67	20	56	2568832
4	Fits in Goats	28.00	60	20	2520000
5	Foot and mouth disease in cattle	68.00	65	100	3536000
6	Rice green leaf hopper	74.00	8	38	179968
7	Rice stem borer	94.67	30	263	5975570
8	Green gram spotted pod borer	62.60	30	180	4056480
9	Ranikhet disease in Poultry	68.67	60	60	6180300
10	Rat menace in rice	76.67	10	113	693096
11	Water scarcity for rice based cropping system	99.30	100	118	9373970
12	Rice blast	64.00	15	188	1443840

What	Who	Where	When	How	Cost	Outcome
Production and marketing prospects of medicinal crops.	Agril Economist	Dept. of Agriculture. Economics, AC & RI KIllikulum	2005-06	*Primary data collection of farms and export houses *secondary export data sources	5 lakhs	To know the production and marketing potential and target the production
Carp seed production – An alternate source of income for the farmers in Thamirabarani river basin.	KVK	AC & RI, Killikulam and Morappanadu village	2005	Training in the villages	1 lakh	The irrigation canals flowing in the Morappanadu village and the major canals of the village could be put into optimal use.
Identification, Characterization and Management of the newly occurring blight type disease in banana.	Plant Pathologist	Plant Pathology laboratory, AC & RI, Killikulam and Morappanadu village	2005- 06	* Characterisation of bacteria in lab * field testing of management practices in disease prone areas	10 lakhs	Sustain the economic viability of banana cultivation.
Marker aided improvement of maintainer and restorer line(s) for grain and cooking quality traits	Plant Breeder	Department of Plant breeding, AC & RI, Killikulam	2005-08	* Characterisation of land races for amylose content * Marker assisted backcrossing to improve the quality	25 lakhs	To develop hybrids suited for SRI

Adult and Action Learning Techniques for Participatory Natural Resource Management

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One of the major challenges facing farmers in the rainfed areas of SAARC countries in general and India in particular, is to manage their lands to produce food economically and without degradation of the natural resources on which production is based, particularly soil and water resources. Farming systems in India's rainfed lands are complex, diverse and risk prone. Cultivation in these areas is largely dependent on ill distributed and erratic rainfall with many areas experiencing problems associated with variable rainfall, poor soils and land degradation. Land degradation in the semi-arid tropics of India affects some 166 million ha or 50% of the total geographical area (Sehgal and Abrol 1992). Erosion by water is the single most important mechanism affecting an area of 86.9 million hectares.

Addressing these issues calls for a holistic strategy that involves the affected community at all stages of planning, implementation, monitoring and evaluation. Participation encourages sharing of decision-making power with affected communities and ensures that the issues relevant to these communities are addressed in ways that are appropriate to their social and environmental context. Indigenous technical and process knowledge can be integrated with scientific knowledge to develop appropriate pathways for addressing issues of concern. It involves mobilization of the affected communities and enhanced awareness about the need to manage resources in a sustainable way. It is essentially a two-way learning process in which both the farmers and the researchers learn to better understand the dimensions of the problem and how it can be addressed.

Participatory learning, a key principle of community mobilization, recognizes that : (i) researchers, extension agents and farmers have knowledge about agriculture and resource management that can be complementary, and (ii) different realities exist amongst these different knowledge systems. Participation is a key philosophy in community mobilization. Jules Pretty (1995) states that 'the many ways that development and organizations interpret and use the term participation can be resolved into several clear types'. These range from manipulative and passive participation where people are told what is to happen and act our predetermined roles, to self-mobilization, where people take initiatives largely independent of external institutions.

Pretty's typology for describing levels of participation (Pretty, 1995) is as follows:

Typology	Characteristics
Manipulation participation	Participation is simply pretence, with people's representatives on official boards but who are unselected and have no power.
Passive participation	People's participation by being told what has been decided. Involves unilateral announcements by an administration of project management without any listening to people's responses. Information shared only belongs to external professionals.
Participation by consultation	People's participation by being consulted or by answering questions. External agents define problems and information gathering processes, and so control analysis. Such a consultative process does not concede any share in decision-making and professionals are under no obligation to take on board people's view.
Participation for material incentive	People's participation by contributing resources (labour, in return for food, cash or other material incentives). Farmers may provide the fields and labour, but are involved in neither experimentation nor the process of learning. People have no stake in prolonging technologies or practices when the incentives end.
Functional participation	Participation seen by external agencies as a means to achieve project goals, especially reduce cost. People may participate by forming groups to meet predetermined objects related to the projects. Such involvement may be interactive and involve shared decision-making, but tends to arise only after major decisions have already been made by external agents. At worst, local people may still only be co-opted to serve external goals.
Interactive participation	People's participation in joint analysis, development of action plans and formation or strengthening of local institutions. Participation is seen as a right, not just the means to achieve project goals. The process involves interdisciplinary methodologies that seek multiple perspectives and make use of system and structured learning process. As groups take control over local decisions and determine how available resources are used, so they have a stake in maintaining structures or practices.
Self-mobilisation	People participate by taking initiatives independently of external institutions to change systems. They develop contacts with external institutions for resources and technical advice they need, but retain control over how resources are used. Self-mobilisation can spread if governments and NGOs provide an enabling framework of support. Such self-initiated mobilization may or may not challenge existing distributions of wealth and power.

Action Learning

Action learning is based on experimental learning models developed by Lewin (1952) and Kolb (1984). The underlying assumption behind these models is that knowledge, through a process of reflective observation, can be created on the basis of concrete experience, as seen in the **Fig.1** below. By formulation of abstract concepts and generalizations, and testing the implications of these concepts in new situations (active experimentation), concrete experience is built (Zuber-Skerrit, 1995). Other variants of this process exist. Perhaps the two most commonly used for community mobilization are the learning cycle (Kolb, 1984) and the task cycle (Honey and Mumford, 1986) that have often been generalized as 'plan, act, observe, reflect'. Kolb's experiential learning cycle is used to explain action learning, as it reflects more clearly how theory is linked to actual practice, i.e., going from the abstract to the concrete.

Action learning is something that everyone does everyday without being conscious about it. It is a way of solving our everyday problems. The same, if analysed, has several steps and one can improve one's problem solving capacity tremendously. By employing the principle of action learning in an adult learning situation, the ability of adults to solve problems can be enhanced by a great deal. Besides, it involves real life experience to problems solving. All it takes is being conscious of how one normally attends one's problems.

Problems are usually specific. Several steps are involved in solving them. Generally, the steps can be summarized as follows (Heisswolf 1998):

- Planning to do something to solve the problem
- Doing something to solve the problem
- Observing if the problem is solved
- Reflecting and deciding if the problem is solved.

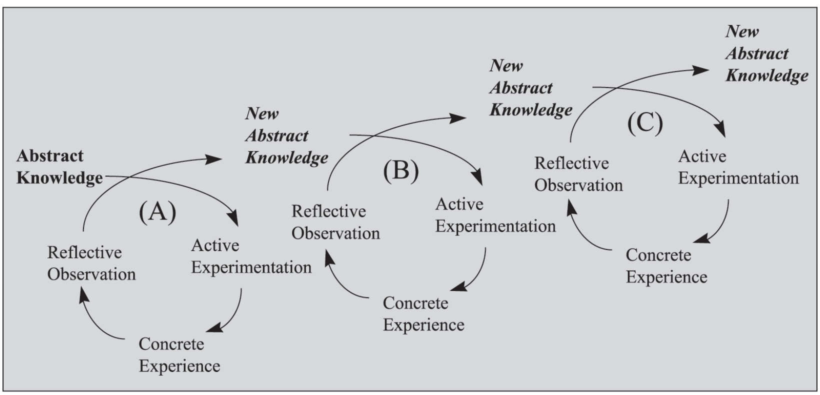

Fig 1: The action learning process: a series of action learning cycles with increase in knowledge as the process continues (adapted from Kolb, 1989) reproduced from King et al., 1999

If the problem solving is not satisfactory, a person may complete another cycle. During the second cycle, he/she uses his/her previous experience and changes the way the problem is approached. Sometimes, he/she may complete several cycles before solving the problem satisfactorily. During the process, he/she may acquire new information and apply the same for problem solving.

Act

It involves a concrete experience or an activity and provides raw data for learning. It will be based on the past experience or newly acquired knowledge. For example: Checking a crop for weeds/insect pests.

Observe

This involves making observations on the experience or activity. Questions like "What did I see, hear, feel during the activity? What was enjoyable?" are asked either within the mind or explicitly. For example: observing that there are insect pests or weeds and thinking about what kind of weeds pets are they. Asking questions like "Do they affect my crops?"

Reflect/Generalize

This step involves forming a theory or drawing conclusions from the experience or activity that can be used in future problem solving. Asking questions such as "What did I learn from the activity ? "What my observations mean to me?" Thus, it involves drawing on past experiences and placing the new once in to context. This may also lead to changing or amending a previously held belief or attitude about a situation. For example: concluding that weeds are affecting the crop by competing for water and nutrients. Insects are damaging crop resulting in reduced yield.

Plan

This involves planning for testing the implications of the previous learning in another situation to determine if the theory or conclusion drawn from the experience or activity is valid under new conditions or situations. Asking questions like "How can I apply? what I have learned from this activity?" For example: planning to get rid of the weeds and insect pests and planning to check for weeds more regularly in the future so that weeds/ insects do not affect the crop production in future.

Principles for Effective Use of Action-Learning Tools and Processes

It is important to distinguish between an action learning tool and an action learning process. Action learning tools are anything that contributes to the action learning process (e.g. mechanical devices, demonstrations, computer modeling programs, group processes). An action learning process is an active process by the learner where she/he 'learns' from an experience and then applies critical reflective observation to determine the usefulness to her/his situation prior to planning the next action or learning experience. Extension agents essentially facilitate these processes.

A useful action-learning tool can be one that enhances the action learning processes by,

- Enabling discussion which helps to share different perspectives and learn from others? experiences
- Allowing repetitive cycles so the learner can build on previous learning in subsequent cycles
- Relating the action to the individuals context through purposeful reflection and questioning which facilitates sense making. Being applicable to the participants' needs by enabling participants to have control over the action and subsequent reflection and sense making

If we take a simplified version of action learning and the plan, act, observe and reflect cycle, we also need to look at what makes the process most effective. Action learning can be seen as a more purposeful and structured way to learning and most of the action learning process is based on some simple adult learning principles. For example, basing things on the participants experience or starting from the participants experience and moving forward from there.

The indicators will be based on adult learning principles and their relation to the action-learning tool and process. In order to initiate or enhance learning to bring about change in a situation, whether it be a change in cognitive or behavioral situation, it is important to understand the factors that influence the learning process, these can then be used to develop more effective and efficient adult process, including, an adult's readiness to learn, orientation to learning, previous experience, self concept and motivation (Knowles, 1990).

Readiness to Learn

Adults' readiness to learning will provide them with knowledge that will assist them in a more effective performance in a current or future situations. By reflecting on the knowledge and skills they have in the present and those they need to function more effectively in the future, adults may recognize the benefits of learning and thus become ready to learn. Learning can assist in this reflective process by providing adults with ways of assessing their own skills and knowledge (Knowles, 1990).

Orientation to Learning

Adults tend to have a problem-centered orientation to learning and consequently they learn most effectively when they can see how learning applies to their own problems. For this reason, we need to design learning strategies that depict real life situations. An adult's learning orientation contrasts that of a child who has a subject-centered orientation to learning (Knowles, 1990).

Self-concept

Brundage and Mackeracher (1980) suggest that adults have an organized and consistent self-concept and self-esteem, which allows them to participate as self, separate from others and capable of acting independently of others. With this in mind, adults appear to learn best when they are involved in developing learning objectives for themselves, which are congruent with their current and idealized self-concept. Knowles (1984) states the implications of this self-concept by suggesting that adults can be opposed to those who enforce on them their own ways or beliefs. In addition, Knowles views adults as having a strong need to be seen by other as being capable of directing their own lives. It then follows, that we need to be aware of a learner's self-concept and obtain more of a facilitative role, rather than the traditional 'teacher-student' role.

Motivation

Adults are strongly responsive to internal motivators. Internal motivators include feelings such as self-esteem, work satisfaction and quality of life. Verner and Booth (1964) suggest that motivation comes from the need of an individual that develops behavior. A feeling of belonging, a sense of achievement, public recognition that develops from learning new skills and meeting new challenges are also powerful motivators. Although there are many definitions of motivation in the literature, the general assumption if that people motivation by their needs. Maslow suggests that there is a hierarchical structure of five categories of needs, including physiological (i.e. the lowest level need), social, esteem and self-actualization (i.e. the highest level need), where people need to satisfy the lower needs before satisfying the higher ones. There is some debate to whether or not people really follow this, and hence many authors do not consider Maslow's categories of needs hierarchical.

There are also many benefits in terms of learning in collective discussion and reflection over individual reflection. Collective discussion allows participants to be exposed to new ideas, alternative ways of thinking and critical opposition to set ideas. Collective learning enables participants to be providing challenges and critical reflection.

Research has shown that the effectiveness of the use of the action learning tools and processes was linked to the trust, rapport, confidence and openness that developed between the team and the people participating from the villages. The tools being embedded in an overall participatory action research process where research was implemented on farms using treatment developed by farm men and women with scientist, enable this learning environment to develop over time through many cycles of participation and learning. So, the learning environment in which the tools are used is very important as is embedding the action learning tools and processes strategically into comprehensive participatory programs rather than one off events (Orlando, in progress).

Applications of Action Learning

Action learning is widely applied in several fields such as research, human resource development, sports, management etc.

Research

In research action learning cycles can be used:

- As a continuous improvement framework for research project when coupled with an action research methodology
- To integrate knowledge from different disciplines and knowledge systems in participatory or multi-disciplinary research
- To help build situation- specific theories and principles which can be more generally applied elsewhere. The learning gained from the experience of one action-learning situations can be applied in another situation. Completing repeated cycles of action learning may help provide empiricism to principles and theories.

HRD

The components of action learning cycle help provide a useful framework for structuring capacity building activities, which incorporate a range of adult learning principles. Action learning can be employed for developing the capacity of trainers and farmers alike. While "training the trainers", the emphasis should be on how this learning method can be used to empower adult farmers to make sense of bio-physical and socio-economic issues in their own context. Trainers should be empowered to play more of a 'facilitator' role than a 'teacher' role. Trainers also must be empowered to design and construct appropriate action learning tools and processes, which suit the client-farmers and their learning issues.

First step in application of action learning is to facilitate the trainers' awareness of action learning principles and practice by helping them to experience and reflect on action learning within their own context. The next step is to build their skills to facilitate (rather than teach) an action learning session to empower the farmers and farmwomen.

Action Learning Tools for Community Mobilization

There is a great realization of late about the need for people's participation in community based development activities that involve considerable element of community education. Such efforts need to consider factors affecting adult learning into consideration and should involve simulation of real life situation so that learning is easy and effective.

A Case of Successful Application in Natural Resource Management

Soil erosion by run-off is the main cause of land degradation in rainfed agro-eco system. Rainfall is the only source of water for agriculture here. This agro-eco system chronically suffers from low food and fodder productivity due to erratic distribution of rainfall. Besides, erosion induced land degradation is a serious problem here. Lack of awareness, proper understanding of the process of land degradation and inadequate technological interventions to manage it are the major bottlenecks for community mobilization against land degradation.

The portable rainfall simulator is one such action learning tool which aids easy and effective adult learning to help understand complex land management issues related to run-off, soil erosion, infiltration and crop production. It also enables participants to develop and make sense of various land management options to address these issues, assisting them to determine which option is most appropriate to their environmental, economic and social context. It is mobile gadget introduced to India by the Australian Center for International Agricultural Research (ACIAR) that produces rainfall with a drop size and energy similar to that of natural rain.

Rainfall is applied to two adjacent plots with two different but comparable treatments. The plots are separated by a barrier to maintain independence between the treatments. Rainfall is usually applied at a known rate so that it can be measured for the duration of the activity. Run-off collected at the bottom of each plot is vacuumed in to tank where it can be easily seen and measured. Thus, the device can be effectively used as a demonstration tool to promote initial awareness among farmers about the adverse impact of rainfall on bare soil, and motivating them about the need for capture and storage rainwater in the soil. As an action-learning tool, it can increase the farmers' knowledge about soil and water relationships, allow them to use their experience in this context, test and review options through selection of treatment. In all, it is a multi-purpose and multi-outcome action-learning tool. Rainfall simulator has many other uses, action learning, co-learning (within farmer groups and between farmer groups and scientists, and within groups of scientists belonging to different disciplines), facilitating participation and sharing of power in research and also for bio-physical research. Following are normally adopted in mobilizing the communities through the action learning process by using the rainfall simulator.

The Process

The key elements in the process of simulating rainfall include (1) mutli-channel publicity prior to the event, (2) participants nominate the treatments (plan), (3) participants actively construct the treatments chosen (act), (4) rainfall is applied (act), (5) monitoring of the effects by the participants (observe) and (6) small group discussion (reflect). The process of self-learning among participants is facilitated by the scientists (Subba Reddy et al., 2000).

Planning and Execution

The action learning groups under leadership of Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad used the rainfall simulator as an action-learning tool at Nallavelli, Pampanur (Ranga Reddy and Anantapur districts, respectively in Andhra Pradesh) and Madhubhavi (Bijapur district, Karnataka). The key concept of the field process was to ask the farmers to suggest the treatments, to enrich the participation by constructing the treatments and, set up and discuss the cause and effect of events. Scientists acted as facilitators to help farmers learn for themselves the working of rainfall simulator and the process of runoff and soil loss.

In the collaborative ACIAR - CRIDA project the use of the rainfall simulator as an action learning tool was embedded in a participatory action research process. The rainfall simulator was used not only for learning but also as a tool for facilitating farmer and farm family participation in the research process. Treatments to be implemented in on-farm research trails were determined by people from the villages and scientists from many disciplines together. The evaluation of treatments was also conducted participatively.

Farmer Participation

- The rainfall simulator attracted both farmers and farmwomen. The participants liked the opportunity to participate, test their ideas particularly with respect to traditional practices. The tribal farmwomen involved actively in selecting the treatments. Modifications were carried out after a good deal of debate. In fact, the selection and application of treatments always inspired positive and willing debate.
- Farmers were encouraged to suggest other strategies as per their choice to test with rainfall simulator. The equipment created lively discussion on management practices to control soil loss and improve soil water intake.
- Farmers measured infiltration by using a metal probe or digging with a shovel/mattock **(Table 1).**
- Farmers measured runoff by comparing amount and level of water in vacuum drums.
- Farmers enthusiastically helped set up rainfall simulator as well as implementation of treatments.
- The rainfall simulator as a tool proved successful in creating thorough discussion on management practices to control soil loss.
- Farmers found it interesting to vary rainfall intensity during the activity in order to replicate rainfall patterns.

Limitations

- Lack of water source at farmers' fields.
- Planning the best time to hold the activity is critical, e.g., avoid time clashing with important social, farming and household activities (such as picking children up from school).
- Since considerable time for networking with participants is required, advance planning is necessary.
- Facilitating a reflection session among the participants at the end of the activity is warranted.
- It is often hard and for scientists to operate in facilitation mode and not impose their own ideas on selection or design of treatments.

Reflections

- The experiences using the rainfall simulator revealed that it is a powerful tool it educated community. It motivates the farming community to screen various technology options for sustainable soil management and allows them to test their own ideas in a group participatory process.
- The key factor to the success of the action learning process with the rainfall simulator as a decision making tool was to avoid the domination of the activity by scientists, and allowing the community to work it out and learn for themselves.
- The rainfall simulator needs to be supported by other extension processes and activities. When used as an extension tool on its own it does not consider a systems approach but focuses on soil surface treatments, runoff, and infiltration and land management. For example:
  - Crop stubble may have a good impact on increasing infiltration and reducing runoff, but may not be available with most farmers due to its competing use as fodder.
  - Farmyard manure may be a valuable source of mulch and useful in decreasing runoff by increasing infiltration besides improving soil fertility. But the quantity required to achieve this may not be available.
- The results from the rainfall simulator are applicable to small plots only. This often means farmers try and replicate whole field conditions on a small scale, which limits the validity of results.
- Farmers can find it frustrating, as they are unable to consider changes in fallow treatments over a greater period of time and their inability to modify rainfall intensity to more accurately reflect the storm conditions.

- There is good potential for further action learning in extension programmes. This hypothesis is supported by the fact that active involvement of farmwomen was obtained in all the rainfall simulator activities conducted so far. Such activities need to be sensitive to sociological issues in each community.

Table 1 : Observations recorded with the help of farmers in rainfall simulator demonstration (summer)

Center	Comparisons	Parameters	
		Wetting front of soil (cm)	Runoff volume (1)
Nallavelli	Bare soil	11.6	54.4
	Paddy straw mulch	17.6	38.9
	Grazed grass cover (60%)	21.3	31.9
	Non-grazed grass cover (85%)	18.6	6.8
	Furrows along the slope	11.8	43.3
	Furrows across the slope	12.7	20.6
Pampanur	Ploughing and harrowing along the slope	26.6	21.5
	Ploughing and harrowing across the slope	39.3	17.0
	Ploughing across the slope+No FYM	17.5	16.5
	Ploughing across the slope+FYM (10 t/ha)	22.6	5.2
Madhabhavi	Straw mulch (95% cover)	20.0	35.6
	Straw mulch (100% cover)	23.0	16.6
	Ploughing and harrowing across the slope	21.0	40.3
	Ploughing and harrowing across the slope	22.0	39.5

Design and Development of Action Learning Tools

The experience gained by the Indo-Australian collaborative project in developing and testing action-learning tools has produced interesting results both in India and Australia. Several workshops and training programmes were organized for bio-physical and social scientists, and farmers in both the countries to design and develop problem-specific and need based AL tools. The workshops have been successful in training trainers of development departments and academic institutions on the concept and application of action learning. The major output of AL workshops can be summarized as checklist for developing AL tools and template for description of AL tools.

Action Learning Tool Checklist

- Focused on solving a problem
- Focused on building understand of a set of principles
- Show immediate results
- Uses more than one treatment/intervention to show differences
- Show effectiveness of different treatments
- Has a live demonstration
- Simple to understand
- Easy to build, use and operate
- Show quantitative measures where ever possible
- Takes minimum time to demonstrate
- Shows differences/changes
- Adaptable to local conditions
- Stimulates curiosity and fun
- Community members are able to exercise their own options and make choices
- Community members see results (e.g. colour and quantity of runoff, time to runoff, depth of infiltration)
- Low cost
- Keeps their interest
- Simple mechanism
- Tries to simulate field conditions when ever possible or appropriate
- Made of locally available materials and uses locally available resources
- Planning for its use avoids negative aspects of having many people in the field (e.g. trampling of soil and crops)

Development of Need-based AL Tools

AL tools can be used for community mobilization in the fields of natural resource management and social resources management, and to help translate the consequence of sustainable natural resources management into economic benefits. This section deals with some simple AL tools that can aid adult learning.

Action-Learning Tools for Mobilizing Community Action

Socio-economic principle: Based on ancient wisdom "United we stand; divided we fall"

Materials required: 15-20 brittle sticks of different thickness.

Methodology

Step 1 : Divide the farmers group into two

Step 2 : Hand out one stick each to the farmers of Group 1 & Group 2

Step 3 : Ask Group 1 to break the stick in the middle while Group 2 observes with the sticks intact

Step 4 : Ask member of Group 2 to collect all the sticks at one place

Step 5 : Bundle the sticks so collected, pass them on to the members of Group 2 and ask them to break the bundle of sticks

Reflection Follows on:

- Why the individual sticks broke while the bundle of the same could not be broken. Drive home the point that there is strength in UNITY

Complex Idea Made Easy

- Watershed development activities do not produce effect on the whole village ecosystem if adopted in piece-meal.
- Collective adoption on micro-watershed scale only will result in sustainable natural resource management.
- Tool can be applied for community organization for collective bargaining power: buying inputs, selling produce, demanding civic amenities etc.

Using Indicators of Learning in Practice

If we look at the rainfall simulator (RFS) as a tool and the rainfall simulator field day as a process, we can use indicators that are based on some of these principles of action learning, useful action learning tools and adult learning principles to enhance both the tool and the process. With these, we can evaluate how useful the tool and process may have been in relation to 'purposeful' learning. The objectives for the facilitator are to improve the effectiveness and efficiency of learning during the RFS field day.

i) Have we related the activity to participant's experience?

ii) Have participants been involved in the setting up of the experiments?

In the action phase, the facilitator might ask:

Are the concepts and generalizations from the first RFS field days with farmers, discussion between runs sometimes fails to make link between observations from one set of runs and the next. Usually discussion is generated at the end of a number of runs. This means that usually one learning cycle takes place during the field day as opposed to a number of learning cycles, each building upon the generalization and conclusions drawn from previous cycles. This is a less efficient way of running a field day and it doesn't capitalize on the fact that the RFS as a tool has the ability to allow for repetitive learning cycles in a short time frame.

In the Observation Phase, the facilitator might ask:

i) Have participants been made aware of what we are trying to measure and why?
ii) Have participants been shown how to collect the data?
iii) Are participants aware of our assumptions behind why we think it is important to collect accurate data?

In the Reflection Phase, the facilitator might ask:

i) Have we put the generalizations and concepts that have been drawn into a future context?
ii) Have we allowed for participants feel from their own generalizations and concepts?

We may also need to facilitate the process in such a way that participants feel that they can express what they really think as opposed to what they think we want to hear.

In terms of indicators of participation, Pretty's typology can be used to distinguish the types of participation. Three attributes that can be used here are:

i) The number of participants involved at each level
ii) The type of involvement
iii) Evidence of participants' ideas in action

Alternatively, in terms of developing specific questions to ask ourselves or ask farmer in an evaluation, we can again use Pretty's typology. We go through the criteria of each type and ask ourselves some simple questions that relate to the criteria. If we want to gain a better understanding, then we ask the participants a few questions that help us distinguish the type of participation. There are number of ways we can do this, such as a simple questionnaire, a focus group or an oral feedback session. The choice of method we use is determined by the depth of information we like and the resource we have available.

Conclusion

Adults learn new practices when they are related to their life situations. Action learning which is a systematic process of ensuring involvement of learners is a handy technique for development professionals. This technique is particularly useful when the target group is either illiterate or semi literate which is the case in most of the SAARC nations. Though action learning is a proven and effective tool aimed at bringing conceptual clarity and practice change among adult learners, it needs to be backed up by capacity building of master trainers who can design and develop a range of AL tools suitable to different situations.

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Emerging Community Based Organizations and Their Role in Participatory NRM

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Community based organizations provide a social platform for self reliant development with the help of internal resources. It helps in improving the ownership of community over the various type of interventions (particularly over community oriented structures / measures). It also helps in improving the relevance of above interventions (through adoption of demand-driven approach) particularly in situations where investment is made from external sources.

During the last three decades there had been a gradual shift towards demand- driven approach in the developmental programme funded by Government. In such cases the developmental fund is released by govt. directly to the CBOs, and the outsiders work with them as facilitators. While there had been a significant improvement in the relevance of developmental interventions, their long-term sustainability continues to be a challenge during the post-project period.

It is now well recognized that sustainability of physical structures depends primarily upon sustainability of social structures.

Different Streams of Community Based Organizations

- Stream 1: Charitable societies registered under charitable society act (1860)
- Stream 2: Cooperative societies registered under cooperative society act (1964)
- Stream 3 : Self help groups without formal registration with govt. department (organized mainly from mid eighties onwards)
- Stream 4: Producers companies registered under producers company act (2002)

Stream 1: Charitable Societies

These societies are not expected to earn profit for its members. There is no specific need to have a govt. representative in these governing bodies if financial transactions are done through internal sources. However if govt. fund is taken for developmental agenda, it is essential to have a representative of the concerned developmental department in the governing body. During the last three decades, GoI has been carrying out development of natural resources through a variety of such societies, viz. watershed development society, forest development society, irrigation development society, etc. By and large, post-project sustainability of above social structures is low with the result sustainability of physical structures is also low (particularly of community oriented structures / measures). Usually credit worthiness, gender sensitization, and democratic functioning of these societies is low, with the result they become unsustainable soon after the completion of project period.

Stream 2: Cooperative Societies

These societies can earn profit for its members. The governing body of these societies consists of a representative from the govt. department. These societies can avail loan from external sources. Developmental projects through external funds can also be taken by these societies.

The members of these societies are having a large heterogeneity, leading to difficulty in facilitation of democratic processes. Gender sensitization is also low as majority of members are men. Credit worthiness of these societies is usually low due to limited assets as well as lack of regular saving as well as internal lending.

These societies include primary agriculture credit cooperative society, commodity based cooperative societies (e.g. shepherds cooperative society, fishermen cooperative society, milk cooperative society, etc), agricultural marketing cooperative society, input supply cooperative society, etc. Majority of these societies are functioning at a low level of efficiency except in cases where leadership is of good quality.

Stream 3: Self Help Groups

These groups are relatively smaller in size (usually 10-19 members per group) and their members are largely homogenous with respect to socio-economic aspects. They regularly carry out saving and internal lending with their common fund. These groups are not expected to submit any asset as a security to bank for availing loan. The loan is given to them on the basis of group (as a co-lateral security) once the process for internal lending is stabilized for about 6 months with proper record keeping.

These groups are expected to focus not only on financial aspects during their regular meetings but also address other needs related to individual, social, and livelihood related aspects. The above concept is making a significant impact in the country by enhancing the social capital among the community members particularly the women. It is facilitating not only self-reliance in financial aspect but also overall empowerment of its members.

These groups are having higher degree of credit worthiness, sensitivity to gender and democratic functioning. Recovery of bank loan has by and large been good. Also these groups are functioning satisfactorily even beyond the project period. There is however a need to evolve a suitable community managed regulatory mechanism for addressing issues related to their long-term sustainability.

Producers Companies

These companies are now registered under a simplified company act passed during 2002. Under this social structures only the producers associated with a particular commodity are eligible to become the numbers. Usually these companies are registered at apex level (cluster of villages or even at high level). At the village level however there are producers groups (associated with the above companies). These companies usually carry out higher level functions for producers which may include aggregation of produce, collective marketing, collective procurement of inputs, access to external fund, market intelligence, etc.

Emerging Innovations under Each Stream of the CBO

Stream – I: Charitable Societies

As indicated earlier, these societies are organized mainly for carrying out participatory development through financial assistance from govt. or other sources. Wherever capacity building of the office bearers had been adequate, these societies have functioned properly during the project period to utilize the funds available under the project. Post-project sustainability of these societies is however low, with the result sustainability of physical structures is also low. The following two structural refinements have been found to be helpful in improving sustainability of these societies.

1. Integration of SHG concept into its general body and executive committee

Under this approach, the general body members are divided into a number of small size and homogenous groups (with about 10-15 members per group). These groups carry out credit and thrift activity on regular basis (like SHGs) which helps in improving their creditworthiness, democratic functioning, solidarity and trust among each other.

Likewise functioning of the executive committee (EC) of the above societies is also improved by gradually replacing its office bearers / members with representatives of the SHGs. Once all members of the E.C. are replaced with SHG representatives, their capacity to deal with revolving fund and other functions of the apex body is also enhanced which eventually improves their post-project sustainability.

2. Co-existence of different types of CBOs

During post-project period, the societies are expected to deal with profit oriented enterprises besides maintenance of community oriented assets. As discussed earlier, such functions can be performed by other forms of CBOs like cooperative society, producers companies, etc. Hence the same members of the charitable society may like to organize themselves into another set of CBOs (indicated above) which may co-exist with it so that multiple functions are performed by different CBOs as per their provisions.

Stream – II: Cooperative Societies

As discussed earlier many of these societies are not functioning to the desired level even though they may be existing on paper. This is also due to lack of credit worthiness, democratic functioning, gender insensitivity, equity, etc. Sometimes functioning of the executive committee is adversely affected due to procedural delay which is partly due to the compulsory presence of a govt. representative as an office bearer in its governing body. The following three types of structural refinements have been found to be helpful in improving the functioning of above societies.

1. Registration of cooperative society as per the new act for self-reliant cooperative society

These societies are registered under a new act which was initially known as Mutually Aided Cooperative Society Act 1995. The above act was initiated in Andhra Pradesh which has later on been adopted in 9 states in the country with minor variations. As per this act, the cooperative society has no need to have a representative from govt. department in its governing body (like charitable society) and at the same time it is authorized to earn profit for its members (like the cooperative society).

In Andhra Pradesh, a number of self-reliant cooperative societies have been organized which are based on credit and thrift concept (as being done in case of SHGs). The size of the general body of above cooperatives is however bigger than the SHGs (usually 75 – 100). At present there are about 450 such thrift based societies in Andhra Pradesh out of which about 60% are women societies and rest are men societies. At mandal level these societies are federated as associations for providing additional support. Many of the conventional cooperative societies registered under 1964 act are switching over to the self-reliant cooperative society act 1995 which is found to be helpful in improving their functioning.

2. Integration of SHG concept into its general body and executive committee (as already discussed)

3. Co-existence of different types of CBOs particularly at apex level (as already discussed)

Stream – III: Self Help Groups (SHGs)

At present, majority of SHGs are having only women members which are homogenous with respect to socio-economic aspects but heterogeneous with regard to the livelihood related aspects. Hence SHG could provide a suitable institutional platform for management of financial aspects but it is not an ideal platform for facilitating livelihood development. Over the years, the following innovations have emerged in the SHG concept to address the above issues.

1. Organization of not only women SHGs but also mixed SHGs, men SHG and family SHGs

At present majority of SHGs are having women members. They are generally sustainable with the result enough encouragement is given to them to involve in multiple types of developmental agenda. Initially it was a desirable phenomenon which helped in empowerment of women besides moving towards sustainable development. However excessive dependence on women SHGs (for all types of developmental initiatives) is creating an overload on women (on the one hand) and also adversely affecting the involvement of men members within the family as well as in the community. In view of this, a number of alternatives have emerged which includes mixed SHGs (in which either men or women member from a family could become the member of SHG), men SHG (in this case, separate groups are organized exclusively for men); and family SHGs (in which both spouses of the family are advised to become members with an understanding that any one of them can participate in the regular meetings but both have to sign on the application for loan).

2. Organization of livelihood groups at village level

As discussed earlier SHG members are heterogeneous with respect to the livelihoods. It is therefore essential to organize the groups separately for each livelihood so that developmental interventions can be facilitated properly. These groups are also called as Producers groups / Common Interest groups. Sustainability of these groups is found to be higher if SHG concept has been integrated in them. There are three different options to achieve the above objectives.

- **Livelihood group to become a SHG:** In this case, each livelihood group is encouraged to carry out credit and thrift activity on regular basis (like SHG). This option is usually successful with those groups whose members are nearly homogenous with regard to socio-economic status. In case, size of a particular livelihood group is large (more than 30), it can be sub-divided into a number of small size livelihood groups (having 10-15 members) based upon their affinity / socio-economic homogeneity.
- **Livelihood group members to emerge out of existing SHGs:** In situations where size of livelihood group is small (less than 20), the members may emerge out of existing SHGs. The livelihood groups may carry out production related deliberations but financial transactions are to be carried out by their respective SHGs.
- **Livelihood group members to join in other SHGs:** In situations where size of livelihood group is small (and members are heterogeneous in socio-economic status), they may choose to join other SHGs where the members are having affinity and socio-economic homogeneity. As mentioned above, the livelihood groups will focus on production related deliberations but financial transactions will be carried out by their respective SHGs.

3. User groups

These groups are largely associated with community oriented structures (related to natural resource) namely water harvesting structures, commonly bore wells, biomass in common land, etc. Proper management of developed natural resources is very essential for sustainability of the structure / measure as well as utilization of the resource in an equitable manner. At present sustainability of user groups is low. A cluster of processes are required for improving the sustainability of these groups which includes :

- Improving the structure of UGs by integrating SHG concept into it (as already).
- Enhancing the ownership of UG members towards the community oriented structures by facilitating demand-driven planning, collection of genuine contribution in advance, participation in implementation of approved structures, etc.
- Formal allocation of user's rights at three levels – ownership right over the structures to gram panchayat, management right over the resource to federation of UGs and usufructs over the resource to the members of the UG
- Payment of users fee by the members as per the proportion of utilized resource

4. Area groups

It has been observed that size of area under the watershed association is usually too large (about 500 ha) which is not conducive for carrying out meaningful deliberations. Its functioning could however be improved if it is divided into a number of small size area groups (30-50 ha each). Sustainability of the area group is further enhanced if the members carry out credit and thrift activity on regular basis. On the whole, the functioning and sustainability of area group is found to be satisfactory even if about 60% members participate in credit and thrift activity (including those who are having affinity and socio-economic homogeneity).

As expected, sustainability of area group has a positive bearing on functioning of watershed association (WA) since the members get a chance to prepare in the smaller size groups (during the normal credit and thrift activity meeting) before they go for WA meetings.

5. Federation of SHGs at apex level (village / mandal / block / district)

There are a number of additional functions which need to be performed besides what can be done at individual SHG level. This includes capacity building of new and old SHGs, monitoring the grade of SHGs, development of livelihoods, linkage with banks and other developmental organizations, collective marketing, decentralized processing, etc. For this purpose, federations of SHGs are organized at different levels with an understanding that their roles would be to build the SHGs rather than replacing their functions. Usually financial transactions with banks are carried out directly at SHG level. However revolving fund / community interest fund from govt. department could be handled by the federations through the SHGs. These federations are managed by two types of bodies (i) executive committee (with limited number of representatives from SHGs / lower level of federations) and (ii) governing body (with representatives from large number of SHGs)

6. Registration of apex bodies of SHGs under the self-reliant cooperative society act (as already discussed).

7. Constitution of thematic sub-committees besides executive committees of SHG federations

The executive committee of SHG federations has been able to facilitate financial transactions (management of revolving fund / community investment fund, bank loan, etc) as well as govt. schemes for social welfare. However development of livelihoods was becoming difficult by the normal executive committee since all members of the body are not having same interest in a particular livelihood. This issue is addressed successfully by constituting thematic sub-committees. All members in the thematic committee have interest in a particular livelihood. Separate thematic sub-committees are to be constituted for each major livelihood. One member in their sub-committee could be represented by the concerned executive committees to provide better linkage and feedback. It is always better to have a separate bank account with each thematic sub-committee. These thematic sub-committee works with respective livelihood groups at village / habitation level.

8. Co-existence of apex bodies of SHGs with other CBOs namely producers cooperatives, producers companies, etc (as already discussed).

9. Organization of community managed resource centres (at apex level):

These resource centres have been created at a cluster of villages (with about 40-50 SHGs) to provide professional support to various SHGs on service charge basis. The field experience with MYRADA has shown that with initial support towards building a reasonable infrastructure as well as handholding of the unit, it becomes feasible to make them self-reliant in about 5 years. It would be useful if these resource centres could also play the governance role for regularly watching the functioning of SHGs, and their apex bodies to address conflicts and prevent them from becoming non-functional.

Producers Companies

Although, producers company act is relatively more user-friendly (in favour of actual producers of a commodity), sustainability of the company has been low after the withdrawal of the facilitating agency. The following two structural refinements have been found to be helpful in improving the sustainability of these companies :

- Adoption of credit and thrift concept for organization of producers groups (as already discussed).
- Co-existence of producer companies with apex bodies of SHGs (as already discussed)

Role of Different CBOs in Participatory NRM

Under the changing scenario particularly in the watershed programme, the overall agenda has been diversified to include three categories of functions namely :

- Development of natural resources
- Management of developed natural resources
- Development of livelihoods

Hence a matching diversification is required in the community based organizations for addressing the three types of interventions indicated above. The proposed CBOs are to be organized at two levels which include (i) groups at habitation level and (ii) higher bodies at apex level. Groups at habitation level include SHGs, LGs, UGs, CIGs, AGs, Producers groups, etc. Higher bodies at apex level include WC, WA, federation of SHGs, federation of UGs, producers companies, producer cooperatives, self-reliant cooperative societies, etc. The CBOs dealing with development of natural resources are as follows: (i) User groups, (ii) Area groups, (iii) Watershed Committee and (iv) Watershed Association. These CBOs help in facilitating demand-driven and development of natural resources. The CBOs dealing with management of developed natural resources are as follows: (i) federation of UGs and federation of WCs. These CBOs help in repair and maintenance of structures, efficient use of developed natural resources, management of conflicts, facilitation of user rights, facilitation of user charges, etc. These CBOs however work with UGs and AGs at village level.

The CBOs dealing with development of livelihoods are as follows: (i) SHGs, producer groups, producers companies and federations of SHGs. These organizations deal with production, processing and collective marketing of produce. Supply of need-based inputs including credit support is also facilitated by these CBOs.

Conclusion

There is a need for a separate project (with a dedicated spear heading team of resource persons) to organize sustainable CBOs (as a preparatory work for handling participatory developmental projects). Priority may be given to locate development programmes in those villages where sustainable CBOs already exist. Upscaling of emerging innovations related to CBOs may be given focused attention. Systematic study and documentation of emerging experiences in different streams of CBOs may be carried out so that they may help in re-designing of existing CBOs.

Generation of DPRs/Action Plans for Watershed Development Using Satellite Imagery and Topo sheets - A Geo-informatics based Approach

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Watershed Concept

In India more than 75% of population depends on agriculture for their livelihood. Agriculture plays a vital role in ours country's economy. Our scientific surveys have revealed that more than 70% of the total geographical area is under distress due to frequent occurrence of droughts and agriculture is seriously affected by uncertain monsoon. In order to mitigate droughts which occur frequently in several parts of the country especially in dryland areas the Ministry of Agriculture and Co-operation has launched an integrated watershed concept using easy, simple and affordable local technologies. A watershed is basically a geo-hydrological unit where the excess water collected through rainfall drains to a common point in the form of surface run-off after infiltration in to the top permeable layers of the earth. Generally watershed area is encircled by a ridgeline following ridge and valley topography. Watershed concept has now become one of the major programmes of the Ministry of Rural Development to improve environment by developing our natural resources like soil, water and vegetation.

Need for a Watershed Approach

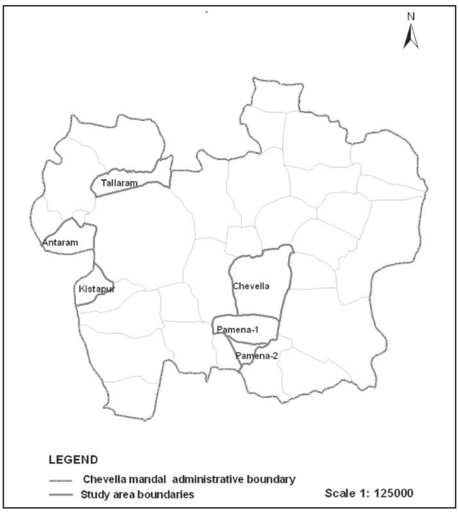
The community based integrated watershed approach is highly essential in order to meet the needs of ever-growing population i.e. for providing food, fodder, fiber and shelter by rejuvenating land and water resources especially in rural areas. To achieve this goal proper management of natural resources by adopting suitable scientific solutions for optimum development of land, vegetation and water resources in a sustainable manner is essential to the maximum possible extent. It is felt that in our country a majority of the areas still require great thrust and appropriate measures.

Scope of the Present Study

In order to generate optimum utilization of existing natural resources like land, vegetation and water in selected watershed proper scientific surveys should be conducted. These include soils, hydro-geomorphology, land use/land cover pattern, surface & ground water potential surveys in addition to gradient of the terrain particularly, slope and aspect which plays a vital role in suggesting/implementing various soil and moisture conservation measures. Based on the mapping and analysis (using GIS as a powerful information tool) of various natural resources mentioned proper soil and moisture conservation practices can be adopted to mitigate the adverse effects of drought conditions which led to the degradation of natural resources. The natural resource data thus generated will be useful to conserve and manage watershed properly to achieve sustainable development particularly, in ecologically fragile areas in order to meet the living standards of the rural communities. The restoration of ecological balance and the productivity of various land based activities which can indirectly generate gainful employment to the rural poor can be achieved through the effective use of this reliable decision support system.

Study Area

Six micro-watersheds in Chevella mandal of Ranga Reddy district have been selected under DPAP (Drought Prone Areas Programme) for the present study in which some have been under treatment since last few years, some are with recent watershed treatment measures and a few with where delineation has been completed with proposition of different watershed activities for approval. The selected watersheds under DPAP scheme are (i) Chevella (ii) Pamena-1 (iii) Pamena-2 (iv) Talaram (v) Antaram and (vi) Kistapur.



Location of the study area in Chevella Mandal

Data Collection

(i) Primary data

Detailed watershed reports comprising micro-watershed boundaries with various watershed activities of soil and moisture conservation have been collected from District Water Management Agency (DWMA) of Ranga Reddy District. Survey of India toposheets

(Numbers 56K/3 & 56K/4) have been acquired from Survey of India, Hyderabad. False color composite (FCC) and panchromatic (PAN) satellite imagery (IRS P6 of the year 2003) have been acquired from National Remote Sensing Agency, Hyderabad. Cadastral maps have been acquired from Deputy Director, Central Survey Office, Hyderabad. Rainfall data of Chevella mandal has been collected over a period of 8 years from the Chevella mandal revenue office. Temperature data of the Ranga Reddy District has been collected from the Director, India Meteorological Centre, Hyderabad)

(ii) Secondary data

Field survey for Pamena-2 micro-watershed has been conducted to check the accuracy/ validity in terms appropriate location of existing structures like check-dams and vegetative barriers proposed based on hydrology modeling.

Map Preparation

Different thematic maps namely base map, land use/land cover, hydro-geomorphology, slope, ground water potential and soils have been prepared based on the standard methodology defined by National Remote Sensing Agency, Dept. of Space, Govt. of India as per IMSD guidelines. In addition to these, cadastral maps have also been digitized using Arc Info software.

(i) Base Map

Base map has been prepared from Survey of India toposheets on 1:50,000 & 1:25,000 scale comprising drainage system, settlements, village administrative boundaries and road network within the watershed based on the boundaries obtained from watershed treatment maps presented in detailed project reports.

Methodology for Base Map Preparation

Scanning of maps

All watershed treatment maps that are acquired from District Water Management Agency and toposheets from Survey of India have been scanned using Ao size flat bed scanner. The possible source and expected outcome of different layers are presented in table the table given below:

S.No.	Source	Output layers
1	Watershed Treatment maps	Watershed boundaries, treatment structures, village boundaries
2	Survey of India Toposheets	Drainage network, village bound aries, settlement boundaries

Registration of scanned maps

Scanned maps have been registered with respect to grid base using Erdas Imagine software in order to have real world coordinates. The 16 intersecting points of longitudes and latitudes have been considered as GCPs (Ground control points) and developed a GCP model with mean residual error. Each toposheet on 1:25000 scale (covering 4 sheets per one 1:50000 scale toposheet) toposheet has been registered separately. After registration of individual toposheets a mosaic has been prepared for the entire study area. Similarly, the same process has been continued for registering watershed treatment maps.

Registration of satellite image

Georeferencing process has been done using ERDAS Imagine software. This process requires high accuracy (mean residual error and standard deviation less than half a pixel size. The permanent features like rail-road intersections (junctions), dams, bridges and confluences of rivers have been taken as GCP reference points. Care has been taken during image geometric correction process to distribute all GCPs evenly over the whole area. After assigning all GCPs transformation model has been calculated. GCPs with maximum residual errors have been deleted. The calculation process has been repeated to check the minimum mean residual error and standard deviation. Image orientation has been verified with reference to toposheets.

Vectorization and labeling

Conversion of point, line and polygon attribute data from raster to vector form has been done through digitization process using ArcInfo GIS software. After digitization the errors such as pseudo nodes/dangle nodes, undershoots, overshoots have been corrected. Labels have been entered in all polygons and also to different arcs (arc-ids) of the features.

Topology creation

After labeling process to create topology, all coverages have been cleaned with line as well as poly options.

Projection

Projection is the process of transformation of three dimensional space onto the two dimensional process. The arc coverages thus generated from rectified toposheets through digitization process and watershed treatment maps have been projected in to real world coordinates by adopting standard projection procedure for the purpose of integration during spatial analysis.

Establishing tics

A tic is a registration point or geographic control point which represents x and y coordinates (longitudes and latitudes) of real world coordinate system. At least four control points are required for projection. For all toposheets and watershed treatment maps tics have been established for transformation process.

Transformation

After projecting coverages to real world coordinates by standard projection procedure, all features like polygons and lines have been transformed to real world coordinates by transformation process.

Here the problem lies with cadastral maps i.e., they do not possess known map coordinates. In order to solve this problem these maps have been transformed on to the toposheets by identifying well known reference points on the toposheets in the watershed area.

(ii) Ground Water Potential Map

Ground water potential map plays a vital role in proposing structures. Preparation of ground water potential map requires pre and post monsoon ground water level data. Due to lack of any field data substitute/alternate method has been adopted. For this purpose land use/land cover map generated based on satellite image interpretation has been used. The ground water potential in the watershed area has been categorized in to three classes based on the cropping pattern. They are (i) Good (ii) Moderate and (iii) Poor.

Hydrological analysis

The hydrological modeling process deals with assessing various hydrological characteristics of a surface. The basic parameter which controls the surface water flow (run-off) is the shape of the surface (terrain). Slope and aspect play a vital role in determining the shape of a surface. The basic inputs required to generate a hydrological model for a region are slope, aspect, sinks, flow direction, flow accumulation, pour points and a possible stream network. The whole hydrological process can be broadly divided in to 2 phases i.e. (1) Surface analysis and (2) Hydrological analysis.

Surface analysis

Surface analysis process involves creation of Triangular Irregular Network (TIN) and Digital Elevation Model (DEM) from elevation data either in the form of spot heights or contours. In the present study contour data in the vector form extracted from the Survey of India toposheets on 1:50000 and 1:25000 scale through digitization process has been used.

Conversion of contour data to vector form from raster data

Firstly, Survey of India toposheets on 1:50000 and 1:25000 scale have been scanned using Ao size flat bed scanner and converted to Tiff raster format. These maps have been projected to real world coordinate system. Contours (poly lines of equal elevation) have been digitized using Arc-Info GIS software. After digitization editing has been done to remove pseudo nodes, overshoots and undershoots. Arc topology has been created by 'Clean' command. The coverage has been projected to polyconic projection after establishing tics to generate TIN which is an essential part in surface modeling.

Generation of TIN (Triangular Irregular Network) & DEM (Digital Elevation Model)

In order to establish flow accumulation points and possible stream network an elevation raster has been created. For this contour data thus generated in the vector format has been used to generate TIN using Arc-Map 3D analyst functions. Later this TIN has been converted to DEM (Elevation raster) raster form by spatial analyst functions. Slope map has been generated from the elevation raster by surface analysis tools under spatial analyst functions. Similarly, aspect map has also been prepared from the slope map in the same method mentioned.

Slope and aspect

Slope and aspect maps play a crucial role in addition to flow direction and flow accumulation in hydrological modeling. Slope is one of the important terrain parameters which is explained by horizontal spacing of the contours. In general, in the vector form closely spaced contours represent steeper slopes and sparse contours exhibit gentle slope whereas in the elevation output raster every cell has a slope value. Here, the lower slope values indicate the flatter terrain (gentle slope) and higher slope values correspond to steeper slope of the terrain. In the elevation raster slope is measured by the identification of maximum rate of change in value from each cell to neighboring cells. The slope values can be calculated either in percentage or degrees in both vector and raster. The percentage of slope can be calculated by using this equation i.e. Rise/Run*100. It is important to note that when the slope angle equals to 45^{o} the rise and run are equal and the slope angle is equal to 100%. The slope map thus generated from elevation raster exhibits different slope categories depending up on the slope of the terrain. The output cell size plays a very important role in generating output slope raster. In the output slope raster, steeper slopes are shaded in red colour. We can reclassify this slope map as per our requirement. In general slope map comprises of seven broad classes as per AIS&LUS (All India Soil and Land Use Survey). The slope classification is as follows:

Class	Percentage	Slope Category
1	0-1	Nearly level
2	1-3	Very gently sloping
3	3-5	Gently sloping
4	5-10	Moderately sloping
5	10-15	Strongly sloping
6	15-35	Moderately steep to steep sloping
7	>35	Very steep sloping

Aspect is the direction of slope with respect to north. In output slope raster generation, aspect identifies the down-slope direction from each cell to neighboring cells. The aspect values of the output raster will be measured in the compass direction. i.e. from N-NE-E-SE-S-SW-W-NW (i.e. 0^o -360^o in clock-wise direction).

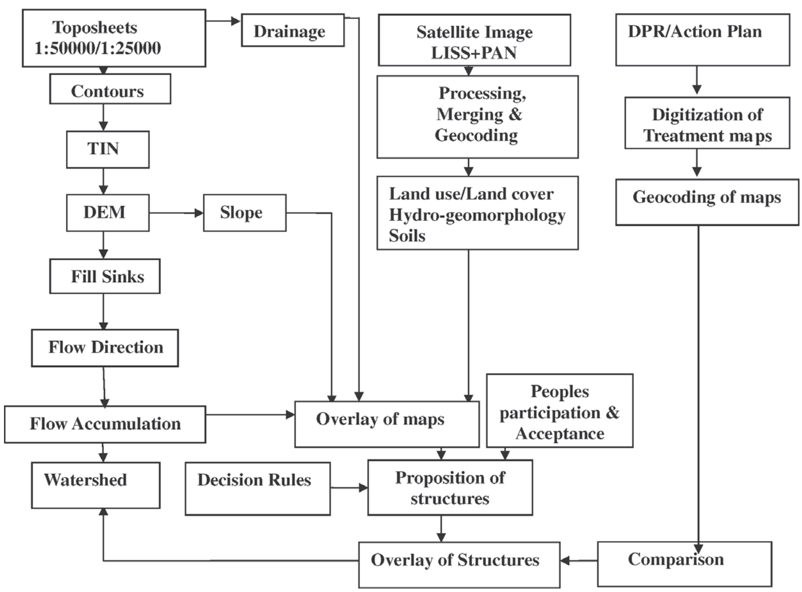
Hydrological Analysis

The hydrological analysis process includes filling of sinks, identifying maximum flow directions, possible accumulation points, creating a stream network, basin demarcation based on flow direction, by locating pour points (lowest point along the boundary of the watershed) at the edges, sinks and by identifying the contributing area above each point. An elevation raster is required to process hydrological modeling. The flow diagram is shown here.

Sinks

Sinks are the junction features which pull flow from the ends of the network as per the definition in hydrology, but the sinks that appear in the elevation raster data are due to errors like sampling effects and rounding of elevations to integer numbers. Sinks in this model have undefined directions of one of the eight valid values in a flow direction raster (i.e. 1 to 128). Sinks generally occur in elevation raster due to neighboring cells are higher than the processing cells. The elevation raster data should be free from sinks to create an accurate representation of flow direction and accumulated flow. 'Fill sinks' option has been used under hydrology function to remove sinks from the elevation raster data (DEM).

PROCESS METHODOLOGY

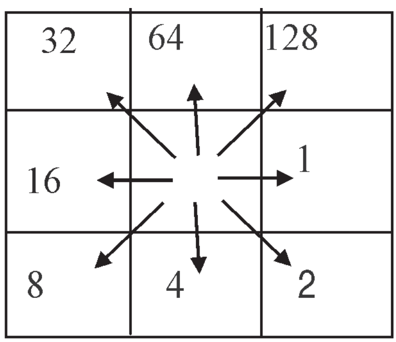


Flow direction

Flow direction indicates the direction of surface flow which is an integer raster value ranges from 1 to 255. In an elevation raster if a cell is lower than its neighboring cells, the direction of the flow will be towards that cell. In some elevation rasters when multiple neighbours have the lowest values then the flow will be defined by filtering out one cell sinks. In some cases if a cell has the same change in 'Z' value in multiple directions the resulted flow direction will be sum of those directions. The flow direction can be determined by finding steepest descent from each cell which can be calculated from the following expression:

Change in Z value/Distance *100.

The elevation raster thus generated free of sinks has been used to generate the flow direction in the study area using 'Flow direction' option in hydrology analysis function. The output flow direction raster shows eight (8) possible directions in which the possible surface will be existed.



Flow Direction

Flow accumulation

Flow accumulation will be generated from the error free elevation raster data. The cells of undefined flow directions other than (1 to 8) will only receive flow accumulation. The accumulated flow in the output raster will be calculated based upon the number of cells flowing into each cell. The high flow areas in the output raster are the areas of concentrated flow which area important to identify possible stream channels similarly, those areas with flow accumulation value zero (low) are the areas of topographically high like ridges. A stream network can be created by using the results of the high accumulated flow. Similarly, this stream network can be used as input to the stream order, stream line and stream link.

Basin/watershed/ catchment/ contributing area

Basin can be defined as the total area flowing to a given outlet or pour point. Basin function in hydrology delineates all drainage basins by identifying ridgelines between adjacent basins. Here the basin analyzes flow direction raster to find all sets of connected cells which belong to the same drainage basin. The drainage basin will be created based on the identification pour points (outlet of the drainage) all along the edges and sinks and by identifying the contributing area above each pour point in the source raster. Pour points are the lowest points along the boundary of the watershed. The elevation raster (DEM) has been used to generate a contributing area. The stream channels thus generated based on basin function in hydrology can be checked with the original drainage layer that has been extracted from toposheet.

Criteria for Proposing Structures

Proposing of different soil and water harvesting structures plays a very crucial role which requires a well qualified and well experienced man power with thorough knowledge in various water conservation programmes. For this purpose we have to take slope, flow direction and flow accumulation output raster maps along with drainage coverage which has been created from Survey of India toposheets into consideration. First, overlay the drainage layer on the slope map and identify the medium sloping areas (3-5%) along the drainage. Similarly, overlay the drainage layer on flow accumulation layer and identify all high flow areas (high accumulation). The high flow areas are normally displayed in white colour otherwise based on the reference can be identified very easily. After identifying high accumulation areas on medium sloping areas suitable structures have been placed at appropriate locations across the stream by a symbol using Arc Map. The mentioned criterion has been followed for proposing check dams and vegetative barriers (up to 10% to 15% slope has been considered).

Integration for Water Resource Assessment and Water Resource Developemnt

Integration of structure map (proposed based on hydrology model) over different thematic layers is very important part in order to assess their validity or requirement. Overlay techniques have been used for integration of different thematic layers like land use\land cover, hydro-geomorphology, soils and ground water potential maps prepared as per IMSD guidelines in order to test their validity and also to understand real field conditions. After analyzing these structures with each of these themes mentioned we felt that some of the structures are not required. Following this observation some of the structures which have been proposed based on hydrology modeling have been deleted. Similarly, some more structures have been added at places where they are required based on the analysis of the themes mentioned.

Water resource development plan

Water resource management plays a vital role in sustainable development of watershed which is possible only through the implementation of various water harvesting techniques. The efficient way for sub-surface water storage, soil moisture conservation or ground water recharge technologies should be adopted properly under water resource development plan. Similarly, developing of wastelands by appropriate measures can improve water resources on uplands in the watershed. The various measures adopted under soil and water harvesting are

- Vegetative barriers
- Building of contour bunds along contours for erosion
- Furrow/Ridges and Furrow ridge method of cultivation across the slope
- Irrigation water management through drip and sprinkler methods
- Planting of horticultural species on contour bunds

In addition to these measures, the following water harvesting structures should be implemented all along the gullies at problematic sites. These structures include:

- Construction of check-dams across gullies
- Building of mini-percolation tanks
- Construction of wire gabion structures across gullies
- Building of farm ponds in the plain areas
- Building/digging of inversion wells particularly in places where vesicular basaltic rock is overlain by massive basaltic rocks
- Recharge pits at some selected locations along water divide areas
- Gully plugging to prevent gully erosion and further down cutting of gullies particularly at places where gully erosion is predominant

Some other methods for soil and water conservation

The following methods may be adopted in areas with black soil & low rainfall.

- Field bunds with waste weirs
- Land leveling and deep ploughing
- Surplus water through field to field by stone waste weirs

Mechanical measures to prevent water erosion

- Graded bunds
- Bench terraces
- Grassed water ways
- Diversion drains

Limitations

It is felt that field information is required to support structures proposed based on hydrology modeling. For instance ground water potential can be estimated only from intensive filed observations of water table at least during two seasons i.e., pre and post monsoon periods. Similarly, for proposing structures the following parameters like soil depth, texture, terrain conditions and slope all along the gullies at micro-level (on large scale) are required. This type of micro-level information is not available from any other published evidence so far.

Soil and Moisture Conservation Measures

The following ***in-situ* soil moisture** conservation measures may be adopted on the agricultural lands (out side the gully course) to harvest rain water and soil conservation.

Vegetative Barriers

This is a semi-permanent soil and water conservation structural measure which can be adopted in almost areas irrespective of rainfall and soil type. Vegetative barriers are closely spaced stiff-stemmed dense plantations like grasses, legumes or shrubs grown in a few narrow parallel rows along contours for erosion in agricultural lands with flat and undulating topography **Fig.1** in order to prevent soil erosion and also silting of percolation tanks, check-dams and minor irrigation tanks. These act as barriers in concentrated surface run-off areas to reduce the velocity thereby to prevent sheet, rill and gully formation

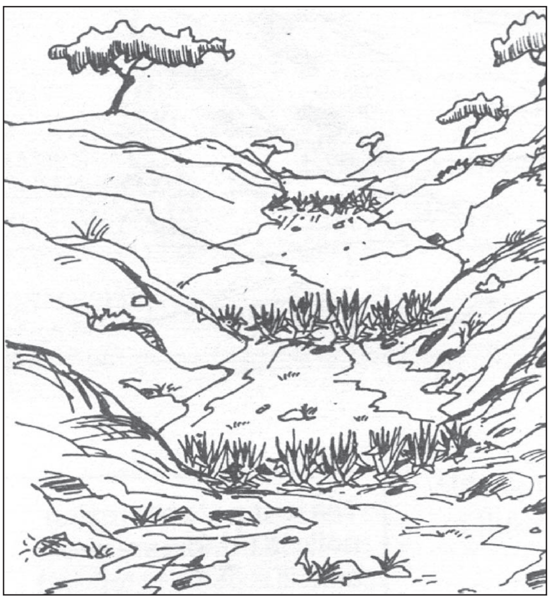


Fig. 1 : Vegetative Barriers

(ephemeral gully formation), to trap sediment to maintain soil fertility and allow more water to recharge the ground.

Site condition

Vegetative barriers can be established in all types of lands with flat and undulating topography except in class-VII lands and also in desertic environments. Vegetative species can be selected on the basis of soil type and climatic conditions.

Design criteria

The most important item in designing vegetative barriers in addition to the selection of vegetative species is spacing (interval) between rows which depends up on the vertical drop of the land. Vertical interval of vegetative barriers should be nearly half of the mechanical barriers. Depending up on the habitat of species selected, number of rows and plant to plant spacing will be decided. The following points should be taken into consideration while selecting vegetative species. The vegetative species should be perennial with stiff stems that remain intact through out the year, tolerant of both dry and wet soil conditions and should have ability to penetrate several inches of sediment and capability to grow even from buried stem nodes with rhizomatous or stoloniferous growth characteristics.

The following species like ***vetiver, agave, swithgrass,(Panicum Virgatum L., leucaena, lemongrass, cenchrus ciliaris*** and ***eastern gamagrass(Tripsacum dactyloides)*** are the suitable warm-season plants, can be selected for soil conservation. In addition to these plants, grass strips of 1 to 2 m wide can also be used in cultivated areas, pasture and also in forest areas to prevent soil erosion.

Farm Ponds

Farm ponds are man made water reservoirs built in agricultural lands by constructing an embankment across a water course or excavating a pit with small diameter and moderate depth. This is one of the best measures particularly, in rainfed dryland areas to store rain water during monsoon period in order to provide drinking water for live stock, human beings and irrigation purpose.

Site condition

Farm ponds are effective especially in black soil areas. Dug out farm ponds are suitable in areas having flat topography where water table is very close to the ground level. Similarly, impounding type (embankment) of farm pond is ideal in places where well defined waterways and low soil permeability with rolling topography.

Design criteria

The size of the farm pond can be decided based on the total requirement of water for irrigation, livestock and also for domestic use. In addition to these the total run-off entering the pond also should be taken into consideration while designing the pond. The pond capacity can be estimated based on the equation given below.

Pond capacity = Irrigation requirement + Livestock requirement + Domestic requirement + 20% of the sum of the above towards evaporation and other losses.

In general, in low rainfall areas 1 ha catchment area can provide 100m^3 of run-off and similarly, in medium rainfall areas 1 ha of catchment can yield 200m^3 run-off. The actual size of the farm pond should be one half or less than the total amount of annual run-off taking into consideration of the above observation. One farm pond can be recommended for every 25 ha of land.

Excavated farm pond **(Fig.2)** an be constructed either in square or rectangular shape whereas embankment type will **(Fig.3)** be determined purely based upon the physiography of the area. The side slopes of the excavated farm ponds should be preferably flatter (1:1) which will be decided based on the type of the soil. 'Drop inlet' types of spillways are generally used for farm ponds. Each farm pond should have 'Sod' type spillway or emergency spillway in order to dispose overflow during heavy rains. For watersheds ranging 4 to 12 ha require a combination of both mechanical and vegetative spillways .

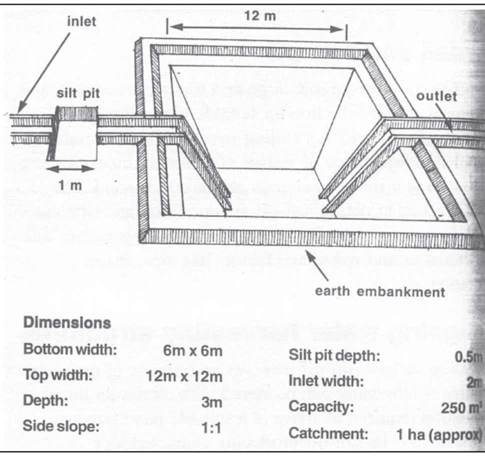


Fig.2: Excavated Farm Pond

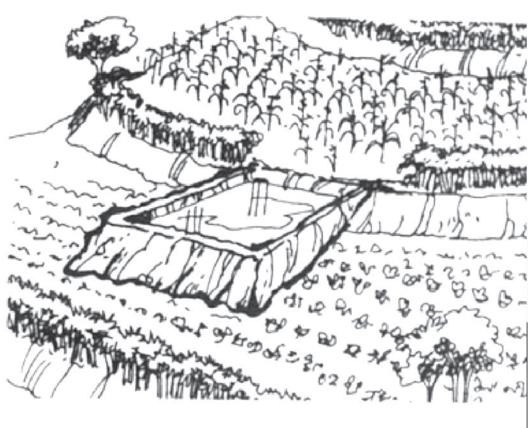


Fig. 3 : Embankment Farm Pond

Bunds

Bunds are small earthen barriers constructed in agricultural lands on 1-6% sloping lands to avoid gully formation by reducing velocity of run-off, percolation into the soil and to reduce sand deposition in down stream areas. These are semi-permanent mechanical measures built all along the contours for erosion by means of earthen to delay surface run-off in order to allow more water to be infiltered into the earth (soil layers as well as ground water recharge).

Here the velocity of the surface run-off will be reduced and delayed by converting long slope splitting into several smaller ones. This measure will be useful to undertake agronomic operations for man and animals by field to field access.

Bunds are broadly divided into (i) Graded bunds and (ii) Contour bunds which can be adapted to suite different environments depending upon the annual rainfall.

Site condition

Both graded and contour bunds can be built on 1-6% sloping agricultural lands to avoid gully formation, to reduce surface run-off velocity thereby increase recharge to the ground water and reduce sand deposition particularly, in lower lands.

(i) Graded bunds

Graded bunds are suitable in areas with medium to high rainfall (i.e. annual rainfall of 600 mm and above) and soils with poor permeability and soils of crust formation nature.

(ii) Contour bunds

Contour bunds are suitable in low rainfall areas (i.e. annual rainfall of less than 600 mm) and areas with light textured soils. Vegetation can be grown on these bunds.

Design criteria

(i) Graded bunds

Graded bunds can be constructed in two ways one with providing a channel and the other one without channel. Graded bund without channel is found to be effective. The minimum cross section area for shallow soils is $0.3m^2$, **(Fig.4)** for red and alluvial soils $0.5m^2$ and for heavier soils $0.675m^2$ The minimum cross section area can be considered as $0.5m^2$. The following equation can be used to fix the distance between successive beds.

$$V.I = (s/a + b)\ 0.3$$

Where V.I is the vertical interval in metres
s = slope in percentage
a = constant value ranging from 3 to 4 for permeable soils
b = constant with average value of 2

(ii) Contour bunds

The design of contour bunds is presented in **(Fig.5)** can be made considering water storage equivalent to 50 mm of rainfall. The contour bund specifications which are suitable for different soil environments are presented here. For gravelly soils cross section area of the bund is $0.45\ m^2$, for red soil areas $0.72\ m^2$, for shallow to medium black soils $1.07\ m^2$ and for deep soils $1.32\ m^2$.

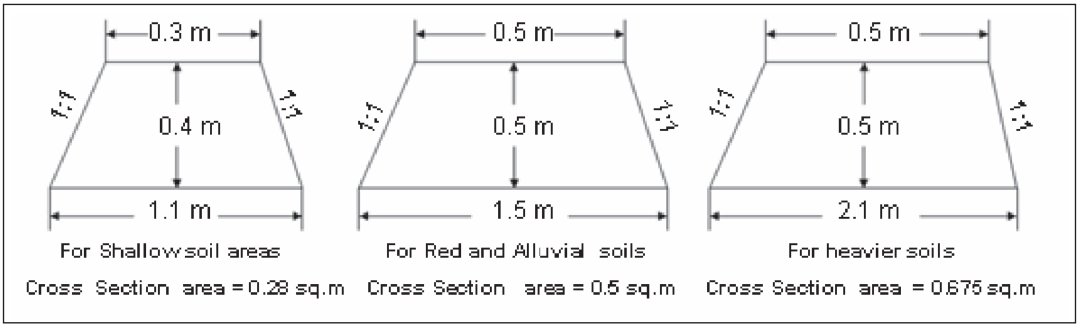


Fig. 4 : Cross sections of graded bunds for different soils

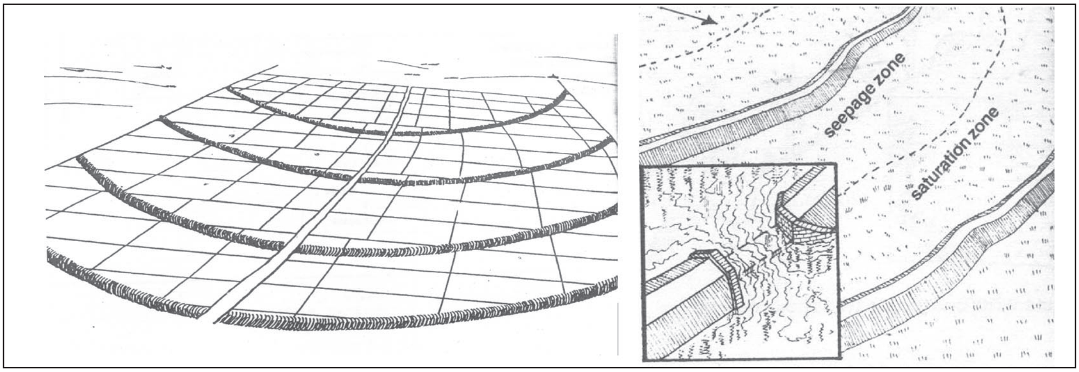


Fig. 5 : Contour Bunds

Contour Furrow/Ridge and Furrow

This is a mechanical and vegetative barrier. Contour furrows are trapezoidal/ V-shaped trenches dug all along the contours for erosion. This measure is effective in reducing surface run-off to increase infiltration particularly, at high sloping areas.

Site condition

This measure is suitable for areas where slope of the cultivated land is more than 5% to conserve rain water.

Design criteria

These V-shaped trenches should have a width of 0.6 to 1 m at the top and 0.4 m at the bottom with a depth of 0.4 m. These trenches can be made as continuous or staggered and they may be planted as well.

Irrigation and Water Management

In dryland agriculture water management plays a very important role. The efficient method to economize water application is through drip and sprinkler method. Similarly, planting of horticultural species on field bunds can reduce water through evaporation from crops and also act as shelter-belt in preventing wind erosion at specific locations.

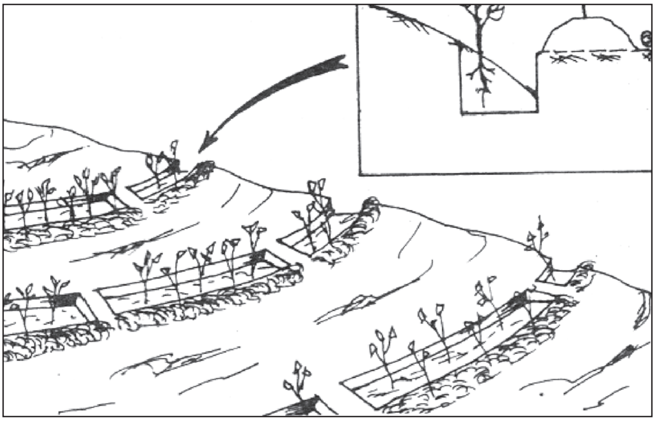


Fig. 6 : Contour Trenches

Water harvesting measures

Water harvesting measures are purely dependent up on rainfall and soil type in a selected area. Several indigenous practices as well as *in-situ* rain water harvesting measures are available for water harvesting to implement in different parts of the country. The indigenous practices include (i) run-off farming (ii) ground water recharge and (iii) river based systems. The indigenous water harvesting structures are suitable for several tropical and sub-tropical regions where run-off is only 10-40%.

In dryland areas rainwater is the only source for agriculture production. The infiltration of water into the soil layers affected by various parameters like (i) slope of the terrain (ii) capping of the surface and (iii) large areas without any barriers which require various methods in the form of vegetative /mechanical barriers to stop surface run-off to some extent in order to allow infiltration to recharge ground (top layers of the earth). The following gully control measures may be adopted to recharge ground water in the upstream and middle reaches of the streams.

Checkdam

A check-dam is also known as an anicut which intercepts the rain water from the upstream of the local catchment and stores for direct use and/or ground water recharge of the down stream wells. A check dam has an earthen dam with a masonry spill way. Under permanent check dams concrete or masonry or earth dams to store and slow down water are suggested.

Site condition

Check-dams will be constructed across 1st and 2nd order streams particularly, in medium sloping areas (0-5%). Temporary check dams are suggested in the case of head ward erosion of gullies where gullies encroaching into the adjoining agricultural lands.

Design criteria

These structures are designed based on the analysis of recurrence interval of rainfall over a period of about 50 years. Local guidelines should be followed while designing structures. One check-dam with a capacity of 0.5mcft for about 25 ha of land is sufficient to recharge ground water and also as points for cattle.

The water thus retained at check dams may be also used for irrigation crops. Synthetic bags filled with sand or loose boulders can also be used instead of earthen structure. Particularly, in areas with high rainfall and medium black soils gabions (wire boxes filled with stones) are suggested.

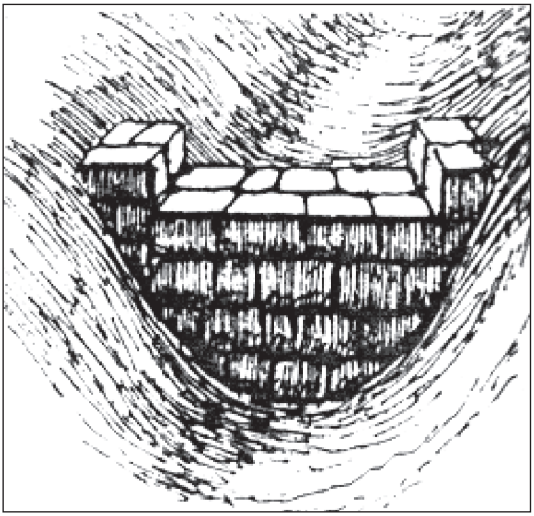


Fig. 7 : Check dam (masonry)

Loose Boulder Check-dams/Rock Fill Dams

This is a semi-permanent mechanical structure constructed across stream/nala with variable sizes of stones (boulders) or over burnt bricks to check the velocity of watershed, recharge the ground and also to arrest silt. This is one of the most effective and economical measures for gully control and it is an arrangement of loose boulders across stream/nala. These structures are of permeable type in order to arrest suspended sediment load.

Site condition

This structure is effective in all areas irrespective of rainfall and soil type. This measure is successful in the reclamation of broad and shallow gullies by promoting vegetative growth. These are suitable in places where width of the gullies are not wider than 10 metres and where loose bouders are available locally and cheaply. Gabions are preferred where foundation conditions are unstable. Rock fill dams need better foundation conditions rather than earthen dams or earthen gully plugs.

Design criteria

Rock fill dams need special design because gullies which origin from hill slopes, normally have high velocity during peak flows. Rock fill dams should be constructed at a vertical interval of 1.5 to 2 m along the gully bed and also at gully heads. The stones used for rock fill dams should be larger than 30 x 30 x 30 cm. The average height of the rock fill dam should be 4 to 5 metres. The minimum rock fill in the dam should be not less than 0.5 m. And the side slope of the dam should be 2:1 or flatter. The central portion of the rock fill dam should be low or a rectangular free board in order to allow peak flows. The trapezoidal or tapering cross section of these type dams reduces the friction and resultant damage during peak floods. In order to reinforce the dam the down slope side should be constructed with rock rubble. Cut-off walls with a thickness of about 20cm should be provided at the upstream and they should extend into the rock surface or disintegrated material. The structure should have strong foundation with adequate notch capacity and sizeable anchorage into the gully walls. Voids in the dam can be filled with small size metals also. For notch portion dimensions the following weir formula can be used.

$Q = 1.75 \, LH^{3/2}$

Where Q = Peak discharge,(m^3/sec)

L = Length of rectangular waste weir,(m) and

H = Depth of flow of water over the waste weir,(m)

(Depth of flow of 0.3 m can be used)

The hydraulic structures including side walls, wing walls and aprons should be constructed similar to masonry drop structures.

The schematic diagram is shown in **Figure .8:**

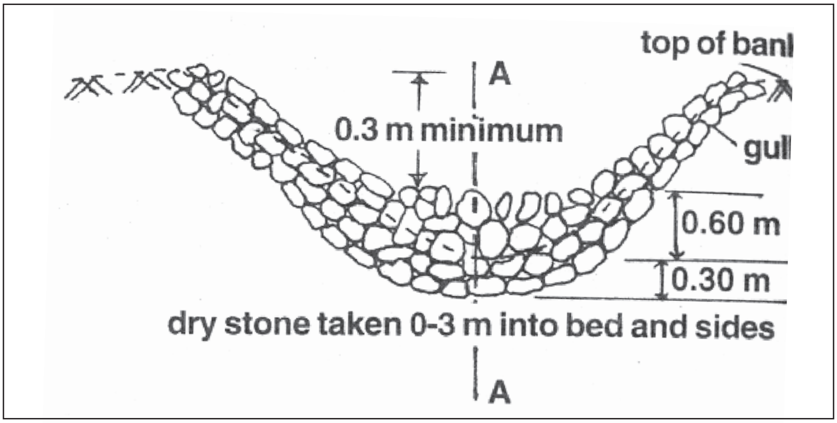


Fig. 8 : Loose boulder check dam

Wire Gabion Structures

Wire gabion structure is a semi-permanent mechanical structure suitable in steep sloping gully areas to prevent sediment erosion and also to recharge ground water. In wire gabion structures loose boulders are enclosed with wire mesh to reinforce the structure**(See Fig.9).**

Site condition

These structures are suitable in areas with high rainfall and steep slopes. This measure is not effective in boulder strewn gullies with high rock mass flow. These semi-permanent check dams should be constructed across steep sloped gullies.

Design criteria

In this structure wire-woven baskets should be filled with pebbles and cobbles and built across gullies to prevent sediment erosion during heavy rains. These structures should have openings less than the average size of the rocks. The wire mesh reduces the corrosive action by rock mass flow. In badland areas thin perforated and fabricated GI sheets are recommended.

Gully Plug

Gully plugs are generally earthen embankments or loose boulder bunds with a spillway and some vegetative cover built across active gullies with less than a metre depth where active erosion is prevalent. Gully plugs act as grade stabilization structures by depositing silt load which creates micro-environment for establishing vegetative cover. Gully plugging generally adopted to prevent down cutting of gully heads and also to prevent silt load movement towards down stream areas.

Site condition

Gully plugs are suitable in small and medium gullies where run-off velocity is low and the slope of the gullies ranges between 2-3%. Gully plugs are suggested particularly where foundation conditions are unfavourable for loose or masonry structures.

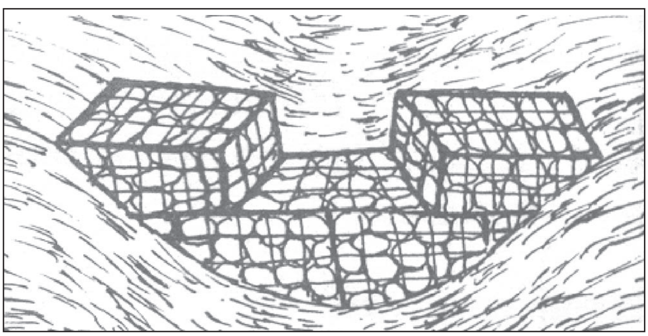


Fig. 9 : Wire Gabion check dam

Design criteria

The designing of gully plugs includes an embankment, a mechanical spillway and a grass ramp. The grass ramp should be constructed with a crest about 60cm below the top of the embankment. A pipe outlet should be installed 30cm below the ramp level. The minimum cross section of the embankment of earthen dam for gully plugs is 1.25m^2 and it should be ranged between 2.5 to 25 m^2. Similarly, the embankment should be grassed and also by raising vegetation like babul.

The specifications for type of gully plug up to 10% slope, infiltration materials and the location of the gully plug are presented in the **Table 1** as follows:

Table 1 : The specifications for type of gully plug upto 10% slope, infiltration material and location of the gully plug

Slope of the gully	location	Width of gully bed in metres	Type of gully plug	Vertical interval in metres
0-5%	Gully bed	up to 4.5	Brushwood	up to 3
5-10%	Gully bed Gully bed	up to 4.5 4.5 to 6	Brush wood Earthen and side branch	up to 3 1.5 to 3
	Confluence of two gullies	7.5 to 15	Sand bags	2.25 to 3

Nala Bunds and Percolation Tanks

Nala bunds and percolation tanks are the permanent mechanical recharge structures constructed across nalas to check the velocity of run-off and to increase water percolation in order to improve soil moisture regime. Nala bunds and percolation tanks are similar structures used alternatively at different places.

Percolation tanks are small storage tanks constructed across the streams and minor valleys by means of earthen bunds mainly to recharge the irrigation wells in the down stream sections.**(See Fig.10).**

Site condition

Percolation tanks are suitable in relatively flatter areas where the slope of the nala should be less than 2%. There should be a nala bund for every 40 ha of catchment area. The sub-strata at this location should be preferably hard rock and soils of the nala bund should be permeable or they should be disintegrated if it is composed of hard rock at greater depths.

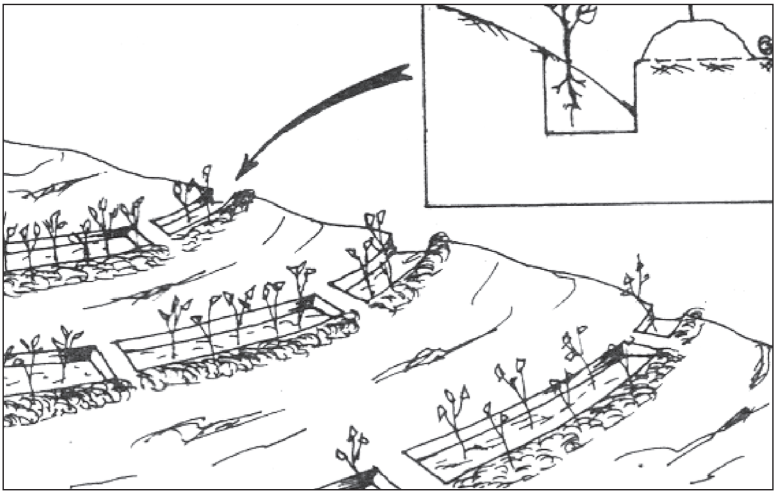


Fig. 10: Nala Bunds / Percolation Tanks

Design criteria

The top width of the nala bund of not less than 1 m (1/3rd of the impounding depth) should be provided. The bund section should comprise a core wall and a puddle trench. Similarly, an emergency spillway may be provided by the side of the nala bund. The width of the cut outlet varies depending upon the rainfall variation. The capacity of the percolation tank can be about 5 to 20mcft.

Sunken Pit

This is one of the structures adopted in recent watershed development activities which occupy less area and less submergence of land. This structure acts as a water point for cattle, human beings in addition to recharge water table through deep percolation.

Site condition

These are dug along nala/streams at certain selected locations.

Design criteria

Sunken ponds do not have any problem of breaching as they are constructed in the ground. A spillway may be provided to allow excess water to be flown into the drainage line.

The Consortium Approach for Integrated Watershed Management for Improving Livelihoods in Asia

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Management of natural resources in dryland areas is very important not only because livelihoods of millions of rural poor (>500 million) are directly connected to these areas but also due to the fact that these areas will continue to play a crucial role in determining food security for growing population and reducing poverty in the coming decades (Rockström et al., 2007). Enhancing efficiency and sustainability of natural resource management (NRM) projects in these areas has been the challenge faced by all the concerned stakeholders.

In the beginning watershed development in rainfed areas had become synonymous to soil and water conservation by putting up field bunds and structures to harvest runoff (Singh, 1998; Wani et al., 2002). In these activities techno-centric, compartmental and target oriented approaches were followed by involving one or two departments of the Government without much coordination among each other. It was a top-down target-based approach with hardly any involvement of the stakeholders in planning, implementation, and maintenance. Hence, such efforts did not make headway in impacting livelihoods of the rural poor in the rainfed areas (Farrington and Lobo., 1997; Joshi et al., 2000; Kerr, 2001; Dixit etal., 2001; Wani, 2002; Kerr and Chung, 2005and Shah, 2007). Learning from such experiences, in the later stages watershed management in rainfed areas has been attempted by various watershed development programmes implemented through different agencies such as Government departments, NGOs and Research institutes.

Watersheds are not only hydrological units but provide life support to rural people making people and animals integral parts of watersheds. Activities of people/animals affect the productive status of watersheds and *vice versa*. Currently there is a vicious cycle of 'poverty – poor management of land and crop – poor soils and crop productivity – poverty' is in operation in most of the watersheds in rainfed areas. This results in a strong nexus between drought, land degradation and poverty. Appreciating this fact, the new generation of watershed development programmes are implemented with a larger aim to address problems such as food security, equity, poverty, gender, severe land degradation and water scarcity in dryland areas. Hence in the new approach, Watershed, a land unit to manage water resources has been adopted as a planning unit to manage total natural resources of the area. Improving livelihoods of local communities is highlighted by realizing the fact that in the absence of them, sustainable NRM would be illusive. Due to these considerations watershed programmes have been looking beyond soil and water conservation into a range of activities from productivity enhancement through interventions in agriculture, horticulture, animal husbandry to livelihoods, community organisation and gender equity (Wani et al., 2002; NRAA, 2008 and APRLP, 2007). This holistic approach required optimal contribution from different disciplinary backgrounds creating a demand for multi-stakeholder situation in watershed development programmes.

During 1990's there has been a paradigm shift in the thinking of policy makers based on the learnings of earlier programmes. In India, watershed programmes are silently revolutionizing rainfed areas (Joshi et al., 2005 and Wani et al., 2006) and till 2006 up to 10^{th} five year plan, about US $ 7 billion have been invested by Government of India and other donor agencies treating 38 million ha in the country, During detailed evaluation of on-farm watershed programmes implemented in the country, ICRISAT team observed that once the project team withdrew from the villages the farmers reverted back to their earlier practices and very few components of the improved soil, water and nutrient management options were adopted and continued. Although, economic benefits of improved technologies were observed in on-farm experiments, adoption rates were quite low. Individual component technologies such as summer ploughing, improved crop varieties and intercropping were continued by the farmers. However, soil and water conservation technologies were not much favoured. (Wani et. al., 2002).

Detailed meta-analysis of 311 watershed case studies from different agro-eco regions in India revealed that watershed programmes benefited farmers through enhanced irrigated areas by 33.5%, increased cropping intensity by 63%, reducing soil loss to 0.8 t ha^{-1} and runoff to 13%, of rainfall and improved groundwater availability. Economically the watershed programmes were beneficial and viable with a benefit – cost ratio of 1: 2 with the internal rate of return of 27.0% **(Table 1)** (Joshi et al. 2008). However, about 65% of the case studies showed below average performance **(Fig. 1).** Based on the learning from the meta-analysis and earlier on-farm watersheds study we developed and evaluated an innovative farmers participatory integrated watershed consortium model (Wani et al., 2003)

Importance of making local communities to participate in watershed programmes to enhance efficiency and sustainability has been widely acknowledged. (Samra et al. 2000; Kerr et al., 2000; Joshi et al., 2004 and Wani et al., 2002) As a result, through a series of policies and guidelines responsibilities have been shifted more towards local communities. But achieving participation of primary stakeholders has not been easy. One of the major learnings over a period of time has been that, unless there is some tangible economic benefit for the community, people's participation does not come forth (Olson, 1971and Wani et al., 2002). To enhance community participation it is necessary to achieve tangible impact of the watershed development activities for all the sections of the society. Such an impact is feasible only through holistic livelihood approach where small and marginal farmers, landless people, women, educated youths and children could benefit from the impact of integrated watershed management. To achieve a tangible impact, it is necessary that different agencies such as research centres, development line departments of Government, training institutions, community-based organizations (CBOs), and non-government organizations (NGOs) come together and share their expertise in a complementary way through convergence of approaches, actors and actions.

Table 1 : Summary of benefits from the sample watersheds

Indicator	Particulars	Unit	No. of studies	Mean	Mode	Med-ian	Mini-mum	Maxi-mum	t-value
Efficiency	B:C ratio	Ratio	311	2.0	1.7	1.7	0.8	7.3	35.09
	IRR	Per cent	162	27.40	25.9	25.0	2.0	102.7	21.75
Equity	Employment	Person days/ha/ year	99	154.50	286.7	56.5	5.00	900.0	8.13
Sustaina-bility	Increase in irrigated area	Per cent	93	51.5	34.0	32.4	1.23	204	10.94
	Increase in Cropping intensity	Per cent	339	35.5	5.0	21.0	3.0	283.0	14.96
	Runoff reduced	Per cent	83	45.7	43.3	42.5	0.34	96.0	9.36
	Soil loss saved	Tons/ ha /year	72	1.1	0.9	1.0	0.1	2.0	47.21

Source: Joshi et al., 2008

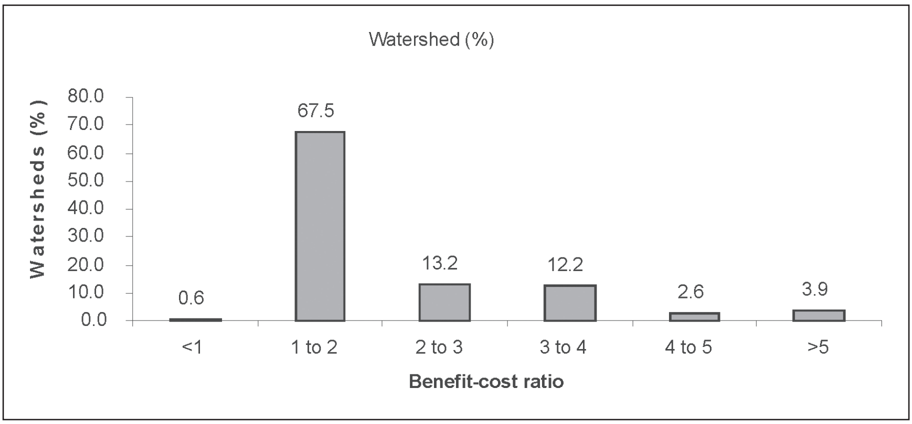

Fig. 1 : Distribution (%) of watersheds according to benefit-cost ratio (BCR)

These different agencies that have implemented watershed development programmes independently have had varied degrees of success. NGOs are generally action oriented field level agencies with their inbuilt strengths in community organization but, in majority of the cases, lack technical competencies in development and management of natural resources. They depend heavily on technical resource agencies for building capacities of their own staff and community members involved in NRM. Since different resource agencies have their compartmental specializations in specific areas, there is a lack of holistic approach in technical support to NGOs, affecting their performance in implementing watershed programmes. On the other hand, research organizations are usually mandated to work at the individual farm level. Bio-physical scientists often have limited experience in the dynamics of forming the collective action groups that is essential for water-based activities. However, with the approach of ultra disciplinary specialization (reductionist approach) and lack of professional reward mechanisms in the research institutions, and disciplinary hierarchy, scientists are more comfortable to work in their own area of specialization rather than working in multi-disciplinary teams. In projects that have been led by research centres, researchers seem to document results and findings mainly for the scientific sector (Gündel et al., 2001). Focus on social organisation is less in these programmes reducing their effectiveness. Government departments have their strengths in specific technical competencies and wider reach but lack skills in social organisation. Traditionally Watershed programs implemented by government departments have been supply-driven and target based. The Central and State governments allocated resources for watershed development. Subsequently, the officials used to identify locations

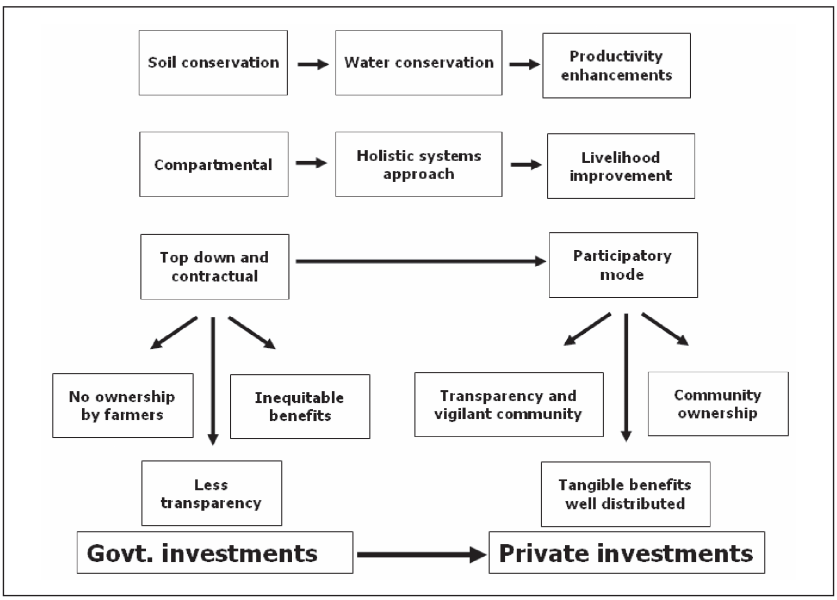

Fig. 2 : Journey through watershed approach in India

and decide various activities for implementation. Such an approach did not match the needs of stakeholders in the watershed (Kerr et al., 2000 and Joshi et al., 2004). Since these departments operate mostly in a compartmental way, integrated approach was lacking in such programmes. Programmes implemented by these departments also failed due to lack of participation of communities. Due to such deficiencies in capacities of implementing agencies, most of the watershed programmes failed to achieve optimal benefits (Farrington and Lobo, 1997 and Kerr and Chung, 2005). This situation has strongly supported the idea of different agencies coming together to support watershed programmes.

But bringing together organisations with different strengths, weaknesses and styles of functioning on a common platform to work together for a common cause is challenging. ICRISAT accepted the challenge and successfully evolved a scalable model termed 'the Consortium Approach' in the Asian Development Bank (ADB) supported watershed development programme at Kothapally in Rangareddy district of Andhra Pradesh (Wani et al., 2003). The results of the Consortium Approach adopted at Adarsha watershed, Kothapally in terms of tangible economic benefits to individual farmers through doubling of crop productivity due to improved cultivar and nutrient management options in the first season of 1999 triggered the community participation **(Table 2).** The success has been scaled up/out to many areas henceforth. We elucidate the process of evolution and associated learnings in this paper.

Evolution of the Consortium Approach

ICRISAT was one of the earliest CG centres to give formal recognition in its mandate to supplement research on individual crops with research into farming systems. Watershed-based research was an example of interdisciplinary research even before the term assumed significance (Shambu Prasad et al., 2005 & 2006). This interdisciplinary research, over the years, has shaped up into an Integrated Genetic Natural Resources Management (IGNRM) approach within ICRISAT (Twomlow et al., 2006). But in the beginning ICRISAT also faced the problems of hierarchy of disciplines among scientists who were working together. After realising the importance and potential of combining disciplinary expertises in a complimentary way such issues were sorted out which gave rise to the idea of the Consortium Approach based on the success of multi-disciplinary approach at the research station.

The Consortium is a convergence of agencies/actors/stakeholders who have a significant role to play in watershed development project. Facilitated by a leader/leading organization, member-organizations prepare common plans and work towards achieving the agreed common objectives.

ICRISAT has been involved in an intensive on-station watershed development work for about 25 years before the new approach was adopted. After witnessing the quality work

Table 2 : Average crop yields (Kg ha $^{-1}$) with equivalent of maize crop with different cropping systems at Adarsha Watershed, Kothapally, 1999-2009.

Cropping systems	Yield (Kg ha $^{-1}$)													
	Before 1998	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	Mean	CV %	SE±
Improved Systems														
Sole maize	-	3250	3760	3300	3480	3920	3420	3920	3630	4680	4810	3820	17.8	80
Maize/ Pigeonpea inter - crop system	-	5260	6480	5600	5650	6290	4990	6390	6170	6120	6680	5960	16.7	116
Sorghum/ Pigeonpea inter crop system	-	5010	6520	5830	-	5780	4790	5290	5310	-	-	5500	13.4	154
4. Sole Sorghu m	-	4360	4590	3570	2960	2740	3020	2860	2500	-	-	3330	23.9	141
Farmers practice														
Sole Maize	1500	1700	1600	1600	1800	2040	1950	2250	2150	-	-	1890	17.2	53
Sorghum/ Pigeonpea inter crop system	1980	2330	2170	2750	3190	3310	3000	3360	3120	-	-	2900	19.2	110
Hybrid Cotton	-	2295	7050	6600	6490	6950	-	-	-	-	-	5880	37.0	511
BT Cotton	-	-	-	-	-	-	-	6210	5590	7310	9380	7120	26.1	315
Mean		3477	4970	3833	4018	4814	3651	4584	4320	6268	7396			
CV%		11.9	31.4	10.7	8.0	14.5	20.3	10.8	12.2	16.7	16.2			
SE±		415	1559	410	323	698	742	495	525	1049	1201			

Note: The farmers practice Sorghum/Pigeonpea inter-crop system improved pigeonpea variety ICPL 87119 was grown along with local sorghum variety (Pacha Jonna) from 2001 year onwards discontinued the old variety which was highly susceptible for fusarium wilt.

and its results, many agencies have approached ICRISAT for sharing of knowledge/ technology in their areas. After a series of deliberations within the Institute, decision was taken to support Bhartiya Agro-Industries Foundation (BAIF), a prominent NGO, through technical advice in their watershed programmes in Madhya Pradesh during the year 1997. Though it was restricted, in the beginning, to on-farm demonstrations, this experience of working with a voluntary organisation helped significantly in strengthening the idea of the Consortium Approach.

> "ICRISAT considers itself as a premier research institution holding the implicit responsibility to give guidance in the right direction to other regional agencies. There has been a strong feeling within its scientific communities after years of deliberations in various forums that the target of IGNRM research is not just the farmer or the NARSs researchers but changing the thinking of actors in the system. This gave motivation to try to this challenging approach."

During the year 1999, ADB came forward to support ICRISAT's idea of testing the model in a watershed in Kothapally village of Rangareddy district in Andhra Pradesh, called Adarsha (meaning model) watershed to minimize the gap between research findings and on-farm development. Secondly the purpose was also to adopt the learning loop in planning of strategic research based on the participatory research for development. There was also a request from the Government of Andhra Pradesh to demonstrate the benefits of increasing crop productivity substantially through watershed approach in the rainfed areas under farmer's situation.

For this model, as opposed to single institution, relevant organizations were identified and brought into the network to form a consortium of institutions for technical backstopping of the project. ICRISAT, M Venkatarangiah Foundation (MVF) an NGO, Central Research Institute for Dryland Agriculture (CRIDA), National Remote Sensing Agency (NRSA), Drought Prone Areas Programme (DPAP) which is now called as District Water Management Agency (DWMA), Rangareddy district administration of government of Andhra Pradesh along with farmers of the watershed formed the consortium **(Fig. 3)** (Wani et al., 2003).

The first success of the new approach was evident when more number of farmers came forward to undertake participatory evaluation of technologies except knowledge farmers had to pay for the inputs in cash or kind. During second year, people from surrounding four villags of Kothapally came to ICRISAT and asked for the technical help promising that they will show similar/ better results than Kothapally in shorter period. This indicated to the Consortium team members that the approach is self replicating as people from surrounding villages saw tangible benefits from the approach. ICRISAT and DWMA of Rangareddy district decided to provide technical support and necessary inputs on cost basis to these four villages. True to their words, villagers showed the benefits in terms of doubling their crop productivity **(Table 3).** The model has become a success story and henceforth the model has been suitably adapted and scaled up/out in many locations.

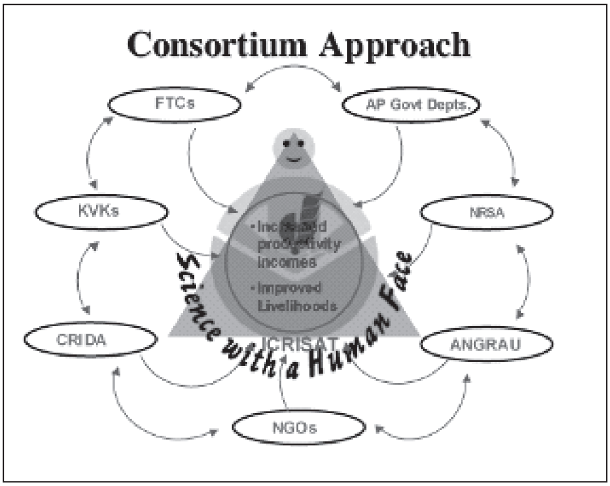

Fig. 3 : A pictorial representation of different partners in the Adarsha Watershed Consortium

Table 3 : Results from evaluation of yields of 98 farmers' from four villages around Kothapally during the year 2001

Cropping system	Farmers' practice (kg ha^{-1})	Improved practice (improved seed + management) (kg ha^{-1})
Maize/ Pigeonpea		
Maize	1900	4365
Pigeonpea	350	1130
Sorghum/ Pigeonpea		
Sorghum	1200	2725
Pigeonpea	330	1185
Maize/Chickpea		
Maize	2200	4800
Chickpea	650	1085

During the process of scaling-out of the consortium model for Andhra Pradesh Rural Livelihoods Program (APRLP) of Government of Andhra Pradesh supported by the Department of International Development (DFID, U.K), in the states of Rajasthan, Madhya Pradesh, Gujarat and Karnataka, supported by Sir Dorabji Tata Trust, Mumbai, The Asian Development Bank (ADB) Manila, Philippines, Sujala Watershed (Program of Government of Karnataka supported by World Bank) baseline characterization of soils was used in watersheds as a knowledge-based entry point activity. Analysis of 3600 soil samples from the farmers fields in different states of India revealed that soils in the tropics were not only thirsty but hungry also particularly for micronutrients like zinc, boron and secondary nutrients like sulphur along with macronutrients like N and P. Eighty to 100% farmers fields in several states of India were found critically deficient in Zn, B and S **(Table 4)** (Sahrawat et al., 2007). Subsequent participatory research and development (PR&D) trials in 50 micro watersheds in Andhra Pradesh with amendments of Zn, B and S showed increased yields by 30-174% for maize, 35-270% for sorghum, 28–179% for groundnut, 72–242% for pearl millet and 97-204% for pigeonpea (Rego et al., 2007).

Table 4 : Percent farmers' fields deficient in plant nutrients in various states (districts within a state) of India

State	No. of Farmers	OC [a] %	Av P ppm	Av K ppm	Av S ppm	Av B ppm	Av Zn ppm
Andhra Pradesh	3650	76 [b]	38	12	79	85	69
Chattisgarh	40	-	63	10	90	95	50
Gujarat	82	12	60	10	46	100	85
Jharkhand	115	42	65	50	77	97	71
Karnataka	17712	70	46	21	84	67	55
Kerala	28	11	21	7	96	100	18
Madhya Pradesh	341	22	74	1	74	79	66
Rajasthan	421	38	45	15	71	56	46
Tamilnadu	119	57	51	24	71	89	61
Total	22508	69	45	19	83	70	58

[a] OC = Organic Carbon; AvP = Available phosphorus, AvK = Available Potash, AvS = Available Sulphur, AvB = Available Boron, AvZn= Available zinc

[b] = Percent farmers fields deficient i.e, below critical limit for a particular nutrient.

* = Extensive soil sampling undertaken to interpolate analysis at district level using GIS.

Source: Based on Rego et al., 2007; Sahrawat et al., 2007; Wani et al., 2008 and unpublished data sets of ICRISAT.

Farmer's participatory selection of improved crop cultivars in 150 micro watersheds of APRLP in five districts resulted in identification of improved cultivars of sorghum, pearl millet, maize, castor, green gram, groundnut, pigeonpea and chickpea **(Table 5).** Further, to ensure availability of seeds of improved cultivars of varieties, self help groups (SHGs) in the villages were trained to handle village seed banks (Dixit et al., 2005 and Reddy et al., 2007). Trained farmers undertook seed production using breeders' seed for sowing and with the help of consortium partners farmers maintained purity. The village seed banks were very effective in overcoming the bottleneck problem of good quality seed availability in villages particularly of improved varieties of low-value matricides cereals like pearl millet, sorghum and legumes such as groundnut, chickpea and pigeonpea which private seed companies do not like to handle.

The Government of Andhra Pradesh in India has scaled-up this initiative by providing Rs. 100,000 (US$ 2500) as a revolving fund to each SHG and organizing breeder or foundation seeds for the SHG. In all 200 village seed banks are operating in the state (Shanti Kumari, 2007). During 2004, 255 farmers' participatory evaluation trials with improved cultivars of castor, maize, groundnut, sorghum and chickpea along with improved nutrient management showed 41-70 percent increased crop yields over the farmers' management practice **(Table 5).**

Table 5 : Farmers' participatory evaluations for productivity enhancements in watersheds of 5 districts of Andhra Pradesh under APRLP during 2002-2004

District	Watershed villages	Crop	No. of Trials	Culti-vars	Yield (kg ha^{-1})		Yield gain (%)
					FM	Best bet	
Kurnool, Nalgonda Mahabubnagar	17	Castor	41	Kranthi	780	1240	59
Mahabubnagar Nalgonda	22	Maize	40	Ratna 2232	2770	4510	63
Kurnool	13	Groundnut/ Pigeonpea	53	ICGS 76 ICGV 86590	775	1320	70
Kurnool	19	Sole groundnut	52	ICGS 76 ICGV 86590	1075	1605	49
Kurnool	2	Chickpea	34	ICCV 37	1370	1930	41
Anantapur	19	Sole groundnut	35	ICGS 76 ICGV 86590	770	1100	43

In 208 watersheds in Asia, yields of several crops increased by 30 to 242% over baseline yields varying from 500 to 1500 kg ha^{-1}. Recently under the World Bank aided Sujala-ICRISAT initiative in 22 villages in five districts of Karnataka 232 on-farm PR&D trials showed increased crop productivity by 56–148 per cent with groundnut, maize, finger millet, sunflower etc. **(Table 6).**

Table 6 : Farmers' participatory evaluations for productivity enhancements in watersheds of 5 districts of Karnataka under ICRISAT-Sujala project during 2005-2006.

District	Watershed villages	Crop	No. of Trials	Culti-vars	Yield (kg ha^{-1})		Yield gain (%)
					FM	Best bet	
Kolar & Tumkur	7	Groundnut	63	JL 24, ICGV 91114, K1375, K6	915	2260	146
Kolar & Tumkur	9	Ragi	62	MR 1, L 5, GPU 28	1154	1934	67
Chitradurga	2	Sunflower	30	KBSH-41, KBSH-44, GK	760	2265	198
Chitradurga & Haveri	4	Maize	49	PA 4642, GK 3014	3450	5870	70
Haveri	4	Sole	16	ICGV 91114 groundnut	1100	1720	56
Dharwad	4	Soybean	12	JS 335, JS 9305	1350	2470	83

In northern Vietnam watersheds, from maize-based systems farmers diversified their systems with groundnut and vegetables resulting in increased productivity as well as income. **(Table 7).** Inclusion of groundnut **(Fig . 4),** a legume reduced chemical N fertilizer for maize and also increased yield by 18%. Soil and water conservation measures such as staggered contour trenching, planting of *Glyricidia*, or pine apple vegetative border, rainwater harvesting pits and loose boulder gully control structures on slopping lands improved water availability in open wells and enabled the farmers to grow high-value water melon crop with the highest B:C ratio amongst the cropping systems **(Table 7).** In Tad Fa and Wang Chai watersheds of Thailand, farm incomes increased by 45% within three years. Average net income is now $1,195 per cropping season. Lucheba watershed in Guizhou, China, transformed its economy through crop-livestock integration with buckwheat as an alley crop that controlled soil erosion, provided fodder and increased per capita income from $200 to $325 in two years. Improved soil, water, nutrient and crop management options reduced runoff and soil loss in the nucleus micro watersheds in the four countries **(Table 8).**

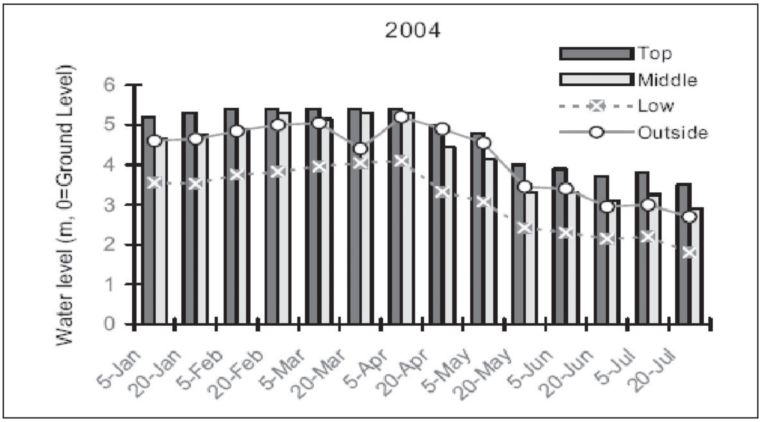

Fig. 4 : Groundwater levels in the open wells in the Thanh Ha watershed during 2004

Table 7 : Details of crops grown in Thanh Ha commune, Ho Binh Province, Vietnam.

Crop	% area	Yield (t ha^{-1})		Income (US$)	B:C ratio
		Average	Range		
Maize	83	3.4	0.9-7.0	421	1.41
Watermelon	6	17.8	10.0-36.0	2015	1.73
Sugarcane	8	58.3	20.0-83.0	1270	1.06

Table 8 : Seasonal rainfall, runoff and soil loss from different benchmark watersheds in India and Thailand.

Watershed	Seasonal rainfall (mm)	Runoff (mm)		Soil loss (t ha^{-1})	
		Treated	Untreated	Treated	Untreated
Tad Fa, Khon Kaen, NE Thailand	1284	169	364	4.21	31.2
Kothapally, Andhra Pradesh, India	743	44	67	0.82	1.90
Ringnodia, Madhya Pradesh, India	764	21	66	0.75	2.2
Lalatora, Madhya Pradesh, India	1046	70	273	0.63	3.2

Detailed household survey in Adarsha Watershed, Kothapally revealed that 59.4% land holders belonged to backward, scheduled casts, scheduled tribes and minority communities. The dominant land-owning group was at the middle and not at the top of the cast hierarchy (Hughes et al., 2005). The consortium adopted IGNRM approach for community watershed management and most interventions were for enhancing productivity and generating additional income for the small, marginal farmers and other vulnerable groups including landless and women to ensure tangible economic benefits. In all the community watersheds equity issues are addressed through productivity enhancement and income-generating activities in addition to the normal soil and water conservation measures. The results in **Table 9** showed that only 36.6 per cent of the 1962 direct beneficiaries in Sujala-ICRISAT watershed initiative belonged to other categories and 67.4 per cent beneficiaries belonged to SCs, STs, OBCs categories. Similar distribution of beneficiaries was there in other watersheds also **(Box 1).**

Table 9 : Number of farmers from different categories selected for Sujala-ICRISAT Demonstrations in seven districts during Kharif 2007.

District	SCs	STs	OBCs	Others	Total
Kolar	46	30	15	183	274
Chikkaballapur	52	43	90	139	324
Tumkur	20	8	60	143	231
Madhugiri	59	11	49	55	174
Chitradurga	150	40	553	47	790
Haveri	1	4	-	83	88
Dharwad	-	13	-	68	81
Total	328	149	767	718	1962
Percentage	16.7	7.6	39.1	36.6	

The consortium approach has vastly improved livelihoods of 250,000 poor people in watersheds of 368 villages across Asia. Vulnerable groups, such as women and the landless, are empowered to undertake livelihood activities, including the rehabilitation of degraded common lands with bio-diesel plantations **(Box 1).**

Key Features of Facilitating the Consortium Approach

Need for a common goal – Team building workshops

It is a well known fact that, working in partnership becomes successful only if all the members share common goal. For the Consortium Approach ICRISAT tried to achieve this by identifying important institutions whose objective is to enhance agriculture productivity, incomes and reduce rural poverty, and are working in the area of watersheds. A series of team building workshops were conducted to internalize the goal and objectives amongst consortium members and also to build rapport and trust amongst the partners. Team building workshops addressed the objectives of:

- A common vision of the watershed development programme among consortium partners
- Inculcate a team spirit among the members to achieve the goal of sustainable NRM for improved rural livelihoods,
- Develop an understanding of and appreciation for the efforts and initiatives taken up by various teams
- Discuss and develop action plans for desired impact
- Develop a combined strategy to up-scale the impact to the neighboring watersheds.

The series of team building exercises started with the core team in the first round and spiraled up further to include the entire network of consortium partners in the fourth round using the cascade approach. This was helpful in reinforcing the project objectives at all levels and across all the partner organizations of the consortium. These exercises helped partners to discuss the objectives, know their roles and responsibilities and develop a sense of belonging with their fellow partners and most importantly to build tolerance amongst the members for divergent views.

Building on the strengths:

The consortium's principle was to harness the strengths of the partners and overcome the weaknesses. This principle was ingrained amongst all the partners and strengths of each partner were highlighted to ensure the feeling of importance and each member's valuable inputs.

Institutionalization of partnerships:

The process of institutionalization started with identification of suitable institutions and people for the project. Efforts were made to identify partners with common goals and willingness to collaborate. Once such people were identified, their parent organizations were contacted for collaboration. This approach was found to be more effective than identifying organizations first and then trying to find people within those organizations who can get represented in the consortium. While being part of the consortium, participating organizations appreciated strengths of each other and rapport was built. This collaborative spirit has been shared in many other projects that took shape later.

Internal and external institutional arrangements

For facilitating the Consortium there was a need to put in place an institutional mechanism both internal and external – to review the progress of the project from time to time and to take necessary action.

Institutional arrangements have been different to suit the needs of different projects. For instance for the project funded by the Sir Dorabji Tata Trust, Mumbai in Madhya Pradesh and Rajasthan, a national level Project Steering Committee also called Project Advisory Committee (PAC) was constituted with representatives from the Ministry of Agriculture of Government of India, state governments of Madhya Pradesh and Rajasthan where the project is being implemented, NGO representative and Indian Council of Agriculture Research (ICAR) are part of the committee.

In addition to the external arrangements ICRISAT has evolved internal arrangements among scientists involved in the project for project implementation and necessary technical backstopping. This internal arrangement has been tried during the ADB project and has evolved since then. It is a three-tier functional structure **(Fig . 5)** consisting of a project manager assisted by a team of scientists and scientific officers. Site coordinators and activity coordinators report to the project manager and assist him in planning and execution of the project activities. Project manager besides being in that position acts as site coordinator for one of the regions to set the standards and create competitive spirit amongst the site coordinators.

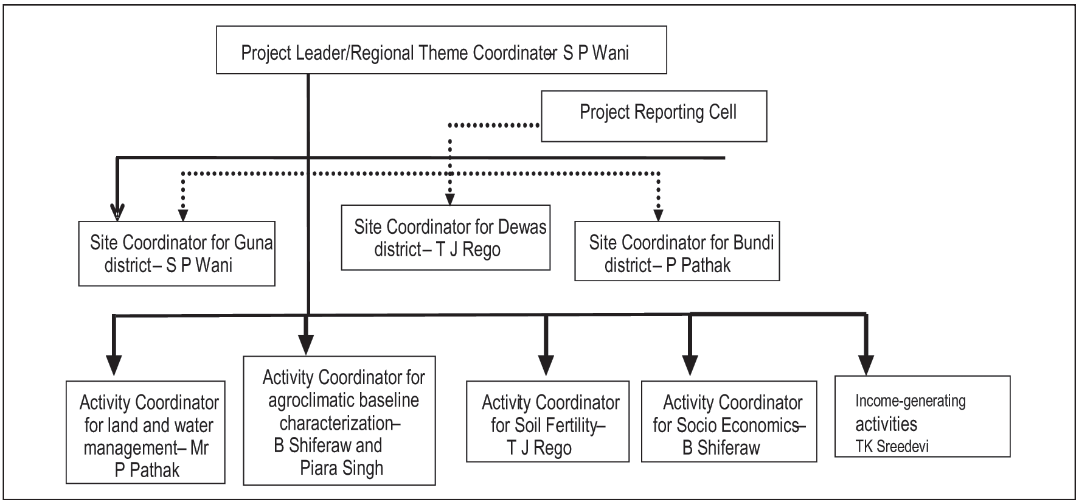

Fig. 5 : Internal arrangements made among different scientists within ICRISAT for the consortium approach

For day to day support in the project areas Visiting Scientists have been put in place. They offer technical support to the NGO partners. Along with staff located that they are also instrumental in data collection and communication with multi-disciplinary team of scientists supporting project activities. In a way they act as link between ICRISAT and Project Implementing Agency (PIA).

Dynamic and evolving

Consortium Approach is not a static model but should be adapted based on field situation and requirements. It provides the philosophy and framework while specific components need to be added to make it a relevant one as per the situation. In addition to the critical stakeholders such as NGOs, NARSs, State and Central Government line departments and farmers' organizations; based on the need, relevant private industries can also be brought into the consortium. For example, initial consortium for Adarsha watershed consisted of CRIDA, NGO and DPAP and subsequently NRSA and BAIF were included. In other watersheds private industrial partners and credit institutions were also brought in to ensure market linkages and credit sources.

Scaling up/ out of the approach

Following the success of the model, The Consortium Approach has been scaled up to many locations. In Andhra Pradesh, it facilitated scaling up in Andhra Pradesh Rural Livelihoods Programme of Government of Andhra Pradesh funded by the United Kingdom's Department for International Development (DFID). ICRISAT-led the consortium in ten nucleus watersheds and 40 satellite watersheds in Mahabubnagar, Kurnool and Nalgonda districts and later extended to 150 villages in five districts. Through a programme with funding support from the Sir Dorabji Tata Trust (SDTT), the approach

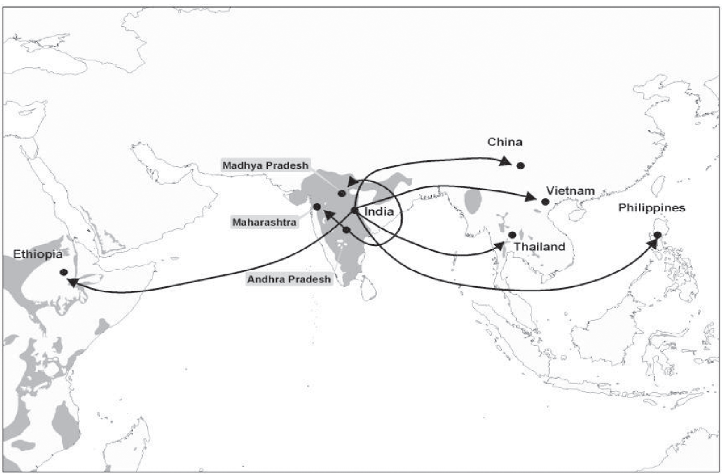

Fig. 6 : Flow of the Consortium Approach

is scaled up in Madhya Pradesh and Rajasthan. Through ADB supported projects, the approach is adapted and facilitated in India, China, Vietnam and Thailand. The Bureau of Agriculture, Government of Philippines has established four community watershed sites as sites of learning in four provinces with the technical support from ICRISAT. There has been spill over of the learnings concerning the approach in Africa, particularly in Eastern Africa through ICRISAT's association with Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The South – South collaboration between Indian Council of Agriculture Research (ICAR) and ASARECA in the area of integrated watershed management is facilitated by ICRISAT and IWMI. From all the places there has been positive feedback about the approach. In all, there are more than 368 watersheds which are supported by the Consortium.

Advantages of the Consortium Approach

Synergy and Creativeness – Quite often in NRM challenges are thrown for which answers hardly remain with one discipline, for example livestock – fodder, fisheries – water, different crops, (breeding, pest management, soil fertility etc.,), credit-markets etc.,. In the Consortium Approach where multi-disciplinary team is addressing the problem situation, there is a possibility for creative thinking and new ideas which benefit the farmers as well as researchers and development workers.

Sustainability – The Consortium Approach facilitates members of the network to have ownership of the objectives of the programme. This leads to optimal contribution from diverse disciplinary backgrounds providing a holistic systems approach. As a result solutions for problems are effective. Since activities are planned demand driven, implemented in a participatory manner, and solutions offered are effective ones, there is a good chance for the long-term sustainability of project initiatives.

Cost effectiveness – At the time of project implementation, working linkages are established among actors in the consortium. This ensures quick access to relevant people when primary stakeholders encounter a situation and timely solutions. **(See Box 1 & 2)** One of the main issues in NRM work is involvement of different departments independently and in many cases resulting in duplication of work. In the Consortium Approach, each of the actors knows what other departments are doing. So there is less chance for duplication of the work.

Win-win solution through empowerment of partners – The Consortium Approach allows members to learn from each other. It spreads inter-disciplinary knowledge among partners. Strengths of each of the partners are harnessed and help is provided mutually by partners to get over their weaknesses. When there is an effort to build upon strengths of each of the partners, weaknesses get covered with strengths of other partners. In the team not only bio-physical scientists started offering solutions for issues related with other related disciplines but also got sensitized with socio-economic, gender and institutional issues. One team became more cohesive overcoming conventional disciplinary hegemony.

Faster scaling-up – Many studies on NRM indicated that it is important to work with different partners to facilitate scaling-up. The Consortium Approach ensures intensity and closeness in which communication and collaboration take place among partners, which contributes for effective scaling up. Impact could be further enhanced through new innovative partnerships. Since different partners are involved, necessary enabling institutions and policies are put in place in a short time. For example, while working on a model to benefit landless people through bio-diesel plantations in CPRs **(Box 1),** we could get the usufruct rights for landless people from the administration in six months. In addition, this example would enable the administration to develop CPRs to benefit the vulnerable groups without giving land rights. Now GTZ and Kirloskar engines Ltd., a private company joins the consortium to pilot use of straight vegetable oil (SVO) for energy generation at village level.

Change in organizational behavior – General tendency of a researcher is to develop technology in the laboratory/research station and transfer it to the field through extension agencies. This tendency got reengineered into working closely with primary stakeholders and developing technology in a participatory way. Governmental and non-governmental extension agencies also find it worthwhile to play a role in developing the technology by listening to farmers carefully and contributing through feedback and sharing indigenous knowledge options with researchers. Different researchers within ICRISAT and other partner institutions also got sensitized about social, gender, equity, and other disciplines and overcame disciplinary biases. Good research and management practices got internalized amongst the partners.

Public-private partnerships are facilitated (multiplier effect) – For enhancing incomes and agricultural production in rural areas, backward and forward linkages are important. Private entrepreneurs came forward to join the consortium for harnessing the opportunity. For example during baseline characterization, wide spread deficiency of boron, zinc and sulphur in addition to nitrogen and phosphorus was observed in 80–100% of the farmers' fields (Sahrawat et al. 2007). Farmers' participatory trials with amendments of deficient nutrients showed substantial yield increases and enhanced incomes (Rego et al. 2007). However, availability of boron and other micronutrients in remote villages was a problem. The Borax Morarji Ltd. producers of boron fertilizers in India came forward to join the consortium to ensure availability of boron fertilizers in villages through SHGs. Similarly for handling market produce and processing, different industries came forward to join the consortium, for example – in case of biodiesel initiative a PPP amongst GTZ-Southern Online Bio-Technology (SBT) – and ICRISAT is ongoing under which SBT is operating

40 Kl d^{-1} biodiesel plant in Nalgonda district, Andhra Pradesh with German technology provided by Lurgi and ICRISAT is providing technical support to the farmers for cultivating biodiesel plantations and facilitating buy-back arrangements between the farmers and the SBT (Kashyap 2007). There are number of other examples of PPP through consortium in the area of biodiesel and medicinal and aromatic plants also. In addition to fulfill their corporate social responsibilities [For example Sir Dorabji TATA trust (SDTT), Mumbai; Sir Ratan Tata Trust (SRTT), Mumbai, India; TVS Foundation. Chennai, India; Coca Cola Foundation, USA) different industries and their formal associations such as Confederation of Indian Industries (CII) and Federation of Indian Chambers and Commerce Industries (FICCI)] are collaborating with the Consortium.

Conclusion

The most crucial issue that determines success of a Consortium is the capable leading/ facilitating partner. Partnerships need to be nurtured by the lead partner. As mentioned earlier, Consortium Approach is not a static model. Following the framework and philosophy, lead partner should be innovative enough to facilitate adaptation and evolution of the model to suit the local needs. Quite often there would be conflicting values of working among partners. Consortium leader needs to understand this fact and ensure flexibility and transparency among partners to accommodate opinions of certain members without causing damage to the overall objectives.

Each member of the team should know that he/she can influence the team agenda. There should be a feeling of trust and equal influence among team members that facilitates open and honest communication. This allows each member to provide their technical knowledge and skills in helping to solve the problem, complete the project, and develop new programs.

The Consortium leader, where possible, should help select or influence the composition of consortium members. Selection of members should be based on their willingness to work in a team approach and share their resources, both technical skills and financial that they are able to bring in to the consortium. Selection of right set of partners determines success to a major extent. Learning behavior among partners is essential for the Consortium Approach. More importantly there should be pre-disposition to work collectively for community development.

It is essential to achieve shared understanding of objectives by the members. They should be able to identify themselves with the common objectives. The lead organization should facilitate this process. Once objectives are evolved, it is again the responsibility of the lead partner to always bring members' attention to the objectives and help in ensuring focused work in the correct direction.

There is a need to develop, understand and accept a set of principles by the members which include norms for operating with in the team. Team building measures go a long way in for stronger partnerships and internalizing operating guidelines. Sharing of credit for the impact, publications, and policy guidelines amongst the partners is very critical. The leader has to ensure that in all communications about the consortium activities all partners are recognized, acknowledged, and rewarded. Such measures go along way to build trust amongst the consortium partners. Similarly open communication and conflict resolution mechanisms must be in place.

Tangible economic benefits to individual primary stakeholders are must for community participation. Integration of new science tools such as GIS and remote sensing enhanced the efficiency of recommendations and resulted in higher benefits to the community. Knowledge-based entry point activity is another reason for enhanced sustainable community participation. Their motivation was sustained due to the fact that there is continuous learning which is directly relevant to their fields. Capacity building of partners and sensitization of policy makers helped in building partnerships. Transactions costs (time and money) are higher for partnership building but higher benefits call for partnerships.

Box 1: Model to Benefit Landless People Collectively through rehabilitation of CPRs with Biodiesel Plantation/

As part of National Oilseeds and Vegetable Oils Development Board (NOVOD) – ICRISAT project, during the year 2005 – ’06 an innovative community participatory model for development of wastelands was successfully implemented through a ICRISAT-led consortium of District Collector and District Magistrate of Rangareddy district, District Watershed Management Agency (DWMA), NGOs – Rural Education and Agriculture Development (READ) and HELP, Village Panchayats of Kothlapur and Velcheal, and SHGs of agriculture labourers in these two villages of Rangareddy district of Andhra Pradesh, India.

In the model, 300 ha of *Jatropha Curcas* mixed with *Pongamia Pinnata* plantation was established in Velchal and Kothlapur villages with suitable soil and water conservation measures. Landless labourers in these two villages were organized into 15 groups of 10-12 members in each group. All the 300 ha was geo-referenced and divided into 15 pieces for each group by GIS. These labour groups were made responsible for planting, gap-filling, fertilization and maintenance of plantations. Usufruct rights were awarded by the District Collector, Rangareddy district, for these groups to reap benefits from their respective areas. Soil and water conservation measures were initiated in these plantations. Wherever soils are suitable, groups were encouraged to grow intercrops during rainy season to enhance benefits from the plantation. Thrift and credit activity was initiated in those groups. Groups have opened separate bank accounts and each member saves Rs.5 per day during working days. That amount is used as revolving. Local NGOs (READ and HELP) were involved in the social organization. Now with three year bio-diesel plantation 300 ha, GTZ is sponsoring a PPP model with ICRISAT, Kirloskar Oil Engines Limited, Government of Andhra Pradesh and the CBOs a decentralized oil extraction and renewable energy generation model.

Through this model a win-win situation was ensured with multiple benefits such as rehabilitation of degraded lands, provide livelihood opportunities for land-less villagers, increased availability of seeds for bio-diesel, reduced degradation of natural resources, enhanced greenery cover in the villages and most importantly build the capacity of rural poor for sustainable management of natural resources.

Box 2: Faster formation of new functional alliances/

Due to the rapport built while being part of the ICRISAT-led Consortium, CRIDA approached ICRISAT for their NRSP-DFID Project along with BAIF the existing consortium partner a new consortium for the project was formed with CRIDA's leadership. Similarly, with the emerging bio-diesel field, Government of Andhra Pradesh, India wanted to initiate research on *Jatropha* and *Pongamia* in 2005. The State Agricultural University took the lead. ANGRAU felt ICRISAT and CRIDA as natural partners for a bio-diesel consortium. Time taken for forging these functionally active partnerships was quite less. This was possible only due to the confidence built amongst the consortium partners during the earlier work in the watershed consortium. In addition other relevant partners like National Bureau of Plant Genetic Resources (NBPGR), Directorate of Oil Seeds Research (DOR) and Indian Institute of Chemical Technology (IICT) were also brought into the Bio-diesel Consortium led by ANGRAU. In 2005-06 Ministry of Agriculture and Ministry of Rural Development, Government of India asked ICRISAT to undertake comprehensive Assessment (CA) of the watershed programs in the country. ICRISAT consulted its existing watershed consortium partners and brought together 23 institutions within one month. The consortium completed the CA in two years and number of recommendations and learnings are documented (Wani et al., 2008).

The transaction costs (time and financial) are very less to form new alliances needed for new projects.

Box 3:
Since it has been a success in one of the projects, as part of internal institutional arrangements ICRISAT placed a Visiting Scientist (VS) in a field area to provide technical guidance to the PIA. But that PIA, which is having some technical competency unlike in the other NGO cases, generally was not looking at the VS as the repository of the knowledge. This caused some friction between ICRISAT and the PIA. But there was a mature dealing of the situation and a mutually amicable solution was facilitated by the Consortium Leadership.

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Salient Features of Common Guidelines for Watershed Development Projects in India

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In the early stages, the major focus of Watershed Management was soil erosion control, soil moisture conservation and water resource development. However, it was felt that there must be matching production oriented activities along with soil and water conservation so as to make productive/economic use of the enhanced soil moisture regime and water resources created in a watershed, particularly in dryland areas, for the benefit of farming community. Therefore, crop improvement programmes and alternate land use systems were brought in as components of watershed management. In drylands, agricultural droughts and the resultant crop failures are common. In order to impart stability to the income of dryland farmers in such situations, livestock management particularly small ruminants, poultry, piggery etc., which are suited to dryland environment became integral part of watershed management. In recent times, over-riding emphasis is being given to social equity and providing livelihood security particularly to landless and poor people in the watershed through farm based and non-farm based activities as well. It is also recognized that watershed management will be crucial for reducing vulnerability to climate change and mitigating droughts and migration.

Watershed programmes have been in operation in India for the last couple of decades under Drought Prone Area Programme (DPAP), Desert Development Programme (DDP) and Integrated Wasteland Development Programme (IWDP) of Ministry of Rural Development and National Watershed Development Project for Rainfed Areas (NWDPRA) of Ministry of Agriculture. With the expanding scope of watershed management as explained above and the experiences gained in the past, guidelines have been framed by the concerned authorities from time to time for implementation of their programmes. The background and salient features of the Common Guidelines for Watershed Development Projects – 2008, applicable to all Ministries of Govt. of India are presented in this paper.

Background of Common Guidelines - 2008

In 1994, a Technical Committee under the Chairmanship of Prof. Ch. Hanumantha Rao, was appointed to assess the Drought Prone Areas Programme (DPAP) and the Desert Development Programme (DDP) with the purpose of identifying weaknesses and suggesting improvements. The Committee, after careful appraisal, opined that the programmes have been implemented in a fragmented manner by different departments through rigid guidelines without any well designed plans prepared on watershed basis by involving the inhabitants. Except in a few places, the achievements have been sub-optimal. Ecological degradation has been proceeding unabated in these areas with reduced forest cover, reducing water table and a shortage of drinking water, fuel and fodder.

Against this backdrop, the Hanumantha Rao Committee made a number of recommendations and formulated a set of guidelines that brought the DDP, the DPAP and the Integrated Wastelands Development programme (IWDP) under a single umbrella. The watershed projects taken up by the Ministry of Rural Development (MoRD) from 1994 to 2001 followed these guidelines. In 2000, the Ministry of Agriculture revised its guidelines for its programme, the National Watershed Development Project for Rainfed Areas (NWDPRA). These guidelines were intended to be common guidelines to make the programme more participatory, sustainable and equitable. However, the MoRD revised the 1994 Hanumantha Rao Committee Guidelines in 2001 and yet again in 2003, under the nomenclature 'Hariyali Guidelines'.

In the meanwhile, emerging issues of groundwater recharging and convergence to create a critical mass of investments demanded innovative guidelines. At the advent of the eleventh plan period (2007-2012), our main challenge was to move the nation decisively in the direction of 'inclusive growth'. Rainfed areas of 85 million hectares out of the 142 million hectares of net cultivated area have suffered neglect in the past. High untapped productivity and income potential exists in these areas.

An insight into the rainfed regions reveals a grim picture of poverty, water scarcity, rapid depletion of ground water table and fragile eco systems. Land degradation due to soil erosion by wind and water, low rain water use efficiency, high population pressure, acute fodder shortage, poor livestock productivity, under investment in water use efficiency, lack of assured and remunerative marketing opportunities and poor infrastructure are important concerns of enabling policies. The challenge in rainfed areas, therefore, is to improve rural livelihood through participatory watershed development with focus on integrated farming systems for enhancing income, productivity and livelihood security in sustainable manner.

Various studies have pointed out the central pre-occupation of Watershed Development Projects with soil and water conservation and relative neglect of issues relating to balanced use of natural resources and livelihoods. In order to assess the performance of various ongoing projects/programmes of watershed development, a series of evaluation studies have been conducted by ICAR (Indian Council of Agricultural Research) institutes, State Agricultural Universities (SAUs), National Remote Sensing Agency (NRSA), etc. Besides, impact assessment studies were carried out by the Ministry of Agriculture, Ministry of Rural Development, Planning Commission, International Crops Research Institute for the Semi Arid Tropics (ICRISAT) and the Technical Committee constituted by the Department of Land Resources (DoLR). These studies support the observation that in several watersheds, the implementation of the programme has been effective for natural resource conservation by increasing the productivity of the land, bringing additional area under agriculture, employment generation and social upliftment of beneficiaries living in the rural areas. But these successes have been sporadic and intermittent. The overall impact at the State and National levels has generally been inadequate. Additional demand and supply driven socio-economic and risk management paradigms are emerging. Taking into consideration all these aspects, the Common Guidelines-2008 have been formulated to have a unified perspective and adoption by all Ministries of Govt. of India.

Key Features of Common Guidelines – 2008

Delegating powers to the states, dedicated institutions for managing the watershed programmes, providing financial assistance to the dedicated institutions, flexibility in the duration of the programme from 4 years to 7 years, focus on livelihood orientation, cluster approach i.e., geohydrological units varying from 1000-5000 hectares comprising of clusters of micro watersheds, scientific planning, capacity building of all functionaries and stakeholders involved in the watershed programme and a multi-tier (ridge to valley) approach are the key features of the Common Guidelines-2008.

The institutional arrangements for effective and professional management of watershed development projects at various levels include i) National Rainfed Area Authority - the apex body at the national level; ii) Institutional arrangements at Ministry level; iii) National level data center and national portel; iv) State level nodal agency (SLNA - will sanction watershed projects for the state on the basis of approved state perspective and strategic plan as per procedure in vogue and oversee all watershed projects in the state within the parameters set out in the guidelines); v) Watershed Cell and Data Centre (WCDC) at the district level with specific role of Panchayat Raj institutions at district and intermediate levels. The institutional arrangements at project level include i) Project Implementing Agency (PIA - may include relevant line departments, autonomous organizations under state/central governments, government institutes/research bodies, intermediate panchayats, voluntary organizations) and ii) Watershed Development Team (WDT). The Institutions at the village level for people's participation include i) Self Help Groups (SHGs), ii) User Groups (UGs) and iii) Watershed Committee (WC). For the roles and responsibilities of various institutions and other details, the Common Guidelines for Watershed Development Projects, Govt. of India – 2008 (www.dolr.nic.in/commonguidelines-2008.pdf) may be referred.

The following criteria have been given for selection and prioritization of watershed development projects:

i) Acuteness of drinking water scarcity
ii) Extent of over-exploitation of ground water resources
iii) Preponderance of wastelands / degraded lands
iv) Contiguity to another watershed that has already been developed/treated
v) Willingness of village community to make voluntary contributions, enforce equitable social regulations for sharing of common property resources, make equitable distribution of benefits, create arrangements for the operation and maintenance of assets created
vi) Proportion of schedule caste / schedule tribes
vii) Area of the project should not be covered under assured irrigation
viii) Productivity potential of the land.

Guiding Principles

Following are the guiding principles of the common guidelines –2008:

1. Equity and gender sensitivity
2. Decentralization
3. Facilitating agencies
4. Centrality of community participation
5. Capacity building and technology inputs
6. Monitoring, evaluation and learning
7. Organisational restructuring

Project Management

The major activities of watershed development projects will be sequenced into i) Preparatory Phase (1-2 years), (ii) Watershed Works Phase (2-3 years) and iii) Consolidation and Withdrawal Phase (1-2 years).

The major objective of the preparatory phase is to build appropriate mechanisms for adoption of participatory approach and empowerment of local institutions (WC, SHG & UG). WDT will assume a facilitating role during this phase. The preparation of DPR (detailed project report) is done in the preparatory phase including activities to be carried out, selection of beneficiaries and work sites, design and costing of all works ensuring that the interest, perceptions and priorities of women, dalits, adivasis and the landless are adequately reflected in the DPR. Working out detailed resource-use agreements for surface water, ground water and common/forest land usufructs among user group members in a participatory manner based on principles of equity and sustainability is also done before hand in preparatory phase itself. Watershed works phase is the heart of the programme in which the DPR will be implemented. In the consolidation and withdrawal phase, the resources augmented and economic plans developed in phase II are made the foundation to create new nature–based, sustainable livelihoods and raise productivity levels.

Implementation of Watershed Works

Some of the important activities (works) of Watershed Development Projects are:

a) Ridge area treatment: All activities required to restore the health of the catchment area by reducing the volume and velocity of surface runoff, including regeneration of vegetative cover in forest and common land, afforestation, staggered trenching, contour and graded bunding, bench terracing, etc.

b) Drainage line treatment with a combination of vegetative and engineering structures such as earthen checks, brush wood checks, gully plugs, loose boulder checks, gabion structures, underground dykes, etc.

c) Development of water harvesting structures such as low-cost farm ponds, nala bunds, check-dams, percolation tanks and ground water recharge through wells, bore wells and other measures.

d) Nursery raising for fodder, fuel, timber and horticultural species. As far as possible, local species may be given priority.

e) Land development including in-situ soil and moisture conservation and drainage management measures like field bunds, contour and graded bunds fortified with plantation, bench terracing in hilly terrain, etc.

f) Crop demonstrations for popularizing new crops/ varieties, water saving technologies such as drip irrigation or innovative management practices. As far as possible, varieties based on the local germ plasm may be promoted.

g) Pasture development, sericulture, bee-keeping, backyard poultry, small ruminants, other livestock and micro-enterprises

h) Veterinary services for livestock and other livestock improvement measures.

i) Fisheries development in village ponds/tanks, farm ponds, etc.

j) Promotion and propagation of non-conventional energy saving devices, energy conservation measures, bio-fuel plantations etc.

Budgetary Provision

The distribution of budget for specific watershed projects for the various components therein is given below:

Budget Component	Per cent of the budget
Administrative costs	10
Monitoring	1
Evaluation	1
Preparatory Phase	
Entry points activities	4
Institution and capacity building	5
Detailed project report (DPR)	1
Watershed works phase	
Watershed development works	50
Livelihood activities for assetless persons	10
Production system and micro-enterprises	13
Consolidation phase:	5
Total	**100**

Technology Inputs

Technology enables us, *inter-alia* to strengthen programme management and coordination, undertake activity based project planning, formulate action plans, streamline sanctions and release of funds, create useful data bases, assess actual impacts of projects, make effective prioritizations, prepare sophisticated DPRs, document best practices and case studies and facilitate the free and seamless flow of information data.

Remote sensing data would be utilized for finalizing contour maps for assessment of runoff and for identifying structures best suited for location of projects. This would result in cost and time optimization in project implementation. Technology would also contribute immensely in assessing the actual impact of various programmes in a given area. Due to availability of latest remote sensing techniques, it is now possible to assess periodic changes in geo-hydrological potential, soil and crop cover, runoff etc., in the project area.

Allocation of Funds, Approval of Projects and Release of Funds

By the end of February each year, the states will submit detailed annual action plans indicating on-going liabilities as well as new projects which they wish to take up. The departmental nodal agency at the central level will thereafter, based on total available budget for the year and other criteria, allocate specific amounts for individual states from whom proposals have been received. The central share of funds shall be released to the SLNAs for the three phases of the implementation spread over the project period as per the guidelines. The project fund relating to watershed works, livelihood and production system and micro enterprises may flow from Department of Land Resources (DoLR) to SLNA to WCDC to WC. Administrative cost, Capacity building, Entry Point Activities, DPR, Monitoring component of project funds may flow from DoLR to SLNA to WCDC to PIA.

Watershed Development Fund

One of the mandatory conditions for selection of villages for watershed projects is people's contribution towards the watershed development fund (WDF). The contributions to WDF shall be a minimum 10 per cent of the cost of NRM works executed on private lands only. However, in case of SC/ST, small and marginal farmers, the minimum contribution shall be 5 per cent of the cost of NRM works executed on their lands. For other cost incentives, farming systems activities such as aqua culture, horticulture, agro-forestry, animal husbandry, etc., on private land directly benefiting the individual farmers, the contribution of farmers will be 20 per cent for general category and 10 per cent for SC and ST beneficiaries.

Convergence with other Schemes/Projects

All efforts must be made to converge and harmonize resources of different schemes and programmes by different line departments / agencies operating in the area. The DPR may elaborate gaps to be filled for watershed activities to be taken up under these programmes such as, Backward Regions Grant Fund (BRGF), Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), artificial groundwater recharging, renovation repairs of tanks, water bodies, etc. Marketing and value addition may also be possible under relevant schemes.

Capacity Building

Capacity building support is a crucial component to achieve the desired results from watershed development projects. Reputed national and state level organizations including voluntary organizations could impart capacity building inputs to stakeholders of various levels.

Monitoring, Evaluation and Learning

Regular monitoring of the project will have to be carried out at each stage. Each evaluation will include physical, financial and social audit of the work done. Systematic efforts are to be made by the WDT/WC to learn from the field experiences as also from feedback of independent sources. Each watershed development project is expected to achieve the following results by the end of the project period.

i) All the works /activities that are planned for the treatment and development of drainage lines, arable and non-arable lands in the watershed area are completed with the active participation and contribution of the user groups and community.

ii) The UGs/Panchayats have willingly taken over the operation and maintenance of the assets created and made suitable administrative and financial arrangements for their maintenance and further development.

iii) All the members of WC and staff including watershed secretary and volunteers have been given orientation and training to improve their knowledge and upgrade technical/management and community organizational skills to a level that is appropriate for the successful discharge of their responsibilities on withdrawal of the WDT of the project.

iv) The village community would have been organized into several homogeneous SSGs for savings and other income generation activities which would have achieved sufficient commitments from their members and built up financial resources to be self sustaining.

v) The increase in cropping intensity and agricultural productivity reflecting in overall increase in agriculture production.

vi) Increase in income of farmers / landless labourers in the project area.

vii) Increase in groundwater table due to enhanced recharge by watershed interventions.

Conclusion

The salient features of the common guidelines-2008 for watershed development projects in India have been discussed. The guidelines, incorporating decades of experiences of various programmes with watershed approach, envisage uniformity in perception and adoption of watershed programmes by all Ministries of the Government of India. It is hoped that this could serve as a model, with necessary modifications, for implementation of watershed projects in South Asian Association for Regional Co-operation (SAARC) countries.

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Framework for Assessing Land Management Practices for Sustainable Agriculture – An Application of Multidisciplinary Indicators and Tools

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Measuring sustainability is a challenge that needs to be met, if the world has to withstand the increasing environmental challenges it faces now and in the long-term. Since 1980s, much research has been undertaken to qualify sustainability through comparison with benchmark or through use of indicators or their surrogates where suitable ones were unavailable. In view of the need to produce more food and fibre for feeding the ever-increasing population without undermining the earth's natural resource base, it is rightfully deemed essential to evaluate and assess how land is currently being used, how natural resources are being managed and how agricultural production is being undertaken to meet the demands of today and how the resource base can be conserved and restored to their productive capacity for the future.

Thus, agricultural production systems across the world especially in Asia, Africa and South America must necessarily be productive ensuring that everybody's demands are met; they must be economically viable to both - producers and the end-users while ensuring livelihood security to the farmers' who toil and simultaneously protect the environment where cultivation it being undertaken in addition to, finally being socially acceptable to all parties involved – the producers, consumers, the government and the environmentalists. In view of this definition, the measure of sustainability must certainly include study of trends of natural resources over time, evaluation of status of soils, water resources, crops, pasture, livestock, etc., together with the resulting production and the economic outcome. In order to achieve this, the impact of land management practices (LMP) must be evaluated especially in rainfed regions of the world especially like India where agriculture is a dominant economic activity and source of livelihood to a population of over 600 million persons as elsewhere in South Asia.

Characteristics of Rainfed Regions

Rainfed agro-ecological regions in India encompass the semi-arid tropics (SAT) and the hot dry and moist sub-humid regions of India, that extends over 76.74 Mha out of a total geographical area of 90.4 Mha in the four states of Andhra Pradesh, Maharashtra, Karnataka and Tamilnadu in Peninsular India. Watershed-based development has been an important component in the schemes for economic planning for development in this region since 1980s. In order to increase agricultural productivity, enhance livelihood and rural lifestyle, many improved Land Management Practices (LMP) have been propagated in this region. According to the Census of India - 2001, over 140.48 million persons lived in rural areas in these four states alone who were involved in agriculture and allied activities (Registrar General & Census Commissioner, Govt. of India, 2001). With a population growth rate ranging between 1.8 to 2.1 percent annually, it was estimated that by 2008, an estimated population of 160.83 million persons would depend on agriculture and hence, the importance of adhering to improved LMP in rainfed agriculture is immense.

Rainfed Agro-ecological sub-regions (AESR) encompassing the peninsular part of India receive an average annual rainfall of 500 mm although it actually ranges from 450 mm in the dry arid tracts of Anantapur in Andhra Pradesh to more than 900 mm in the hot moist sub-humid areas in Rayalseema encompassing the districts of Kurnool and Chittoor, in the Telengana region rainfall occurs in a period of 52 to 55 days. However, since 2008 there has been an increase in number of rainy days and volume of rainfall received with no specific discernable trends. In 2009, there was a major delay in onset of SW monsoon due to occurrence of Cyclone '*Aaila*' resulting in deficit rainfall. The Telengana region received only 503 mm of rainfall which was 65 percent of normal for the season. The post-monsoon season (Oct- Dec) received 107 mm rainfall which was normal. Thus, the region saw a loss of *Kharif* crop due to weather aberration in 2009.

Rainfall associated with southwest monsoon occurs in the form of thunderstorm that last for over a few hours, thus making soil and water conservation (S&WC) measures absolutely critical. In addition water-harvesting, storing and its' utilization for agriculture and other allied activities during the rest of the year, is critical for the whole region. The intensive rainfall events also induce severe soil erosion in bare and sparsely vegetated land surface which is a common sight in the rainfed region. Hence, Watershed-based Development Program (WDP) which was initiated in early 1980s became a popular strategy for a comprehensive development of rainfed agriculture in India and improved Land Management Practices (LMP) was implemented to improve agricultural productivity and ecological sustainability in the vast area in the country.

According to India Vision 2020 document, the country envisages to achieve a sustainable agricultural growth rate of 4.0 to 4.5 percent annually, in order to, reduce food insecurity and poverty while increasing rural purchasing power. Hence land management practices and watershed development program are required to be implemented with care. This holds good for the other South Asian countries also.

Agricultural Land Management strategies in rainfed regions include conservation of soil and water resources and protection of soil fertility status, groundwater, ground cover and other biotic and abiotic resources. More recently in 2008, Common Guidelines for Watershed Development was laid down to give a fresh outlook to the next generation watershed projects in India. The projects were to be implemented in three phases to comprehensively improve productivity and securing livelihood and conserving resources and land management practices would play a critical role in this approach to watershed development. Evaluation of land management practices for their impact on sustainable development is an important development in this context and several indicator based studies have been published and a brief review is included here for reference.

Study Area

Four treated watersheds located in Rangareddy and Nalgonda districts in Andhra Pradesh were selected for evaluating the impact of improved LMP on sustainability of agriculture in the area. One of the study site – Chintapatla village is located over 65 km towards southeast of Hyderabad on the State Highway to Nagarjunasagar Dam. The village is home to over 150 farm households that own landholding that measure 0.5 to 5 ha each. Soils are essentially Alfisol and are eroded and poor in soil OC and low in fertility. Dominant Crop grown are paddy and sorghum, while livestock-rearing has increased in recent years. Watershed Development Program was initiated by the State Department of Agriculture in 1998 and S&WC structures were constructed. Since the beginning of WDP, villagers were enthusiastic as they could perceive the accrual of higher crop yield, rise in groundwater-table and better livelihood and hence it was easy to implement improved LMP in the village.

In Dontanpalli village located to the southwest of Hyderabad at a distance of 60 km in Osmansagar reservoir catchment, watershed program was initiated by Dept. of Agri., Govt., of AP, over a prolonged period of six years (1995 to 2001) during which six concrete check-dams were built besides other S&WC structures. Over 100 farm household populate the village with each owning small landholdings ranging between 0.5 to 1.0 ha each. Soils predominantly belong to Alfisols and major crops grown are sorghum, paddy and vegetables during *Kharif* (monsoon) season while pigeonpea, tomato and chili were grown using residual moisture during *Rabi* (post-monsoon) season. Floriculture was introduced in the village in early 1990s which was later replaced with agri-horticultural systems. Recent trends indicate the consolidation of land - holdings by enterprising city-dwellers who have established large orchards of mango and guava in the village, while the small and marginal farmers of the village work in these orchards as labour.

A third village called Pamana is located at a distance of 70 km from Hyderabad in Chevella mandal in Rangareddy district not very far from Dontanpalli. It is home to over 280 farm households, and the total geographical area of the village extends to over 1100 ha. Most of the land- holdings in the village measure between 1 to 2 ha and the soils belong to Vertisols and their associated groups. Dominant crops are cotton, paddy, maize and vegetables including tomatoes, carrot, coriander and onion, besides a few cash crops like sugarcane, garlic and flowers, introduced in the village in the 1990s. Agriculture is the primary source of occupation in the village and provides employment to farmers for a period of four to six months only. WDP was implemented in 1995 and 2001 when a number of improved LMP were propagated in the village that essentially involved improving soil fertility levels, S&WC and introduction of agri-horticulture and agri-silviculture in treated watersheds.

The fourth village Gollapalli is located farthest from Hyderabad at a distance of 90 km towards the southeast in Nalgonda district. It has 225 farm households who own landholding of 2 to 5 ha in size; some landholdings are as large as 10 to12 ha.

Improved land management practices that were introduced here essentially belonged to crop management, soil fertility improvement and introduction of agri-horticulture besides S&WC measures.

Sustainable Land Management Practices - a Review

Evaluation of Land Management Practices has been undertaken and two works on development of farm-level indicators for Sustainable Land Management (SLM) have been particularly notable. These are by Gameda *et al*. (1997) and Gomez *et al*. (1996). Besides these, a few generic indicators were set out by Dumanski (1993) which were used as objectives and parameters for construction of a SLM model by Bie *et al.* (1995). Geo-information technology was harnessed to help land use planning and the GIT model was used to simulate dynamic land use interactive processes as indicated by Groot (1993). Emergence of digital geo-information infrastructure and policy framework for global, regional, national and local levels are now fast emerging. The National Natural Resources Management System (NNRMS) and National Spatial Database Initiative (NSDI) in India and the recent Bhoosampada interactive digital database of National Remote Sensing Centre (NRSC) of ISRO are steps in this direction. Gomez *et al*. (1996) based sustainability valuation of the production system that they studied on the multifaceted FESLM developed by FAO and IBSRAM (Smyth *et al.,* 1993). The team evaluated sustainability at farm - level and proposed a preliminary list of field indicators, providing examples from actual measurements from the field and outlined a method to visually and quantitatively represent the results for ease in analysis and comparison. In yet another study by Gameda *et al.* (1997), a Decision Support System (DSS) for farm-level indicators of SLM was attempted. In 1999, the Centre for Development & Environment (CDE) located in Bern, Switzerland brought out a comprehensive document on Sustainable Land Management - Guidelines for Impact Monitoring (SLM –IM) by Herweg *et al.* (1999). The document succulently deliberates over why SLM - IM is essential.

It is now generally believed that natural resources can potentially be used in a sustainable way, if appropriate land management technology and practices are in place and if regional planning and policy framework complement one another in a purposeful manner as the principles and concepts of Sustainable Land Management (SLM) revolves around the concept of ecosystem balance as indicated by Hurni in 1997. Hence, SLM is deemed to be composed of three developmental components - technology, policy and land use planning for sustainable development of land. This concept has benefited immensely from the Framework of Land Evaluation (FAO, 1976 & 1979) wherein a methodology was proposed for land quality evaluation and land suitability for specific crops and in the recently revised framework from FAO (2007) wherein the need to check over-exploitation and degradation of land rather than any drastic change in land use has been emphasised. This change in stance has been necessitated by the paradigm shift in the focus of the world at large, i.e., the need to solve practical issues concerning technical, socio-economic and environmental problems in order to achieve sustainable development rather than philosophy and ideology (Beek et al., 1997 & Bouma, 1997).

Importance of SLM

The fact that the world is fast losing new land that could be taken up for agricultural expansion, and that the same agricultural land that has been in use for the last 5000 years or more in various parts of the world including India and other South Asian nations, is now required to be managed in a sustainable manner with its productive potential intact for the benefit of future generations, the importance of SLM is obvious and cannot be over-emphasized. In fact, to achieve an equitable world as stated in the UNCED AGENDA 21 (Chapter 14, 1992), sustainable development with poverty alleviation, is a necessity for the world at present and cannot be deemed an option.

The impact of land management decisions could be tremendous in any part of the world not only because of the fact that land provides environment to agricultural production but remains an essential condition for improving environmental condition and management, such as recycling of nutrients, being an important component of hydrological cycle, ameliorating pollutants, performing the source and sink function for greenhouse gases, etc. The impact of land management in rural areas could be massive even if small-scale farmers make their independent decisions in their field and invest their capital due to the sheer number of these small farms. Thus, although land use decision of individual small farmers may seem insignificant, these decisions when repeated over and over again in any rural landscape could collectively amount to major impact that could be significant at a regional and even global -scale.

Similarly, land management practices introduced under WDP in rainfed regions in India could have a tremendous impact on sustainability of agricultural production systems not only in rainfed regions but the entire country. In the same manner, study of impact of LMP in the SAARC countries would indicate whether these practices would help achieve sustainable development in future. In case the assessment indicates otherwise, than it is essential to undertake corrective measures at the earliest before irreparable damage occurs.

Unlike elsewhere in the world where agriculture is cited as part of the environmental problem leading to non-point source pollution and environmental degradation, in India and the SAARC nations, agriculture is a major source of livelihood for millions of farmers who can neither be displaced nor absorbed in any other sector of the respective economies. In addition to being an employment provider, the agriculture sector is a major source of food, fodder, fibre, oilseeds and pulses that cannot be underestimated. Sustainable development could be achieved only through the collective efforts of those immediately responsible for managing the land resources even if the concerns for sustainability may seem global and remote immediately because corrective actions are required to taken at the local – level although policy instruments to encourage and support those measures are the responsibility of Governments at the national-level.

In large parts of India unlike in irrigated areas, agriculture is restricted to 5 to 6 months each year and seasonal migration is rampant leading to poor land care in off-season period. Hence Govt. of India implemented the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) in 2008 in order to dissuade farmers from migrating and tending to their land and livestock in the off-season. The aim of MGNREGS is to help create resource capital in the village that would help agricultural production systems in each village in the long run.

SLM cannot be the responsibility of millions of cash-strapped rainfed farmers and Govt. and society at large must be responsible for sustainable development which is indeed a mammoth task that cannot be left to the farmers alone. On its part, the Govt. must ensure that policies do not create negative environmental impact while the society must define the requirements of land maintenance and land use and support the farming community with a pro-farmer stance.

The Land Conversion Policy of Govt. of India (2006) aimed to stimulate the rural economy has had negative fallout as in several locations prime agricultural land have been converted to urban and allied uses, which has caused havoc in rainfed agriculture system in Andhra Pradesh, Karnataka and Maharashtra. In Telangana region in Andhra Pradesh, the real estate boom around Hyderabad has lead to unsustainable land use as prime agricultural land have been converted to real estate development, an act that is detrimental to sustainable land management. History and governance have taught us that the preferred mode to ensure SLM is not to tell farmers what to do through command and control legislation, but to create a policy environment where farmers are empowered and accountable for achieving the objectives of SLM. However, the lack of infrastructure facility, timely availability of inputs, poor access to credit facility and competitive price of land in addition to, low procurement prices of agricultural produce etc., have all adversely affected the interests of farmers resulting in unsustainable land use at several places.

Hence, there is an urgent necessity to treat agriculture as an independent enterprise and not as a last resort of farmers. They must be permitted to avail facilities like the industrial entrepreneurs in the country and only then can SLM be ensured. Society demands farmers to become stewards of the rural landscape, and agriculture is asked to play a larger role than merely providing food, fodder and fibre. However, to be only fair, if farmers have to shoulder the burden of SLM with agriculture, they must be adequately compensated with cheap loan, assured electricity, development of infrastructure, higher support price, crop insurance etc., on par with sun-rise industries as is done under the Five-Year Plans in India. Farmers' lot must be improved on par if not better than the urban folks, as environmental concerns cannot be shouldered by the farmers alone.

Material & Methods

To study the impact of improved LMP implemented under WDP in the study area as described in this paper, a set of sixty-one multidisciplinary indicators were constructed in the lines suggested by Gomez *et al*. (1996) to evaluate five aspects of sustainability impacts discerned at household- level and at field – level in rural areas. Actual measurements were taken in field for all measurable parameters under each indicator while scores were assigned to those indicators that prompted a qualitative response. This approach facilitated a quantitative evaluation of impact of improved LMP as far as possible. Wherever actual indicators were unavailable, surrogate indicators were employed for the impact evaluation purpose. The five aspects of sustainability on which the impacts of improved LMP were evaluated were – agricultural productivity, livelihood security, economic viability, environmental protection and social acceptability.

Development of an evaluation methodology for assessing the impact of LMP is a trans-disciplinary, target-oriented approach that necessarily requires processing of a large set of data for which a number of tools and techniques including Geo-informatics are required. The present paper indicates how the concept of SLM was used to evaluate the impact of improved LMP in the watershed projects implemented in the rainfed region of *Telengana* in Andhra Pradesh. It is believed that the methodology must hold good for other rainfed regions in the country as well as other countries in SAARC region.

SLM requires a multi-level stakeholder approach to land management that would be feasible, acceptable, viable, and ecologically sound at local-scale. In this approach management is defined as an activity on the ground using appropriate technologies in the respective land use systems. In the context of sustainability paradigm, sustainability would require that a technology follow five major pillars of sustainability - (a) ecologically protective (b) socially acceptable (c) economically productive (d) economically viable, and (e) reduce risk. Land Use Resilience and Social Equity concepts have since been added to these criteria.

Land refers to the spatial units where ownership, resource availability, boundary conditions and the policy and economic environments play an important role. Thus, the issue of Sustainable Land Management (SLM) would have to address the question of its sustainability for whom, how to be sustainable (denoting approach), what is to be sustainable, by what means would it be sustainable, and with what impact? Hence the stakeholders are an important consideration for the concept of SLM as they could be target group, interest group with common interests, Land Users, consumers, the Govt., or the revenue and tax agencies of a country, and of course, the future generations for whom the present land resources have to be conserved and protected.

A major hurdle in SLM research has been the lack of quantifiable definitions for specific sustainability targets and hence in the current study a quantifiable evaluation model has been developed to enable a quantitative evaluation of the impact of improved LMP under Watershed Development Program. Of course, the lack of quantifiable definitions also provides flexibility to the concept of SLM such as sustainable soil management, sustainable agriculture, sustainable land management, sustainable resource management, sustainable development, etc., which could be applied at various spatial scales such as in field, watershed or higher–order levels like agro-ecological region. Moreover, for practical reasons, estimating whether our chosen LMP are taking us towards or away from sustainable development, is often as useful as attaining any specific sustainability targets as in case of economic theory.

According to FESLM concept, it may be stated that the objective of SLM is to harmonize complementary goals of production, environmental, economic and social opportunities for the benefit of the present and future generations while maintaining and enhancing the quality of land resources viz., soil, water and air (Smyth & Dumanski, 1993). Land provides environment to agriculture production but remains an essential condition for improving environment and management as stated earlier. SLM if properly designed and implemented can ensure that agriculture becomes part of environmental solution rather than remaining an environmental problem. Land management can achieve economic and environmental benefits and hence, must be the foundation for further rural intervention and investments. The debate of short-term gains over long-term sustainability (as is case of free electric power supply to farmers in Andhra Pradesh and in Punjab that has caused groundwater exploitation and depletion), agriculture intensification to increase yield using more inputs in stark contradiction to the concept of sustainability and instead, optimizing local inputs rather than maximizing external inputs etc., must help in correcting land management practices (LMP) to achieve sustainable development.

Land Management Practices Implemented under WDP in India

Evaluation of Land Management Practices is essentially experiment-based in India. Several evaluation studies have been undertaken to assess impact of WDP in the country, duly acknowledging the shortcomings suffered by such impact assessment studies in the area of natural resource management (NRM) research as highlighted by SPIA of CGIAR (CABI & FAO, 2007; Walker *et al.,* 2008). Notable among these studies are Kerr & Sanghi (1992); Kerr *et al*., (2002), Amita Shah *et al.,* (2004), Joshi *et al.,* (2005), Sreedevi *et al.,* (2004), Wani *et al.,* (2002 & 2003), Mishra *et al.,* (2004), Sharma *et al.,* (2005), Singh (2000), Ram Babu & Dhyani (2005), Arya & Samra (1995), Omprakash *et al*., (2004), Kaushalya *et al.,* (2006, 2007, 2009 & 2010) and Mandal *et al.,* (2011).

Besides these, there are a few studies on review of policy on watershed development, for e.g., evaluation of watershed projects in Andhra Pradesh by Oliver Springate - Baginski *et al.,* (2004), watershed development program in India by Hanumantha Rao (2000), costs of resource degradation like groundwater depletion in Andhra Pradesh by Ratna Reddy (2003) and sustaining rural livelihood in fragile environments by Ratna Reddy *et al*. (2004). Reports of two Technical Committees chaired by Prof. C.H. Hanumantha Rao (1994) and S. Parthasarthy (2006), as mentioned earlier, have clearly recommended the necessity to change the way WDP were implemented in the country primarily for making land management sustainable.

The present paper aims to describe the methodology developed to evaluate the impact of improved land management practices implemented under watershed projects in rainfed regions in India. For this purpose baseline information was generated for pre-watershed

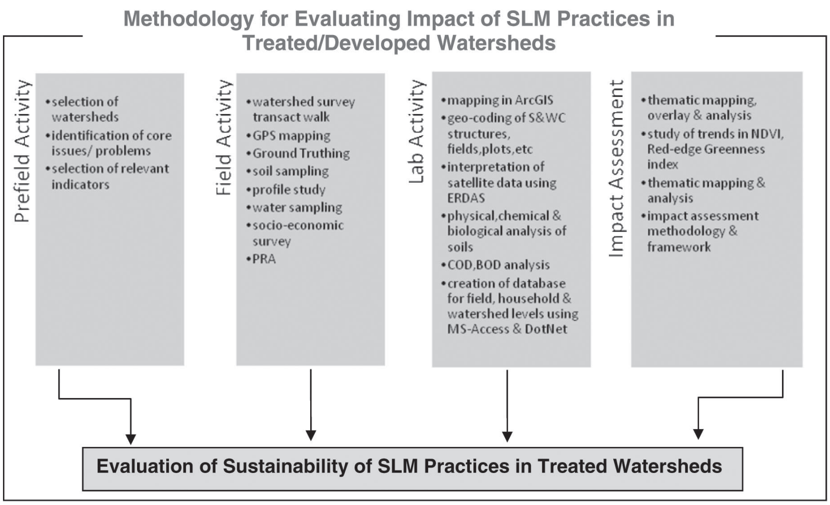

Fig.1 : Multidisciplinary methodology used to evaluate sustainability of LMP implemented under WDP in rainfed regions in India

project phase which was compared with averages and weighted Threshold Values (TV) generated from various parameters as a result of improved LMP implemented in the treated watersheds (Kaushalya & Mandal, 2008). Sustainability indicators were constructed and used to evaluate the impact of improved LMP introduced in the treated micro-watersheds in study area (Kaushalya, 2009). **Fig.1** indicates the scheme based on which the evaluation methodology was developed (Kaushalya & Ramakrishna 2006; Kaushalya *et al.,* 2009 & 2010). Details of the exhaustive list of sustainability indicators constructed for evaluation of improved LMP implemented under WDP have been presented in a forthcoming book (Kaushalya *et al,* 2011).

Construction of Sustainability Indicators

Since 1990s there have been several attempts to develop Land Quality Indicators (LQIs), however, the cause-effect relationships defining human interventions on landscapes have not been dealt with in depth. The LQI program was spearheaded by FAO (1976), World Bank (1996), CGIAR (2000), UNDP (2004) and UNEP (2005) and various bilateral agencies. In 1996, a World Bank (WB) initiative was started to identify strategic land quality indicators through defining and testing cause-effect relationships among land quality, land use and rural poverty. The objective was to develop a hierarchy for bio-physical and land quality indicators for evaluating sustainable development.

The indicator development process was hindered due to the dilemma on level of detail required as it varies with scale. Also there is a necessity to link indicators with the level of detail and scale in order to, develop a pyramid or hierarchy of land quality, so that a seamless evaluation is possible both ways from local to regional levels or from a large-scale to a small-scale. Integration of socio-economic aspects with biophysical indicators also poses a challenge.

Another approach in indicator development process is the Pressure-State-Response framework, which has been accepted as an operative framework. The framework has been conceptualized in the form of multiple streams denoting levels of details based on scale. For instance, under Stream-I, Core LQIs were to be developed as International Reference Standards, while national and sub-national LQIs were to be developed under Stream-II involving more in-depth and long-term research. Core LQIs as international reference standard are those for which sufficient research has already been conducted across the world in order to, establish a sound theoretical base with sufficient data or where development procedures have been tested and are already available (e.g., Remote Sensing). Core LQIs have been developed for managed ecosystems viz., agriculture and forestry, in major agri-ecological zones in tropical, sub-tropical and temperature environments (Dumanski, 1997). These relate to: Nutrient balance; Yield trends and yield gaps; Land use intensity; Land use diversity (agro-diversity) and Land cover.

Under Stream-II, a long-term program was initiated for a more thorough analysis of *cause-effect relationships* between land use and land quality changes. It is understood that robust LQIs can be developed only through a thorough analysis and understating of the *cause-effect relationship* of human intervention in rural landscapes. The general indicator themes under the Stream-II category are - *soil quality*, *land degradation*, *agro-biodiversity* and *land resilience*. Besides these, water quality, forest land quality, range land quality and land contamination / pollution have also been included to the core list. These are essential bio-physical components of SLM which have been added to other pillars of sustainability viz., economic viability, system resilience, social equity and acceptability. For the present study a similar method was used to develop indicators for studying the impact of improved land management practices (LMP) for sustainable land management (SLM) under watershed program.

To evaluate impact of improved LMP on agricultural sustainability, it was deemed fit to construct indicators which would serve multiple purposes like tracking performances, monitoring consequences of alternative management practices and for scientific exploration. For the present study, three terminologies have been used namely, measures, indicators and indices. The term measure (or measurement) has been used to refer to the actual measurement of a state, quantity or process derived from observations or monitoring. For example, measuring slope in a given field or estimation of yield of a crop, etc. An indicator serves to indicate or give a suggestion of something of interest and is derived from measurement. For example, yield compared over time show a trend which can indicate success of management practices for a specific crop, in a field or in the watershed. Indicators are typically used for a specific purpose such as providing policy makers with information about progress towards a target. An index or multiple indices comprises a number of measures combined in a particular way to increase its' sensitivity, reliability or ease of communication. These are useful in the study of land management practices where multiple attributes and measures related to land management have resulted in a long list of measures and indicators. For example, Crop Cafeteria Index (CCI) was constructed to denote the ratio of land cultivated by a farmer in a particular season/ year to the total size of his land holding. This index thus indicates the actual area cultivated by the farmer during a particular season/ year that would in turn, be useful to measure crop-wise yield besides, indirectly informing how much area was left under fallow and what were the reasons for fallowing. B: C ratio is another popular index which is used to measure economic viability or profitability of a cropping system or an agricultural enterprise and includes multiple measures like costs, charges, rent, depreciation, value of produce, market price, etc.

For the present study a suite of sixty-one sustainability indicators were constructed. The indicators were drawn from multiple disciplines like geomorphology, agronomy, hydrology, S&WC, soil science, economics, agro-meteorology, remote sensing, etc. While some indicators could be actually measured other indicators provided qualitative information that required to be converted into a measurable entity for ease in interpretation. Certain aspects could not be measured directly for which surrogate indicators were constructed. For example, Normalized Difference Vegetative Index (NDVI) derived from satellite data was used to measure extent and vigour of vegetation cover in a target area over a specific time-period.

Plan of Work

As a prelude to the actual study, a reconnaissance survey was conducted in the study area to understand the situation of agriculture, the level of natural resource base and livelihood of farming community in the region. This was followed by a Participatory Rural Appraisal (PRA) that was conducted in each village with a set of key informants chosen carefully from the village community who were stakeholders; in addition a few were also selected who were residents in the village. The objective of the PRA was to identify the core issues affecting rainfed agriculture in these villages and to match them with the improved LMP introduced and implemented therein under watershed program. This was followed by the development of a Methodology for *Ex-Post* Impact Assessment (epIA) of Land Management Practices to evaluate efficacy of improved land management practices (LMP), their impact was assessed in agriculture in treated watersheds selected for this purpose.

Rainfed agriculture although simplistic in concept, faces multiple constraints related to land quality, climatic condition, poor natural resources, poverty among farmers and other associated socio-economic problems. During the PRA these issues were identified for each one of the selected watersheds. One of the primary issues that could have a significant impact on sustainable development of any agricultural production system was the land management practices. Hence, effort was made to list all improved LMP promoted under the WDP in the study area (Kaushalya *et al.,*2011). Survey indicated that the other core issues affecting agriculture related to the intensity and diversity of land use, land quality and the prevalent land use practices in the study area. Besides these, the institutional support from the current government and other agencies, the level of awareness among land users' and the extent of risk - buffering capacity among farmers, equity, the societal value of farmland in a rapidly growing economy like that of India and other SAARC countries, and the issue of livelihood security in rural areas, etc., were very critical. If rainfed agriculture had to be made sustainable, all these issues listed above needed to be dealt with adequately.

The impact assessment strove to evaluate the farming systems and the available natural resource base at the field and watershed -level in addition to the resources available with the farmers. In view of the varied nature of the core issues identified in the study area as impacting agriculture, it was necessary to develop a large suite of indicators, sixty-one in number to be precise. Notwithstanding the large numbers of sustainable indicators, it was understood that out of these sixty-one indicators, there would be a few that would be critical for achieving sustainable development in agriculture. In order to identify these critical indicators to assess the impact of LMP on the five aspects of sustainability mentioned earlier, two statistical techniques were employed namely, Bivariate Correlation technique (BVC) and Principal Component Analysis (PCA). The two methods were used independently of each other at each watershed, to identify the critical indicators denoting the relevant improved LMP.

For example, to evaluate the impact of LMP in treated watersheds (TMW), the prevailing condition of various parameters, such as, soil fertility level, NDVI, cropping intensity, agricultural productivity, fodder availability situation, etc., were assessed and compared with the situation prevailing in an untreated micro-watershed located within the village taken as control, where improved LMP was not implemented. For undertaking this analysis, it was assumed that the benefits of general factors like geographical location, natural resource base, infrastructural setup, social and economic situation in the village, etc., could be discounted for or nullified in case of both watersheds as they were located in the same village.

An important merit of this Ex-Post Impact Assessment (epIA) methodology developed for evaluation of improved LMP is that the indicators constructed for the purpose are quantifiable, easily comparable, mappable and could be monitored at any given point of time at any spatial scale that is field- or watershed -level. A detailed description of the evaluation methodology has been presented in a recent publication (Kaushalya *et al.,* 2011). The study indicates that the epIA developed and presented in the book can be used as a generic model for evaluation of LMP in several regions in India and the SAARC region.

Due to variations in core issues that impact agriculture in selected watersheds, prescriptions for improved LMP and their emphasis may also differ. In view of the heterogeneity of issues affecting sustainability of rainfed agriculture in the treated watersheds, a large suite of indicators was constructed. This necessitated the identification of critical indicators for which two statistical methods were employed namely – Bivariate Correlation technique (BVC) and Principal Component Analysis (PCA) for which SPSS software (ver.16.0) was used. The epIA methodology comprises of three distinct phases namely, field work during which soil sampling was undertaken and socio-economic survey was carried out; lab work including database creation, construction of relevant indicators, interpretation of satellite data and mapping, followed by analysis of impact of the improved land management practices in the selected watersheds.

Complete Methodology for Carrying Out Ex-Post Impact Assessment *(epIA)*

A. Undertaking Field Survey

Step 1: Field trips were undertaken during *Pre*- and *Post Kharif* season each year to conduct socio-economic survey in each of the village. For example in case of *Pamana* village 123 farm households were surveyed which included 74 households from treated micro-watershed (TMW) and 49 from untreated micro-watershed (UTMW). Similarly, 113 farm households were surveyed in *Chintapatla* village which included 72 from TMW and 41 from UTMW. In case of *Dontanpalli* village, 49 farm households were surveyed of which 19 belonged to TMW and 30 to UTMW. In *Gollapalli*, 73 households were surveyed of which 40 belonged to TMW and the rest to UTMW.

Step 2: Soil sampling was carried out to undertake soil fertility studies in the laboratory. Soil sampling sites were geo-referenced using DGPS and maps were prepared using **ArcGIS** software.

Step 3: Using DGPS, soil sampling sites and S&WC structures were geo-referenced. Simultaneously, field boundary information was updated in the village cadastral map. The watershed boundary was delineated in the same manner.

B. Scheduling Laboratory Work

Step 4: Preparation of database in MS-Access to store data in the form of Tables (*In all fourteen Tables were prepared using Dot.Net as front-end to store data pertaining to various aspects of the study*).

Step 5: Development of an application in DOTNET for entering data by using forms and a database as back-end of application. The application facilitated calculation and assigning of scores simultaneously while entering data into the database. For e.g., if an indicator contains a quantitative value, namely, size of landholding, agricultural production or yield, the said value was input and stored directly into the database. In case of qualitative data, for e.g., *Security of Tenure,* which is an indicator, a small program was written using 'if' condition. In case of another indicator named '*Land Ownership*', residing within the Form called *Landholding*, an input control called *Land Ownership* was set. Using the 'if' condition, a score was assigned as indicated below:
For leased land, the score provided was : '0'
For owned land, the score provided was : '1'

Step 6: Soil analysis was conducted for 12 physical, chemical and biological parameters followed by tabulation and assignment of scores prior to carrying out statistical analysis.

Step 7: Interpretation of satellite data and preparation of thematic maps using ERDAS Imagine and ArcGIS software in GIS laboratory. For example, indicators like the 'slope' and 'NDVI' were quantified based on interpretation of satellite data of the study area. Thematic mapping of various aspects like soil fertility status, cropping system, yield or land use, were undertaken using ArcGIS prior to the assignment of scores to relevant indicators. This derived data was stored in the database prior to commencement of analysis.

Step 8: Conversion of MS-Access database into MS-Excel for extraction of values for indicators for evaluation of five aspects of sustainability, i.e., *livelihood security*, *economic viability*, *agricultural productivity*, *environmental protection* and *social acceptability*.

Step 9: Identification of Critical Indicators using two statistical techniques – Bivariate Correlation technique (BVC) and Principal Component Analysis (PCA) as mentioned earlier.

Note: Steps 1 to 8 are common for the evaluation procedure and a prerequisite for the rest of evaluation, which includes identification critical indicators. Subsequent steps have been described in the following algorithm that includes methods used for identifying dominant or critical indicators denoting LMP under this study.

C. Ex-Post Impact Assessment

Example: Algorithm for assessing Ex-Post impact of improved LMP or SLM on Livelihood Security among farmers in treated watersheds.

Step 10: Identification and construction of relevant indicators for assessing *livelihood security* as discussed.

Step 11: For this nineteen indicators were constructed and the relevant ones pertain to following aspects: value of crop production; soil fertility; soil OC; size of landholding; soil depth; rainfall; availability of water for critical irrigation; growing fodder crop; availability and depth of groundwater; development of surface water storage; S&WC structures; vegetation cover; planting trees; slope; health awareness among farm household; medical facility; off-farm income sources, and decrease in number of landless persons in the watershed / village, as the case may be.

Step 12: To identify Critical Indicators two statistical techniques were used namely - BVC and PCA.

Step 13(a): *Bivariate Correlation technique (BVC) was applied on relevant data that was available in MS-Excel format and was accessed in SPSS for Windows*

(Ver.16.0) in the following manner. From the main menu the following items were selected:

Analyze → Correlate → Bivariate

To commence analysis, a minimum of two or more numeric variables have to be selected for which the following options are available:

- **Correlation Coefficients** - For quantitative, normally distributed variables, Pearson's Correlation Coefficient technique was chosen. (If data is not normally distributed or contains ordered categories, then a Kendall's tau-b or a Spearman's – rho is to be taken which measures association between scores or orders). Correlation coefficients range in value from –1 (a perfect negative relationship) to +1 (a perfect positive relationship). A value of '0' indicates a non - linear relationship. While interpreting results, one must avoid inference of any cause-and-effect conclusion owing to a significant correlation.
- **Testing the Significance** - One can select a two-tailed or a one-tailed probability method. If direction of association is known in advance, one must select a one-tailed method, otherwise a two-tailed method is more suitable.
- **Flagging Significant Correlations** - Correlation Coefficients significant at $p= 0.05$ level are identified with a single asterisk as they are relatively weaker in their association, while those at $p= 0.01$ level are more significant and are identified with two asterisks indicating higher strength.

Step 13(b): Indicators at $p= 0.01$ level of significance were selected for further analysis.

Note: *In a similar manner PCA was employed to identify critical indicators and for validating the selection process using BVC. As mentioned earlier,* Steps 1 to 8 *were common to both statistical techniques described herein. To identify critical indicators using Principal Component Analysis the following method was applied.*

D. Identification of critical indicators using PCA

Step 14(a): Identifying relevant variables from the database and storing them in a *MS - Excel* sheet.

Step 14(b): Accessing this data in an SPSS Window and selecting the options from Main Menu as indicated below:

Analyze → Data Reduction → Factor

Step 14(c): Selection of indicators into variables text box and clicking **<**OK**>.** This would lead to display of **<***Communities Table***>**, **<***Total Variance Explained Table***>,** and **<***Component Matrix Table***>**

Step 14(d): From the **<***Component Matrix* **>** for each component, a maximum value is selected from which 10% is subtracted to arrive at a figure. This is followed by selecting all indicators which fall within the range of [max value, max value – 10% of max value]

Step 14(e): From the set of indicators identified as stated above under each component, we commence to identify critical indicators. From the resultant set of indicators a correlation is established under each Principal Component.

Step 14(f): From each component, an indicator is identified which correlates most with other indicators at 0.01 level of significance as indicated in Screenshot (**Table 1**).

Step 14(g): For each Principal Component, a weightage is estimated using the formula indicated as follows:

PC weight = % of Variance / Total Cumulative %

For e.g., for PC1 the weight is = 42.837 / 77.97 = 0.55. Similarly, weights of PC2 and PC3 can be estimated.

Table 1 : Screenshot

	Initial Eigen values			**Extraction Sums of Squared Loadings**		
Component	**Total**	**% of variance**	**Cumulative %**	**Total**	**% of variance**	**Cumulative %**
1	4.712	42.837	42.837	4.712	42.837	42.837
2	2.379	21.627	64.464	2.379	21.627	64.464
3	1.486	13.506	77.970	1.486	13.506	77.970
4	0.850	7.731	85.701			
5	0.588	5.342	91.042			
6	0.418	3.803	94.845			
7	0.317	2.882	97.727			
8	0.185	1.683	99.410			
9	0.048	0.434	99.845			
10	0.17	0.155	100.00			
11	2.45E-16	2.229E-15	100.00			

Extraction Method: Principal Component Analysis

Step 14(h): For each selected indicator, a product is calculated by multiplying the indicator with its corresponding PC weight, which is averaged to arrive at a value called the Index. This index value represents the level of sustainability achieved at each farm-holding level.

Note: Limitations of this methodology: The PCA was not found suitable for identifying critical indicators for evaluating impact of improved LMP. One of the main reasons was that the process is not rigorous. For e.g., to evaluate Livelihood Security, the BVC identified five critical indicators and helped us in pinpointing four farm households as sustainable while PCA with the same dataset identified 5 critical indicators and indicated sixty-one farm-households as sustainable, which is grossly inaccurate. After identification of critical indicators using BVC and PCA, Ex-Post Impact Assessment (epIA) of SLM or improved LMP for each aspect of sustainability was carried out.

Step 15(a): For measuring a change in condition of *Livelihood Security*, a reference quantity named 'Threshold Value' (TV) was computed in the following manner:

Wherever actual primary data collected from field or estimated in the lab or computed from GIS / satellite data analysis, etc., was available, then the respective TV was computed by using the relationship: 20% more than average of the community (Gomez et al.1996). Where only scores were available, then maximum score was assigned to TV.

Step 15(b): After generating TV, a ratio was calculated between Actual (AV) and Threshold Values (TV). An average value was again calculated on the basis of all ratios generated pertaining to each sample, viz., Farmer ID or Survey no. This final number would than determine if the sample farmer / field was sustainable or not. If this final value was < 1 it denoted that the entity was unsustainable. On the other hand, if this value was > 1 it denoted that the given sample was sustainable.

Step 16: Impact of improved LMP on Livelihood Security (or for that matter any other aspect of sustainability) could be depicted using Cob -Web diagrams, to show highly sustainable farm-household in a descending order of the Index Values.

Determining Critical Indicators for SLM in Study Area

Undoubtedly, land management practices adopted by farmers can make or mar sustainability of rainfed agriculture. In order to identify the most important and critical improved LMP implemented in rainfed areas in Peninsular India, 61 sustainability indicators were constructed to evaluate impact of improved LMP on five aspects of sustainability of agriculture production system namely - productivity, security, viability, protection and acceptability as described earlier. Principal Component Analysis and Bivariate Correlation techniques were used to identify the most critical indicators for evaluating impact of improved LMP for achieving sustainable land management in the study area. Weights were assigned to each indicator based on their respective PCA loadings. Critical indicators for SLM in rainfed regions like the Telengana region is listed in **Table 2**.

Table 2 : Critical indicators for improving agricultural sustainability in northern Telangana region covering AESR 7.2 in Andhra Pradesh

Critical Indicators identified	Contribution to Sustainability (Weight %)	Impact on various aspects of Sustainability
Soil Fertility Status	6.7	Agri. Prod., Eco.Viab, Envi.Prot. & Live.Sec.
Maintaining Vegetative Cover	5.4	Envi. Prot., Live.Sec. & Soc. Accept.
Education & General Awareness of Farmers	4.3	Eco.Viab., Envi.Prot. & Soc. Accept.
Cereal Yield	4.1	Agri. Prod.
Resource Availability for Purchase of Inputs	3.8	Agri. Prod.
Source of Irrigation Water	3.5	Agri. Prod.
Crop Diversity Index	3.3	Envi. Prot.
Women's Participation	3.3	Soc. Accept.
Availability of Draught Power	3.3	Eco.Viab.
Membership of Watershed	3.2	Soc. Accept.

Based on the analysis, it was seen that in case of Pamana village, soil fertility was the most important issue that impacted agricultural sustainability – with respect to productivity, economic viability, livelihood security and environmental protection. Study indicated that improved LMP related to soil fertility could contribute about 9.7 percent to agricultural productivity and livelihood security. Besides this, source of irrigation water was found to be an important indicator to determine sustainability. Development of sustainable sources of irrigation like digging of farm pond, excavation of dug-wells, construction of rainwater harvesting structures, etc., could contribute up to 6.13 percent to sustainability of agricultural productivity.

Aggregate Yield of Crops excluding Cereals could increase as much as 6.1 percent if improved LMP were adopted. Besides these, livestock management along with agricultural production could provide 4.5 percent towards sustainability while improving education and general awareness among farmers could contribute 4.2 percent towards economic viability and in turn help environmental protection. Reduction in input cost by improving availability of draught power, improving Crop Diversity Index, increasing input-use efficiency, practicing kitchen gardening, adopting short fallowing, using FYM with recommended dose fertilizer and practicing INM, etc., could each contribute up to 3.33 percent towards sustainable economic viability and environmental protection (**Fig. 2**).

Indicators of Agri. Prod.	Weight (%)
Aggregate Yield	6.1
Livestock Management	4.5
Source of Irrigation Water	6.1

Indicators of Envi. Prot.	Weight (%)
Crop Cafeteria Index	1.5
Crop Contingency Planning for Drought Buffering	1.9
Crop Diversity Index	3.3
Practicing Kitchen Gardening	3.4
Use/availability of Crop Residue	2.1
Use of FYM with Fertilizer/ INM	3.4

Indicators of Live. Sec.	Weight (%)
Availability of Ground Water	1.3
Growing Fodder Crop	1.5
Off-farm Income Sources	1.4
S&WC Structures	1.2
Size of Landholding	1.9
Slope	1.1
Soil OC	2.2
Surface Water Storage Facility	2.2

Indicators of Eco. Viab.	Weight(%)
Availability of Draught Power	3.3
B: C Ratio	1.2
Crop Rotation	1.2
Higher Yield	3.3
Income from Livestock Produce	1.7
Input Use Efficiency	3.3
Net farm Profitability	1.9
Off-farm Employment	1.9
Short Fallowing	3.3
Seasonal or Permanent Migration	1.7

Indicators of Soc. Accept.	Weight (%)
Constructing Farm Pond and Maintaining Contour Bund on Own Initiative	2.8
Land Ownership	1.3
Membership of Watershed Comm. or User Association	2.1
Mulching	1.3
Small Family Norm	1.2
Use of Organic Matter for Soil Conservation	2.9
Women's Participation	2.8

Critical Indicators	Contribution to Sustainability (Weight:%)	Impact on Aspects of Sustainability
Soil Fertility Status	9.7	Agri. Prod., Eco. Viab., Envi. Prot. , & Live. Sec.
Education & General Awareness among Farmers	4.2	Eco. Viab. , Envi. Prot. , & Soc. Accept
Maintaining Vegetation Cover	3.1	Live.Sec. , & Soc. Accept.

Fig. 2 : Critical indicators for assessing impact of improved LMP on agricultural sustainability–case study Pamana village

For e.g., in case of Chintapatla village, five indicators were found to be critical for sustainable development. Improved LMP for increasing Cereal Yield could contribute to 5.8 percent of sustainability. Equally important was the resource availability with farmers, his general awareness and education, soil fertility status in his fields and off-farm sources of income available to him. Together all these four indicators could contribute to 21.4 percent towards sustainability of agricultural production system in the village.

In Dontanpalli, soil fertility status was found to be most critical indicator that impacted agricultural productivity, livelihood security and environmental protection. If SLM practices pertaining to soil fertility were practiced diligently, 9.2 percent of sustainability could be achieved. Besides this, maintaining vegetative cover to cut surface albedo, loss of soil moisture and erosion could contribute to 6.2 percent towards sustainability. Use of crop residue, Cereal Yield, Crop Diversity Index and Crop Cafeteria Index were the other critical indicators and SLM practices pertaining to these aspects could contribute to 16.9 percent towards sustainable agricultural development in the village.

In Gollapalli village maintaining vegetative cover seemed an important indicator contributing to 8.3 percent towards achieving sustainable development. Besides this, other important aspects of agricultural production system that contribute to sustainability were improving Cereal Yield (6.37 %), livestock management (6.4%), and resource availability with farmers (6.4%), management of slope (7%) and education & general awareness among farmers (6.0%). These aspects, if managed diligently, could contribute to 32.1 percent towards achieving sustainable agricultural production.

A comparison of all indicators across the study area in four villages indicated that improved LMP pertaining to enhancing soil fertility could alone contribute to 6.7 percent towards sustainability. Improving soil fertility level could ensure livelihood security in all four villages besides being important for environmental protection in Pamana, Chintapatla and Dontanpalli. It was also seen to be critical in Pamana and Dontanpalli for improving agricultural productivity and enhancing economic viability, in addition to improving economic viability in Gollapalli watersheds (Table 3). Improving vegetation cover could contribute to nearly 5.4 percent to sustainable economic viability and environmental protection while increasing farmers' general awareness & education could contribute to as much as 9.3 percent towards sustainable economic viability, environmental protection and social acceptability. Table 3 indicates the contribution of selected indicators towards achieving sustainable agricultural production in the study area. Improving soil fertility status was found to be critical in Pamana for achieving sustainability.

In case of Chintapatla, Cereal Yield and resource availability among farmers were critical unlike in case of Pamana. Source of Irrigation Water was found to be critical in both cases for sustainable agricultural productivity. For ensuring livelihood security, availability of water – both surface and ground water besides quality were found to be critical and hence S&WC measures were also found to be important. Besides these, the size of landholding and pricing of farm produce were also found to be critical. Improving accessibility to loan from Banks was found to be critical for sustainable social acceptability of improved LMP in the village. Critical indicators identified for achieving sustainable development through land management practices in Chintapatla village is indicated in **Table 3**.

Table 3 : Identification of critical components of agricultural production system in study area and their respective contributions (%) towards sustainable development

Pamana **: Production System component**	***Chintapatla*** **: Economic aspects**	***Dontanpalli*** **: Soil - related issues**	***Gollapalli*** **: Soil - related issues**
Availability of draught power	Access to Bank loan	Soil health	Use of FYM with fertilizer/ Practicing INM
Crop Cafeteria Index	B: C ratio	Soil depth	Use & availability of crop residue
Crop Contingency Planning	Income from livestock produce	Soil OC	Soil health
Crop rotation	Equity	Slope	Soil depth
Growing fodder crop	Developing kitchen garden	Vegetation cover	Soil OC
Input use efficiency	Resource availability with farmers		Slope
Land ownership	Value of Agri. Produce (Actual Product Value) Women's participation Off-farm income sources Education & general awareness among farmers		Vegetation cover
26.3	**32.0**	**26.5**	**30.6**

Enhancing education and general awareness among farmers was found to be important along with developing off-farm source of income which could help in securing economic viability and livelihood security among households. The scenario in Dontanpalli was similar to that of Chintapatla. However, for securing livelihood, availability of water for agriculture was seen to be critical. Hence, developing surface water storage facility was identified as critical. Due to pressure on land owing to urbanization processes, land use change, irrigation, higher yield and off-farm income sources were found to be critical for achieving economic viability in agriculture (**Fig. 3**).

In **Table 4** a list of dominant indicators have been indicated that could help achieve sustainable agricultural development through the adoption of improved LMP practices in the study area. These critical indicators could contribute up to 41.1 percent towards achieving sustainable agricultural development.

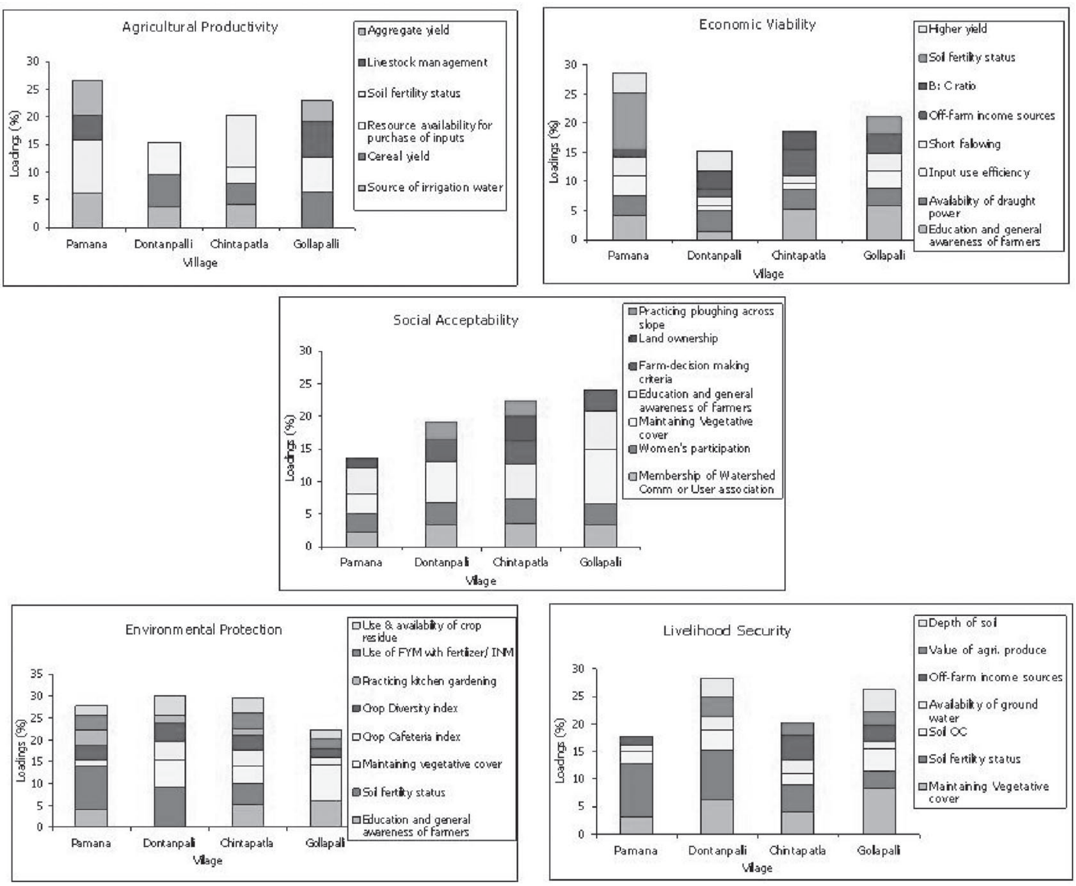

Fig. 3 : Contribution of Critical Indicators to various aspects of Sustainable Development in study area

Table 4 : Identification of dominant critical indicators for achieving sustainable agriculture in the North *Telangana* agro-ecological sub-region

Critical Sustainability Indicator	**Estm. Wt. (%)**	**Aspects of Sustainability Addressed**	**LMP Practices**
Soil fertility status	6.7	Agri. Prod., Eco. Viab. Envi. Prot. & Live. Sec.	For improving soil fertility, incorporation of manure, leaf litter, crop residue and oil cake; practicing crop rotation; application of recommended dose of fertilizers; seed treatment with *Azospirillum;* application of green manure viz., *Subabul* ; application of poultry manure, tank silt; use of in-house organic waste etc. To check soil erosion construction of loose stone surplus bund , waste weir, etc.
Maintaining vegetative cover	5.4	Envi. Prot., Live. Sec. & Soc. Accept.	To maintain adequate ground cover for reducing soil erosion**,** growing vegetative barriers; filtering and retaining silt; use of *Khus* grass or *Vetiver;* growing cowpea as ground cover; constructing miniature bund at lower side of barrier for reinforcement and growing trees viz., *Tectona grandis, Leucocephala, Borassus flabellifera, Cocos nucifea, Acacia nilotica on bunds*
Education & general farmers	4.3	Eco. Viab., Envi. Prot. & Soc. Accept.	Increasing awareness of need-based interventions; buying good farm inputs at reasonable prices; using infrastructure facility, market, availing credit facility, etc.; upgrading skills; health-awareness; sanitation and education; undertaking off-farm income generating activities, etc.
Availability of draught power	3.3	Eco. Viab.	Adopting farm mechanization; use of improved tools & implements viz., seed drill, drill plough, cultivator, modified blade harrow, ridge planter, tractor drawn planter, wheel hoe , ferti-seed-pora plough, with two-bamboo tubes; ridge planter drawn by bullock or tractor
Women's participation	3.3	Soc. Accept.	Setting-up of Self Help Groups (SHG); Implementation of WDP; Conducting training programs
Crop Diversity Index	3.3	Envi. Prot.	Adopting intercropping system (ICS) and multi cropping systems (MCS)

Critical Sustainability Indicator	Estm. Wt. (%)	Aspects of Sustainability Addressed	LMP Practices
Use/availability of crop residue	2.9	Envi. Prot.	Use of crop residue like paddy husk, powdered groundnut shells recommended for improving soil structure & AWC
Soil OC	2.9	Live. Sec.	Adopting INM treatments, for improving soil OC viz., use of diagnostic balanced fertilization; intercropping and crop rotation with legumes; use of fertilizers with FYM; compost and vermi compost; residue recycling and management; green manure; use of bio-fertilizers; etc.; practicing reduced tillage to protect top soil; adopting 100% organic treatment (4t Compost + 2t *Glyricidia* loping) to get high OC content besides N, P and K; conjunctive N management & residue application; incorporation of horse gram biomass
Crop Cafeteria Index	2.7	Envi. Prot.	Crop rotation with pulse crop; intercropping; silvi-pastoral system in wasteland; inclusion of legumes in crop rotation
Short fallowing	2.2	Eco. Viab.	Adoption of crop rotation; seasonal fallow; etc.
Input use efficiency	2.1	Eco. Viab.	Use of FYM/Compost and fertilizers; use of quality seed & soil-test based fertilizer application
Availability of ground water	1.9	Live. Sec.	Conserving groundwater through increased restrictions on ID crops; introduction of alternative crops that are remunerative and require less water, viz., chickpea & maize during Rabi season, etc.
Total	**41.1**		

Conclusion

The study illustrates how improved LMP can become SLM practices implemented under watershed projects in rainfed regions in AP. Evaluation of impact of improved LMP was carried out for five aspects of sustainability-agricultural productivity, economic viability, livelihood security, environmental protection and social acceptability. Sixty-one indicators were constructed to carry out impact evaluation that addressed the core issues relating to rainfed agriculture. The impact of adoption of improved LMP implemented under

Watershed Development Program was undertaken at field-level compared with an untreated watershed taken as control. The assessment of impact of improved LMP was undertaken following the framework indicated in this paper.

A major uniqueness of this study is that we have used the Geomatics and conventional tools of analysis like soil analysis, PRA, socio-economic survey etc., for the evaluation of impact of LMP. Voluminous data was generated, stored and integrated in a digital database. Use of Geomatics facilitated geo-referencing of indicators that could eventually facilitate undertaking of long-term sustainability studies in the rainfed region.

Land management is a function of LULC and exogenous driven and pressures. Hence, a study of agricultural land use, land cover and degradation of natural resource base was undertaken using satellite imagery from the Indian Remote Sensing Satellites namely, IRS-1D - LISS-3 and IRS-P6 LISS–3 & LISS–4 data pertaining to two seasons alone pre- and post-monsoon period annually from 1998 when improved LMP were not implemented in the study area and from 2000 till 2008 when they were introduced under watershed development program and adopted widely thereafter. Sustainability indicators constructed from satellite data relate to land use, land cover change (LCCS), vegetation index indicating plant vigour or crop growth, trends in NDVI, land degradation, etc.

A significant outcome of this study is the development of a framework for evaluation of improved LMP and identification of useful land management practices that would help in achieving agricultural sustainability. This information would be useful to agriculture extension agencies and project implementing agencies of watershed program as well as to farmers who would be able to identify and emphasize on these critical land management practices while discontinuing those that do not contribute towards achieving agricultural sustainability.

Undoubtedly, use of sustainability indicators to evaluate land management practices where multi-disciplinary evaluation procedures are required to be carried out, holds great promise due to its' obvious strengths. The use of Geo-informatics in tandem with conventional methods of evaluation like soil analysis, socio-economic survey and PRA has enriched the evaluation procedure. Use of GIS and Remote Sensing helped in thematic mapping and quantification of several indicators for this study. Use of DGPS helped in geo-referencing soil sampling sites and updating the cadastral maps. Use of indicators for the procedure has facilitated a rational evaluation process. The indicators facilitated the development of an evaluation framework that was quantifiable, comparable and mappable and was relatively easy to use and objective in evaluation. The results of the evaluation procedure are specific and easily comprehensible and useful emphasising the land use or the management practices that are really effective.

To sum up, it may be stated that although at present, land management practices in rainfed agriculture have not received critical attention except in spurts in watershed project areas, their role in securing sustainable development in rainfed region, is beyond doubt. If improvements in land management were to be made as indicated in this study, sustainable development could be possible at the field- and watershed-level in rainfed regions. Critical issues as identified by the indicators at both spatial levels require to be strengthened first and foremost, in order to enable sustainable development of rainfed agriculture in the country. The evaluation framework as indicated here could be readily used by the PIA of various schemes in agriculture and in rural development in India and SAARC countries.

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Design of Rain Water Management Systems for Reliable Irrigation

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Poverty in South Asian countries can be eradicated-not just alleviated by enhancing the productivity of rainfed agriculture. In such a case, agricultural growth serves as an engine for overall economic growth. This win-win scenario of poverty eradication through agricultural and overall growth has been successful throughout history, and continues to be valid today. It provides a strong justification for investing in further water development for small-scale agriculture, in order to increase and stabilize the supply of agricultural outputs throughout the year. Improved water control increases yields and cropping intensities, reduces the risk of crop failure and prevents soil erosion. It also facilitates the adoption of high-yielding varieties of food crops, diversification into cash crops, fertilizer application, pest management and intensification of farm practices. However, the growth of irrigated area has slowed down considerably in last three decades, as the large irrigation projects are no longer financially and environmentally viable. This has led to a sharp increase in exploitation of ground water and the share of ground water in total irrigated area has increased to 75% from 50% two decade ago. This has its own serious consequences of declining ground water table and increasing non-sustainability.

Thus it is necessary that the alternative measures of providing irrigation are explored which are eco-friendly, sustainable and manageable at village level. Rain water management based irrigation systems if properly designed can be a reliable source of irrigation. This article presents components of design of rain water management based irrigation system for different ecosystems.

Design of Rain Water Management Systems

The design of rain water management system is based on reliable estimation of runoff, percolation rate and proposed cropping system of the command. Following sections provide an overview of these.

Runoff Estimation

Estimation of runoff is a prime requirement for design of any water harvesting structure. However most of the water harvesting systems are designed on the basis of predicted runoff without any statistical basis as actual data are not available. This predicted runoff do not allow assessment of reliability of amount of water available for irrigation from water harvesting structure. For achieving this objective, it is essential that runoff predictions are made with the aid of statistical methods. There are two characteristics of runoff which require estimation: maximum rate and amount. While first one is important for design of spillway structure, the second is required to design the capacity. The most common method for estimating peak discharge is rational method. In this method the discharge is estimated as below:

Q = CIA/ 360

Where C = Land use coefficient

I = Rainfall intensity for period of time of concentration, mm per hour

A = Area in hectares

Q = m^3/ sec

The land use coefficient varies from 0.2 for a wooded grassed area to 0.95 for an impermeable surface. The land use coefficient is also affected by the slope and soil type. The land use coefficient has been estimated by different agencies for different location (Chow, 1964; Vandersypen et al., 1972). For accurate estimation, one should be careful to estimate the proper land use coefficient. For a watershed having different land uses, a weighted land use should be estimated by taking a weighted average as below:

C (2) *w= (c1a1+c2a2+c3a3+...................... +cnan)/n*

The rainfall intensity will vary as per the time of concentration and should be estimated as per the watershed characteristics. Murthy (1988) has given the isoclines of rainfall intensity for whole country for different time of concentration and they can be used. For estimation of reliable amount of runoff available during different periods, Srivastava and Rao (1993) found AMC curve number method most easy and reliable. The curve number method is also known as the Hydrologic Soil Cover Complex Method is a versatile and widely used procedure for runoff estimation. It has been used extensively by different researchers (Rao et al., 1996; Chandramohan and Durbude, 2001; Sharma and Kumar, 2002, Pandey et al., 2000). In this method, runoff producing capability is expressed in the numerical value varying between 0-100. Curve number technique takes in account the hydrological soil cover complex, soil group and antecedent moisture content. With this method, runoff availability can be estimated on daily, weekly, monthly, seasonal and annual basis. As per Vandersypen et al. (1972), the daily runoff can be estimated by following formulae:

Q = (*P–0.3S*) 2/ (*P+0.7S*) for all regions and

Q = (*P–0.1S*) 2/ (*P+0.7 S*) for black soil region

Where Q = daily runoff, mm

P = daily rainfall, mm

S = Potential maximum retention, mm= (25400/ CN) - 254

Where CN = Curve Number

However, these relationships do not account for topography and hill & plateau region have been treated same. Srivastava et al. (1987) found that for hilly regions of Himalayas, the second relationship holds better, and therefore for rolling topography, second relationship should be used. Summing up the daily runoff, runoff for different periods, viz, week, month or season can be estimated. Once the runoff for a particular period is estimated for a number of years, a time series of runoff for that period is created. With this time series, probable values of runoff availability can be estimated because for design of irrigation system, this is the prime requirement. For reliable estimation of hydrological parameters by probability distributions, the data series has to be of adequate length, random in nature and some suitable probability distributions could fit the data. To test the aforesaid criteria the data series should be subjected to three tests, namely test for adequacy of length of record, test for randomness and test for fitness to distribution. Once the time series passes these tests, the probable values for a particular probability can be estimated as following:

$X_p = X. \Delta K_T$

Where X_P = probable runoff at p probability level

X = Mean

Δ = standard deviation

K_T = Frequency factor corresponding to probability level

Pre-estimation of seepage loss for site selection of rain water management structures

Seepage rate is a major component for designing percolation tank and runoff storage tanks. For percolation tanks, the tank capacity will be less if seepage rate is higher and *vice versa* (Srivastava et al., 2005). On the other hand, for water harvesting tanks, the tank capacity as well as catchment-command area ratio will be higher for high seepage rate and if seepage loss is more than a particular level, which will decide whether the tank should not be constructed at that site or it should be lined by a suitable lining material (Srivastava and Verma, 2004). Lack of knowledge on seepage rate leads the construction of these structures to sub-optimal designing and economic loss. The seepage of water from a tank is a saturated flow from the tank to the ground water through tank bed and sub-surface strata. Thus, it is governed by Darcy's law of saturated flow through porous media, which states that flow is directly proportional to the gradient of flow line (difference in head/ length of flow) and the saturated hydraulic conductivity of the media. In case of seepage from tank, the water will mostly flow to the groundwater table. Thus, broadly the seepage rate will be dependent upon textural characteristics and hydraulic conductivity of the flow medium and distance it has to travel to reach the groundwater. Thus, the seepage loss is function of saturated hydraulic conductivity, bulk density, clay content and depth of ground water. Based on this, Srivastava *et al.* (2007) developed following empirical equation for pre-estimation of the seepage loss of a site selected for the construction of the percolation tank or runoff storage tank.

SP	=	–538.47 + 250.82 x BD +21.10 x Cl-26.26 x GWD - 2.82 x KC1 = 2.83 x KC2+ 53.18 x BD2 - 12.97 x CL x BD-18.88 x GWD x Cl - 1.98 x GWD2 - 4.12 x KC1x GWD - 1.85 x KC2 x GWD (13)
Where, BD	=	bulk density of the pond-bed in g/cm^3 ;
CL	=	average clay content of bed surface (at 0-15 and 15-30 cm depths) in percent;
GWD	=	depth of ground water in m;
KC 1	=	saturated hydraulic conductivity of 0-15 cm layer in mm per second.

Evaluation of observed and predicted seepage rate showed that the average correlation coefficient between observed and predicted data is 0.76, which can be taken as satisfactory for an empirical equation. The t-values obtained between observed and predicted estimates were non-significant and thereby the t-test also indicates the suitability of the equation. Thus this empirical relationship can be a good tool for pre-estimating the seepage rate before embarking upon site selection, design and construction of the percolation tanks and water harvesting based storage tanks. The coefficients of the equation can be estimated for different agro-ecological regions. For estimating the seepage rate, 1 m x 1 m x 2 m deep pit can be dug out and soil samples can be collected to measure the parameters. The water level can be taken up from nearby open dug well.

Design of Tank Irrigation System

The rainwater based irrigation systems can be divided into three categories: tank based systems, tank cum well based system, and recharge structure cum well based system. Each system is suitable for particular location and therefore has to be designed specifically. Although the rainfall in these areas is sufficient to meet the water requirement of rice, the most important staple crop of the region, its spatial and temporal distribution makes rainfed farming a risky proposition. This is evident from yield difference between that of rainfed rice (1.0 to 1.5 t/ha) to irrigated rice (3.0 to 5.0 t/ha). Although the improved varieties for rainfed areas have potential yield upto 3.0 - 3.5 t/ha, the yield pattern is below 1.0 t/ha in below normal rainfall years, above 2 t/ha in above normal years and between 1-1.5 t/ha in normal year.With this pattern, the rice yield pattern in five years are : 1-1.5 t/ha in two years, >2 t/ha in one year and <1.0 t/ha in two years making an average yield of less than 1.5 t/ha. Thus, two objective of the irrigation system based on rainwater management should be to take maximum advantage of the rainfall and ensure the crops against rainfall aberration. Further, to enhance the cropping intensity, it should be able to provide sufficient water to succeeding crop in post-monsoon season crop based on these principles; the design methodologies for different system have been developed.

Normally a tank based irrigation system is designed with reference to total irrigation requirement and runoff availability and considerable work has been reported on farm scale reservoirs or farm ponds (Srivastava, 1992). However, application of modern mathematical tools for designing water harvesting / runoff recycling systems is a recent phenomena (Sharma and Helweg, 1982). Two types of designing methodologies have been reported: one dealing with a single tank treating it as an independent unit (Srivastava, 1996 & 2001) and another dealing with design of optimal multi-tanks system by taking into account the whole spectrum of the constraints, objectives, options of location, conveyance and application methods, crops and their irrigation levels, productivity, demand of population dependent upon the area in terms of amount of foodgrains, pulses and oilseeds, nutrient and availability of input to obtain a higher level of economic efficiency in irrigation development and management (Srivastava, 1996). Where seepage losses are more than desirable, the tank has to be lined. The design methodology for these two types of system and lining technique have been presented in following sections:

a) Design methodology for single tank unit

A major constraint in realizing the potential yield of rice in rainfed tracts of high rainfall areas of eastern India is late transplanting due to the delay in obtaining ponded condition to facilitate puddling with rainfall alone. Even in canal commands, there is a high yield difference between head and tail reaches due to late availability of irrigation water in tail reaches to facilitate transplanting in time. WTCER (1996) reported that there was a 40% reduction in rice yield in a canal irrigation project command when transplanting was not completed in July. Thus, the first condition, which any irrigation system should satisfy is that the transplanting should be completed by optimum time, i.e. 15 July. The other constraints to be satisfied are:

(1) There should be ponding in the initial stage of transplanting for smooth recovery of rice seedlings,

(2) There should be sufficient water in the tank to meet the demand due to prolonged dry spells and

(3) There should be sufficient water in the tank to provide at least two irrigations to succeeding dry season crop.

The design parameters of a runoff recycling system are:

(1) Minimum catchment / command area ratio,

(2) Size of the tank and

(3) Maximum affordable conveyance loss to meet the objective of providing the required amount of irrigation water at the desired time.

Since the parameters should be able to fulfil the objectives for a desired return period, a time series for these parameters is required. Besides the engineering design of the system, crops planning is also essential to realize the full potential of the irrigation system. Selection of a suitable variety is important in this regard. Since in this system the crop and tank are integrated, simultaneous simulation of the water balance of the cropped area and the tank is required to achieve the objectives. The simulation has to be done for a crop rotation of transplanted rice (July - October) and post paddy crop (November - March). The region gets pre-monsoon showers in May (the normal rainfall for Orissa during May is 40.36 mm) and thus it has been assumed that on 15 May, the soil is at permanent wilting point. The value of permanent wilting point, field capacity and saturation has been taken as 25, 44.1 and 50%, respectively on v/v basis based on actual observations of paddy field soil. A root zone depth of 75 cm has been considered. Adequate drainage is assumed to prevail because of rolling topography. The ground water influence has not been factored, as the ground water depth in plateau areas during the monsoon season is normally below the root zone. Two varieties, a short duration IR-36 (110 days) and medium duration Mashuri (130 days) have also been considered.

Formulation of simulation model

As stated earlier, the model involves simulation of crop water and tank and water interaction. For the crop water balance simulation, the model of Srivastava (1996 b) was modified. This was done because with high rainfall there is wide fluctuation in ponding depth. For the tank water balance simulation, a simple input-output method was used. The input is runoff, and output is evaporation, seepage loss, and water used for irrigation. The model has been divided into three time phases. The first phase deals with the pre-transplanting period and it estimates the date of transplanting by factoring the soil moisture status and the runoff water stored in the tank. The second phase covers the first week after transplanting and estimates the irrigation requirement for the initial ponding period of 1 week to maintain 5 cm ponding for proper establishment of the plants. The third phase of the model estimates the irrigation requirements to maintain the soil moisture above field capacity for the growth period to physiology maturity. No irrigation has been proposed between the period of physiological maturity to maturity, as this period requires drainage. The simulation starts on 15 May and ends at the time of maturity, i.e. 80 days for short duration variety (IR-36) and 100 days for medium duration variety (Mashuri) from the date of transplanting. Any dependence of field duration on seedling age and time of transplanting is neglected here. This model has been further broken up in three parts: model for pre-transplanting period; model for 1 week after transplanting period; and model for subsequent period upto physiological maturity.

Model for pre-transplanting period

This phase of the model deals with the moisture and tank water balancing for the period from 15 May to the day of transplanting. During the period, the soil moisture in the top layer is generally below field capacity except for the time when there are heavy showers. There will be no percolation loss under these conditions and it can be safely assumed to be negligible. The equivalent depth of soil moisture (SM), in the root zone at the end of day is calculated from

$SMi = SMi–1+Pi–Ei$ subject to $SMi > 0$ (1)
Where $i\ P$ and $i\ E$ are daily rainfall and evaporation from bare soil, respectively.

The initial value of soil moisture on 15 May has been taken permanent wilting point. Evaporation from bare soil $i\ E$ is estimated from the open pan evaporation ($o\ E$) subject to the rainfall conditions of the days (Jensen et al; 1993; Srivastava, 1996 a, b). If $i\ P$ =0, then $i\ E$ =0.1 $i\ Eo$ if $i\ P > i\ Eo$ then $i\ E = i\ Eo$, otherwise $i\ E = i\ P$. The 10% for rainless days is adopted from Keulen (1975) as a typical value for an airdried surface which will be an approximately similar condition prior to saturation. The suitable date of transplanting will be a function of soil moisture status and irrigation water availability in the runoff tank. For proper utilization of rain water and minimizing the use of stored runoff water, the model stipulates two conditions to be fulfilled:

(i) The soil moisture is above field capacity and
(ii) Sufficient water is available in the tank to provide irrigation for bringing the soil moisture to saturation level, amount required for puddling and for ponding for at least 2 days (equal to seepage and percolation loss + evaporation).

However, this model does not take into account the age of nursery. To introduce this parameter, a condition has been incorporated that transplanting will not be done before 1 July, by which time the nursery will be about 25 days old in normal conditions. Actually, if this constraint is not factored, in few years of good rainfall in June, the simulation will show transplanting before 1 July and the crop will suffer a dry spell in the early growth period. The model also has to satisfy the conditions of sufficient tank water balance to meet minimum two days water requirement of post- transplanting period to avoid the risk of non-availability of water during the crucial period after transplanting. The ponding depth at the time of transplanting has been assumed at 30 mm.

Water balance for 1 week after transplanting

For the first week after transplanting, a ponding depth of 5±2 cm has to be maintained. The irrigation requirement during this period will be met from tank and therefore the water stored in the tank on a particular day should be more than the irrigation requirement of that day. In case when the tank run dry due to insufficient rainfall, the depth of ponding will reduce.

Water balance for subsequent period

It has been assumed that the irrigation will be done when the soil moisture goes below the field capacity up to physiological maturity stage. No irrigation was sought between physiological maturity to maturity phase when drainage is preferable. During this period, there can be three conditions of soil moisture. In the first phase, there will be ponding when rainfall is sufficient to meet the water demand due to evaporation and seepage & percolation loss. If this is not occurring the ponding depth will reduce and finally the soil will go in moist phase . If it rains the soil will return in ponding stage else, the soil moisture will go below field capacity level. At this stage irrigation will be required to bring a submergence level of 5 cm and there should be sufficient water in tank to meet this contingency. This way the further water balance will be computed and the irrigation requirement will be calculated. The experiment data of WTCER, Bhubaneswar (WTCER, 1994, 1995 &1996) showed that the deep percolation loss is a linear function of depth of ponding and therefore a relationship was developed between deep percolation loss and depth of ponding for use in this study. The relationship is

$$SP = 2.0786 + 0.338D$$

Where SP is rate of seepage and deep percolation (mm per day) and D is the depth of ponding (mm).

Since this simulation does not allow soil moisture to go below field capacity, this equation holds well for the conditions encountered. However, a provision has to be made in the computer program that if soil moisture is below field capacity, the SP will be zero. Another important parameter in water balance of rice is allowable maximum depth of ponding. Working on drainage requirement of the rice, Ghoarai and Singh (1994) have reported that there is significant reduction in yield if the ponding depth is more than 12.5% of the height of the plant at the time of maturity. For varieties under consideration, this translates to 15 cm. Thus, a provision has been made in the computer program that if pounding depth is more than 15 cm, it will be restricted to 15 cm. To take care of the requirement of the post-monsoon crop (two irrigations of 75 mm each) a constraint of minimum tank capacity of 175 mm was included in the model. A computer program was developed for this simulation and the model was run for different catchment/command area ratio (1.0–5.0), different conveyance efficiencies (1.0, 0.8, 0.6, 0.4) and three rates of seepage and percolation loss (mm per day). Three rates $1.956 + 0.29Hi$, $3.912 + 0.58Hi$ and $5.868 + 0.87Hi$ where Hi is the depth of water in tank (m) were used. The first rate was estimated from actual observations in the tank and others were just doubled and tripled to assess the affect of change in seepage and percolation loss from the tank for both varieties for 16 climatological data (1980-1995) and time series for the following parameters:

i. Date of transplanting,

ii. Days of ponding during three periods,viz., (a) transplanting to flowering, (b) flowering to physiological maturity and (c) physiological maturity to maturity,

iii. Required tank capacity,

iv. Whether tank ran dry and was unable to supply water during first week of transplanting,

v. Whether tank was unable to supply water in case f a prolonged dry spell and

vi. Whether the tank had sufficient water left to meet the demand of the post-monsoon crop, were created for all the combinations of catchment area ration, irrigation efficiency, rates of seepage and percolation losses in the tank and varieties.

The numeric parameters obtained from the simulation were fitted to different distributions (normal, Pearson, extreme, log normal, log Pearson, and log extreme) with or without transformation to estimate the probable values as per methodology described by Srivastava and Rao (1993). As the catchment of any system will vary in land use and hydrological cover complex, the amount and pattern of runoff yield will also vary. To evaluate the effect of change in land use and hydrological cover complex, which is denoted by curve number (CN) in the SCS method of runoff estimation, the model was run for sensitivity analysis with a wide range of CN values of antecedent moisture condition II. The CN values used are 70, 75, 78, 84 and 88. This covers land use ranging from good pasture to degraded lands and hydrological cover complex from A to C. Based on above simulation, design parameters of tank have been developed for areas having rainfall between 1150-1600 mm. The conveyance efficiency should not drop below 80% as the design parameters change sharply if the conveyance efficiency drops below 80%. Critically affected parameters by lower conveyance efficiency are date of transplanting and days of ponding during flowering to physiological maturity phase. Thus, the pond location should be such that the conveyance efficiency could be maintained around 80% at an affordable cost. In such systems, the number of irrigations required is low making the higher cost of lining of conveyance system uneconomical (Srivastava and Bhatnager, 1991). If conveyance efficiency is less than 60% then the size of tank has to be increased by about 10% to take care of the losses. Thus an optimal location of the tank can be found by a trade off between cost of an efficient conveyance system and the additional cost of tank construction at a less economic location. These design parameters hold good for whole plateau region because change in catchment characteristics reflected in terms of curve number and do not significantly change the system parameters. The normal irrigation requirement for monsoon rice in eastern India ranges from 300 to 450 mm (four to six irrigation of 75 mm each) depending upon dike height (WTCER, 1996). Accounting the requirement of two irrigations for post-monsoon crop, the total irrigation requirement will be 450-600 mm and the tank capacity required will be between 4500 to 6000 m^3, plus provision for losses due to seepage and evaporation. This methodology gives a more efficient design of a runoff areas.

Since this withdrawal of water from tank for rice is again replenished by subsequent runoff events the water yield / storage capacity ratio (ratio of total water drawn from the tank, i.e. total inflow - outflow - losses due to seepage and percolation and evaporation, and storage capacity is more than 10 m^3 making it more economical than a design based on just irrigation requirement which invariably have a water yield / storage ratio less than 1.0.

b) Multi tank based irrigation system

It has been seen that a single tank based system can serve an individual holding well but for creating an irrigation system to serve a larger area / population, a series of tanks located in the watershed are required. In this system, except for the topmost tank, the command area of first tank will serve as catchment area of succeeding tank. The optimal design of such irrigation system on rolling lands should give information on the number of tanks and their locations, dimensions, capacity, type of conveyance and application methods, cropping pattern of command areas of different tanks along with their irrigation regime. These factors are all interdependent. An efficient conveyance and application system at a higher cost of conveyance and application will reduce the storage requirement per unit of available irrigation water leading to either a reduction in the costs of storage or higher gross returns from an increased irrigated area. Similarly, an intensive irrigation policy will irrigate a smaller area with lower conveyance costs but with greater evaporation and seepage loss from the tank. It will also have a lower water use efficiency and poor social equity (benefits of irrigation limited to a small section of society). The required extent of irrigation development will justify runoff augmentation by the inter watershed transfer of water. For a single tank, the costs as well as the land for tank construction will be less, but there will be a smaller irrigated area and a smaller number of beneficiaries in comparison to having multiple tanks in a series, where the command area of one tank will serve as a catchment area of next tanks.

Thus, for an optimal design of the tank irrigation system, a compromise must be made. To design an optimal irrigation system, all the previous factors should be accounted for. The planning method, therefore, should simultaneously analyze all of the interdependent aspects of the problem and provide a detailed optimal solution giving information on all of those aspects so as to achieve a particular objective or multiple objectives. The selection of the objective depends upon the goal of the water resource development agency-which can either be to maximize total returns from the area, or to maximize food grain production, gross irrigated area, or runoff retardation per unit of investment in the irrigation system or a multi-objective encompassing all the four objectives. For designing such system, Srivastava (1996 a) developed a methodology using the method of decomposition and multi-level optimization that decomposes the large / complex problems into smaller sub-problems and solves through a multi-level iterative process (Dantzing and Wolfe, 1960;

Geoffrion, 1970; Paudyl and Dasgupta,1990). The problem has been formulated on two levels. The first level comprises optimization programs corresponding to a set of number of tanks and a conveyance system. An optimal cropping pattern will be selected on the basis of the benefits of agricultural production and the costs associated with the irrigation water allocations. The technical constraints define the feasible set of the decisions for the command area of each tank. The first level optimization is by linear programming to achieve the single objective and by linear GOAL programming (Ignizo, 1976) to achieve the multiple objectives for each set of number of tanks and conveyance system combinations. The input to the first level is the coefficient of the constraints and the objective function. To start the iteration, the initial cost of irrigation has been assumed to be zero for the first objective. For the other objectives, the initial value of the investment has been assumed as Rs.100/- (it cannot be assumed to be zero, as the term is in the denominator). In subsequent iterations, actual value obtained from the second level has been taken. The output of the first level will be the area allocation to the various crops under the command area of the different tasks. To execute its optimal policy, the command area needs the information on the variables and the parameters that are not exclusively under its control. These include the catchment area, tank size, cost of the tank, evaporation loss and conveyance cost, indicating the total cost of the tank irrigation. This information will be available on the second level. This optimization model has been found versatile. The alteration in crops affinity constraints does not alter the design parameters of the irrigation system significantly. It was also found to be versatile to take care of any size of tank. The optimal design of the system did not change with a change in the discount rate in the range of 6 to 14%. The design methodology gives a detailed optimal design of a multi-tank irrigation system entailing a number of tanks, their locations, size, dimensions, type of conveyance system, type of application system, area under various crops and their irrigation regimes by accounting all the interacting factors in an integrated manner. Instead of each segment, this methodology takes care of conflicting factors as well as their interdependence. This methodology can be used either for single objective or multi-objective optimization.

c) Design of lined tank

As stated earlier, there are several sites where the seepage lossess are excessive to create an irrigation source through tank. The seepage loss from small tanks in mid hills of Himalayas have been reported to be in the range of 300-400 litres per m^2 per day (VPKAS, 1979). Similar results have been reported from several centers of All India Coordinated Research Project on Dryland Agriculture and All India Coordinated Research Project on Water Management, which indicated that economical water yield is not possible from runoff recycling systems in absence of effective lining of the water harvesting ponds. This led to research work on search of effective and economical lining material for lining of the ponds. Several investigations have reported that the gradual siltation and clogging of soil pores resulted in the development of layers of low hydraulic conductivity on the wetted perimeter. However, this is a very slow and long drawn process especially for small tanks and impedes the economic returns from the tank in early years. Few research workers concentrated on accelerating this process of creating layers of low hydraulic conductivity by adding artificial sediments particularly bentonite clay but not much success has been achieved. Asphalt and concrete lining has been tried but they are generally expensive and have maintenance problems (Laing, 1974). With advent of plastic, flexible membrane emerged as an affordable alternative lining material and many workers used different plastic materials for seepage control with varying degree of success. For selecting the appropriate technology, there is need of revising these experiences for formulating strategies for large scale adoption of these technologies in the field. Butyl rubber membranes, vinyl and polyethylene are three major type of flexible membrane being used for lining. Butyl rubber is extremely flexible and will conform easily to any excavation shape. Butyl pond liners differ from most synthetic rubber liners as it is fully cured and vulcanized product that is non-toxic. Due to this quality this is safe to all wild life and plant life. Its life expectancy is over 30 years and it is chosen for most professionally built water features. The longer life expectancy is a positive feature of this material. Most of the companies give 20 years guarantee of the material. The inlet and outlet pipes can also be integrated with either by clamping between pipe work flanges or by a specially made pipe sleeve for pond liners. However its high cost makes it uneconomical for its use for irrigation purposes, although it is very good for lining for landscaping purposes. Similarly vinyl is quite resistant to the impact damage and is readily seamed and patched with a solvent cement. Mostly it is available in 20 mil for fish grade ponds and 35 mil thickness for larger recreational purposes. Nowadays these materials are being customized to suit specific needs. However the cost makes it uneconomical for its use for irrigation purposes. The most extensively used membrane used for lining is black LDPE film. In India most of the experiments on lining have been done with this material. It is flexible and can adjust to any shape and size. However, because of their weakness, the film must be protected from mechanical damage with a cover. Several methods have been suggested by different workers and agencies for lining of tank/pond with LDPE film. The major area of work are on jointing of the film, side slope and covering material. Verma (1981) based on studies at Hoshiarpur (Punjab) recommended lining of the bottom area by soil covered film and side slopes by brick masonry. This method enabled a steeper side slope of the tanks. IPCL (1980) suggested lining by LDPE film covered by soil on a side slope of 3.5:1. However this design required a larger area/volume ratio. Rao et al. (1980) have suggested a 2:1 side slope with steps having film on bottom and side covered with soil. For joining, all of them used heat sealing method. However, using these designs for hilly terrain, Srivastava (1983) and Srivastava and Tandon (1984) did not find them suitable for use. The recommended method of film jointing by heat sealing also poses problems as it requires an experienced and skilled hand to ensure proper jointing. Moreover, this method was not found suitable for repairing damages caused to the film at the site itself, which are inherent in handling of such material in stony hill areas. Further, the side slope cannot be increased beyond 1:1 in most of the cases as it will increase the area requirement. Major investigations for lining have been reported in hilly ecosystem (Srivastava, 1984; Juyal & Gupta, 1985 and DWMR, 1995), plateau ecosystem (WTCER, 1999 and DWMR, 1996) and island ecosystem (CARI, 2010) for standardization of design of plastic film lined small tanks. While LDPE film was used for hilly (Almora, Dehradun and Palampur) and plateau regions (Bhubaneswar), for island ecosystem at Portblair and Konkan region, silpulin film was used. The technique can be divided into three parts: jointing of film, laying of film, and construction of outlet system. Srivastava (2011) has described this technique for all the three ecosystem.

A single or multi-tank system although successful, often do not arouse confidence among farmers that the water will stay during dry season. As indicated in earlier chapter, 53 to 71% of runoff captured by the tank, command area and catchment area goes to ground water recharge. Since this region has hard rock aquifer, this water does not go much below and moves as sub-surface flow. If this flow is captured through open dug wells downstream of tanks, a reliable source of irrigation can be created. The simulation model (Srivastava, 2001) has also shown that the tanks,paddy fields and catchment area contribute to ground water.

Thus, refining further the technology reported by Srivastava (2001 & 2004a), a technology for micro level water resources development through rainwater management comprising of tanks and wells suitable for small and marginal farmers was conceptualized at Water Technology Centre for Eastern Region (WTCER),Bhubaneswar, Orissa, India (Srivastava *et al*., 2003; Srivastava, 2004 and Srivastava *et al.*, 2004b). In this tank cum well system, the runoff water is collected in the ponds of specific designs. This irrigation water availability facilitates conversion of unbunded upland rice to bunded transplanted rice inducing more rainwater retention in the field. This retention along with the seepage from the tanks recharge the ground water, which can be harvested back through an open dug well. This system will function best when the tanks and wells are constructed in a series.

The study of hydrology of the system showed that the rice fields did not face any moisture stress in both the years even after cessation of monsoon, which was in the last week of September, while the crop outside the command area withered. It was found that the seepage water provided the water availability in the fields and it depended upon location of the field from valley line as well as distance from the embankment. It was maximum near the valley line and reduced on both sides. Also as expected, the water levels reduced with the distance from the embankment. This trend continued until January. This gave an indication that these areas were more suitable for long duration paddy (July-December) with single crop instead of trying another crop in rabi season after harvest of medium duration rice (July-October) in *kharif* season as the fields were not ready for any tillage operation at that time. Thus the system converted the uplands which earlier were not able to fully support even 100 days duration rice crop to become suitable for a paddy crop of 160-180 days duration giving yield of about 5 t/ha.

The water levels in the wells were also monitored. Initially the farmers were not convinced that water will stay in the ponds or wells will not run dry after pumping during rabi season and this inhibited the utilization of water in the first year but in the second year and third year it increased substantially but was still lower than the potential. For evaluation of well yield, pumping tests were carried out in wells during different months to see the effect of the season on the well yield. As these wells are located in hard rock areas without any defined aquifer, the traditional well testing method could not be employed. Therefore the water was pumped from the well with pump being at ground until the water level went below the suction limit. During this period, the water level and discharge were recorded. The amount of water pumped from stored water in well was computed as the area of well multiplied by the change in water level before and after pumping. The difference between total volume of the water pumped and amount of water pumped from stored water was computed as the volume of water pumped from recharged water during that period. After cessation of pumping, periodic recording of the water level in the well was done until it recovered back to its original level. The well with a recharge structure at the upstream side was compared with a well without any recharge structure located in almost similar situation. The water level data showed that in 2001-02, the tank got filled early in July itself due to about 95% above normal rainfall in July. The water level remained at almost full level for monsoon period and started declining after monsoon. In 2002-03, which was a drought year,the water was collected in the tanks from rains in early part of June. Later there was a 40 days dry spell from 17th June to 25th July, which created havoc with the rainfed crops. However, with the water available in the tanks as well as in the open dug wells, the farmers in the command area of these tanks could complete the transplanting as well as beushening of direct sown paddy (Beushening is a practice of paddy cultivation where the direct sown paddy is hoed with standing water). After hoeing the plants are readjusted to proper plant population. This practice kills the weeds and the plant population is made uniform. Rains filled up the tanks again in August. Thus, the system mitigated the effects of the drought, which was also reflected on the yield levels. The studies on water balance showed that out of stored runoff, about 37.1% was lost as seepage, about 14.6% was lost as evaporation and 43.1% was utilized for irrigation. Rest 5.2% remained in the tank for pisciculture, duckery and other domestic uses. Without open dug wells, the ratio of water yield and storage capacity is 0.65 which rises to 0.86 with open dug wells as the water lost as seepage is reharvested back through the open dug wells. The ratio is lower as the farmers did not go for full utilization of potential both in kharif as well as in rabi season. Thus, in short, it can be said that the system mitigated the effect of the drought, changed the hydrology of downstream paddy terraces from uplands to suitable for long duration rice, recharged the ground water and provided sufficient water to the crops.

The pumping data for the well located with a recharge structure (well no. 1) and one without recharge structure (well no. 2) in month of March, showed that the well having no recharge structure is able to provide just about 20 m^3 of water in one pumping session while the well with recharge structure provides about 96 m^3 of water in 2.5 hours after which the water level went below suction limit. Thus the well without recharge structure cannot provide sufficient water required for irrigation. Out of 96 m^3 water pumped, 80% of water came from stored water and 20% came from recharged water during the pumping period. This indicates the need of a larger diameter well, *i.e.*, about 6 m diameter. A small diameter well will not serve the purpose of irrigation.

The recovery process of these two wells after the pumping ended showed that the well in the recharge zone of pond recovered 50% of the pumped water within 25 hours. The recharge rate was faster in initial period but declined with time and then stabilized. The condition was totally different in well without recharge structure. Here the recovery was too slow and thus it can be said that once pumped, it will be able to provide water only after a very long time. The time of 50% recovery as well as the constant rate of recharge for recovery varied in different months. It is on expected lines as the time was least in monsoon months and then increased. Similarly the recharge rate was highest during monsoon months and reduced with time. Thus an open dug well can function as irrigation source only if it is supported by a recharge structure upstream. Hydrological and hydraulic study of the system showed that the tank cum well system is able to provide sufficient water with a quite fair degree of reliability for irrigating the *kharif, rabi* and *summer* crops.

However, the increase in the area under the rabi and summer crops took place only in second year and third year. This happened after the farmers saw the water remaining in the tank and wells in the first year which removed their doubts regarding the dependability of the system in providing the water. Thus, a rainfed farmer will shift to irrigated agriculture only if he is convinced about the dependability of the resource. A properly designed tank cum well system provides that dependability which is evident from the increase in cropping intensity from less than 100% in pre-project period to 126% in second year and 132% in third year. It is expected to increase further in future once the farmers are in position to invest more on seed and fertilizer in the rabi crops. Another factor that is evident is reduction in area of post- monsoon rice, which reduced from 0.8 ha to just 0.1 ha. In the first year, the farmers being the rice eater, the first preference was summer rice. But next year, when they saw benefits in other crops, they shifted to non-rice crops with emphasis being on vegetables. The farmers also went for multiple uses of crops by raising ducks, pisciculture, and planting of horticultural crops like papaya, pumpkin and even pigeonpea. The pigeonpea although was of very small quantity provided an additional intake of protein for these tribal farmers.

Economic Analysis

The economic analysis was done on the basis of incremental benefits achieved due to water resource development cum package of practices. It was found that with 5% increment rate, the IRR is 13.4% at the present level of adoption of technology. Thus even at minimum level, the IRR is about 2.4 % more than the prime lending rate of Indian banks and 3.4% more than the lending rate for agricultural purposes. Thus for these small water resources, even partial utilization gives a better return in comparison to major and medium irrigation systems where the large gap between potential and utilization makes the system uneconomical. At a discount rate of 10% which is the prevalent bank lending rate, the benefit-cost ratio at present level of adoption of the package of practices was found as 3.63 which increase with increase in the level of the adoption of the crop production technology. It is therefore evident that the system is economically sound. However this analysis does not include the cost of labour as there is only family labour involved and it has no opportunity cost at present, but the higher values of IRR and B-C ratio shows that the system will remain a viable financial proposition after accounting the family labour cost also.

Recharge Structure Based Irrigation System

It is not possible always to construct tanks at locations from where the water can be conveyed economically to fields or the suitable sites are not available due to socio-economic reasons. Further the seepage loss can be very high due to which it is not possible to economically design the tank and even lining is not feasible. In such cases, the option of constructing recharge structures and harvesting the recharged water through open dug wells is a better and economical alternative. There are different recharge structures depending upon the requirement and site conditions. Normally three types of recharge structures are used: percolation tanks where space is available for construction; gabion in nala itself where space is not available; and bunding of terraces in valleys to allow more water to percolate.

Design of percolation tanks

Percolation tank is an important conservation structure for runoff management and ground water recharge. It is a multi-purpose conservation structure depending on its location and size, and the stored water can be used for livestock, limited irrigation, besides recharge to the groundwater. It is constructed by excavating a depression to form a small dugout reservoir or by constructing an embankment across a natural ravine or gully to form an impounded type of reservoir. (CRIDA, 1990; and Sivanappan, 2002). However, very little could be found about the design procedures of this structure. At best few guidelines could be found viz., it should not be located in heavy soils or soils with impervious strata, suitable and adequate soil should be available for forming embankment, ideal location will be on a narrow stream with high ground on either side of the stream, and simple economic and efficient surplus arrangement should be possible. About size of the pond, it is mentioned that it should be decided on the basis of the catchment area and number of fillings possible for the pond (Samra et al., 2002). In view of lack of work on standardization of design parameters of this structure, most of the time these tanks are either over designed or under designed. Since this structure is being constructed in large numbers under watershed management programme, this shortcoming in the design leads to either poor performance or loss of the money. To overcome this problem a methodology for design of percolation tank has been developed (Srivastava et al., 2007a). For better adoption of this methodology, software 'SODEPT' (software for design of percolation tank) has been developed by Srivastava et al.(2007b). The design parameters of the percolation tank and amount of water recharged to ground water during different months depend upon the area of the catchment of the reservoir, hydrological cover complex characteristics of the catchment,rainfall characteristics of the area, evaporation loss and seepage rate of the tank bed. Since rainfall and evaporation are stochastic variables, their distribution should also be accounted for.

Based on these mathematical formulations, computer software was developed for this simulation. The input data required for the program are rainfall and evaporation data, constants of seepage equation for the tank site, catchment area, weighted curve numbers for all the three antecedent moisture conditions for the catchment area. The other parameters will vary as per the site conditions. Width, length and maximum depth of excavation at the tank site for first type of site condition, and width, maximum permissible height of embankment, and bed slope of the drainage way/gully for the second type of site condition. To initialize the simulation, values of W, L and H were taken as per the site condition or in such a way that total volume is equal to approximate annual runoff. After first iteration, the new values of W and H are taken and the iteration is made till convergence of ± 5% in storage capacity 'VT' is achieved. Once convergence is achieved, the following parameters will be available in output: i) The total storage capacity of the tank (VT), m^3; ii) The amount of earthwork (V1), m^3; iii) Top width of tank/gully (W), m; iv) Total depth of the tank (H), m; v) Free board (F), m; vi) Top width of embankment (T), m; vii) Depth of excavation (h1), m; viii) Height of embankment (h2), m; ix) Total area occupied by tank (At), m^2; x) Total amount of recharge (TR), m^3; xi) Amount of recharge in monsoon season (MR), m^3; xii) Amount of recharge in post monsoon season (PMR), m^3; xiii) Investment required per unit recharge (INV), Rs/ m^3.

Conclusion

Well designed rain water management system can provide reliable irrigation to a two crop rotation in region receiving more than 750 mm rainfall in general and more than 1100 mm rainfall in particular. Unfortunately, most of the high rainfall area are also home to south Asia's most poor people. Providing micro level water resources without any damage to environment will be very effective to poverty alleviation through agriculture having reliable yields and enhanced incomes.

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New Tools and Best Bet Options for Efficient Management of Soil and Water Resources in Drylands of Asia

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The dry areas of the developing world occupy about 3 billion hectares and are home to 2.5 billion people: 41% of the earth's land area and more than one-third of its population. About 16% of this population lives in chronic poverty. Drylands have limited natural resources. They already face serious environmental constraints, which are likely to worsen as a result of climate change. Agricultural production systems in dry areas are over-stretched. Dryland systems are characterized by persistent water scarcity, rapid population growth, frequent droughts, high climatic variability, land degradation and desertification, and widespread poverty. To ensure the future livelihoods of dryland farming communities, it is critical to manage risk more effectively and enhance productivity through efficient management of soil and water resources and sustainable intensification of production systems. In most developing countries, the problem of soil and water resource degradation have been in existence in the past also, however, the pace of degradation has greatly increased in recent times due to burgeoning population and the enhanced means of exploitation of natural resources. There is urgent need to implement the best bet options available for the soil and water conservation. This paper discusses some of the field- and community-based soil and water conservation options that were found promising for improving productivity and reducing runoff and soil loss. The strategies for improving the adoption of soil and water conservation practices by farmers is also discussed. The adequate availability of the hydrological data, which are critical for the proper planning and design of soil and water interventions are lacking in most regions. This paper discusses few new tools, which could be used to collect or generate such information required for effective planning and design of soil and water conservation interventions.

New Tools for Monitoring and modeling Hydrological Parameters

The data on runoff volume, peak runoff rate, soil loss and other related parameters are needed for the proper planning and designing of soil and water conservation interventions. New tools for monitoring and modeling hydrological parameters are discussed below.

Soil loss measurement from agricultural fields/watersheds

The monitoring of soil loss and sediment flow from the agricultural fields/watersheds is a complex and difficult task. There are very few standard equipments available in the market, which can be used for measuring the soil loss from the small agricultural watersheds. Some of the serious problems with commonly used methods and some new developments (Pathak, 1991 and Pathak and Sudi, 2004), which have been made at ICRISAT Center for monitoring soil loss and sediment flow from the small agricultural watersheds are discussed below.

Manual sampling

In most developing countries, manual sampling is still the most commonly used method for monitoring sediment flow from the small agricultural watersheds. However, there are some serious problems with this method. The extreme variation in sediment concentration during the runoff events makes this method totally inappropriate for monitoring sediment from small agricultural watersheds **(Fig. 1).**

Due to these extreme variations in sediment concentration the expected error in estimating the soil loss could be extremely high and are often found in the range of ±30 to 420% that of actual soil loss. Also operationally it is very difficult to collect the runoff samples at the right time particularly during high rainfall events. This makes the data collected by manual method highly unreliable and often useless. Therefore the manual method of runoff sampling is not recommended for monitoring soil loss from the small agricultural watersheds.

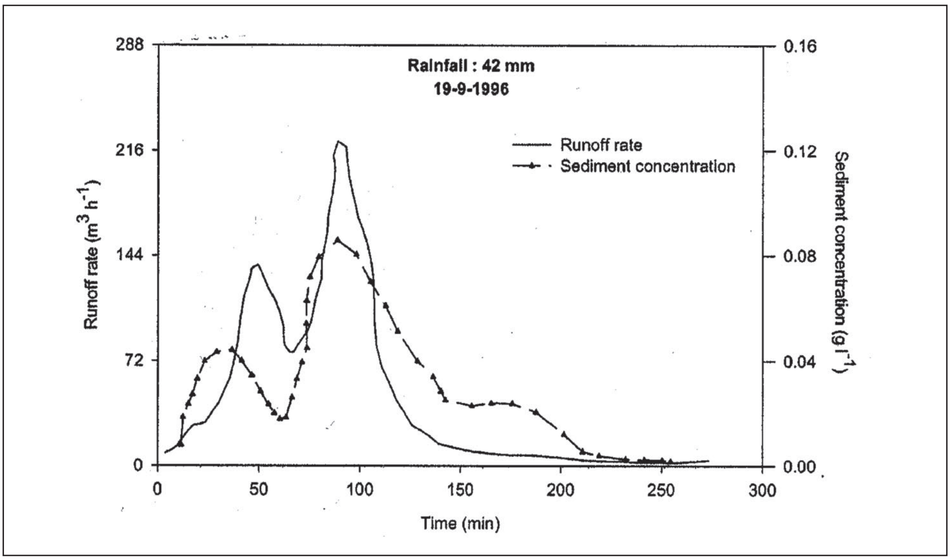

Fig. 1 : Sediment concentration variation with time during one runoff event at BW7 watershed, ICRISAT Center, Pantancheru, A.P., India (Pathak et al., 2004)

Microprocessor-based automatic sediment sampler

The microprocessor-based automatic sediment sampler can be used to measure soil loss as well as temporal changes in sediment movements during the runoff hydrographs from the agricultural Plots watersheds. At ICRISAT a micro-processor based automatic sediment sampler **(Fig. 2)** has been developed for small agricultural watersheds (Pathak and Sudi, 2004).

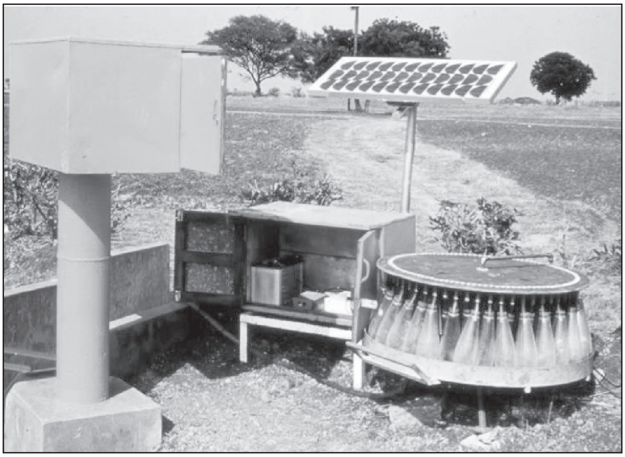

Fig. 2 : Micro-processor based automatic sediment sampler

This sediment sampler consists of circular sample collection unit fitted with DC shunt motor and bottles, microprocessor-based control unit **(Fig. 3),** 12v 55 Amph battery, bilge submergible pump, water level sensors, and solar panel (optional for recharging 12v battery).

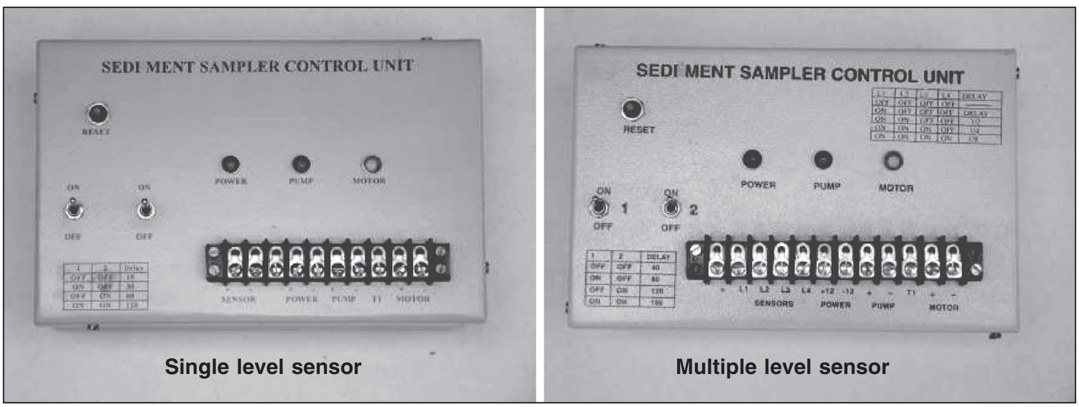

Fig. 3 : Single and multiple level sensors of control unit

Salient features of the Sediment Sampler are as follows:

- Fully automatic runoff samples collection
- Samples can be collected at required time interval (15, 30, 60 and 120 minutes or any desired time intervals) as well as at required flow depths
- Can be used for soil loss estimation as well as temporal distribution of sediments during runoff hydrographs
- The 8748 microprocessor-based controller is used which can be reprogrammed easily
- Suitable even for the remotely located gauging station as well as small to medium size watersheds (1-5000 ha)
- Accurate and reliable data acquisition
- Simple and easy to operate
- Efficient and cost-effective

Runoff measurement from small agricultural watersheds

Accurate determination of runoff volume, peak runoff rate, and other related information from small and medium areas invariably requires the continuous recording of the water level. Stage-level recorders are commonly used for this purpose. Many types of stage-level recorders are commercially available. They can be broadly classified into two types: mechanical type and digital type stage-level recorders.

Mechanical stage-level recorder

In developing countries mechanical type runoff recorders are most commonly used for monitoring runoff **(Fig. 4).** There are several operational problems with the mechanical type runoff recorders. The most common problems are related to clock functioning, gear set functioning, pen and its marking on charts. The processing of data from chart is very time consuming and the recorder needs continuous monitoring.

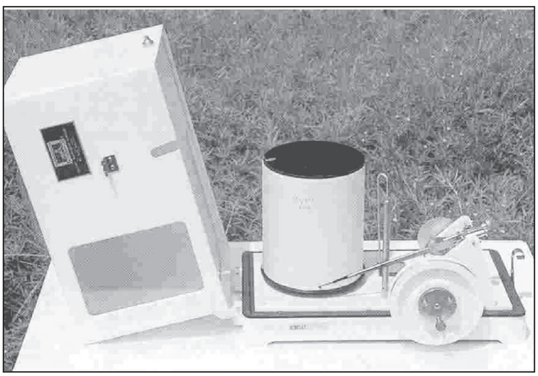

Fig. 4 : A drum-type mechanical runoff recorder

Digital automatic stage-level recorder (Thalimedes)

Thalimedes is a float operated shaft encoder with digital data logger which can be used to continuously monitor the runoff from the watershed/field **(Fig. 5).** It is easy to handle and its cost-effective ratio makes it an appropriate device for modernization of existing mechanical chart-operated stage-level recorder monitoring stations (Pathak, 1999).

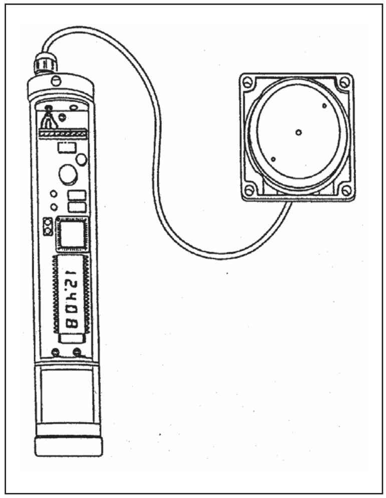

Fig. 5 : Digital runoff recorder

Integrated digital runoff recorder and sediment sampler device

An Integrated digital runoff recorder and sediment sampler device have been developed by ICRISAT Scientists in collaboration with Farm and Engineering Services at ICRISAT (**Figs. 6 and 7**). The main feature of this new equipment is that all the operations (viz. runoff recording, sediment sampler operation and solar panel controller etc.) are controlled by one single micro-processor unit. The unit can store the data up to 130,000 records in 1 MB flash memory, which has a ring memory system. The complete unit works on a 12 v battery with solar panel to recharge it. Even during the emergency power operation or main battery failure, runoff recording is done with its backup battery. This integrated unit makes the calculation of runoff and soil loss very easy and accurate. It is also very cost - effective.

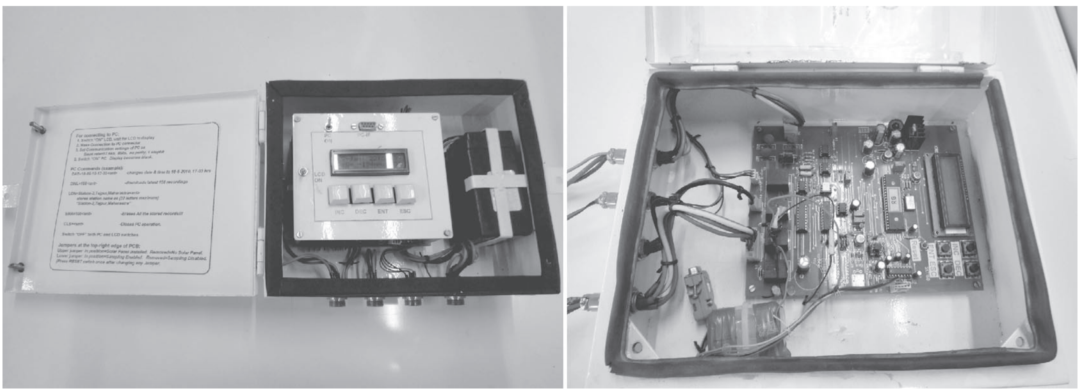

Fig. 6 : Integrated digital runoff recorder and sediment sampler device

Salient features of integrated runoff and soil loss unit

- It is low-cost, easy to handle and accurate data collection equipment
- It is micro-processor based data logger with shaft encoder

- Digital LCD of measured level, date, time and battery status
- Even during the emergency power operation or main battery failure, runoff recording is done with its backup battery
- Stores data up to 130000 measured values with ring memory system
- Programmable setting of sampling and logging intervals from 1 min to 24 h (flexibility not possible with mechanical recorders)
- Less moving parts; no problem due to gear/clock and chart mechanism
- Compact, rugged and light weight equipment
- Suitable for remotely located gauging stations and require minimum maintenance

Fig. 7 : Integrated digital runoff recorder and sediment sampler device (New microprocessor is shown in inset)

Hydrological Models for Proper Planning and Assessing the Impact of Soil and Water Interventions

The long-term hydrological data at the watershed scale are generally not available in most regions of India. The hydrological models can be effectively used to generate such data, which can be used for the planning and design of various watershed interventions. These models can also be used to assess the long-term impact of watershed program on soil and water resources. Some of the hydrological models developed at ICRISAT are discussed below.

Simple Runoff and Water Balance Models

Information on surface runoff is needed in the planning and design of soil and water management system. For example, it is needed in the design of soil conservation structures, runoff harvesting and groundwater recharging structures, drains and other interventions. Runoff models can be used to generate this vital information. Some of the simple hydrological models, which have been developed at ICRISAT for small agricultural watersheds, are described here.

RUNMOD Runoff Model: A parametric simulation model was developed to predict runoff from small agricultural watersheds (Krishna, 1979). The input data for it are the daily rainfall amount, storm duration or rainfall intensity, pan evaporation, and soil moisture. By means of a univariate optimization procedure, measured runoff data are used to determine the proportion of rainfall that infiltrates and the part that runs off. Once these parameters are determined for a particular soil and land management treatment, they can be applied directly to other watersheds of similar cover, topography, and moisture storage and transmission properties for predicting runoff and other water balance components.

SCS Curve Runoff Model: A runoff model based on a modified SCS curve number technique and on soil moisture accounting procedure was developed for small watersheds in the semi-arid tropics (Pathak et al., 1989). In this model, certain soil characteristics which have strong influence on runoff such as cracking and land smoothing are included. The model uses one day time intervals and needs simple inputs, which are normally available such as: daily rainfall, pan evaporation, canopy cover coefficient, soil depth, initial soil moisture, moisture at wilting point and field capacity. The main outputs are daily runoff volume and soil moisture. The model has four input parameters which are estimated through calibration using measured runoff and soil moisture content data. Once the parameters are determined for a particular soil and land management system, they can be used to predict runoff and soil moisture form other ungauged watersheds with similar soils and management systems.

Tests with data from three small watersheds at ICRISAT Center in India show that the model is capable of simulating daily, monthly, and annual runoff quite accurately. It is also able to simulate satisfactorily the daily moisture. The biggest advantage of this model appears to be its simplicity and accuracy. Also since this model is linked to SCS curve numbers, its use and applicability is quite wide.

Runoff Water Harvesting Models

A Runoff cum water harvesting model was developed (Pathak et al., 1989, Ajay Kumar, 1991) to simulate the daily runoff, soil moisture and water availability in the tank. This model has two main components, the first component predicts the daily runoff and soil moisture and second component calculates the daily water balance in the tank... This model has been extensively used in different regions of India for calculating various parameters for water harvesting. For example, this model was used to assess the runoff potential from three watersheds in Andhra Pradesh viz. Nandavaram, Sripuram and Kacharam. Probability analysis applied to the results obtained from runoff model. Probabilities of getting 20, 40, 60 and 100 mm of simulated runoff were done based on the 26 years of climatic data **(Fig. 8).**

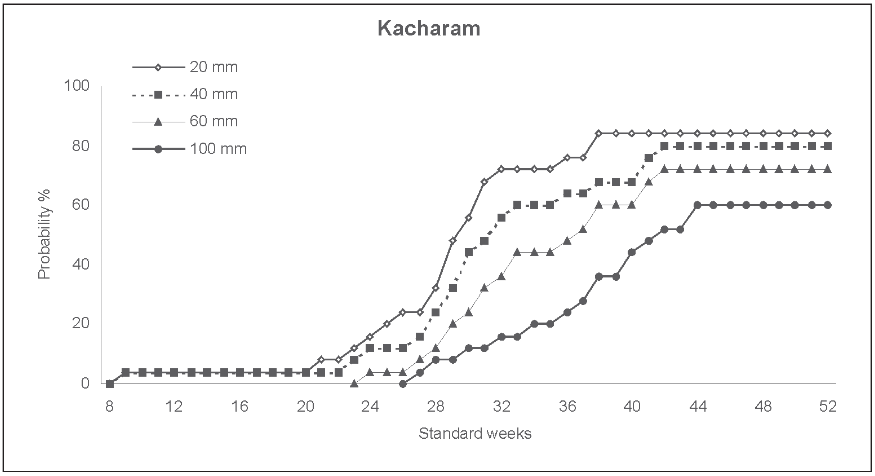

Fig. 8 : Probabilities of obtaining 20, 40, 60 and 100 mm cumulative runoff in Kacharam watershed (based on 26 years of simulated data)

Considerable information on various aspects of runoff water harvesting could be obtained by using the runoff and water harvesting models. These models can assess the prospects of runoff water harvesting. It can also be used to estimate the optimum tank size, which is very important for the success of the water harvesting system.

The runoff and water harvesting model can be used for following objectives:

- To assess the prospects of runoff water harvesting and groundwater recharging and its utilization for agriculture
- To assess the probabilities of getting different amounts of irrigation water in the tank
- To assess the conditional probabilities of getting different amounts of irrigation water in the tank
- To find out optimum tank size and other design parameters
- To develop strategies for scheduling supplemental irrigation

Digital Terrain Model (DTM)

The automation of terrain analysis and use of digital elevation models (DEM) have made possible to easily quantify the topographic attributes of the landscape and to use topography as one of the major driving variables for many hydrological models. These topographic models, commonly called as digital terrain models (DTMs). The DTMs include the topographic effect on the soil water balance and coupled with a functional soil water balance to spatially simulate the soil water balance. ICRISAT in collaboration with Michigan State University, USA, developed a SALUS-TERRAE, a digital terrain model (Bruno Basso et al., 2000), which can be used at the landscape level. Few of the outputs from the model are shown in **Fig. 9.** These digital terrain models are extremely useful for the watershed programs. However, their major bottleneck is on the accurate availability of topographic data.

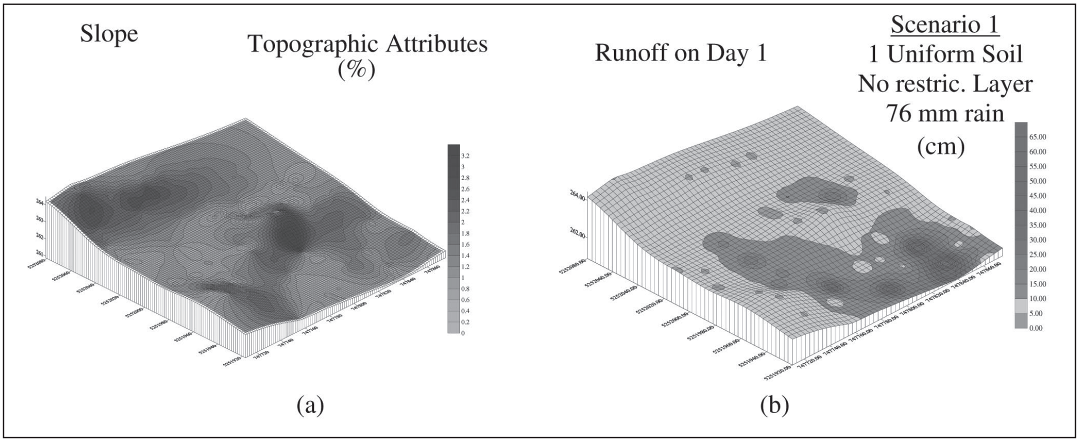

Fig.9 : (a) Slope levels in a landscape (b) Runoff at day 1 and its ponding at landscape level

Best Bet Options of Soil and Water Conservation

Soil and water conservation measures are important for effective conservation of soil and water. The main aim of these practices is to reduce or prevent either water erosion or wind erosion, while achieving the desired moisture for sustainable production. The suitability of any soil and water management practices depends greatly upon soil, topography, climate, cropping system and farmers resources. Some of the promising *in-situ* and *ex-situ* soil and water conservation practices are discussed below:

Field Based Soil Land Water Conservation

Contour Cultivation and Conservation Furrows

In several rainfed regions, the up and down cultivation is still a common practice. This results in poor rainfall infiltration and accelerated soil erosion. Contour cultivation or cultivation across the slope is a simple method of cultivation, which can effectively increase rainfall infiltration and reduce runoff and soil loss on gently sloping lands. The contour cultivation involves performing cultural practices such as plowing, planting and cultivating on the contours. It creates a series of miniature barriers to runoff water when it flows along the slope.

In most situations the effectiveness of the contour cultivation can be greatly enhanced by adding conservation furrows into the system. In this system in addition to contour cultivation, a series of furrows are opened on contour or across the slope at 3.0-7.5 m apart **(Fig. 10).** The spacing between the furrows and its size can be chosen based on the rainfall, soils, crops and topography (Pathak et al., 2009). The furrows can be made either during planting time or during interculture operations using traditional plough. Generally, two passes in the same furrow may be needed to obtain the required furrow size. These furrows harvest the local runoff water and improve soil moisture in the adjoining crop rows, particularly during the period of moisture stress. One of the major advantages of this system is that it provides stability to contour cultivation particularly during moderate and big runoff events. Using the farmer participatory approach, Pathak et al. (2009) reported on the performance of the practices followed by farmers (flat cultivation) as compared with contour cultivation along with conservation furrows based on the results of 121 trails conducted in the farmers' fields in four districts of Karnataka during 2006-08 **(Table 1).** Contour cultivation along with the conservation furrows was found promising both in terms of increasing crop yields and better adaptation by farmers. This land and water management system increased the crop yields of maize, soybean and groundnut by 16-21% over the farmers practice.

Groundnut crop with conservation furrow **Formation of conservation furrows using local implements**

Fig. 10 : Conservation furrow system at Hedigonda watershed, Haveri, Karnataka, India.

Table 1 : Crop yields (t ha^{-1}) in different land water management systems during 2006-08 at Sujala watersheds in different districts of Karnataka, India.

District	Crop	Yield with farmers' practice	Yield with Contour cultivation with conservation furrows	Increase in yield (%)
Haveri	Maize	3.35	3.89	16
Dharwad	Soybean	1.47	1.80	23
Kolar	Groundnut	1.23	1.43	16
Tumkur	Groundnut	1.25	1.50	21
	Finger millet	1.28	159	24

Source: Sujala-ICRISAT watershed project, Terminal Report (2008)

Broad-bed and Furrow and Related Systems

On soils such as Vertisols, the problem of waterlogging and water scarcity occurring during the same cropping season is quite common. For such situation, there is a need for an *in-situ* soil and water conservation and proper drainage technology that can protect the soil from erosion through out the season and provide control at the place where the rain falls. A raised land configuration "Broadbed and furrow" (BBF) system has been found to satisfactorily attain these goals **(Fig. 11).**

BBF formation with tropicultor **Groundnut crop on BBF**

Fig. 11 : The broadbed and furrow system at the ICRISAT Center Patancheru, Andhra Pradesh, India.

After perfecting the BBF system at the ICRISAT Center Patancheru, India this technology was taken up for a large scale adoption by farmers in Madhya Pradesh. Total 140 farmers in 17 villages conducted action research-cum-demonstrations on enhancing water use efficiency (WUE) through increased crop yields during 2007-2009. Significantly higher crop yields were recorded in the improved management system compared to farmer's practice **(Table 2).** The average soybean productivity increased by 24% due to improved technology.

Table 2 : Mean Soybean yield in BBF and traditional management system in Madhya Pradesh during 2007-09.

District	Soybean grain yield (t ha^{-1})		Increase over farmer's practice (%)
	BBF System	Farmer's practice	
Guna	1.7	1.46	16
Raisen	2.28	1.56	45
Vidisha	2.23	1.72	30
Indore	2.90	2.51	15
Sehore	2.50	2.09	19
Mean	2.32	1.87	24

Source:Report on water use efficiency project, (2009) Some of the major benefits of the semi - permanent BBF system are:

- The raised bed portion acts as an *in-situ* 'bund' to conserve more moisture and ensures soil stability; the shallow furrows provides good surface drainage to promote aeration in the seedbed and root zone; prevents water logging of crops on the bed.
- The BBF design is quite flexible for accommodating crops and cropping systems with widely differing row spacing requirements.
- Precision operations such as seed and fertilizer placement and mechanical weeding are facilitated by the defined traffic zone (furrows), which saves energy, time, cost of operation and inputs.
- Can be maintained in the longer- term (25-30 years)
- Reduces runoff and soil loss and improves soil properties over the years.
- Facilitates double cropping and increases crop yields.

Tied Ridges and Scoops

Tied ridges or furrow diking is a proven soil and water conservation method under both mechanized and labor-intensive systems, and is used in many rainfed areas of the world. Tied ridging results in the formation of small earthen dikes or dam across the furrow of a ridge furrow system. It captures and holds runoff water in place until it infiltrates into the soil. Tied ridges are most effective when constructed on the contour. Under mechanized systems, the furrow dykes are usually destroyed by tillage operations and need to be reconstructed each season. They also obstruct cultivation and other field operations.

Scoops have been extensively used in the Asian, Australian and African SAT as an *in-situ* soil and water conservation system. Scoops on agricultural land involve the formation of small basin depression at closely spaced interval to retain runoff water and eroded sediments from rainstorm **(Fig.12).** The scoops can be made manually or by machine. The commonly used machine for making scoops is tractor drawn chain diker equipment, which is extensively used in different countries.

Fig. 12 : Scoops with sorghum crop on an Alfisol, ICRISAT Center, Patancheru, India.
Source: Pathak and Laryea (1995)

Bunding

Bunding is one of the most commonly used methods for the conservation of soil and water on agricultural lands. A bund is a mechanical measure where an embankment or ridge of earth is constructed across a slope to control runoff and minimize soil erosion. Some of the most commonly used bunding systems are given below:

- Contour bunding
- Modified contour bunds
- Graded bunding
- Field bunding
- Compartmental bunding
- Vegetative bunds

Vegetative barriers or vegetative hedges or live bunds of conservation have drawn greater attention in recent years because of their long life, low cost and low maintenance needs. In several situations, the vegetative barriers are more effective and economical than the mechanical measures viz. contour and graded bunds. Vegetative barriers can be established either on contour or on moderate slope of 0.4 to 0.8%. In this system, the vegetative hedges acts as a barrier to runoff flow, which slows down the runoff velocity, resulting in the deposition of eroded sediments and increased rainwater infiltration. It is advisable to establish the vegetative hedges on small bund. This increases its effectiveness particularly during the first few years when the vegetative hedges are not so well established.

In Northeast Thailand, Vetiver hedge and semi-circular vetiver rings around the plants have been successfully used for efficient soil and water conservation **(Fig. 13).** Horticultural plants have been extensively used as vegetative barriers for controlling soil erosion and conserving rainfalls **(Fig.14).**

Tillage

Tillage on such poor soils helps to increase pore space and also keeps the soil loose so as to maintain higher level of infiltration. Laryea et al. (1991) found that cultivation of the surface greatly enhanced water intake of soil particularly in the beginning of rainy season. In the absence of cultivation, the highly crusting Alfisols produce as much or even more runoff than the low permeable Vertisols under similar rainfall situations. Larson (1962) stated that pulling a tillage implement through soil results in the total porosity and thickness of the tilled area being greatly increased temporarily. Surface roughness and micro depressions thus created play greater role in higher retention of water. On many SAT soils, intensive primary tillage has been found necessary for creating favourable root proliferation and enhancing rainfall infiltration. The positive effects of deep tillage on rainwater conservation, better root development and increased crop yields were observed for 2 to 5 years after deep tillage, depending on the soil texture and rainfalls. On Alfisols,

Fig 13 : Vetiver hedge as field bund and Semicircular *vetiver* rings around plants for effective soil and water conservation measure at Tad Fa watershed

Fig. 14 : Cultivation of annual crops with horticultural plants and banana with fruit trees as crop diversification, Tad Fa watershed, Thailand

the off-season tillage serves several useful purposes and should be done whenever feasible. The off-season tillage has been found to minimize the loss by evaporation of stored water by "mulching" effect and thus allowing the acceleration of planting operations and extension of the growing season (Pathak et al. 1987).

In recent times the Zero tillage/minimum tillage/conservation tillage has gained considrable attention. In many regions it has been found to reduce production costs, greatly reduce energy needs, ensure better soil water retention, reduce runoff, water and wind erosion, ensures little or no damage from machinery and save labour (Young, 1982). However, the success of mechanized conservation tillage depends largely on herbicides (which may be expensive and hazardous in nature for use by the resource-poor farmers of the SAT). Crop residues being left on the soil surface to protect it against the impact of torrential rains, and no-till planting equipment to allow precision sowing through trash. Unfortunately, most of the farmers in the SAT use crop residues to feed their animals and to construct fences and buildings. In most parts of semi-arid India, animals are allowed to roam freely on the field after crops have been harvested. Consequently, most of the residue left over is consumed by these animals (Laryea et al., 1991).

Community Based Water Harvesting and Soil Conservation Structures

The community based soil and water conservation can play key role in improving surface and groundwater availability and controlling soil erosion. Studies have shown that the cost of water harvesting and groundwater recharging structures varies considerably with type of structures and selection of appropriate location. Some of the most promising community based soil and water conservation measures are discussed below:

Masonry Check Dam

Masonry check dams are permanent structures effectively used for controlling gully erosion, water harvesting and groundwater recharging **(Fig. 15)**. These structures are popular in watershed programs. The cost of construction is generally quite high. The cross-section of dam and other specifications are finalized considering the following criteria: there should be no possibility of the dam being over-topped by flood-water, the seepage line should be well within the toe at the downstream face, the upstream and downstream faces should be stable under the worst conditions, the foundation shear stress should be within safe limit, proper spillway should be constructed to handle the excess runoff and the dam and foundation should be safe against piping and undermining. Some of the benefits of this type structures are:

- Long lasting structures with little regular maintenance.
- Effective in controlling gully and harvesting water under high runoff flow condition.

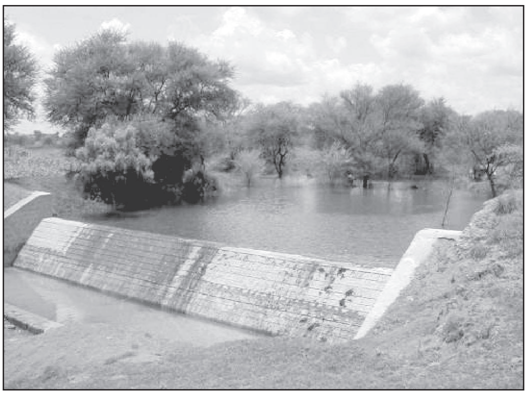

Fig. 15 : A masonry check dam at Kothapally watershed, Ranga Reddy, Andhra Pradesh, India.

Low-Cost Earthen Check Dam

Earthen check dams are very popular in the watershed programs for controlling gully erosion and for harvesting runoff water **(Fig. 16).** These are constructed using locally available materials. The cost of construction is generally quite low. Some of the major benefits of earthen check dam are:

- These structures serve as water storage and recharging groundwater
- These structures can be constructed using locally available materials
- Simple in design and can be easily constructed by local community
- These structures are of low-cost as well as cost-effective in recharging per unit volume of water.

Fig.16 : Earthen check dam at Lalatora watershed, Vidisha, Madhya Pradesh, India.

Farm Ponds

Farm ponds are very age old practice of harvesting runoff water. These are bodies of water, made either constructed by excavating a pit or by constructing an embankment across a watercourse or the combination of both **(Fig.17).**

Farm pond size is decided on the basis of expected runoff and the total requirement of water for irrigation, livestock and domestic use. Once the capacity of the pond is determined, the next step is to determine the dimensions of the pond. To achieve the overall higher efficiency, the following guidelines should be adopted in the design and construction of farm ponds:

Fig. 17 : A dugout farm pond at Guntimadugu watershed, Kadapa, Andhra Pradesh, India.

High-Storage Efficiency (ratio of volume of water storage to excavation): This can be achieved by locating the pond in a gully, depression, or on land having steep slopes.

Reduce the Seepage Losses: This can be achieved by selecting the pond site having subsoils with low saturated hydraulic conductivity.

Minimize the Evaporation Losses: As far as possible, the ponds should be made deeper but with acceptable storage efficiency to reduce water surface exposure and to use smaller land area under the pond.

Gully Checks with Loose Boulder Wall

Loose boulder gully checks are quite popular for controlling gully erosion and for increasing groundwater recharge **(Fig.18)**. These are very low cost structures and quite simple in construction. These gully checks are built with loose boulder only, and may be reinforced by wire mesh, steel posts, if required for stability. Some of the key benefits of these structures are:

- Low-cost and simple in construction with the locally available materials
- These are effective in controlling gully and improving groundwater

Fig. 18 : Series of loose boulder wall gully checks at Bundi watershed, Rajasthan, India.

Improving Adoption of Soil and Water Conservation Practices

In seeking workable conservation prescriptions, research institutions, governments and aid agencies should cooperate closely and fully with local farmers, extension personnel, and community leaders. Such an approach permits information exchanges about what already works well, what might work well, and what would be required to make proposed new soil and water conservation techniques feasible and acceptable. Some of the key points, which can facilitate the greater adoption of soil and water conservation techniques, are:

Short-Term and Visible Benefits To Farmers: Profitability is assessed in the context of financial return to investment, savings in time and labor, modifications needed in the management of farm activities to integrate innovations, increased risk of failure associated with adoption, and many other factors. Unless the economic return associated with adoption is high enough to compensate adopters for all of these costs, farmers will not adopt any recommended technologies. They evaluate all soil and water conservation technologies and techniques in the context of short-run and long-run return to investment. Conservation practices that produce short-run benefits will be more readily adopted than conservation technologies and techniques that produce only long-term benefits.

Participatory Research cum Demonstration: Participatory research cum demonstrations is useful to show potential adopters that soil and water conservation technologies and techniques are appropriate for farming systems. Field demonstrations are also useful to show potential adopters the type of technical skills they must possess to effectively implement recommended soil and water conservation programs on their farm. Before adoption of technology by farmers is expected to take place, the technology must be adequately demonstrated in terms of its benefits as well as its limitations. Farmers must have enough time to assess the improved technology and compare this with what they have become familiar and have been practicing for a long time.

Greater Emphasis to Rainwater Management and Increasing Crop Yields: Increased emphasis should be given to rainwater management. This will enhance the adoption of soil and water conservation practices by farmers. This will provide both short (from moisture conservation) and long-term (from the soil conservation) benefits to the farmers.

Selecting the Appropriate Technologies with Full Technical and Other Assistance: Identify the right soil and water conservation technology as per their socio-economic conditions and which give farmers both short and long-term benefits. Also provide all the assistance and other help including capacity building in effectively implementing the technology.

Encourage More Farmers-to-Farmers Transfer: This facilitates the adoption of new soil and water conservation technologies.

Government Policy to Promote Adoption: Government policy has a very important role to play in the adoption of new practices. For example, in China, terracing has been promoted by the governments as the main soil and water conservation practice for which subsidies are provided.

Technology Which Reduces Risk: Small farmers tend to avoid adopting technologies and techniques that increase the level of risk.

Integrated Watershed Approach: Implementation of soil and water practices in integrated watershed mode for greater impact and increased adoption.

Capacity Building: Important for effective implementation of new technology in the fields.

Increased Farmers' Perception of Environmental Problems and Their Effects: Perception of soil erosion does not mean that farmers are motivated to reduce it. Farmers, without assistance, cannot be expected to know that the erosion of fine, nutrient rich particles of soil reduces soil fertility. Farmers' awareness of environmental problems has been one of the most important factors to affect adoption and continued use of soil and water conservation technologies and techniques at the farm level.

Conclusion

Most rainfed regions are facing multi-faceted problems of land degradation, water shortage, acute poverty and escalating population pressure. Clearly there is an imbalance between natural resources, population and basic human needs in most rainfed regions. Fast deterioration of natural resources is one of the key issues, threatening sustainable development of rainfed agriculture. For improving agricultural production and livelihoods, soil and water resources have to be managed efficiently in sustainable manner.

Improved and appropriate soil and water management practices are most important in the rainfed areas. For both *in-situ* and *ex-situ* soil and land water conservation practices such as conservation furrows, tied ridges, scoops, broadbed and furrow system, bunding, vegetative barriers, tillage systems, check dams and others, considerable body of research knowledge and experiences exist. The real challenge is to identify appropriate technologies, implementation and execution strategies for different rainfed regions. The adoption of soil and water conservation practices is still a major problem in most rainfed regions. Clearly these technologies require new strategies greater and sustained support from the implementing agencies than generally required for other improved agricultural technologies viz. varieties, fertilizers and others.

In most developing countries the availability of adequate hydrological data at the watersheds scale are lacking. This results in higher development costs, less impact and often failure of the structures and other soil and water management interventions. Some of the new equipments/tools, which can be used for monitoring runoff and soil loss viz. digital runoff recorder. Microprocessor-based pumping type sediment sampler and integrated runoff and soil loss monitoring unit are discussed. Some of the key salient features of these equipments in terms of accuracy, reliability and cost-effectiveness are also covered. It was found that the most commonly used method of manual sampling is not suitable for estimating soil loss. This method is found to be highly unreliable and inaccurate. Among the various sediment samplers the microprocessor-based automatic sediment sampler is found to be highly reliable and accurate for monitoring soil loss from small agricultural areas. Recently ICRISAT has developed an integrated unit for monitoring runoff and soil loss from the small agricultural watersheds.

Hydrological models are useful for planning, design and assessing the long-term impact of soil and water interventions and generating long-term hydrological data for the new areas. Some of the hydrological models developed at ICRISAT, which can be used for small agricultural watersheds are discussed. These include a parametric runoff model "RUNMOD", modified SCS curve number runoff and water balance model, and a runoff water harvesting model. Results have shown that considerable information on the various aspects of runoff water harvesting, groundwater recharging and field-based soil and water management interventions can be obtained by using these models. The information generated from these models can greatly assist in the proper planning, development and management of land and water resources.

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Sustainability of Rainwater Management Practices for Rainfed crops under different Agro-ecological Sub-regions of India

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The All India Coordinated Research Project for Dryland Agriculture is a network program in Central Research Institute for Dryland Agriculture (CRIDA) under Natural Resource Management (NRM) Division of Indian Council of Agricultural Research (ICAR). The network has 25 centers (**Fig.1**) viz. twenty centers in State Agricultural Universities, two in technical/other Universities and three in ICAR institutes. The mandate of the centers is to : (i) optimize the use of natural resources, i.e., rainfall, land and water, and to minimize soil and water loss and degradation of environment; (ii) evolve simple technologies to increase crop productivity and viability; (iii) increase stability of crop production over years by providing improvements in NRM, crop management systems and alternate crop production technologies matching weather aberrations; (iv) develop alternate and sustainable land use systems; and (v) evaluate and study transferability of improved

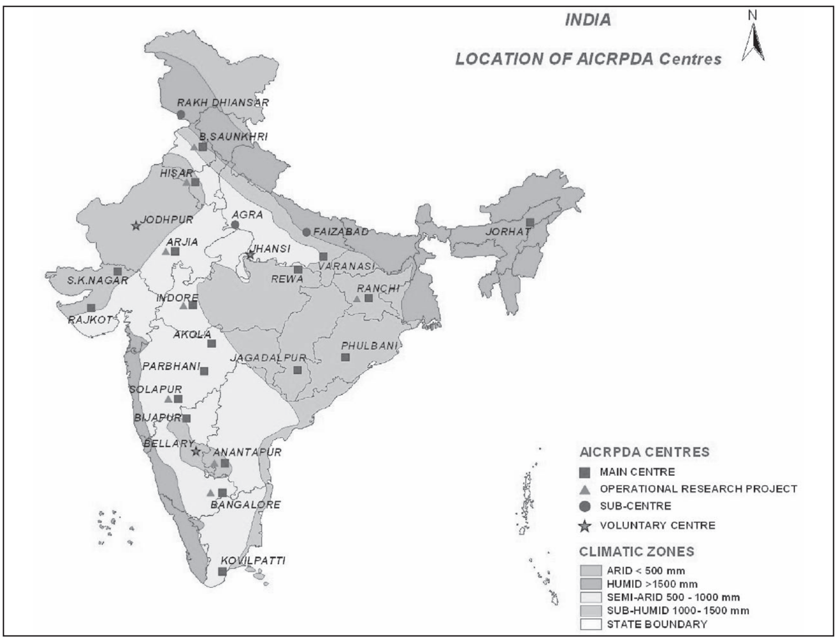

Fig. 1 : Location of AICRPDA centers

dryland technology to farmers' fields. The AICRPDA network also has 8 Operational Research Projects (ORPs) with the main objectives of (i) evaluating the performance of each component of dryland technology under the farmers management conditions; (ii) providing feedback to the research stations for refinement of the recommendations; and (iii) achieving a first hand working experience in the development of micro-watersheds so that they may serve as models for extension agencies. The agro-ecological setting of AICRPDA centers with details of SAU/ICAR institutes, ACZ/AESR, climate, soil type and production system are given in **Table 1**.

Table 1 : Agro-ecological setting of AICRPDA Network Centers

Name of the Centre	SAU / ICAR Institute/ Others (Hqrs)	Agro-Climatic Zone (NARP) / Agro – ecosub region (AESR)	Climate**	Mean Annual Rainfall (mm)	Dominant Soil Type	Major Rainfed Crop based Production System
Agra (SC)	RBSC, Agra	South - western semiarid zone in Uttar Pradesh (4.1)	Semiarid (Hot dry)	665	Inceptisols	Pearlmillet
Akola (MC)	PDKV, Akola	Western Vidarbha Zone in Maharashtra (6.3)	Semiarid (Hot moist)	824	Vertisols	Cotton
Anantapur (MC & ORP)	ANGRAU, Hyderabad	Scarce rainfall zone (Rayalaseema) in Andhra Pradesh (3.0)	Arid (Hot)	544	Alfisols	Groundnut
Arjia (MC & ORP)	MPUAT, Udaipur	Southern zone in Rajasthan (4.2)	Semiarid (Hot dry)	656	Vertisols	Maize
B.Saunkhri (MC & ORP)	PAU, Ludhiana	Kandi region in Punjab (9.1)	Subhumid) (Hot dry)	1011	Inceptisols	Maize
Bangalore (MC & ORP)	UAS_B, Bangalore	Central, eastern and southern dry zone in Karnataka (8.2)	Semiarid (Hot moist)	926	Alfisols	Fingermillet
Bellary (VC)	CSWCRTI, Dehradun	Northern dry zone in Karnataka (3.0)	Arid (Hot)	502	Vertisols	*Rabi* Sorghum
Bijapur (MC)	UAS_D, Dharwad	Northern dry zone in Karnataka (6.1)	Semiarid (Hot dry)	595	Vertisols	*Rabi* Sorghum
Faizabad (SC)	NDUAT, Faizabad	Eastern plain zone in Uttar Pradesh (9.2)	Subhumid (Hot dry)	1051	Inceptisols	Rice
Hisar (MC & ORP)	CCSHAU, Hisar	South-western dry zone in Haryana (2.3)	Arid (Hyper)	412	Inceptisols	Pearlmillet
Indore (MC & ORP)	RVSKVV, Gwalior	Malwa plateau in Madhya Pradesh (5.2)	Semiarid (Hot moist)	958	Vertisols	Soybean
Jagadalpur (MC)	IGAU, Raipur	Basthar Plateau zone in Chattisgarh (12.1)	Subhumid (Hot moist)	1297	Inceptisols	Rice
Jhansi (VC)	IGFRI, Jhansi	Bundhelkhand zone in Uttar Pradesh (4.4)	Semiarid (Hot moist)	870	Inceptisols	*kharif* Sorghum
Jodhpur (VC)	CAZRI, Jodhpur	Arid Western zone of Rajasthan (2.1)	Arid (Hyper)	331	Aridisols	Pearlmillet
Jorhat (MC)	AAU, Jorhat	Upper Brahmaputra valley zone in Assam (15.4)	Perhumid (Hot)	1846	Oxisols	Rice
Kovilpatti (MC)	TNAU, Coimbatore	Southern zone of Tamil Nadu (8.1)	Semiarid (Hot dry)	723	Vertisols	Cotton
Parbhani (MC)	MAU, Parbhani	Central Maharastra Plateau Zone in Maharashtra (6.2)	Semiarid (Hot moist)	901	Vertisols	Cotton
Phulbani (MC)	OUAT, Bhubaneswar	Eastern Ghat Zone in Orissa (12.1)	Subhumid Hot moist)	1580	Oxisols	Rice
Rajkot (MC)	JAU, Junagarh	North Saurashtra zones in Gujarat (5.1)	Semiarid (Hot dry)	590	Vertisols	Groundnut
Rakh Dhiansar (SC)	SKUAS_T, Jammu	Low altitude subtropical zone in Jammu and Kashmir (14.2)	Semiarid (Moist dry)	860	Inceptisols	Maize
Ranchi (MC & ORP)	BAU, Ranchi	Western plateau zone of Jharkhand (4.1)	Semiarid (Hot dry)	1149	Inceptisols	Rice
Rewa (MC)	JNKVV, Jabalpur	Keymore plateau and Satpura Hill zone in Madhya Pradesh (10.3)	Subhumid (Hot dry)	1088	Vertisols	Soybean
S.K.Nagar (MC)	SDAU, Dantewada	Northern Gujarat in Gujarat (2.3)	Semiarid/Arid (Hot dry)	670	Entisols	Pearlmillet
Solapur (MC & ORP)	MPKV, Rahuri	Scarcity zone in Maharashtra (6.1)	Semiarid (Hot dry)	732	Vertisols	*Rabi* Sorghum
Varanasi (MC)	BHU, Varanasi	Eastern Plain and Vindhyan Zone in Uttar Pradesh (4.3 / 9.2)	Semi arid (Hot moist) Subhumid (Hot dry)	1049	Inceptisols	Rice

MC- Main Centre; SC - Sub Centre; VC - Voluntary Centre; ORP - Operational Research Project

**: Climate details as per AESR given by NBSSLUP (ICAR)

The research at AICRPDA centers has been focused to address the location-specific problems considering agro-ecological characteristics, predominant rainfed production systems and socio-economic settings with specific emphasis on (i) soil conservation and rainwater management; (ii) evaluation of crops/varieties; (iii) cropping/farming systems; (iv) contingency crop planning; (v) integrated nutrient management; (vi) tillage and farm machinery; and (vii) alternate land use systems. In the last few years, more focus was given on cropping/farming systems, tillage and integrated nutrient management, alternate land use for diversification and efficient implements on a template of resource management particularly rainwater management. The on-station research findings generated at the centers were evaluated on farmers' fields in ORP watersheds/villages.

Materials and Methods

Distribution of rainfall at different centers

The rainfed areas are spread out widely in the country. They can be broadly classified into arid, semi-arid and dry sub-humid regions. The arid areas forming 19.6% of the total geographical area (329 M ha) are characterized by low and erratic rainfall (< 500 mm) and sandy soil texture. The growing season is very short (upto 75 days) with millets and short duration pulses dominating the production systems. Livestock farming is an important component of production in the arid ecosystem. The semi-arid areas can be further classified into dry and wet areas. Dry semi-arid areas form 12% of geographical area and receive a mean annual rainfall ranging from 500–700 mm with a growing season of 75-199 days. The wet semi-arid region constituting 25.9% of geographical area receives mean annual rainfall ranging from 750–1100 mm with a growing season up to 120 days. The crops and cropping systems are quite diverse in the semi-arid part of the country depending on the length of growing season. Sorghum, cotton, soybean, groundnut and pulses are major crops grown in this zone. The dry sub-humid areas constitute 21.1% of geographical area and receive a mean annual rainfall ranging from 1100–1600 mm. The high rainfall in these areas provides opportunities for water harvesting which can be linked with advantage to control water congestion of soil on the one hand and runoff driven soil erosion on the other.

Based on the mean normal rainfall occurred during the last four decades, one center at Hisar is under arid climate (< 500 mm); 8 centers viz., Bellary, Rajkot, Bijapur, Anantapur, Arjia, Agra, Solapur and Kovilpatti are under dry semi-arid climate (500-750 mm); 5 centers viz., S.K.Nagar, Akola, Rakh Dhiansar, Bangalore and Indore are under wet semi-arid climate (750-1000 mm); 4 centers viz., Ballowal Saunkhri, Faizabad, Varanasi and Rewa are under dry sub-humid climate (1000-1250 mm); and 2 centers viz., Chianki and Phulbani are under wet sub-humid climate (1250-1500 mm) groups. The details of mean monthly rainfall received at different centers during the last 40 years are given in **Table 2**. About 80 to 90% of the rainfall is received during June to October at all the centers.

Table 2 : Normal monthly rainfall (mm) received at different AICRPDA centers under different climatic situation

Center	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Arid (< 500 mm)													
Hisar	13	16	12	6	20	47	122	126	40	5	0	4	411
Dry semi-arid (500-750 mm)													
Bellary	4	1	5	21	54	63	43	53	123	102	33	11	513
Rajkot	1	1	2	1	3	97	221	166	74	9	15	0	590
Bijapur	4	2	6	21	38	86	73	78	152	96	31	7	594
Anantapur	2	0	1	31	38	64	99	123	112	113	32	10	615
Arjia	4	3	5	4	6	73	196	249	97	10	7	4	658
Agra	15	12	11	3	11	51	186	262	90	24	2	2	669
Solapur	2	5	4	11	37	113	128	140	172	80	24	6	722
Kovilpatti	21	18	23	68	60	17	23	32	75	181	150	60	728
Wet semi-arid (750-1000 mm)													
S.K.Nagar	0	0	0	0	0	87	278	275	142	20	3	1	806
Akola	10	9	11	3	18	155	224	221	103	47	15	9	825
R.Dhiansar	0	0	0	0	0	73	329	278	119	15	13	33	860
Bangalore	1	8	13	34	101	84	100	133	211	167	59	15	926
Indore	9	2	3	2	9	121	261	225	247	40	18	7	944
Dry sub-humid (1000-1250 mm)													
B.Saunkhri	1	0	4	4	0	79	328	345	188	32	1	30	1012
Faizabad	15	12	7	7	21	134	279	324	195	46	9	10	1057
Varanasi	26	18	10	4	12	87	338	312	210	49	7	5	1078
Rewa	22	19	15	6	10	120	309	337	199	32	10	8	1087
Wet sub-humid (1250-1500 mm)													
Chianki	19	30	29	32	40	187	315	283	271	77	8	9	1300
Phulbani	9	14	21	31	58	182	340	381	221	88	28	5	1378

* Mean of 40 years

Major Characteristics of soils of AICRPDA centers

The soils of rainfed regions are characterized by low organic matter, alkaline to slightly acidic reaction on $CaCO_3$ accumulation in the upper of 150 cm of soil, weak to moderate profile development, coarse to medium texture and low biological activity. The AICRPDA centers have different soil types viz., alfisols, aridisols, inceptisols, oxisols and vertic inceptisols (**Table 3**). Except vertisols, most of the soils are coarse textured and are poor in retaining rain water and nutrients. The crops grown on these soils are normally prone to drought and nutrient deficiencies. Due to low organic matter content, particle aggregation is inadequate. High friability makes the soils prone to erosion. The infiltration rate of water is low both in vertisols and alfisols due to swelling of clay in the former and crust formation in the latter. With the exception of some vertisols, which are rich in bases, the rainfed soils are generally low in fertility because of poor organic matter content and their origin from nutrient poor base.

Table 3 : Major characteristics of soils of dryland research centers in India

Center	AESR	Climate	AWC (cm)	pH (1:2)	Electrical conductivity (ds m-1)	Organic carbon (%)	P (kg/ha)	K (kg/ha)
Alfisols								
Anantapur	3.0	Dry semi-arid	5-6	6.0-7.0	0.03-0.05	0.25-0.30	10-15	50-200
Bangalore	8.2	Wet semi-arid	5-13	5.5-6.5	0.05-0.20	0.50-0.75	8-12	180-250
Aridisols								
Hisar	2.3	Arid	5-9	7.5-8.0	0.15-0.20	0.15-0.22	-	280-400
SK Nagar	2.3	Wet semi-arid	10-15	7.5-8.0	0.05-0.08	0.25-0.30	20-35	125-200
Inceptisols								
Agra	4.1	Dry semi-arid	5-6	7.5-8.0	0.75-0.90	0.20-0.38	15-25	250-350
B. Saunkhri	9.1	Dry sub-humid	20-25	7.5-8.0	0.75-0.90	0.20-0.38	15-25	250-350
Varanasi	9.2	Dry sub-humid	20-25	7.0-7.5	0.05-0.30	0.10-0.25	15-35	80-150
R. Dhiansar	14.2	Wet semi-arid	20-25	7.0-7.5	0.05-0.30	0.10-0.25	15-35	80-150
Oxisols								
Phulbani	12.2	Wet sub-humid	12-24	5.0-6.0	0.02-0.30	0.30-0.45	10-25	200-350
Chianki	12.3	Wet sub-humid	12-24	5.0-6.0	0.02-0.30	0.30-0.45	10-25	200-350
Vertic Inceptisols								
Rajkot	2.4	Dry semi-arid	9-11	7.5-8.0	0.15-0.20	0.50-0.70	25-30	350-425
Kovilpatti	8.1	Dry semi-arid	10-12	7.8-8.5	0.25-0.40	0.40-0.60	8-15	500-650
Akola	6.3	Wet semi-arid	18-40	7.5-8.5	0.20-0.35	0.20-0.35	20-40	500-800

Experiments on rain water management conducted at different centers

Field experiments to manage rain water are being conducted at different centers every year. The experiments involved treatments of (i) *in-situ* moisture conservation; (ii) application of mulches for better management of soil moisture; (iii) *ex-situ* water harvesting and re-use for giving supplemental or critical irrigation to crops; (iv) vegetative barriers to control runoff and soil loss and better management of rain water; and (v) growing of crops based on the slope and water movement (upstream and downstream water management). The rain water management practices were also tested in combinations with fertilizer N, P, and K nutrients; organic sources of nutrients; mulches; different levels of tillage; intercropping systems; varying seed rates and other treatments depending on the soil type, crop, rainfall and other variables in a given situation (Vittal et al., 2003). The field experiments at centers conducted during 2010-11 on rain water management along with treatment details are given in **Annexure-1**.

Rain water use efficiency and profitability of treatments

Using the observations of yield attained by different fertilizer treatments, and cumulative rainfall from June to October, a comparison of the ratios of yield and cumulative rainfall was made for assessing the performance of treatments for RWUE in each year and were averaged over years (Rockstrom et al., 2003). Based on the ANOVA, the treatments which gave significantly higher RWUE could be considered as superior compared to those with significantly lower RWUE under rainfed conditions. The per ha gross monetary returns accrued could be computed as a product of the mean yield of each treatment attained over years and value of the crop (Nema et al., 2008). The per ha net monetary returns is derived as a difference of the per ha gross monetary returns accrued and cost of cultivation involved for each treatment. The benefit–cost ratio could be derived as a ratio of the gross monetary returns and total cost of cultivation for each treatment and could be compared for assessing the superiority of treatments.

Results and Discussion

Effect of RWM practices on productivity of different crops

In-situ moisture conservation practices

Under *in-situ* moisture conservation practices tested at different locations, ridges and furrows method was superior for castor at SK Nagar with yield of 1390 kg/ha compared to flat bed method with 1079 kg/ha with yield increase of 28.9%. This practice was also superior for lentil at Agra (together with 8 cm irrigation at 45 DAS); pigeonpea at Faizabad and soybean at Indore (together with seed rate @ 60 kg/ha) with yield of 1387, 2218 and 1921 kg/ha compared to flat bed sowing with yield of 1162, 1834 and 1159 kg/ha, respectively. The yield increase with ridges and furrows method was 19.4, 21.0 and 65.8% at Agra, Faizabad and Indore, respectively. The practice of 30 cm distance between rows having 3 rows on broad bed of 90 cm and furrow of 45 cm was superior for groundnut at Rajkot with a pod yield of 992 kg/ha (15.8% increase) compared to control spacing 45 cm (857 kg/ha). The method of sowing across the slope together with vegetative barrier with 'Rosha grass' was superior at Indore with significantly higher maize yield of 1725 kg/ha (30.4% increase) compared to farmers practice of sowing along the slope without any vegetative barrier (1323 kg/ha).

At Arjia, strip cropping of maize + blackgram with deep tillage and ridging after sowing was superior with significantly higher maize equivalent yield of 2262 kg/ha (yield increase of 98.3%) compared to maize + blackgram in 2:2 ratio (1141 kg/ha). At Hisar, deep ploughing was superior for mustard with yield of 1580 kg/ha (16.2% increase) compared to shallow ploughing (1360 kg/ha). At Agra, significantly higher pearlmillet yield of 2940 kg/ha (34.1% increase) was attained by adopting flat bed + line sowing + conservation furrow compared to 2192 kg/ha attained by flat bed + broadcast sowing method. At Parbhani, conservation furrow at 2.7 m interval was highly efficient with sorghum equivalent yield of 5688 kg/ha (40.4% increase) compared to control yield of 4052 kg/ha. The effect of *in-situ* moisture conservation practices on productivity of crops along with yield increase over control are given in **Table 4.**

Application of different mulches

At Ballowal Saunkhri, paddy straw was superior for African sarson with yield of 1064 kg/ha compared to control of 'no mulch' with 750 kg/ha (yield increase of 41.9%). This was also superior for wheat with yield of 2060 kg/ha compared to control with yield of 1290 kg/ha (yield increase of 59.7%). At Ranchi, paddy straw together with 100% recommended seed rate was superior for lentil with yield of 955 kg/ha compared to control with yield of 702 kg/ha (yield increase of 36.0%). The crop residue mulch was superior for castor at SK Nagar (1387 kg/ha), pigeonpea at Indore (1309 kg/ha), and sorghum at Akola (5695 kg/ha) compared to control yield of 1079, 1204 and 5177 kg/ha, respectively. The yield increase was 28.5, 8.7 and 10.0% at SK Nagar, Indore and Akola, respectively.

At Anantapur, the crop residue mulch together with micro-catchments at 45 cm apart for every 4 lines was superior for groundnut with pod yield of 1026 kg/ha (increase of 7.9%) compared to control yield of 951 kg/ha. Application of straw mulch to overcome early season drought was superior for rice at Varanasi with yield of 1325 kg/ha (increase of 19.4%) compared to control of 1109 kg/ha. At Indore, application of polythene mulch was superior for soybean with yield of 2566 kg/ha (increase of 42.7%) compared to control of 1798 kg/ha. At Ballowal Saunkhri, sugarcane trash was superior for maize with yield of 3066 kg/ha (increase of 56.8%) compared to control of 1917 kg/ha; while subabul mulch was superior for lentil with yield of 654 kg/ha (increase of 35.2%) compared to control of 484 kg/ha. The effect of mulches on crop productivity and increase over control for rainfed crops at different locations are given in **Table 5**.

Application of critical irrigation

At SK Nagar, two life saving irrigations + FYM @ 5 t/ha was superior for castor with yield of 981 kg/ha compared to control of 615 kg/ha (yield increase of 59.4%). At Jorhat, two life saving irrigations (one at stolon & one at tuber formation) was superior for potato with yield of 6839 kg/ha compared to control of 5745 kg/ha (increase of 19.0%). At Rajkot, one irrigation at 40% soil moisture deficit was superior for groundnut with pod yield of 950 kg/ha compared to control of 303 kg/ha (yield increase of 213.5%). At Rakh Dhiansar, two life saving irrigations (one at pre-sowing and one at branching stages) + 100% RDF was superior for mustard with yield of 1649 kg/ha compared to control of 625 kg/ha (increase of 163.8%). In case of maize at Rakh Dhiansar, one life saving irrigation during stress + 100% RDF was superior with yield of 1912 kg/ha compared to control of 1033 kg/ha (increase of 85.2%). At Varanasi, one life saving irrigation during late season drought was superior for rice with yield of 1614 kg/ha compared to control of 1434 kg/ha (increase of 12.6%). At Phulbani, two irrigations from lined pond with soil : cement ratio of 6 : 1 (8 cm thickness) was superior for tomato with yield of 18076 kg/ha compared to control of 14578 kg/ha (increase of 24.0%). At Rewa, one pre-sowing irrigation was superior for wheat with yield of 2756 kg/ha compared to control of 2460 kg/ha (increase of 12.0%). The effect of critical irrigation on crop productivity and yield increase over control at different locations are given in **Table 6**.

Vegetative barriers

At Ballowal Saunkhri, kannah grass as a vegetative barrier was superior for blackgram for attaining yield of 793 kg/ha (increase of 23.9%) compared to control (640 kg/ha). The grass was also superior for maize with yield of 1746 kg/ha (increase of 42.9%) compared to control (1222 kg/ha); and sesame with yield of 551 kg/ha (increase of 27.5%) compared to control (432 kg/ha). At Bangalore, nase grass live barrier was superior for finger millet with yield of 2690 kg/ha (increase of 47.9%) compared to control (1819 kg/ha). In case of horsegram, khus live barrier was superior with yield of 4616 kg/ha (increase of 52.9%) compared to control (3018 kg/ha). At Indore, vegetative bunding + sowing across the slope was superior for soybean for attaining yield of 2794 kg/ha (increase of 41.9%) compared to control (1969 kg/ha). The effect of vegetative barriers on productivity of crops along with increase in yield are given in **Table 7**.

Effect of RWM practices on profitability of crops

In-situ moisture conservation practices

Under *in-situ* moisture conservation practices tested at different locations, ridges and furrows method was superior for castor at SK Nagar with net profit of Rs.20522/ha and BC ratio of 4.25 compared to flat bed method with Rs.16040/ha with BC ratio of 3.50. This practice was superior for lentil at Agra (together with 8 cm irrigation at 45 DAS); and soybean at Indore (together with seed rate @ 60 kg/ha) with net profit of Rs.44013/ha and Rs.31387/ha and BC ratios of 4.84 and 3.35, respectively compared to flat bed sowing (net profit of Rs.35563/ha and BC ratio of 4.26 at Agra; and net profit of Rs.14486/ha with BC ratio of 2.09 at Indore). In case of groundnut at Rajkot, 30 cm distance between rows having 3 rows on broad bed of 90 cm and furrow of 45 cm was superior for attaining a net profit of Rs.17586/ha and BC ratio of 2.26 compared to control of 45 cm spacing (net profit of Rs.13347/ha and BC ratio of 1.98).

At Arjia, strip cropping of maize + blackgram with deep tillage and ridging after sowing was superior with significantly higher net profit of Rs.13171/ha and BC ratio of 2.72 compared to maize + blackgram (2:2) (net profit of Rs.6227/ha and BC ratio of 1.18). At Hisar, deep ploughing was superior for mustard with net profit of Rs.14806/ha and BC ratio of 1.86 compared to shallow ploughing (net profit of Rs.9898/ha and BC ratio of 1.56). In pearl millet at Agra, maximum net profit of Rs.18559/ha with BC ratio of 2.68 was attained by adopting flat bed + line sowing + conservation furrow compared to Rs.11962/ha with BC ratio of 2.09 attained under flat bed + broadcast sowing method. At Parbhani, conservation furrow at 2.7 m interval was highly effective for sorghum with net profit of Rs.21420/ha and BC ratio of 2.84 compared to control (net profit of Rs.12265/ ha and BC ratio of 2.09). The effect of *in-situ* moisture conservation practices on gross and net monetary returns and BC ratio of crops are given in **Table 4**.

Application of different mulches

At Ballowal Saunkhri, paddy straw was superior for African sarson with net profit of Rs.9820/ha and BC ratio of 1.96 compared to control (net profit of Rs.4453/ha and BC ratio of 1.46). This was also superior for wheat with net profit of Rs.12358/ha and BC ratio of 2.05 compared to control of Rs.3505/ha and BC ratio of 1.30. At Ranchi, paddy straw together with 100% recommended seed rate was superior for lentil with net profit of Rs.8929/ha and BC ratio of 1.80 compared to control (negative net returns of Rs.1130/ ha and BC ratio of 0.86). At SK Nagar, crop residue mulch was superior for castor (net profit of Rs.16594/ha and BC ratio of 3.51) compared to control (net profit of Rs.12595/ ha and BC ratio of 3.01). The crop residue mulch was superior for pigeonpea at Indore (net profit of Rs.23812/ha and BC ratio 3.22) compared to control (net profit of Rs. 21766 and BC ratio 3.18) and sorghum at Akola (Rs.37803/ha and BC ratio 3.94) compared to control (net profit of Rs.34012/ha and BC ratio 3.75). At Anantapur, the crop residue mulch together with micro-catchments at 45 cm apart for every 4 lines was superior for groundnut with net profit of Rs.19879/ha and BC ratio of 2.66 compared to control of Rs.18145/ha and BC ratio of 2.53. Application of straw mulch at early season drought at Varanasi was superior for rice with net profit of Rs.3799/ha and BC ratio of 1.30 compared to control of Rs.1802/ha and BC ratio of 1.15.

At Indore, application of polythene mulch in soybean gave maximum net profit of Rs.34839/ha and BC ratio of 3.87 compared to control of Rs.23666/ha and BC ratio of 3.82. At Ballowal Saunkhri, sugarcane trash was superior for maize with net profit of Rs.8359/ha and BC ratio of 1.67 compared to control (net profit of Rs.660/ha and BC ratio of 1.06); while subabul mulch was superior for lentil with net profit of Rs.9042/ha and BC ratio of 2.03 compared to control (net profit of Rs.4462/ha and BC ratio of 1.51). The effect of mulches on gross and net returns and BC ratio are given in **Table 5**.

Application of critical irrigation

At SK Nagar, two life saving irrigations + FYM @ 5 t/ha was superior for castor with net returns of Rs.17049/ha and BC ratio of 3.01 compared to control (net returns of Rs.9725/ ha and BC ratio of 2.62). At Jorhat, two life saving irrigations (at stolon & one at tuber formation) was superior for potato with net returns of Rs.12224/ha and BC ratio of 1.22 compared to control of Rs.8850/ha and BC ratio of 1.19. At Rajkot, irrigation at 40% soil moisture deficit was superior for groundnut with net returns of Rs.22058/ha with BC ratio of 2.41 compared to control (net returns of Rs.1176/ha and BC ratio of 1.09). At Rakh Dhiansar, two life saving irrigations (one at pre-sowing and one at branching stages)

+ 100% RDF was superior for mustard with net returns of Rs.19879/ha (BC ratio of 3.71) compared to control (net returns of Rs.3413/ha and BC ratio of 1.49). In maize at Rakh Dhiansar, one life saving irrigation during stress + 100% RDF was superior with net returns of Rs.2769/ha and BC ratio of 1.24 compared to control (negative net returns of Rs.-1739/ha and BC ratio of 0.80). At Varanasi, one life saving irrigation during late season drought was superior for rice with net returns of Rs.3311/ha and BC ratio of 1.27 compared to control of Rs.2217/ha with BC ratio of 1.18. At Phulbani, two irrigations from lined pond (soil : cement ratio of 6:1 with 8 cm thickness) was superior for tomato with net returns of Rs.146380/ha and BC ratio of 2.79 compared to control of Rs.85910/ ha and BC ratio of 1.76. At Rewa, one pre-sowing irrigation was superior for wheat with net returns of Rs.28956/ha and BC ratio of 4.51 compared to control of Rs.25460/ha with BC ratio of 4.29. The effect of critical irrigation on monetary returns and BC ratio of crops are given in **Table 6**.

Vegetative barriers

At Ballowal Saunkhri, vegetative barrier with kannah grass was superior for blackgram gave net returns of Rs.14883/ha (BC ratio of 2.09) compared to control (net returns of Rs.10045/ha and BC ratio of 1.78). This grass was also superior for maize with net profit of Rs.4012/ha (BC ratio of 1.26) compared to control of Rs.-1098/ha (BC ratio of 0.93); and sesame with net profit of Rs.10813/ha (BC ratio of 1.96) compared to control of Rs.6691/ha (BC ratio of 1.63). At Indore, vegetative bunding + sowing across the slope for soybean gave maximum net profit of Rs.43705/ha (BC ratio of 4.97) compared to control of Rs.27839/ha (BC ratio of 3.53). The superior vegetative barriers for monetary returns and BC ratio of crops are given in **Table 7**.

Successful rain water management technologies

About 19 technologies of rain water management were developed by conducting field experiments at AICRPDA centers located at Agra, Akola, Anantapur, Arjia, Bangalore, Bijapur, Indore, Rajkot, Chianki, Solapur, Varanasi and SK Nagar. The improved technologies are given in **Table 8**.

Table 4 : Effect of *in-situ* moisture conservation practices on productivity and profitability of crops at different AICRPDA locations

Center	Crop	IP	FP	Y IP	Y FP	I (%)	C IP	C FP	GR IP	GR FP	NR IP	NR FP	BC IP	BC FP
SKNagar	Castor	Ridges & furrows	Flat bed	1390	1079	28.9	6310	6410	26832	22450	20522	16040	4.25	3.50
Rajkot	Groundnut	30 cm distance between rows having 3 rows on broad bed of 90 cm & furrow of 45 cm	Control (45 cm spacing)	992	857	15.8	14000	13650	31586	26997	17586	13347	2.26	1.98
Agra	Lentil	Ridge sowing + Irrigation at 45 DAS (8 cm depth)	Flat sowing + control	1387	1162	19.4	11447	10917	55460	46480	44013	35563	4.84	4.26
Indore	Maize	Sowing across slope + vegetative barrier (Rosha grass)	Farmers practice	1725	1323	30.4								
Arjia	Maize+ black gram	Strip cropping with deep tillage& ridging after sowing	Control (maize +blackgram (2:2)	2262	1141	98.3	7650	9130	20821	10792	13171	6227	2.72	1.18
Hisar	Mustard	Deep ploughing before onset of monsoon	Control	1580	1360	16.2	17300	17738	32106	27635	14806	9898	1.86	1.56
Agra	Pearl millet	Flat bed + line sowing + Gurr /No live barrier	Flat bed + broad cast sowing	2940	2192	34.1	11031	10621	29589	22246	18559	11962	2.68	2.09
Faizabad	Pigeonpea	Ridges & furrows	Broadcasting	2218	1834	21.0								
Parbhani	Sorghum eqt.	Conservation furrow (2.7 m)	Control	5688	4052	40.4	11777	11464	33448	23827	21420	12265	2.84	2.08
Indore	Soybean	Ridges & furrows (60 cm) + seed rate @ 60 kg/ha	FBS-45 cm with seed rate 40 kg/ha	1921	1159	65.8	11567	11000	38750	22987	31387	14486	3.35	2.09

IP : Improved practice FP : farmers practice Y : Yield (kg/ha) I : Yield increase C : Cost of cultivation (Rs/ha)
GR : Gross monetary returns (Rs/ha) NR : Net monetary returns (Rs/ha) BC : Benefit-cost ratio

Table 5 : Effect of mulches on productivity and profitability of crops at different AICRPDA locations

Center	Crop	IP	FP	Y IP	Y FP	I (%)	C IP	C FP	GR IP	GR FP	NR IP	NR FP	BC IP	BC FP
B.Saunkhri	African Sarson	Paddy straw	Control	1064	750	41.9	10193	9683	20013	14136	9820	4453	1.96	1.46
SK Nagar	Castor	Crop residue mulch	Dust mulch	1387	1079	28.5	6610	6260	23204	18855	16594	12595	3.51	3.01
Anantapur	Groundnut	Mulch + micro-catchments at 45 cm apart for every 4 lines	Control	1026	951	7.9	12007	11840	31886	29985	19879	18145	2.66	2.53
B.Saunkhri	Lentil	Subabul	Control	654	484	35.2	8778	8678	17820	13140	9042	4462	2.03	1.51
Ranchi	Lentil	Mulching with paddy straw (10 t/ha) + 100% rec. seed rate	Control + 50% seed rate	955	702	36.0	11216	7966	20145	6836	8929	-1130	1.80	0.86
B.Saunkhri	Maize	Sugarcane trash	Control	3006	1917	56.8	12545	11875	20904	12535	8359	660	1.67	1.06
Indore	Pigeonpea	Crop residue mulch	Control	1309	1204	8.7	10744	9994	34556	31760	23812	21766	3.22	3.18
Varanasi	Rice	Straw mulch (during early season drought)	Control	1325	1109	19.4	12400	12200	16179	14002	3799	1802	1.30	1.15
Akola	Sorghum	Furrow opening+ Crop residue mulch + Thinning	Control	5695	5177	10.0	12864	12368	50667	46380	37803	34012	3.94	3.75
Akola	Soybean	Thinning	Furrow opening	1842	1595	15.5	9517	9517	37700	35286	28183	25769	3.96	3.71
Indore	Soybean	Polythene mulching	Control	2566	1798	42.7	13000	9000	50367	34420	34839	23666	3.87	3.82
B.Saunkhri	Wheat	Paddy straw	Control	2060	1290	59.7	11817	11562	24174	15067	12358	3505	2.05	1.30

IP : Improved practice FP : farmers practice Y : Yield (kg/ha) I : Yield increase C : Cost of cultivation (Rs/ha)
GR : Gross monetary returns (Rs/ha) NR : Net monetary returns (Rs/ha) BC : Benefit-cost ratio

Table 6 : Effect of critical irrigation on productivity and profitability of crops at different AICRPDA locations

Center	Crop	IP	FP	Y IP	Y FP	I (%)	C IP	C FP	GR IP	GR FP	NR IP	NR FP	BC IP	BC FP
SKNagar	Castor	Two life saving irrigations + FYM @ 5 t/ha	Rainfed	981	615	59.4	8500	6000	25549	15725	17049	9725	3.01	2.62
Rajkot	Groundnut	Irrigation at soil moisture deficit of about 40 %.	Rainfed	950	303	213.5	15650	13650	37708	14826	22058	1176	2.41	1.09
Rakh Dhiansar	Maize	RDF + life saving irrigation	Rainfed	1912	1033	85.2	11570	8500	14339	6762	2769	-1739	1.24	0.80
Rakh Dhiansar	Mustard	RDF + life saving irrigation + One irrigation at branching	Rainfed	1649	625	163.8	7330	6900	27209	10313	19879	3413	3.71	1.49
Jorhat	Potato	Two Irrigations (One at stolon & 2nd at tuber formation)	Rainfed	6839	5745	19.0	54465	46000	66675	54850	12224	8850	1.22	1.19
Varanasi	Rice	Life saving irrigation (late season drought)	Rainfed	1614	1434	12.6	12350	12200	15661	14417	3311	2217	1.27	1.18
Phulbani	Tomato	Lined pond with soil cement plaster 6:1 (8 cm thickness)	Unlined pond	18076	14578	24.0	81920	112390	228300	198300	146380	85910	2.79	1.76
Rewa	Wheat	Irrigated	Rainfed	2756	2460	12.0	8250	7750	37206	33210	28956	25460	4.51	4.29

IP : Improved practice FP : farmers practice Y : Yield (kg/ha) I : Yield increase
C : Cost of cultivation (Rs/ha) GR : Gross monetary returns (Rs/ha) NR : Net monetary returns (Rs/ha) BC : Benefit-cost ratio

Table 7 : Effect of vegetative barriers on productivity and profitability of crops at different AICRPDA locations

Center	Crop	IP	FP	Y IP	Y FP	I (%)	C IP	C FP	GR IP	GR FP	NR IP	NR FP	BC IP	BC FP
B.Saunkhri	Black gram	Kannah	Control	793	640	23.9	13599	12960	28482	23005	14883	10045	2.09	1.78
Bangalore	Finger millet	Nase grass live barrier	No live barrier plot	2690	1819	47.9								
Bangalore	Horse gram	Khus live barrier	No inter terrace management	4616	3018	52.9								
B.Saunkhri	Maize	Kannah	Control	1746	1222	42.9	15514	14876	19526	13778	4012	-1098	1.26	0.93
B.Saunkhri	Sesame	Kannah	Control	551	432	27.5	11227	10589	22040	17280	10813	6691	1.96	1.63
Indore	Soybean	Vegetative barrier (bund) + sowing across the slope	Sowing along the slope	2794	1969	41.9	11000	11000	54705	38839	43705	27839	4.97	3.53

IP : Improved practice FP : farmers practice Y : Yield (kg/ha) I : Yield increase C : Cost of cultivation (Rs/ha)
GR : Gross monetary returns (Rs/ha) NR : Net monetary returns (Rs/ha) BC : Benefit-cost ratio

Table 8 : Improved RWM technologies developed over years

Sno	Centre	Title	Crop	Yield (kg/ha)/ BC ratio	Area/ Production
1.	Agra	Ridge planting of Pearl millet for higher productivity in Agra region of Uttar Pradesh	Pearl millet	2288 (44.3%) *BCR 2.23*	1.07 lakh ha
2.	Agra	Deep tillage and compartmental bunding for enhanced Pearlmillet productivity in Agra region of Madhya Pradesh	Pearl millet (WCC-75)	1.5-2.0 t/ha 1875 (31%)	Adoption by 20% farmers
3.	Agra	Higher Mustard productivity in rainfed regions of Agra through supplemental irrigation with harvested rainwater	Mustard	2076 (42.3%)	79,000 ha
4.	Akola	*In-situ* moisture conservation through toposequence based cropping in Vidarbha region of Maharashtra	Soybean (PKV-1) Chickpea (ICCV-2) Cotton	915 410 498	Akola region
5.	Anantapur	Water harvesting and supplemental irrigation to rainfed groundnut in Rayalaseema region of Andhra Pradesh	Groundnut	1023 (24.8% increase)	20-25% area
6.	Arjia	Early rabi cropping of chickpea for green pods with harvested rain water in southern Rajasthan	Maize, Chickpea	550-700	35% area
7.	Bangalore	Vegetative barrier and cover crop incorporation for higher fingermillet productivity in southern dry zone of Karanataka	Nase grass (*Pennisetum hohenekere*) Horsegram (PHG-9) Fingermillet (GPU-28)	*BCR 1.95* 2500	1 M ha/ 1.8 M/t
8.	Bijapur	Compartmental bunding for moisture conservation in northern dry zone of Karnataka	*Rabi*-Sorghum, Sunflower, Safflower, Chickpea	870 675 620 450	800 ha
9.	Bijapur	Gravel and sand mulching in Sodic soils for moisture conservation in northern dry zone of Karnataka	Groundnut/ Greengram- *Rabi*-sorghum/ Sunflower/ Chickpea	1400 1400 2200 2000 1500	30000 ha
10.	Bijapur	Cover cropping for *in-situ* moisture conservation in black soils of northern dry zone of Karnataka	Sorghum, Sunflower, Chickpea	43-300%	500 ha
11.	Bijapur	Inter plot rain water harvesting in northern dry zone of Karnataka	Sorghum, Sunflower, Chickpea	1000-1500 2200-2500 1000-1200	30% area
12.	Bijapur	Ground water recharging through defunct open wells in northern dry zone of Karnataka		Rs.23000/ha	5 ha
13.	Indore	Earthling up in Maize for higher productivity in deep black soils of Malwa region of Madhya Pradesh	Maize Soybean	338 *BCR 1.60*	Adopted on considerable area under rainfed maize in Malwa region
14.	Rajkot	Recharging open wells through filters in Saurashtra region of Gujarat		Filters should be used to retain 67% of sedimentt load of runoff water	Northern Saurashtra region

Sno	Centre	Title	Crop	Yield (kg/ha)/ BC ratio	Area/ Production
15.	Ranchi	Use of harvested rain water for production of short duration leafy vegetables in Ranchi region of Jharkhand	Palak (Pusa jyothi) Coriander (Sel-81) Radish (Chetki)	2238 (BCR 1.28) 2206 (1.89) 1245 (1.99)	15% framers have adopted
16.	Solapur	Ridges and furrows *for in-situ* moisture conservation in scarce rainfall zone of Maharashtra	*Rabi* Sorghum	826 (53% increase) *BCR 1.76*	60% area in Solapur
17.	Varanasi	Ridge–furrow planting of Pigeonpea + rice in Eastern Plain zone of Uttar Pradesh	Rice (NDR-97) Pigeonpea (Bahar)	2200 2000	25% area in the region
18.	Varanasi	Summer tillage for *in-situ* moisture conservation in Eastern Plain zone of Uttar Pradesh	Rice (NDR-97) Pigeonpea (Bahar/MA-13) Sesame(Pant-4)	2620 1018 290 (15, 86, 38% increase)	Farmers have adopted the practice of summer ploughing
19.	SK Nagar	Compartmental bunding for moisture conservation and higher productivity of pearlmillet in north Gujarat	Pearlmillet	(41% increase)	Adopted by 20-25% farmers

Rainfed agriculture in SAARC Countries

Cropping systems

The main rainfed cropping systems in Asia have been described by Devendra et al. (1997). These include systems based on major food crops, perennial tree crops, and a wide range of secondary annual and perennial crops. Both monoculture (e.g. sorghum in India) and multiple cropping systems (inter-cropping, relay cropping, sequential-cropping) are common, with crops grown for subsistence and cash. Single Lowland Rice Crop Systems are found in most countries of South Asia (except Pakistan), and are particularly important in Bangladesh. Single Upland Crop Systems are major systems in India, Nepal, Pakistan and Sri Lanka. Substantial areas of Multiple Rice Crop Systems exist in Bangladesh and India, while Multiple Upland Annual Crop Systems exist in India and Pakistan. Only in Bangladesh is aquaculture integrated with rice-based systems, particularly deepwater rice. Perennial Tree Crop Systems are less important than in South-East Asia, with notable exceptions of south India and Sri Lanka. Shifting cultivation is not a major system in south Asia, although it is practised in very small areas of Bangladesh, Bhutan, India, Nepal and Sri Lanka (**Table 9**).

Hoque (1984) reviewed traditional cropping systems in both South-East and South Asia; a review of major crops is given by ADB (1989). In rainfed wetland areas, single and double cropping of rice is predominant. After a rainfed rice crop, wheat, maize, barley, millets, pulses and oilseeds may be grown with residual soil moisture. In other cases jute, maize and greengram are also grown during the early part of wet season before rice is transplanted. In some areas intensive multiple cropping with three- or four-crop patterns is also practised. Inter-cropping and relay cropping are commonly used particularly in the dry season. In rainfed dryland areas, growing of drought-resistant, short-duration cultivars has been an important feature of crop production. There is an extensive use of mixed cropping, relay cropping and inter-cropping of annual species. Cropping pattern may include up to six crops, with upland rice and maize as most important commodities. In irrigated wetland areas, farmers use single, double or triple cropping patterns. The rice–rice sequence is important in a vast area. Triple rice cropping patterns are possible because of the availability of improved short-duration varieties. Where low temperatures are a limiting factor during the dry winter season (as in Bangladesh and Nepal) wheat, mustard and potato are grown after one or two rice crops. In irrigated dryland areas, wet season crop is often direct-seeded rice. However, in some patterns in the wet season maize, jute, sugarcane, cotton and greengram are also grown. During dry season wheat, potato, mustard, chilli and vegetables are grown under irrigation. Double cropping is a common practice. In some cases, cropping intensity is increased through inter-cropping. In Bangladesh, potato, chickpea and wheat may be intercropped with sugarcane during its early growth stage.

Table 9 : Rainfed crops and cropping systems in SAARC Countries

Country	Crops	Cropping systems
Bangladesh	Rice, wheat, pulses, oil-seeds, jute, sugar-cane	Rice–wheat; Rice–rice–barley + chick-pea; Upland rice–barley; Upland rice–barley + chickpea +linseed
Bhutan	Maize, rice, wheat, barley, buckwheat, pulses, potato	Maize–oilseed; Rice–wheat; Rice–rice; Rice–maize
India	Rice, wheat, sorghum, maize, pearl millet, pulses, oilseeds, cotton, sugarcane	Rice–wheat; Rice–chick-pea; Rice–lentil; Rice–mustard
Nepal	Rice, maize, wheat, finger millet, oilseeds, potato	Rice–wheat; Rice–finger millet; Rice–wheat–fallow; Maize/finger millet–wheat
Pakistan	Wheat, rice, maize, sorghum, millet, barley, chick-pea, rapeseed, cotton, sugar-cane	Rice–potato; Sorghum–wheat + mustard ; Groundnut– wheat; Maize + beans–potato
Sri Lanka	Rice, maize, pulses, oilseeds, cassava, chilli	Rice–onions; Rice–rice; Maize–onions; Rice–potato

Sources: Hoque (1984); ADB (1989); Anon (1995); Reynolds et al. (1995)

Soils

There are 16 major soil groups in South Asia with different textural characteristics and fertility profiles. The four largest soil groups are the Lithosols, Luvisols, Cambisols and Vertisols in that order. The Yermosols, Arenosols, Acrisols, Nitosols, Fluvisols and Xerosols follow these again in order of importance. The remaining soil groups occupy relatively small areas of land regionally. The three major soil groups, in descending order of area covered, are given in **Table 10**.

Table 10 : The most important soil groups in the six countries of South Asia

Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka
Gleysols	Acrisols	Luvisols	Cambisols	Lithosols	Luvisols
Cambisols	Lithosols	Vertisols	Lithosols	Yermosols	Acrisols
Fluvisols	Cambisols	Cambisols	Fluvisols	Arenosols	Fluvisols

In Bangladesh, 78.5% of arable land is under Gleysols; in India, 27.4% of arable land is under Luvisols and 22.4% under Vertisols; and in Sri Lanka, 69% of arable land is under Luvisols and 25.6% under Acrisols (ADB, 1989).

In an earlier assessment of the role of livestock in mixed farming systems in the AEZs of South-East Asia, the report dealt exclusively with rainfed agriculture (Devendra et al., 1997). In this evaluation, although priority is given to rainfed AEZs, some discussion of irrigated systems relevant for livestock, particularly in countries such as Bangladesh, India, Pakistan and Sri Lanka, is included.

In Asia and the Pacific, the area under rainfed agriculture is 223 million hectares, which is about 67% of the total arable land (ADB, 1989). Within this rainfed area, approximately 52% of the land is found in 6 countries of South Asia, amounting to some 116 million hectares (**Table 11**). The proportion of arable land under rainfed agriculture varies from 26.7% for Pakistan to 84% for Nepal. Only in Pakistan (73.3%) and Sri Lanka (50.6%), does the proportion of irrigated land exceed that in the rainfed areas. However, in absolute terms, the largest amount of irrigated land, 43.8 million hectares, is located in India.

Table 11 : Importance of rainfed agriculture in South Asia

Country	Total rainfed area (x 10^6 ha)	Rainfed area as proportion of total arable land (%)	Rainfed production as proportion of agricultural GDP (%)	Population dependent on rainfed agriculture (%)
Bangladesh	7.70	81.6	40.5	41.0
Bhutan	0.07	81.0	28.9	93.0
India	100.00	69.5	25.7	42.2
Nepal	2.63	84.0	40.9	74.8
Pakistan	5.43	26.7	4.6	11.5
Sri Lanka	0.53	49.4	20.1	29.1

Source : ADB (1989)

Conclusion

Field experiments are conducted at 22 centers of All India Coordinated Research Project for Dryland Agriculture on rainwater management, nutrient management, energy management, cropping systems, crop improvement, alternate land use, integrated farming systems every year. An attempt is made in this paper to assess the effects of *in-situ* and *ex-situ* moisture conservation practices on productivity, gross and net monetary returns, and benefit-cost ratio under different soil and agro-climatic conditions in India. The effect of supplemental irrigation was assessed for castor, groundnut, maize, mustard, potato, rice, tomato and wheat. The net monetary returns influenced by supplemental irrigation ranged from Rs.2769/ha from maize grown under semi-arid Inceptisols at Rakh dhiansar to Rs.28956/ha from wheat under sub-humid Vertisols at Rewa. The benefit-cost ratio of critical irrigation ranged from 1.22 for potato under per-humid Inceptisols at Jorhat to 4.51 from wheat under sub-humid Vertisols at Rewa. With application of mulches, the net monetary returns ranged from Rs.3799/ha for rice under dry sub-humid Inceptisols at Varanasi to Rs.37803/ha for sorghum under semi-arid Vertisols at Akola. The benefit-cost ratio of mulch application ranged from 1.30 for rice under dry sub-humid Inceptisols at Varanasi to 3.96 for soybean under semi-arid Vertisols at Akola. The details of efficient rain water management practices for attaining maximum productivity and profitability of rainfed crops, along with a few successful technologies of rain water management practices are described in the paper.

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Annexure-1

Details of experiments conducted by AICRPDA Centers during 2010-11

S.No.	Title of the experiment	Treatments	Period
Chianki			
1.	Evaluation of suitable crop varieties under limited irrigated condition	*Crops:* Wheat, Chickpea, Lentil, Barley, Mustard **Irrigation :** (i) 21 DAS (ii) 50 DAS **Crops (5) & Varieties (4)** Wheat: C306, K9107, BG-3, HUW468 Barley: DL36, BR32, Jyoti, Ratna Mustard: Shivani, Varuna, Pusa bold, Kranti Chickpea: Pant G114, Radhey, BG256, H208 Lentil: PL 406, PL 39, L4079, K75 Split plot, 3 Reps	2009-12
2.	Evaluation of suitable sealant material to control seepage losses from farm pond	**Seepage control** T1: Cement + sand lining (5:1); T2: Clay lining/ mud block masonry ; T3: PVC lining; T4: Cow dung + straw lining; T5: Ash lining ; T6: Control ; T7: Soil: Cement (6:1) RBD, 3 Reps	2009-12
Faizabad			
3.	*In-situ* moisture conservation in rice-pigeonpea inter cropping system	*Crops:* Rice and pigeonpea T1: Sole pigeonpea; T2: Sole rice; T3: Pigeonpea + rice (1:2) T4: Pigeonpea + rice (1:1) (ridge–furrow) T5: Paired row sowing of pigeonpea on ridge and rice in furrow RBD, 3 Reps	2010-13
Jagdalpur			
4.	Catchment-storage-command relationship for the farming situation of bunded midland (Mal) and Lowland (Gabhar) (Area 1.5 ac) for efficient use of harvested rainwater	*Rabi* crops*:* Linseed, lentil, fieldpea, chickpea, safflower and vegetables. T_1 - Utera cropping (Rice followed by a crop) T_2 - Farmers' practice (Monocropping of rice) RBD, 3 Reps	2010–LT
Phulbani			
5.	Water harvesting through farm pond and utilization of conserved water for rainfed olericulture	*Crops:* Tomato, Radish T1: Lined pond with soil cement plaster (6:1) with 8 cm thickness; T2: Unlined pond; T3: No pond RBD, 3 Reps	2005-11

S.No.	Title of the experiment	Treatments	Period
Varanasi			
6.	Drought management in upland rice	*Crop:* Rice (NDR 97) T_1 - Control; T_2 - Straw mulching (4 t/ha) T_3 - Life saving irrigation at panicle initiation stage; T_4 - Straw mulch + life saving irrigation at panicle initiation ; T_5 - Life saving irrigation at grain filling stage ; T_6 - T5 + Straw mulch T_7 - Rice + greengram on raised bed system T_8 - Late seeding of pearlmillet RBD, 3 Reps	2008-11
7.	Effect of improved methods of sowing on productivity of maize	*Crop:* Maize (Pragathi Composite) T_1 - Broadcasting ; T_2 - Sowing by raised bed planter; T_3 - Sowing by ridger seeder; T_4 - Sowing by seed drill RBD, 3 Reps	2008-11
8.	Effect of improved methods of sowing on productivity of pearlmillet (at Barkacha)	*Crop:* Pearlmillet (MBH-163) T_1 - Broadcasting; T_2 - Sowing by raised bed planter; T_3 - Sowing by ridger seeder T_4 - Sowing by seed drill RBD, 3 Reps	2008-11
9.	Tillage and weed management for upland rice- lentil system	*Crops:* Rice (NDR-97) ***Tillage*** T1: Reduced tillage; T2: Criss cross cultivation ***Weed management*** W1: Weedy check; W2: 2 Intercultures; W3: Pendimethalin (0.5 kg ai/ha); W4: Puetlachlor (0.5 kg ai/ha) W5: W3 + 1 interculture ; W6: W4 + 1 interculture Split plot, 3 Reps	2006-11
10.	Suitabilty of rainfed maize for baby corn, cobs & grain	*Crops:* Maize (Pragati composite) Fertility levels of NPK (kg/ha) F1- 30-20-15; F2- 60-40-30; F3- 90-60-45 *Harvesting Time* S1- Baby corn; S2- Green cob; S3- Grain purpose RBD, 3 Reps	2010-11
11.	Catchment-storage-command relationship for enhancing water productivity in micro- watershed	*Crops:* Mustard (Pusa Jai Kisan 902) T1- No irrigation; T2- Pre-sowing irrigation T3- Irrigation at 50% flowering; T4- Irrigation at 75% flowering RBD, 3 Reps	2009 - LT

S.No.	Title of the experiment	Treatments	Period
Arjia			
12.	Catchment–storage–command relationship for enhancing water productivity	Rainfall (amount & intensity); Weekly water level ; Evaporation & seepage *Crops:* Maize, Vegetables (A) ***Kharif*** (a) Vegetables T1: Bottle guard (2 x 2 m^2); T2: Ridge guard T3: Kachari ; T4 : Veg. Cowpea ; T4: Maize (5 cm irrigation) control ; T5: Maize (unirrigated) (b) Irrigation T1: Drip (50% PE) T2: Surface (5 cm) (Drip irrigation would be applied in vegetables weekly of 50% weekly PE). (B) ***Rabi*** (a) Crops : Pea ; Cumin ; Brinjal (b) Irrigation T1: Drip (between two rows) (50% of PE); T2: Conservation; T2: 5 cm (C) **Seepage study** (i) Partial polyfilm linning a bottm and stone masonery with pointing (ii) Cement concreat lining (iii) Polyfilm lining (D) **Water lifing device** (i) Electric motor (ii)Desiel engine (iii) Gassifer	2009-12
13.	Evaluation of maize hybrids for rainwater and nutrient management	*Crop:* Maize **Hybrids** (i) HIM-129 (Extra early maturing) < 70 days (ii) PHM-1 (early maturing) < 75 days (iii) PEHM-2 (medium maturing) < 85 days **Nutrient management** (i) RDF (inorganic) (50:30 NP) (ii) INM (50 % N (inorganic) + 50 % N (organic) + biofertilizer) **Rain water management** (i) Flat sowing (ii) Ridging after sowing RBD, 3 Reps	2007-11

S.No.	Title of the experiment	Treatments	Period
14.	Effect of tillage practices and mulching operations on productivity of maize under dryland conditions	*Crop:* Maize **Tillage practices** (i) Conventional tillage; (ii) Minimum tillage (iii) Raised bed sowing **Mulching Operations** (i) No mulching; (ii) Farm-waste mulch ; (iii) Polyphone mulch; (iv) Soil mulch Split plot, 4 Reps	2010-14
15.	*In-situ* moisture conservation system in blackgram for enhancement of productivity in southern Rajasthan	*Crop:* Blackgram **Summer deep ploughing** (i) Raised bed (40 cm); (ii) Raised bed (70 cm) (iii) Compartment bunding at 5 m interval (iv) Sowing across slope **Shallow tillage** (i) Raised bed (40 cm); (ii) Raised bed (70 cm) (iii)Compartment bunding at 5 m interval (iv) Sowing across slope (v)Absolute control (Framer's practice) Split plot, 3 Reps	2010-14
Ballowal Saunkhri			
16.	Effect of vegetative barriers on soil loss, runoff and nutrients	*Crops:* Vegetative barriers & Crops *Kharif:* Maize, Blackgram, Groundnut *Rabi:* Wheat, Raya, Lentil ***Vegetative barriers*** T1. Control; T2. Vetivar grass (*Vetivar zizanoides*) T3. Bhabbar grass *(Eulaliopsus binata)* T4. Kana grass *(Sachharum munja)* T5. Lemon grass *(Cymbopogon)/* Subabul *(Leucaena leucocephala)* T6. Napier hybrid bajra *(Pennisetum purpureum)* RBD, 3 Reps	2009– LT
17.	Identification of locally available material for mulching and *in- situ* moisture conservation	*Crops:* Maize (*kharif*), Wheat (*rabi*) Source of mulch @ 6 t/ha T1: Control; T2: Kana (*Sachharum munja*); T3: Hoeing ; T4: Raya stalks ; T5: Subabul leaves (*Leucanea)* T6: Nara *(Arundodonax spp)* RBD, 3 Reps	2009-14

S.No.	Title of the experiment	Treatments	Period
Rakh Dhiansar			
18.	Permanent manurial trial in maize based cropping system	*Crops:* Maize, Gobi Sarson, Chickpea T1: Control ; T2: 100% NPK (60:40:20 kg/ha) T3: 50% NPK (30:20:10 kg/ha) T4: 50% N (crop residue); T5: 50% N (FYM) ; T6: 50% NPK + 50% N (crop residue) T7: 50% NPK + 50% N (FYM) T8: FYM @ 10t /ha;T9: 100% NPK + 20 kg $ZnSo_4$/ha T10: Farmers method (FYM @ 4t/ha+40 kg N/haurea) RBD, 4 Reps	1995- LT
19.	Nutrient management in maize-wheat rotation	*Crops:* Maize, Wheat T1: Control; T2: FYM @ 10 t/ha + 20 kg N/ha T3: FYM @ 10 t/ha + 30 kg N/ha T4: FYM @ 10 t/ha + 40 kg N/ha T5: Green manuring with sunhemp + 20 kg N/ha T6: Green manuring with sunhemp + 30 kg N/ha T7: Green manuring with sunhemp + 40 kg N/ha T8: *Leucaena* @ 5 t/ha + 20 kg N/ha T9: *Leucaena* @ 5 t/ha + 30 kg N/ha T10: *Leucaena* @ 5 t/ha + 40 kg N/ha (40 kg P + 20 kg K/ha will be common to all treatments) RBD, 3 Reps	
Bangalore			
20.	Catchment-storage- command relationship for enhancing water productivity in micro-watershed	*Crops:* Fingermillet, Pigeonpea, Papaya, Banana, Curry leaf, Guava, gourds, Vegetables, Amla, pomello plants T1: Life saving irrigation (Fingermillet, Pigeonpea, Onion); T2: Fish culture T3: Horticulture components around the pond (Papaya, curry leaf, guava, gourds, leafy vegetables) T4: Nourishing horticultural crops planted elsewhere (Non replicated)	2009-LT
21.	Efficient utilization of farm pond water for intensive and profitable crop production	*Crops:* Fodder crops M_1: Pearlmillet (giant bajra) M_2: Fodder maize (South Africa Tall) M_3: Sweet sorghum (SSV-74) **Varieties of onion** V_1: Bellary light red; V_2: Dark red **Fertilizer levels** F_1: 100% RDF (125:50:125 kg/ha NPK) F_2: 75% RDF (94:37.5: 94 kg/ha NPK) Split-split plot, 3 Reps	2009-12

S.No.	Title of the experiment	Treatments	Period
22.	Recharging of borewell by the use of runoff water	T1: Without filtration bed T2: With filtration bed (Non replicated study)	2009-11
Agra			
23.	Catchment–storage–command relationship for enhancing water productivity	*Crops:* Bottlegourd, Chillies (green), Okra (*kharif*), Carrot, Radish, Cabbage (*rabi*), Fodder crop (pearl millet+ cowpea) in *kharif* and Lentil in *rabi* **Sowing method** T1: Flat sowing; T2. Ridge and furrow sowing **Irrigation schedule** T1: Control; T2: Pre-sowing (8 cm); T3: 30 DAS (8 cm); T4: 60 DAS (8 cm) Split plot, 3 Reps	2009-LT
24.	Effect of indigenous management practices on production of pearlmillet under rainfed condition	*Crop:* Pearlmillet ***Conservation practice*** M1: Flat bed & broadcast sowing M2: Flat bed & broadcast sowing + Gurr M3: Flat bed & line sowing M4: Flat bed & line sowing + Gurr M5: Ridge and furrow sowing ***Fertilizer*** F1: Control; F2: 100% RDF at sowing F3: 100% RDF in 2 splits (½ at sowing + ½ at tillering) F4: 100% RDF in 3 splits (½ at sowing + ¼ at tillering + ¼ at earing) F5: 100% RDF in 3 splits (1/3 at sowing + 1/3 at tillering +1/3 at earing) Split plot, 3 Reps	2007-11
SK Nagar			
25.	Efficient use of harvested rain water for sustainable castor production	Crop: Castor T_1: Control ; T_2: FYM @ 5 t/ha ; T_3: One life saving irrigation; T_4: One life saving irrigation + FYM @ 5 t/ha; T_5: Two life saving irrigations ; T_6: Two life saving irrigations + FYM@ 5 t/ha. RBD, 4 Reps	2007-10
Hisar			
26.	Effect of intra-plot rain water harvesting and *in-situ* moisture conservation on water use efficiency and yield of pearlmillet and green gram	Land slopes : a) 1% b) 1.5-2% Donor Area **:** a) 2/3 b) ½ **Crops** : a) Pearlmillet b) Greengram RBD, 3 Reps	2010-13

S.No.	Title of the experiment	Treatments	Period
27.	Effect of intra-plot rainwater harvesting and *in-situ* moisture conservation on the water use efficiency and yield of mustard and chickpea	Land Slope : a) 1% b) 1.5-2% Donor Area : a) 2/3 b) ½ Crops : (a) Mustard (b) Chickpea	2010-14
28.	Water use pattern of mustard under dryland conditions	*Crop:* Mustard T1. Disking after each effective rainfall (>20 mm) T2. Ridges and furrows sowing T3. Green manuring of *dhaincha* T4. Green manuring of sunhemp T5. Addition of FYM @ 4 t/ha T6. Low tillage (One harrowing followed by one cultivator with lanker) T7. Deep ploughing before onset of monsoon (30 cm) T8. Control RBD, 3 Reps	2007-11
29.	Efficient use of harvested rainwater through supplemental irrigation	*Crops*: Pearlmillet, Greengram, Mustard, Chickpea T1: *Kharif* (Pearlmillet) - *Rabi* (Chickpea) T2*: Kharif* (Greengram) - *Rabi* Mustard) T3: *Kharif* (½ area Pearlmillet + ½ area Greengram) T4*: Rabi* (half area Mustard + half area Chickpea) T5: *Kharif* (Pearlmillet) - *Rabi* (Chickpea) + 1% $ZnSO_4$ foliar spray after 35 DAS T6: *Kharif* (Greengram) + *Rabi* (Mustard) + 1% $ZnSO_4$ foliar spray after 35 DAS T7: *Kharif* (½ area Pearlmillet + ½ area Greengram) + 1% $ZnSO_4$ foliar spray after 35 DAS T8: *Rabi* (½ Mustard + ½ Chickpea) + 1% $ZnSO_4$ foliar spray after 35 DAS RBD, 3 Reps	2010-LT
30.	Effect of sowing direction on harvesting of rainwater	*Crops:* Pearlmillet, Mustard/Chickpea Sowing directions a) Along the slope (b) Across the slope	2010-LT
Bijapur			
31.	To study the effect of set furrow on moisture conservation and crop yields	*Crops:* Pigeonpea + seasame T1:Set-furrows with Greenleaf manure+crop residue T2: Set-furrows with tank silt + Green leaf manure + crop residue T3: Set–furrows with out any GLM and crop residue T4: Set-rows on flat bed T5: Set-rows on perfectly leveled land (0.1 to 0.2% grade) RBD, 4 Reps	207-12

S.No.	Title of the experiment	Treatments	Period
32.	To study the effect of set furrow on moisture conservation and yield in cotton	*Crops:* Cotton **Planting geometry** M_1 _ 60 cm x 30 cm; M_2 - 75 cm x 24 cm M_3 - 90 cm x 20 cm; M_4 - 45-75-45 cm x 15 cm M_5 - 45-90-45 cm x 13 cm; M_6 - 45-135-45 x 10 cm **Genotypes :** RARS-14 ; DB3 – 12; Jaydhar Split-plot, 3 Reps	2007-11
33.	Effect of set row cultivation on Pigeonpea in medium deep black soils under different onset conditions of monsoon	*Crop:* Pigeonpea, chickpea Normal onset : Pigeonpea Delayed onset: Pigeonpea + chickpea **Planting geometry (Population/ha)** T1: 75-225-75 cm X 10 cm (133333) T2: 75-225-75 cm X 20 cm (66667) T3: 75-225-75 cm X 30 cm (44445) T4: 75-225-75 cm X 45 cm (29630) T5: 75-225-75 cm X 60 cm (22222) T6: 75-225-75 cm X 90 cm (14815) T7: 135 cm X 10 cm (74074) T8: 135 cm X 20 cm (37037) T9: 135 cm X 30 cm (24691) T10: 135 cm X 45 cm (16461) T11: 135 cm X 60 cm (12346) T12: 135 cm X 90 cm (8231) T13: 90 X 20 cm With Furrow (55555) T14: 90 X 20 cm Without Furrow (55555) RBD, 3 Reps	2009-12
34.	Evaluation of intercropping system under set-furrow cultivation in medium to deep black soil under normal and delayed onset of monsoon conditions	*Crops:* Pigeonpea + Greengram **First year** *I. Normal on set of rains* T1: Pigeonpea + G gram (1:2) 90x20 cm T2: Pigeonpea + G gram (1:2) 135x20cm T3: Pigeonpea + G gram (2:2) 135x30cm T4: Sole Pigeonpea (135 x 45 cm) T5: Pigeonpea + G gram (2:1) 120x20cm T6: Pigeonpea+ G gram (2:4)75-225-75x 30cm T7: Pigeonpea + G gram (2:2) 45-135-45 X 30 cm T8: Sole Greengram (135 cm X 45cm) RBD, 3 Reps *II. Delayed on set of monsoon* T1: Pigeonpea+Chickpea (1:2) 90 X 20 cm T2: Pigeonpea + Chickpea (1:2) 135 X 20 cm	2009-12

S.No.	Title of the experiment	Treatments	Period
		T3: Pigeonpea + Chickpea (2:2) 135 X 30 cm T4: Sole Pigeonpea (135 cm X 45 cm) T5: Pigeonpea + Chickpea (2:1) 120 X 20 cm T6: Pigeonpea+C pea (2:4) 75-225-75 x30cm T7: Pigeonpea+ Cpea (2:2) 45-135-45X30cm T8: Sole Chickpea (135 cm X 45cm) RBD, 3 Reps **Second year** *I. Normal on set of rains (during kharif)* Sole Green gram *II rabi season* T1: Sorghum+ Chickpea (1:2) 90 X 20 cm T2: Sorghum + Chickpea (1:2) 135 X 20 cm T3: Sorghum + Chickpea (2:2) 135 X 30 cm T4: Sole sorghum (45-135-45cm) T5: Sorghum + Chickpea (2:1) 120 X 20 cm T6: Sorghum + Cpea (2:4) 75-225-75X30cm T7: Sorghum + Cpea (2:2) 45-135-45X30cm T8: Sole Chickpea (45-135-45cm) RBD, 3 reps	
35.	Quantification of soil loss and runoff under *in-situ* (mulched) conservation measures	*Crops:* Greengram, Sorghum/Sunflower T1. Sand mulch T2. Pebble mulch (100% surface cover) T3. Control RBD, 3 Reps	2008-10
36.	Catchment-storage-command area relationship for increasing water productivity in micro watersheds	*Crops:* Sorghum, Sunflower, Pigeonpea, Greengram, Sapota, Jasmine T1: One irrigation of 5 cm depth T2: Control plot with out irrigation RBD, 3 Reps	2007-LT
Solapur			
37.	Catchment-storage-command relationship for efficient use of harvested water for Neem-based silvi-pasture & Agri- Horti based farming system in scarcity rainfall region of Maharashtra	Trees: Neem, *glyricidia*, Anjan, Acacia, Pongamia, *Jatropha,* Simaruba, Bakan (Melia) *Austrailan babul,* Subabul, Aonla, Drumstick *Crops:* Sunflower, Sorghum, Chickpea, Horsegram, Maize, Grasses *Cenchurs ciliaris,* Stylo **Set I: Shallow soil (less than 45 cm depth) (1 ha)** S.No. Components of IFS Area (ha) 1. Silvi-pasture system neem based 0.30 2. Pearlmillet +Mothbean 0.20 3. *Rabi* sorghum 0.20 4. Horsegram 0.10	2010-15

S.No.	Title of the experiment	Treatments	Period
		5. Chickpea 0.15 6. Livestock (1buffolo + 10 Goats) 0.03 7. Subabul + Gylricidia + Grasses 0.02 **Set II: Medium deep soil (45 to 60 cm depth) (1ha)** 1. Agri-Horti system (Anona + Drumstick + Sunflower + pigeonpea) 0.30 2. Cowpea + *rabi* sorghum 0.40 3. Fodder crops (Madras Anjan /Pavana/ Maize/ Sorghum fodder) 0.10 4. Chickpea 0.15 5. Livestock (1Buffalo + 10 Goats) 0.03 6. (*Subabu*l + Gylricidia + Grasses) 0.02 **Details of silvi-pasture module** * Neem (*Azaridachta indica* 10 x 10 m) T_1: Neem Anjan (*Hardwikia binata*) $T_{2:}$ Neem + *Acacia nilotica;* T_3: Neem + *Jatropha* T_4: Neem + *Pongamia,*T_5: Neem + *Glyricidia* T_6: Neem + *Simaruba glauca* T_7: Neem +Bakan (*Melia azadirachta*) T_8: Neem + Australian babul Cenchurs + Stylo	
Indore			
38.	Effect of drip irrigation and mulch on growth and productivity of guava and aonla grown under dryland conditions in shallow to medium vertisols of western Madhya Pradesh	***Fruit Crops:*** Guava (Allahabadi safeda), Aonla (N 7) **Irrigation :** I_{1-} Basin method; I_{2-} Drip irrigation **Mulch :** M_1- Plastic mulch; M_2- Organic residue mulch @ 3t/ha; M_3- *Gliricidia* leaves mulch @ 2t/ha; M_4- Control (in each treatment 1m dia initially around stem and 5cm depth)	2008-LT
39.	Catchment-Storage-Command relationship for enhancing water productivity in micro–watershed	***Crops:*** Field crops & Horticultural crops (Soybean – Chickpea) Vegetables – Flowers – Fodder - Animal (Cow) **1. Rainfed cropping system** A. Soybean-Chickpea **2. Stored water recycle using drip irrigation** A. (i) Sweet corn maize-Linoleum Flower (ii) Sweet corn-Vegetables (drip irrigation) B. Soybean-Potato C. On boundary of experiments, Napier grass will be planted for feeding animal.	2009-LT

S.No.	Title of the experiment	Treatments	Period
Rewa			
40.	Judicious use of harvested water to get suitable crop sequences for sustainable agriculture	***Crops:*** Soybean, Wheat, Chickpea T1: Irrigation T2: No irrigation	2008-11
41.	Impact of land elevation on *kharif* & *rabi* crops	***Crops:*** Rice, Blackgram, Pigeonpea, Lentil, Chickpea T1: Lower zone; T2: Middle zone ; T3: Upper zone	2008-11
42.	Catchment-Storage-Command relationship and for enhancing water productivity in a micro-watershed	***Crop:*** **Catchment area** T1: Suitable soil and water conservation measures T2: Provide vegetative water ways from pond T3: Assess inflow and out flow from pond T4: Assess seepage and evaporation losses in pond **Command area** T1: To provide protective irrigation to crops	2010-14
Anantapur			
43.	Effective utilization of rainwater for contingent crops	***Crops:*** Groundnut and other crops **Irrigation :** T1: Micro irrigation ; T2: Rainfed **Crops :** T1: Pigeonpea ; T2: Castor; T3: Groundnut ; T4: Cluster bean; T5: Sorghum; T6: Field bean; T7: Horsegram - Split plot, 3 Reps	2007-10
44.	Effect of dikes in alfisols for increasing rain water productivity under groundnut based cropping system	***Crop:*** Groundnut T1: Control; T2: 4 rows 1 dike; T3: 6 rows 1 dike T4: 4 rows 1 dike with mulching (groundnut shells); T5: 6 rows 1 dike with mulching (groundnut shells); T6: Paired row ; T7: Paired row with earthing up; T8: Paired with mulch (groundnut shells) RBD, 3 Reps	2009-11
45.	Catchment-storage-command relationship for enhancing productivity	***Crop:*** Groundnut, Pigeonpea T1: Farmers practice T2: Supplemental irrigation of 10 mm each	2009-LT
46.	Cluster sowing and sowing geometry of groundnut for higher water use efficiency under rainfed conditions	***Crop:*** Groundnut T1: Control; T2: 4 seed cluster+40cm Intra-row spacing T3: 5 seed cluster with 40 cm intra-row spacing T4: 6 seed cluster with 40 cm intra-row spacing T5: 4 seed cluster + decomposed organic matter with 40 cm intra-row spacing T6: 5 seed cluster + decomposed organic matter + 40 cm intra-row spacing T7: 6 seed cluster + decomposed organic matter + 40 cm intra-row spacing RBD, 3 Reps	2009-11

S.No.	Title of the experiment	Treatments	Period
Rajkot			
47.	Effect of mulching on growth of guava under drip irrigation system	***Crop*: Guava** T1. Groundnut shell T2. Wheat straw T3. Subabul twigs and leaf T4. Sesame stalks T5. Castor stalks T6. Plastic mulch T7. Control (without mulch) CRD, 4 Reps Note: In each treatment mulching of 1 m diameter around the stem and 5 cm depth	2006-14
48.	Response of groundnut to supplementary irrigation	***Crops:*** Groundnut (GG-20) T1: Control T2: Irrigation at soil moisture deficit of 40 % T3: Irrigation at soil moisture deficit of 50 % T4: Irrigation at soil moisture deficit of 60 % T5: Irrigation at soil moisture deficit of 70 % T6: Irrigation at soil moisture deficit of > 70 % RBD, 3 Reps	2009-15
49.	Evaluation of rainfall erosivity index and soil erodibility factor in medium black soil under different cropping systems	***Crops:*** Groundnut, cotton, castor T_1: Absolute fallow; $T_{2:}$ Cultivated fallow; $T_{3:}$ Sole Groundnut (GG-20); $T_{4:}$ Sole Cotton (NHH-44); T_5: Groundnut (GG-5) + Castor (GCH-2) (3:1) RBD, 3 Reps	2010-15
Akola			
50.	*In-situ* moisture conservation practices for sustainable productivity of major crops in Vidarbha region	***Crops:*** Soybean, Cotton, Sorghum $T_{1:}$ Furrow opening; $T_{2:}$ Crop residue mulching $T_{3:}$ Thinning ; T_4: Combination of T_1, T_2 , T3 T_5: Control RBD, 4 Reps	2007-11
51.	Response of cotton productivity and quality to land configuration and nutrients under dryland condition	*Crop:* Cotton **Land Configuration** L_1: Flat bed; L_2: Ridges and furrows; L_3: Opening of furrow after every two rows; L_4: Opening of furrow after each row **Organic manures** M_1: RDF (50:25:25 kg/ha NPK through urea) M_2: FYM @ 10 t/ ha + PSB + *Azotobacter* M_3: FYM @ 10 t/ ha+50% RDF+PSB+*Azotobacter* M_4: Vermicompost @ 2.5 t/ ha+PSB+*Azotobacter* M_5: Glyricidia @ 10 t/ ha + PSB + *Azotobacter* Split-plot, 3 Reps	2008-10

S.No.	Title of the experiment	Treatments	Period
52.	Catchment-Storage-Command relationship for enhancing water productivity in micro- watershed	***Crops:*** Soybean, wheat, chickpea T1: Irrigation T2: No irrigation	2010-LT
Kovilpatti			
53.	Catchment- storage - command relationship for enhancing water productivity in a micro - watershed	***Crop:*** Hybrid Cotton T1: Crop (Pure rainfed); T2: Crop with supplemental irrigation through drip method with normal row spacing T3: Crop with supplemental irrigation through drip method with paired row spacing Strip Plot, 5 Reps	2006-10
Parbhani			
54.	Performance of *in-situ* rainwater conservation techniques for dominant cropping systems	***Crops:*** Sorghum, Pigeonpea, Soybean, Cotton **Cropping system** C1- Sorghum + pigeonpea (4:2) C2- Soybean + pigeonpea (4:2) C3- Cotton Bt.+ soybean (1:1) ***In-situ* conservation** T1- Conservation furrow after 2 rows T2- Conservation furrow after 4 rows T3- Conservation furrow after 6 rows T4- Conservation furrow after 12 rows T5- Control RBD, 3 Reps	2006-10
55.	To study the performance of moisture stress management techniques for dominant cropping systems	*Crops:* Sorghum, Pigeonpea, Soybean, Cotton **Cropping systems** C1- Sorghum + pigeonpea (4:2) C2- Soybean + pigeonpea (4:2) C3- Cotton Bt.+ soybean (1:1) **Stress management** S1- KNO_3 spray @ 1.5% S2- Soil mulch (additional hoeing during dry spell) S3- Vegetative mulching @ 2 t/ha S4- Combination of S1 to S3 ; S5- Control RBD, 3 Reps	2008-10
56.	Evaluation of rainwater conservation practice for soybean + pigeonpea (4:2) in farmers field condition	**Crops**: Soybean, Pigeonpea T1- Opening of furrow after every 4 rows at 4 weeks after sowing; T2- No furrow opening (10 farmers from 3 eco-zones of Marathwada region)	2009-11

Operational Research Project (On-farm trials)

S.No.	Title of the experiment	Treatments	Period
Anantapur			
1.	Mitigation of drought through application of small amount of supplemental irrigation	***Crops:*** Groundnut + Pigeonpea T1: Control T2: Application of 10 mm of water from farm pond during dry spell of more than 10 days depending on the availability of harvested water	2010-14
2.	Participatory evaluation of different micro irrigation methods for reuse of rainwater in groundnut	***Crops:*** Groundnut + Pigeonpea T1: Supplemental irrigation with sub-surface sprinklers; T2: Supplemental irrigation with surface drip irrigation; T3: Rainfed	2010-13
Arjia			
3.	Development and evaluation of *in-situ* moisture conservation model	***Crops:*** Maize/ Sorghum **A. SWC measures** (i) Peripheral bunding; (ii) Deep ploughing; (iii) Chieseling **B. Conservation farming** (i) Tillage operation against the slope; (ii) Sowing against the slope; (iii) Soil mulching; (iv) Ridge after 30 DAS; (v) Crop residue/mulch	2010-14
Bangalore			
4.	*In-situ* moisture conservation through furrow for improving the productivity	***Crops:*** Finger millet, Pigeonpea T1: Finger millet + pigeonpea (8:2) with soil and moisture conservation furrow between paired rows of pigeonpea; T2: Farmers practice (Finger millet + Akkadi fodder jowar)	2010-13
Chianki			
5.	Bund Stabilization / Rainwater management	***Crop:*** Upland Rice T_1-Farmers' practice (Unbunded or partially bunded land); T_2-Bund Stabilization/ *in- situ* water harvesting RBD, 7 Reps	2009-14
Hisar			
6.	Effect of moisture conservation on productivity of chickpea and mustard	***Crops:*** Mustard, Chickpea T1. Disc harrow; T2. Country plough	2010-13
Solapur			
7.	Effect of *in-situ* moisture conservation measure on the yield of pigeonpea under dryland condition	***Crop***: Pigeonpea T1- Opening of ridges and furrows at 30 DAS; T2- Control- (farmers practice)	2010-14
8.	Effect of *in-situ* moisture conservation practice on the performance of *rabi* sorghum	***Crop***: Sorghum T1- *In-situ* moisture conservation practices - ridges and furrows at 30 DAS T2- Control- (farmers practice) (harrowing)	2010-14

Water Resource Development and Recycling in Hill and Mountain Agro-ecosystem of North-west Himalaya

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The Himalayan region of India accounts for 14 % of land area supporting 6 % of population. The hill people face difficulties in raising crops to meet their needs. The average farmer's family produces only 5-8 months of food from their cultivated terraces (Ved Prakash and Kumar, 2006). Negi and Dhar (2006) enlisted the major ecological and economical factors which make agriculture unsustainable. These include rainfed cultivation (82.6 % of the cultivable area), small and fractured holding distributed over rugged terrain, insufficient crop yield and limited scope to adopt intensive agriculture. Shortage of land and low productivity are the causes for cultivation of steep and unstable hill slopes. Srivastava et al. (1988) reported that 33 % of cultivated land belongs to class V, VI and VII against the norm of not cultivating any land having capability beyond class IV which leads to more soil erosion causing environmental threats and loss of crop productivity.

To address these issues, three-pronged strategies need to be adopted. These include 1) remedial in-situ moisture conservation 2) water harvesting and surface storage and 3) energy efficient techniques for "more crops per rain drop". The techniques addressing these strategies were transferred to farmers' field through training and large scale on-farm demonstrations and are discussed in subsequent section of this text.

Remedial In-situ Moisture Conservation

Soil-plant-water-atmosphere system inhibits empirical nature and complex relationship among the various interacting factors of the water balance. This lead to simulation modeling by several researchers in the past to determine the optimal design of the runoff recycling based systems for crop production. For hill and mountain agro-ecosystem an innovative design of seepage trenches was envisaged. It is essential to determine the optimal size of seepage trenches since excessively large trenches are wastage of precious land resources with high cost of construction and trenches too small can not meet the crop-water requirement. The study is to determine the optimal size of seepage trenches and its functional and economic evaluation was carried out in terraced land of hilly region, where provision of on-farm-reservoir (OFR) water storage system for surface irrigation is usually not feasible because of several reasons. These include, the area of most of the individual terraces is limited to 200 m^2, and width usually less than 10 meters and average soil depth is limited to 1.0 meter. The land modification was done to enhance the sub-surface flow of water in the soil which improved the soil moisture regime. Response of soil moisture to the crop yield under the rainfed farming system is highly site-specific, depending on the climate, soil and availability of water.

Works Implemented

The theoretical framework of soil water balance model was simulated for soil moisture stress factor using 6 years (1998-2003) climatic data between meteorological weeks of 24 to 41 coinciding the onset and recession of monsoon. Duration for four critical crop stages namely, germination, tillering, panicle initiation and reproduction were taken as 3, 3, 3 and 4 weeks, respectively. Different sizes of seepage trenches (33%, 25%, 20%, 17%, 14% and 12.5% area of the terrace land) were simulated for soil moisture stress. On the basis of simulation and experimental results, a trench having width equal to 1/6th part of the respective terrace width and 50 cm deep was constructed. The average soil depths were 1.0 and 2.1 m at the riser end and shoulder bund end of the terrace respectively **(Fig. 1)**. The trenches were constructed at the riser end of the terrace. The trenches receive water as runoff from the micro-catchment of the terrace riser (Slope length 2 meter and 50^o slope angle) and direct rain. The capacity of the trenche was 12.9 m^3. The terrace riser was completely covered with grass (*Cynadon Dactylon*).

The rice variety, *Vivek Dhan 154* was selected for the field experiments because it is recommended for the rainfed conditions of hills. The length of growing period (LGP) of this variety is 100-110 days. The agronomic practices such as sowing method, seed rate, fertilizer application, interculture operation and harvesting were done as standardized by VPKAS, 2005.

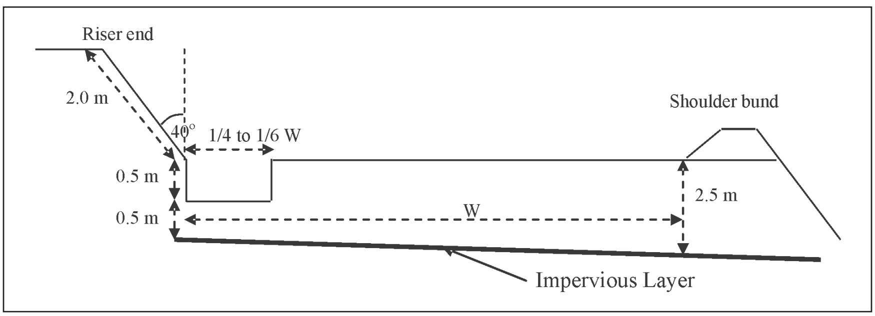


Fig. 1 : Cross sectional view

Benefits Accrued

The water infiltrate horizontally from trench to the soil profile through matric suction force. After infiltration process, redistribution starts and the nearest plot to the trench which is wetted to near saturation, begins to transmit water to the successive portion horizontally. After certain length, however, the soil first wets during redistribution and then transmits. Hence the wetness gradually decreases as the length increase and thus the soil moisture content decreases gradually towards the far end (shoulder bund end) of the terrace. In all the cases, the moisture distribution in the soil was higher near to the trench and gradually decrease to the far end.

i) Yield response

Rice crop experienced drought during most of the growing season. Though much of the rainfall received during the monsoon season but its temporal distribution is highly skewed. The soil moisture stress during the critical growth stages of the crop played significant role in rice yield. The average yield significantly increased to 64.7 % than the control (1.73 t/ha).

ii) Economic analysis

The per ha initial investment, annual costs and returns from different trenches were calculated. The per ha initial investment and present worth value were worked out to be Rs. 49,573 and Rs. 125,896 respectively. The present worth of annual returns was calculated Rs. 189,866. The present worth of cost and returns in case of control was calculated as Rs. 77,965 and Rs. 114,647 respectively. The BCR value was found as 1.51.

Scope of Replication

In terraced agriculture of hills, where 90 % of the area is rainfed, this innovative technology is highly suitable and recommended. This technology has been demonstrated in one of the farmers' field in FPARP project (Demonstration of Storage and Application System for Efficient Water Utilization in Major Crops of Uttarakhand Hills through participatory approach) to show the benefits to other farmers for adoption and the awareness is being generated.

Water Harvesting and Surface Storage

Insufficiency of soil moisture, particularly when it coincides with the critical stage of crop growth, is one of the major constraints for low yield. The reproductive phase of short duration crops (100-110 days duration), usually has 30 days, typically between August -September and February-March in case of *kharif* and *rabi* season respectively. In this region, half of the duration of the reproductive phase experiences soil moisture deficit of 20%, below saturation moisture content (SMC) that adversely affects the crop yield. The provision of supplemental irrigation is necessary to maintain the soil moisture regime at optimal level for obtaining higher production. The lift irrigation system demands high investment in the hills, where lift varies between 40 to 80 m. This high cost makes the agriculture in the hills a risky proposition. Several studies on supplemental irrigation using on-farm water storage system have been carried out in the past. The geographical limitations and terrain conditions indicate the possibilities of small tanks which can be well integrated with the hill farming system and household. Construction of small tanks of capacity less than 200 m^3 is a good economical alternative for storage of excess rainwater and its utilization as supplemental irrigation during dry spell of monsoon season and pre-sowing irrigation to the crops of *rabi* season. In hill terrains prevailing overhead cement-concrete tanks are not only expensive but also prone to geological disturbances. Use of flexible and impervious layer such as LDPE film in water storage structures is an answer to this problem. This technology is not only economical and resistant to geological disturbances but also reduces the seepage loss, thus, maximize the water availability for irrigation.

Work done

The prevailing source of perennial flow from natural springs exists in the hilly terrain. However, the discharge is substantially low (1 – 10 litres/minute). These can be harvested in impervious collection tanks. However, substantial runoff water from existing catchment can also be collected in these tanks. The design for collection and storage has been standardized as described in **Fig. 2.**

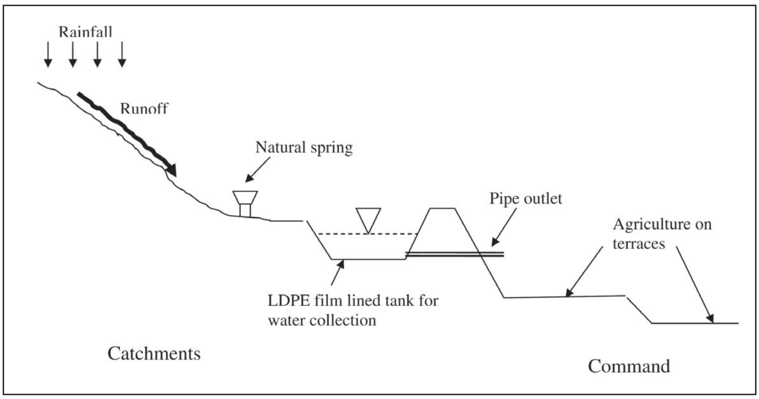


Fig. 2 : Schematic diagram of water harvesting components

Low density polyethelene (LDPE) film has been successfully used to control the seepage loss effectively at much lower cost than the cement tanks. The film used should have minimum thickness of 200µ (0.2 mm). To avoid the physical damage and weathering from sunlight, protection of the film was realized through application of anchoring material such as tarfelt sheet.

i) Design

The design of LDPE tank involves various components such as capacity, dimension of tank, site and crop water requirement. The capacity of the tank designed considering the availability of water stored and catering the irrigation need during the acute water shortage period. The various steps in the designing of tank are illustrated as follows :

The following considerations for designing the standard size LDPE tank for vegetable production under micro-irrigation system were:

- Area of command: 400 m^2
- Crop season : March (Transplanting) to June (Harvesting)
- Spacing: 50 X 50 cm

Assumption:

- The experimental site represents the typical mid-hill conditions of NW Himalaya.
- Irrigation is provided at uniform rate.
- The region receives the winter rain and the tank is full by the 31st December of the year.
- The stored water in the tank lost only due to evaporation.

Irrigation schedule:

- Average operation time of the system: 30 min
- System operation: Alternate day

Computation of tank dimension:

- Total water lost as evaporation: 600 mm (Based on the weekly evaporation data over 6 years i.e. 1998 to 2003). Thus the depth of the tank should be greater than 60 cm plus 15 cm as free board *i.e.* 75 cm.
- Water application:
  - No. of irrigations : 50
  - Volume of water required per irrigation: 0.5 (discharge during 30 min) X 1600 (No of plants) = 800 litres
- Total volume of net irrigation water: 800 X 50 = 40,000 liters i.e. 40 m^3. excluding the evaporation losses.

ii) Standardization of construction procedure for LDPE film lined tanks

The construction of LDPE film lined tanks mainly involve four major steps, which are site selection, excavation and treatment of pit, laying of LDPE film and covering the film.

The site in construction of tank should be nearer to the command area. However, due consideration must be given to the location of water source. The points considered while selecting site for LDPE film lined tanks are : 1) location and availability of water source; 2) soil depth; 3) proposed land use; and 4) obtainable gravity head.

Selected area based on the considerations listed above is marked on the ground. Marking is done considering the provision for burying the film at the corner of the tank, side slope and bottom dimension. Marking is done by the procedure illustrated in the **Fig. 3**. L and W are the length and width of the land where tank is proposed; n is the side slope, h is the height of embankment and d is the depth of excavation.

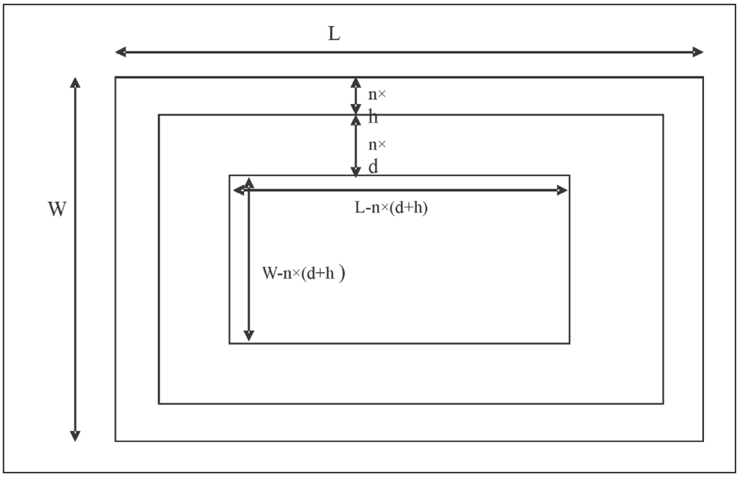


Fig. 3 : Layout procedure of the tank

The top and bottom dimensions are marked on the land using pegs before beginning of the excavation process. The excavated soils are kept on side of the tank thereby forming embankment (**Fig. 4, Plate 1**). After excavating the pit, the bottom and the side wall should be compacted in order to suppress the angular projections (**Plate 1**). After compaction, the side walls and bottom are treated with 0.4 per cent Atrazine (herbicide solution) so that the plastic film could be saved from puncture caused by weed infestation. The surfaces of side wall and bottom are smoothened using dung and soil mixed with water before laying the LDPE film.

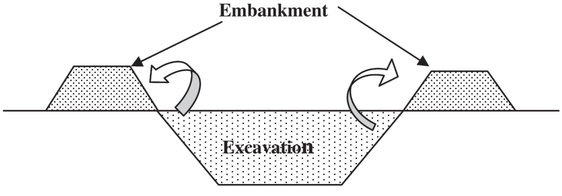


Fig. 4 : Excavation of pit and embankment of the dug out soil

The LDPE (Low Density Poly Ethylene) films are spread over the excavated pit. The minimum specifications of the LDPE film are given in **Table 1**. Care should be taken to avoid the wrinkles. The film must be pleated at the corner (**Plate 2**). The LDPE films are joined using bitumen, used in hot mix road construction. For joining, both films are spread on the flat surface. The edge (15 cm) of both the films is then scrubbed using emery paper or sand paper (120 grade). The bitumen is heated to 80°C, when it starts flowing freely, are then pasted over the scrubbed edge of the film and films are then overlapped (15 cm). Some weight is kept over the joint for setting. After 30 minutes, the film joint firmly. Another joining method is by the application of SR 989 adhesive pasted over the scrubbed surfaces of the films (**Plate 3**).


Plate : 2


Plate : 3

The film is punctured at the bottom corner and 25 to 40 mm pipe (GI, PVC or HDPE) is inserted inside the tank, from tank side. To fix the pipe with the film, 10 cm thick CC is applied. One gate valve is provided outside of the tank to regulate the flow (**Plate 4**). The LDPE film has the lower dart impact resistance (110 gm; ASTM D1709) and thus it is prone to puncture. To avoid the puncture and provide protection from sunlight tarfelt sheet (mica impregnated coal tar sheet) was extensively used in anchoring the film (**Plate 5**).

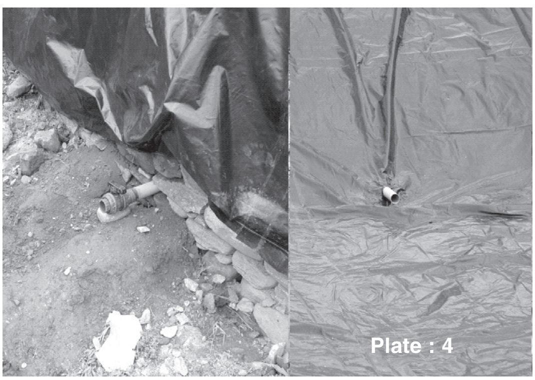


Plate : 4


Plate : 5

iii) Field demonstrations

Based on the methodology described earlier, water resources of 2417 m^3 were developed at the farmers' field under the outreach activities of the Institute. The water resources were developed in two clusters namely Bhagartola (Almora District) and Darim (Nainital district) through the series of tanks accounting to 26 and 52 tanks, respectively.

iv) Cost sharing through participatory mode

The length, width and depth of these tanks were varied from 2.4 to 33m, 1.5 to 7 m and 0.7 to 2.6 m, respectively. The capacity of these tanks ranged from 10 to 288.75 m^3. Nearly one third LDPE tanks were having the capacity of 10 to 15 m^3 because of the available terrace size and smaller land holdings of the farmers. More than half (27) of the total number of polytanks were of 15 to 30 m^3 size and only 15.4% of tanks constructed were above 30m^3 capacity (**Table 1).**

Table 1 : Details of water resources development at farmers' field, Darim, Nainital and Bhagartola, Almora, Uttarakhand, India

Capa3city of tank (m^3)	**No. of tanks**	**Earthwork Cost @ Rs.100/ m^3 (Rs)**	**LDPE sheet cost, @ Rs.28/ m^2 (Rs)**	**Coal tar sheet cost, @Rs. 50/ m^2 (Rs)**	**Institutional share (Rs)**	**Farmer's share (Rs)**	**Total cost (Rs)**
Darim (Nainital District)							
10-15	17	21065	22540	13552	36092	21065	57157
15-20	9	15627	14056	9214	23270	15627	38897
20-25	9	19785	15989	10610	26599	19785	46384
25-30	9	23602	18216	12369	30585	23602	54187
30-40	4	12852	8564	6142	14706	12852	27558
70-100	3	26050	8289	8320	16609	26050	42659
280-300	1	28875	3722	1906	5628	28875	34503
Total	**52**	**147856**	**91285**	**62113**	**153489**	**147856**	**301345**
Bhagartola (Almora District)							
25-50	9	21570	19216	16654	35870	21570	57440
50-75	10	37130	21410	17355	38765	37130	75895
75-100	4	34733	13289	9932	23221	34733	57954
>100	3	43300	11166	7624	18790	43300	62090
Total	**26**	**136733**	**65081**	**51565**	**116646**	**136733**	**253379**

Unit cost of these tanks decreased as sizes of the tanks increased. Average unit cost for 10-15m^3 tank sizes were Rs 271.34 per m^3, whereas the lowest unit cost for 290 m^3 capacity tanks was found to be Rs.120.00 (**Fig 5**). But due to smaller land holdings and terrace sizes, large polytank (more than 100 m^3) construction is having limited scope. It is evident in the cluster of polytanks at Darim where only one tank out of 52 was having more than 100 m^3 capacity. Secondly, due to lack of land consolidation farmers had limited option to go for big size polytanks.

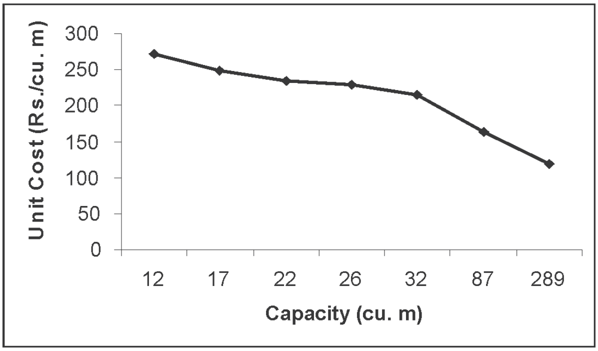
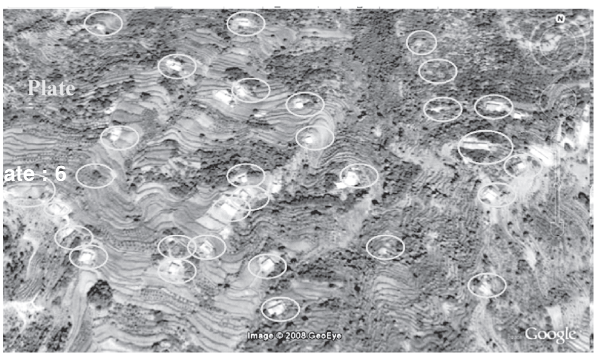


Fig. 5 : Unit cost of LDPE lined tank constructed at farmers' field at Darim

The source of water for these tanks was runoff and low discharge natural springs. The maximum discharge of these sources during summer was measured as 18 litres per minute. So, timeliness of irrigations can be ensured by these tanks for a frequent irrigation through micro irrigation systems.

The aerial view of tanks in Darim cluster is partially shown in **Plate 6**. The image was captured from web resources and 31 tanks were located in the present scene.

Water Resource Development at Darim village, Nainital



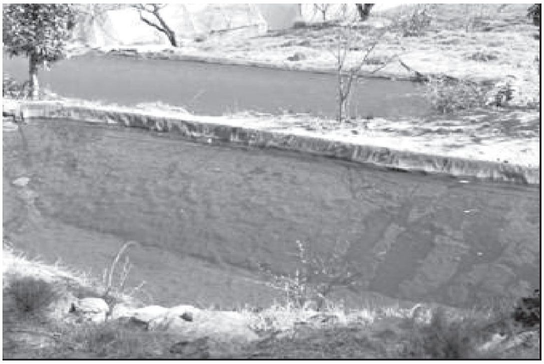
With the construction of these 52 polytanks, a total of 1404 m^3 capacity water resources were created. The irrigation potential of the developed water resources was 12.5 ha when irrigated through micro-irrigation system. In case of flood irrigation system, this resource can irrigate 4 ha land. Some of the tanks were also used of fish cultivation to enhance the farmers' income.

Success Stories of Individual Farmer (Darim and Bhagartola)

In the development of these water resources in farmers' field, the contribution of farmer was in terms of labour. The success stories of few farmers benefited from this project are given in the following sections in brief. This type of work can be replicated through the hills without harming the environment.

	Farmer: Inder Singh, Darim
	Tank Capacity: 232 m^3
	Command: 1.2 ha
	Productivity (% increase) in: 1. Tomato (29.8), 2. Capsicum (21.0), 3. French bean (15.0), 4. Veg Pea (28.6), 5. Potato (27.8)
	Farmer: Dhan Singh, Darim
	Tank Capacity: 70.2 m^3
	Command: 0.56 ha
	Productivity (% increase) in: 1. Tomato (30.2), 2. Capsicum (12.0), 3. Cabbage (31.3), 4. Veg Pea (24.5), 5. Potato (26.3)
	Farmer: Queraj Singh, Darim
	Tank Capacity: 21 m^3
	Command: 0.3 ha
	Productivity (% increase) in: 1. Tomato (23.7 %), 2. Capsicum (17.0 %), 3. French bean (19.8%), 4. Veg Pea (14.9%), 5. Cabbage (29.8%)

	Farmer: Narendra Kumar, Darim Tank Capacity: 45 m^3 Command: 0.32 ha Productivity (% increase) in: 1. Tomato (32.0), 2. French bean (19.0), 3. Veg Pea (22.0), 4. Cabbage (29.0), 5. Potato (18.5)
	Farmer: Ishwar Dutta Pandey, Tank Capacity: 35 m^3 Command: 0.2 ha Productivity (% increase) in: 1. French bean (16.0), 2. Tomato (23.0), 3. Veg Pea (19.0), 4. Cabbage (27.0), 5. Potato (22.0)
	Farmer: Kheemanand Pandey, Bhagartola Tank Capacity: 190 m^3 Command: 1.1 ha Productivity (% increase) in: 1. Tomato (35.0), 2. Veg Pea (21.0), 3. Cabbage (28.0), 4. Cucumber (22.0) 5. Potato (14.0)
	Farmer: Anand Bhatt, Bhagartola Tank Capacity: 47 m^3 Command: 0.22 ha Productivity (% increase) in: 1. Tomato (28.0), 2. Veg Pea (24.0), 3. Cabbage (32.0), 4. Cucumber (25.0) 5. Potato (18.0)

	Farmer: Harish Pande, Bhagartola Tank Capacity: 38.4 m^3 Command: 0.12 ha Productivity (% increase) in: 1. Tomato (30.0), 2. Veg Pea (19.0), 3. Cabbage (24.0), 4. Cucumber (21.0) 5. Potato (16.0)
	Farmer: Harish Prasad, Bhagartola Tank Capacity: 52 m^3 Command: 0.24 ha Productivity (% increase) in: 1. Tomato (33.0), 2. Veg Pea (14.0), 3. Cabbage (23.0), 4. Potato (19.0) 5. Cucumber (22.0)
	Farmer: Krishnanand Pande, Bhagatola Tank Capacity: 48 m^3 Command: 0.4 ha Productivity (% increase) in: 1. Tomato (26.0), 2. French bean (12.0), 3. Veg Pea (16.0), 4. Cabbage (28.0), 5. Potato (18.0)
	Farmer: Rewadhar Pandey, Bhagartola Tank Capacity: 37 m^3 Command: 0.3 ha Productivity (% increase) in: 1. Tomato (30.0), 2. Cucumber (21.0), 3. Veg Pea (12.0), 4. Cabbage (20.0), 5. Potato (22.0)

Energy Efficient Techniques of Water Resource Utilization

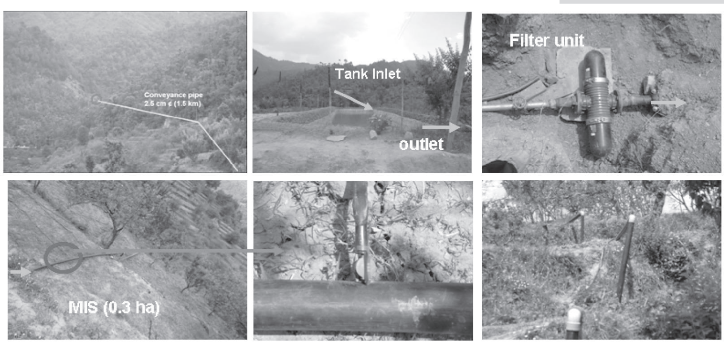
Efficient application of water is a major issue in hill agriculture. The present wastages occurring through storage, conveyance and distribution ultimately result in delivering 30 to 35 % of stored water for plant uptake. The traditional methods of flood or ridge and furrow irrigation suffers from numerous problems such as considerable seepage, conveyance and evaporation losses, higher energy costs, lower water productivity, irrigation induced soil erosion and leaching of costly agricultural inputs causing pollution of sub-surface water. Moreover, this method is supply driven rather than crop-demand driven thereby causing mismatch between need of the crop and the quantity of water supplied. The projected decrease in the share of water for agriculture, coupled with the needs of the higher agricultural productivity, necessitates improvement in the water use efficiency. This requires efficient utilization of available water which otherwise would evaporate or percolate beyond the root zone of the soil. The frontier technology of micro-irrigation system not only provides higher water productivity but also minimize the drudgery and other problems associated with the traditional irrigation system.

Work Done

The prevailing terrace cultivation in the region provides ample scope for gravity-fed micro-irrigation system. This minimizes the fuel based energy or electricity requirement in operation of system which further increases the profitability. This concept envisaged the scope of water resources development and its utilization in crop production through gravity-fed micro-irrigation system by enhancing water use in the mid hill and high hill conditions of NW Himalaya.

Keeping this concept in view, micro-irrigation system (MIS) was integrated with the developed water resources in Darim and Bhagartola villages. One such integration was depicted in **Plate 7** where water was conveyed from remote source (1.5 km) and stored in

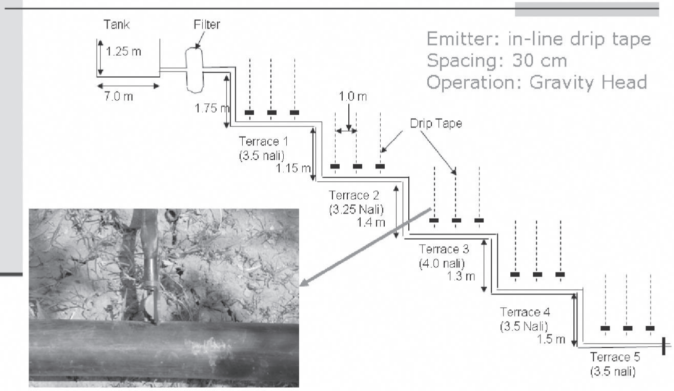
Plate 7. Integrating Water Harvesting and MIS



a tank (Capacity 290 m^3). The MIS was installed in the fields and farmers cultivated garden pea (Variety: Arkel) and frenchbean (variety: Contender) in October-March and April-June respectively because of better price for the crop at this time of the year. But normally there is little or no rain at this time. The storage and MIS was used to irrigate these crops.

The outlet pipe was installed at the bottom of the tank, and fitted with the screen filter closer to the tank. No submain pipe was connected to the main pipe because the terraces were small. The micro-irrigation system, comprising of in-line drip tape as water emission device (WED), was installed at the terraces which are downside to the tanks. The spacing of WEDs was kept as 30 cm. The rated discharge of the chosen WEDs was 4 lph (liter per hour) at the nominal pressure of 3.0kgf/cm^2 (30.0 m of hydraulic head). The terrace wise design and layout of one of the systems is presented in **Fig. 8**. The main line was fixed at

Figure 8. Micro Irrigation System : Design and Layout



the corner of terrace to minimize the cost of main line. The system was operated using the gravity head available in the respective terrace which varied from 1.75 (terrace 1) to 5.6 m (terrace 4) after moderating the head loss in different components of irrigation system. This caused more flow variation and low uniformity coefficient of emitter resulting in low field emission uniformity. This problem can be addressed by rescheduling the operational time for individual terrace after hydraulic evaluation. This method is easy to adopt since no alteration in the standard design procedure of micro-irrigation system is suggested and irrigation time can be adjusted according to per plant water requirement. However before initializing the irrigation, hydraulic evaluation is required to fix the terrace-wise irrigation time.

The irrigation system was evaluated for both functionally and economically to demonstrate the benefits from this integration.

i) Functional Evaluation of Irrigation System

The average discharge of the emitters were normally low (1.06 lph) in the terrace near to the supply tank and more in the terrace far from tank (2.09 lph). The energy loss gradually increases as length of the lateral pipe increases and thus the available operating pressure reduces which resulted in the gradual decrease in the emitter discharge along the lateral lengths. The average discharge obtained at the 4th terrace was double the 1st terrace, hence operation time was rescheduled (**Table 2**). In order to meet the water requirement of 3 and 5 mm per irrigation, the required discharge volume from the single emitter was calculated as 0.75 liter and 1.25 liter during winter (vegetable pea) and summer (frenchbean), respectively.

Table 2 : Terrace-wise operation time of irrigation system

Terrace No	Average Discharge (lph)	Operation time (minutes)	
		Vegetable pea	Frenchbean
1	1.06	42	70
2	1.24	36	60
3	1.67	27	45
4	2.09	21	36

ii) Hydraulic Performance of the System (Rescheduled Irrigation)

The overall variation of 26.54 % was found in emitter flow rate variation q_{var}, which was slightly higher than the acceptable limit of 20 % (ASAE 1985). The Christiansen uniformity coefficient CUC of the system was computed as 86.29 % which is within the permissible limit of ASAE criteria (ASAE 1985). The acceptable limit of the CUC for the drip irrigation system is greater than 85 %, thus the system qualifies the design criteria of CUC. The overall distribution uniformity (Du) was found as 87.46%.

iii) Yield Benefits

Garden pea yield was 6.3 % higher in case of micro-irrigation system as compared to the check basin irrigation (120.0 q/ha). The water use efficiency was increased to 0.486 from 0.286 in case of check basin irrigation system that results into the saving of 41.1 % irrigation water. The frenchbean yield was at par for both the irrigation systems. However, the water use efficiency was increased to 0.377 q/ha-mm in case of micro-irrigation system that saved 33.33 % irrigation water. The water use efficiency was significantly higher for micro-irrigation system in both garden pea as well as frenchbean **(Table 3).** Though the vegetable yield was not increased using micro-irrigation system, the system helps in increasing the area under irrigation.

Table 3: Comparative performance of irrigation system

Irrigation system	Vegetable pea			Frenchbean		
	Irrigation water (mm)	Average Yield (q/ha)	WUE (q/ha-mm)	Irrigation water (mm)	Average Yield (q/ha)	WUE (q/ha-mm)
Check Basin irrigation	419.6	120.0	0.286	342.3	95.5	0.279
Micro-irrigation	262.3	127.5	0.486	256.5	96.7	0.377
CD (*P*= 5%)	-	NS	0.032	-	NS	0.028

iv) Economic Benefits

Net present value (NPV) was calculated as Rs. 160,523 and 65,223 for micro-irrigation and check basin irrigation, respectively for the current market price of Rs 7 each for vegetable pea and french bean respectively (**Table 4**). The micro-irrigation system provided higher BCR (1.78) value and IRR in comparison with check basin irrigation (1.38). The pay back period of the micro-irrigation system under present set of condition was calculated as 3.4 and 4.8 years for micro-irrigation and check basin irrigation system, respectively. The IRR for check basin irrigation system was found as 6.4 %, less than the current interest rate for agricultural loan, 9%. Hence the check basin irrigation system was not found economically viable as compared to micro-irrigation system for which IRR was 12.2%. However, the different values of economic indicators may change under other cropping system and sets of conditions.

Table 4 : Economic analysis of different irrigation systems

Economic parameters	Irrigation system	
	Check basin irrigation	Micro-irrigation
Net Present Value (Rs)	65223	160523
Benefit Cost Ratio	1.38	1.78
Internal Rate of Return (%)	6.4	12.2
Pay Back Period (Years)	4.82	3.38

The price and yield fluctuations are crucial sources of uncertainty in most of the rural settings. For different price and yield scenario the sensitivity analysis showed that the threshold price should be Rs 7.00 at normal production level in case of check basin system. The system becomes uneconomical when price crashes down to Rs 5 at normal production level. The micro-irrigation system, however, remained economical at this price level. In contingency situation where the yield reduces substantially (20%), the MIS will not lead to loss (**Table 5**).

Table 5 : Effect of price and yield of crops under different economic indicators

Price	% change in yield	Check basin irrigation system				Micro-irrigation system			
		NPV	BCR	PBP	IRR	NPV	BCR	PBP	IRR
5	+20	31,618	1.19	5.63	3.2	108,315	1.53	3.94	8.6
	+10	14,816	1.09	6.14	1.5	82,245	1.40	4.30	6.7
	0	-1,986	0.99	6.75	-0.15	56,106	1.27	4.73	4.7
	-10	-18,867	0.89	7.51	-2.1	30,000	1.14	5.25	2.6
	-20	-35,592	0.79	8.44	-4.1	4,048	1.01	5.90	0.2
7	+20	112,270	1.66	4.02	10.5	234,204	2.14	2.81	17.0
	+10	88,747	1.52	4.38	8.4	197,069	1.96	3.07	14.6
	0	65,223	1.38	4.82	6.4	160,523	1.78	3.38	12.2
	-10	41,700	1.25	5.36	4.2	123,977	1.60	3.75	9.7
	-20	18,176	1.11	6.03	1.8	87,693	1.43	4.22	7.1
9	+20	192,922	2.13	3.13	16.8	359,674	2.76	2.19	24.5
	+10	162,678	1.95	3.41	14.5	311,928	2.52	2.39	21.7
	0	132,433	1.78	3.75	12.1	264,940	2.29	2.63	18.9
	-10	102,189	1.60	4.16	9.6	217,953	2.06	2.92	16.2
	-20	71,994	1.42	4.69	7.0	170,965	1.83	3.22	12.9
11	+20	273,575	2.61	2.56	22.7	485,144	3.37	1.79	31.5
	+10	236,609	2.39	2.79	20.1	426,788	3.08	1.95	28.3
	0	199,643	2.17	3.06	17.3	369,358	2.80	2.15	25.1
	-10	162,678	1.96	3.41	14.5	311,929	2.52	2.39	21.7
	-20	125,714	1.74	3.84	11.6	254,499	2.24	2.67	18.3

Conclusion

The Hill and Mountain agro-ecosystem of NW Himalaya is characterized by very less irrigated land and difficult terrain. Large scale water resource development is not feasible. The on-farm water management and improvement in soil moisture regime are possible solutions. The prevailing terrace cultivation in the region provides ample scope for gravity-fed micro-irrigation system. The difficult terrain of the NW Himalaya, water management at the small and fragmented land is the biggest challenge to improve the agricultural productivity and profitability. The simple gravity-fed low pressure irrigation system could effectively address the most important issue of water management and increasing the area under irrigation in hill and mountain agro-ecosystem.

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Strategies for Rainwater Management Using Plasticulture Techniques

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Most of the area under the south Asia region has been characterized as monsoon region, where it gets rainfall during a certain period in a year, while rest of the period remains relatively dry. This rainfall is the only source of water for almost all human activities in all the SAARC countries, except a small portion of desalinized sea water for drinking purposes in coastal regions, especially in Maldives. The rainfall recharges the ground water and flows in rivers or streams which is used in one way or the other for different purposes. However, during the dry period, the water demand needs to be met out from stored water only may in subsurface or on surface in the form of snow or subsurface water. Such storage is getting diminished due to high pressure from industrialization, urbanization and ever increasing population. To supplement such need as well as enabling water availability in topographical disadvantageous area, we need to preserve the rainwater. Rainwater harvesting has been found one of the remedies for reducing the drought risk in south Asian region (Anonymous, 2010).

The rainfall distribution is widely varying in this region may be between 150 mm in Thar desert spread over west India and east Pakistan, while more than 11,000 mm in Meghalaya hills in India. The duration of rainfall is also widely varying as it occurs in monsoon months of June-October in India, Pakistan, Nepal, Bhutan, and Bagladesh, while in Maldives it is May to December. The need and opportunity for rainwater harvesting also varied largely and more pronounced in hilly and mounteneous regions as compared to plain areas where better management of subsurface and surface waters is needed.

Water is a crucial input in all types of agricultural production systems, whether it is food grain production, horticulture, fishery, livestock, forestry, piggery, poultry, and so on. However, paucity of water during dry period reduces the productivity of all the agricultural commodities especially during summer periods. Rainwater harvesting and efficient utilization are very important to sustain such production systems which can provide water on a limited scale, though not meeting the full demand. The productivity is too low under rainfed condition, mostly because of uncertain rainfall. Rainwater harvesting may improve the productivity level of such areas by providing supplementary irrigation, may be on a limited level, but it can improve the overall scenario, if the water is used judiciously with proper strategy.

Harvesting of rainwater in upland areas is most crucial, as they are water scarce areas with low productivity due to lack of water, and needs diversification to realize the actual potential using natural and other resources available. If water is stored, seepage and evaporation are major constraints which limits quantity of usable water out of stored water. Storing water in small ponds is a viable technique, but the ponds needs lining to protect water from seepage. Several methods of lining of ponds have been practicing since a long time including cement concrete. Cement concrete or cement mortar lining are very costly, and once the walls develop cracks then they become almost irrepairable. Plastics film lining has become more popular now-a-days, but, not much success is obtained in propagating the technology among the small and marginal farmers. Even after successful construction of ponds, water utilization strategies are weak link to realize the real benefits.

Efforts have been made at several places to prepare a appropriate technology to construct the effective plastics lined ponds and their efficient utilization pattern. Micro-irrigation is one of the important plasticulture techniques which enables use of such precious water with high water use efficiency. Plastics mulching has been found to reduce unnecessary water losses with micro-irrigation and improves the overall productivity of the water and land resources. An attempt is made to discuss some of the strategies worked out in All India Coordinated Research Project on Application of Plastics in Agriculture operated under Indian Council of Agricultural Research and elsewhere.

Rainwater Harvesting and Pond Lining

Rainwater harvesting means capturing the rain water where it falls, or capturing the runoff in small ponds or suitable structure from where it can be used for beneficial purpose. Technically, rainwater harvesting has three components viz. catchment, reservoir and command. For designing an effective rainwater harvesting system, it is important to consider all the three components individually and then design the system that can be sustainable to provide water at a reasonable probability. Source of the system may be direct rainfall, runoff from overlying catchments, seasonal or perennial streams or springs, in few cases lifted subsurface water in uplands where it is supposed to vanish soon due to lateral seepage, or combination of these.

Assessment of water availability from catchment may be done using hydrologic soil cover complex method (Bhatnagar et al., 1996) using appropriate curve numbers relevant to topography and land use pattern. The temporal and spatial water requirement in available command area where the water application using gravity is feasible. In some cases water may be lifted for use in catchment area itself for irrigation. Catchment – command area ratio is to be worked out to decide actual water availability at different probability periods. Water available through direct rainfall and runoff is stored in a pond for its further use in command area. Lining of ponds is required to save water from seepage losses. Unlined ponds are very poor in storing water for longer periods. In uplands of eastern plateau region having lateritic soil, the water stored in ponds disappears in few days only due to seepage losses.

Plastic Pond Lining

Among the various methods of lining available, plastics film lining has been found very effective in preventing seepage losses, cheap and relatively more sustainable. However, it requires skill and care while film laying and protecting it from damages. Three types of plastics film are being used for lining of ponds:

- Geo membrane high density poly ethylene (HDPE) film (1.5-4.0 mm thick)
- Multi-layered cross laminated (MLCL) or Silpaulin (150 – 200 gsm)
- Low density poly ethylene (LDPE) film (150-250 micron or 600 – 1000 gauge)

HDPE and silpaulin are UV stabilized and do not need to be covered. HDPE film may last for a life varying from 5-10 years depending upon thickness and other factors, while silpaulin is relatively stronger in mechanical strength but get deteriorated in sunlight. The life of the silpaulin may also be 5-8 years depending upon condition in which it is used. LDPE film is relatively cheaper than the two materials, but needs covering as it is not UV stabilized and has fast strength deterioration in sunlight. However, if the film is protected from the sunlight, it can have life more than 20 years (Srivastava and Bhatnagar, 1991). Covering of the film not only protects from chemical deterioration in the sunlight, but it protects from damage due to human or animal activities also.

Construction Technique for Plastics Lined Ponds

In order to construct the plastic film lined ponds, the ponds needs to dug out with appropriate dimensions and side slopes. The sides & bottom need to be cleaned properly by removing stones and roots of the plants. If there are some roots of nearby trees, it should be cut properly. Use some herbicides to prevent further plant / root growth. Then plastic is laid on the surface in one sheet and folded in corners. If LDPE film is used, it needs to be covered. Covering may be provided using brick pitching, stone pitching or soil layer. Coal tar serves as sheet to cover the LDPE film to protect it from sunlight, but it may provide covering for 3-5 years only and then needs to be replaced. If the film is to be covered using soil layer then side slopes are required to be made in the form of steps and film is laid properly such that it penetrates inner corner of the steps and then soil is spread on the sides so that it gets anchored and does not slide down **(Fig.1).** Soil covered polythene lined ponds are suitable for fish culture as they provide good environment for plankton growth which is natural feed for fishes.

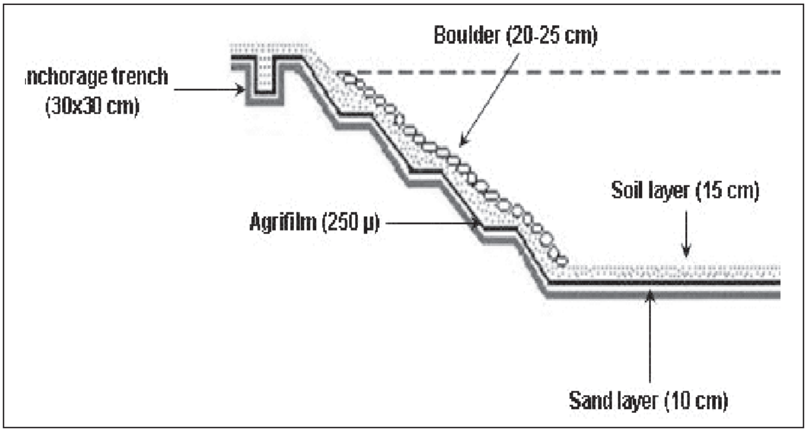

Fig. 1 : Cross section of LDPE lined pond

Safety of Lining from Seepage Water Pressure

When a pond is constructed in lower land having higher land nearby, the water percolated through the higher land creates uplift pressure for the polythene and results in failure of the pond lining. A technology to protect the polythene lining against the uplift pressure due to overland flow of water on sloppy terrains was developed. Perforated plastic pipes of 2'' diameter were laid in trenches made in bottom of the pond. All the pipes (06 nos.) were made to converge to an outlet which led the water outside pond **(Fig.2).** Pipes were wrapped with coir rope to prevent choking of the perforations in the pipe. Then pipes were covered with sand. Above that plastic film was laid. Due to this arrangement seepage water was disposed out of pond safely and hydraulic pressure was released. Hence the damage to the lining was avoided.

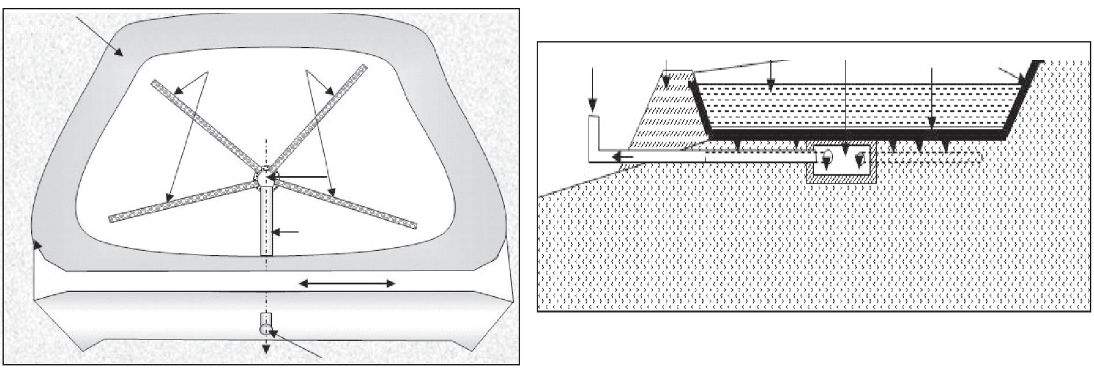

Fig. 2 : Schematic diagram of safety mechanism for LDPE lined ponds against uplift pressure from overland water flow

Strategies for Efficient Rainwater Utilisation

There may be a good number of strategies that can be formulated to use the harvested rainwater efficiently. Storing water in plastics film lined pond and using the water for vegetable cultivation, fruit tree irrigation, supplemental irrigation to cereal, pulse and oilseed crops, etc. using efficient method of irrigation i.e. micro-irrigation system or pipe irrigation have been worked out at various locations for different crops and proved profitable. Following such techniques in a strategic manner, certainly enhance the overall benefits, in terms of higher productivity and income, better accessibility to nutritious food material especially for people located in remote areas and overall livelihood improvement of farmers. Few such strategies are discussed below; however, implementation of such strategies at various locations may need some correction depending upon local opportunity, needs and social and economic conditions.

Multiple Uses of Harvested Rainwater

A model of multiple uses of harvested rainwater in a small pond in the sloping topography of eastern plateau region was developed. The region gets a rainfall of 1200-1400 mm. In order to harvest the direct rainwater and runoff from a small overlying catchment of about 2.5 ha, a pond was constructed having capacity of about 1200 m^3. The dug out pond had side slopes in the form of stairs, which was covered with LDPE sheet of 250 micron and then covered by soil layer. A 15 cm thick soil layer was provided at the bottom. This provided soil environment all around the pond which is congenial for plankton growth and higher fish production.

The multiple uses of so harvested rain water include fish, irrigation to multi-tier horticulture in command, supplemental irrigation to cereal production in area between outlet and pond, pulse / vegetable production on bunds or outer side slopes **(Fig 3).** As per assessment of the water requirement in the command area comprising of 70 x 100m for multi-tier horticulture, the water available in the pond is enough to meet the water demand up to mid-June for the plantation of 60 plants of Litchi (1st tier), 180 plants of Guava (2nd tier)

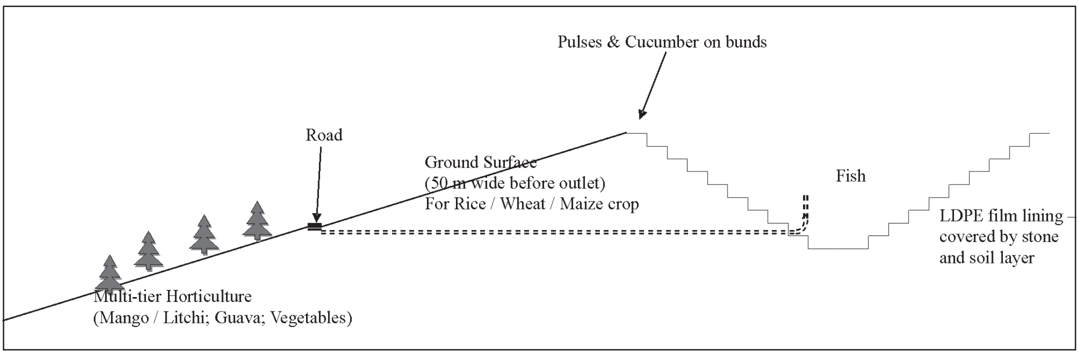

Fig. 3 : Sketch diagram for multiple uses of rainwater harvesting pond in eastern plateau region

and vegetable cultivation on 1000 m^2 in two seasons (Oct-Feb and Feb-mid May) considering the daily surface evaporation (Pan E x 0.7). The fish to be stocked at a level more than 25 cm (in mid July) and to be harvested gradually after February when it attains weight of 100 g or more. By mid-May the water level goes down to 25 cm and all the fishes need to be harvested by that time. A small amount (50 mm) of water may be used to irrigate rice crop grown in 50 x 70 m land when rainfall fails during grain filling stage in late September, which will boost the yield level substantially. As the tree plants grow, their water requirement increases, and the area under vegetable goes on reducing. Till they attain fully matured, no vegetables can be grown as the harvested rainwater is enough to meet the water demand of trees only. However, if we plan to grow only vegetables, an area of 1500 m^2 can be cultivated for two seasons with the water available in the pond.

The outlet of the reservoir was connected to water conveyance pipe such that irrigation may be provided gravitationally in the command area. Gravity fed drip irrigation system has been laid out in the command to irrigate the fruit and vegetable plants which had emission uniformity of 89% with pressure head varying between 1.0 to 2.5m for emitters lay on sloppy land. Average discharge was 3.02 L/s with 89 % uniformity and 13.57% CV. The variation was due to head loss in the lateral as the discharge was reduced along the lateral and increase in discharge along the slope.

Small Water Tank for Direct Rainfall Collection in Upland Areas

Small water tanks (named as Jalkunds) were recommended for collection of direct rainwater to establish plantations or irrigate them subsequently based on the research conducted at Dapoli, Barapani and Ranchi under different projects. At Ranchi, the rainwater occurring 1200-1400 mm annually was considered to be collected in the Jalkunds (named as *"doba"* as per local name) of 3.0 x 1.5 x 1.0 m depth. The Jalkunds were full by the end of September. In order to sustain the plantations, the water needs to be applied till June, otherwise they will get die in summer. To sustain the water availability in plateau region is a challenge in view of higher evaporation. Assessment of temporal availability indicated that even without taking a drop of water for irrigation, all the water will get evaporated by the end of mid June considering pan factor 0.8. With a structured irrigation application as per evaporative demand in particular months, if 10 plants are irrigated, then all the Jalkund get emptied by 25th April and no water is available subsequently. However, if the pan factor is reduced to 0.25 then 10 plants can be sustained upto 30th June. An experimental study was carried out to work out strategies to reduce the pan factor at ICAR RCER Research centre, Ranchi and found that if the Jalkund is kept covered using a thatch cover made from bamboo frame and grass netting, the pan factor can be reduced to 0.35-0.47 when the cover is lifted all the time for removal of water for irrigation (weekly). However, if a small hole of 50 x 50 cm is created in a corner and water lifter using a bucket and rope from it and again closed with a small cover, then pan factor can be reduced to 0.26-0.28. This was the desired level and hence it is recommended. However, the pan factor was futher reduced to 0.07 to 0.18 when a black polythene cover was provided below the grass thatch which reduced the evaporation loss to minimum. Such Jalkunds can be used for providing irrigation to small plants upto 3 years to have them established. Afterwards, the plants may survive rainfed as the plants choosen for this are hardy in nature like Aonla, etc. However, if irrigation is needed subsequently, more Jalkund may be needed to meet the demand. An analysis was made and recommendations were made in this respect. For example, for a litchi plant having canopy diameter of 5 m, pan factor 0.25, 2.5 Jalkunds will be required for each plant to irrigate at IW/CPE = 0.5.

Growing Transplanted Paddy in Upland Using Surplus Harvested Water

A study was conducted at VPKAS, Almora to use surplus run-off water received during monsoon period for growing transplanted rice having higher productivity then prevalent direct sown rice under rainfed conditions in upland areas of mid-hills (Bhatnagar et al., 1996). The transplanted rice was recommended to be transplanted in the first fortnight of July when the rainwater was enough for puddling and could not be accumulated. Hence, the water obtained as runoff in the pond between 1-20 July can be utilized for puddling and keeping one week ponding following the transplanting. This treatment showed very encouraging results as it enhanced the yield substaintially as compared to rainfed. However, without surety of water for puddling, no farmer can think of going for transplanted rice in upland areas. The rainfall – runoff analysis conducted and obtained catchment command area ratio for different curve numbers which directly gives information on amount of command to be covered using the technique for a given catchment area with defined topography and land use **(Fig 4).**

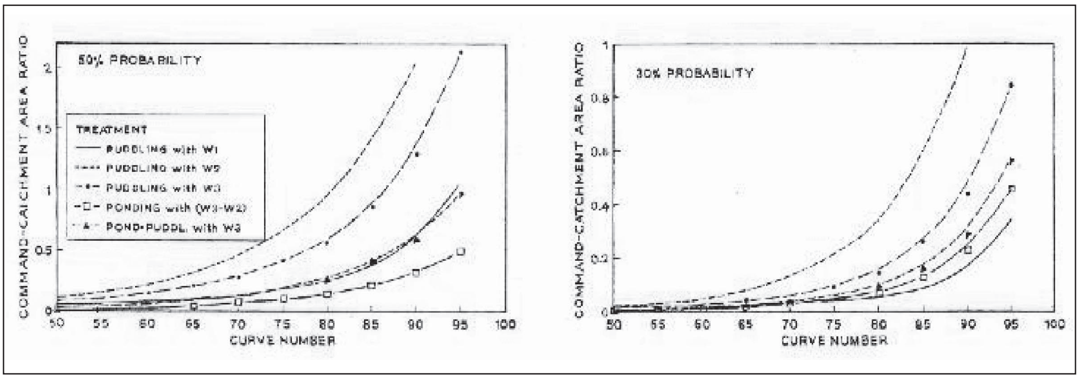

Fig. 4 : Command-catchment area ratio and runoff curve number for different treatments used for using surplus runoff during 1 June - 20 July at 50 and 80% probability.

Runoff Water Harvesting for Irrigation in Hilly Terraces

A runoff water harvesting system using LDPE lined tanks with strategies for its utilization for diversified land use was developed for mid-hill conditions in Himalayas. (Anonymous, 2008). Details regarding site selection, excavation, treatment to the pit, preparation of flim with proper dimension, laying of film and covering was worked out. The water storage dynamics with respect to different alternative irrigation scheduling to probable cropping pattern has been worked out considering the water availability in different meteorological weeks. Construction cost of the LDPE film lined tanks with tarfelt covering for 80m^3 capacity is estimated as Rs 15220 with desilting needs once in five year and replacement of film once in ten years. It can irrigate 16 *nali*s (1 *nali* = 200 m^2) of field with different combination of cereals, pulses, and vegetables in *kharif* and *rabi* seasons. The return from such combinations were worked out assuming farmers get minimum support price for cereals and average farm gate price for vegetables with assured market. When rice (10 *nali*es) and horse gram (6 *nali*es) in *kharif*; wheat (10 *nali*es) and lentil (6 *nali*es) were considered, the total cost of cultivation and returns were worked out to be Rs. 17,122 and Rs. 21,798, respectively with a net income of Rs. 4676 only. It provided pay back period of 3 yr 4 months with IRR of 32.8% and B-C ratio of 1.27. If tomato & capsicum is introduced in *kharif* in 2 *nali*es each followed by garden pea in *rabi*, the income enhanced to Rs 21,762 with B-C ratio of 2.2 and pay back period of only 4 months. The third scenario has diversification of 10 *nali*es to vegetables (tomato – 5 *nalies*; capsicum – 5 *nalies* in *kharif*; and garden pea-6 *nalies* and lentil – 4 *nalies* in *rabi*), the income enhanced to Rs 44,085 with B-C ratio 2.7 and pay back period less than 4 months.

Plastics Mulching

Plastic film was found to be very effective material for mulching, which has been used since eighties in European countries. But in South Asian region, it is yet to get popularized for several preferential crops where plastic mulch can improve the overall production scenario. The advantages of using plastics mulching are several, which include reduction in soil water evaporation, soil water temperature manipulation, herbicidal effect for weed control, reducing rainwater impact and hence soil erosion, manipulates the soil micro environment congenial for earthworms and other microbes, and all the advantages produced beneficial effect on crop by enhancing the production and quality of produce. Using special reflecting type of mulch film further enhances the production by reflecting the sunrays to lower portion of leaves that enhances the photosynthesis. However, drip irrigation with fertigation is required to be employed with plastic mulch, to obtain better results.

The advantages of the mulch are also being realized by visible light to reflect back towards the plants which aid in photosynthsis. The colour and texture of the film also matters in this respect. In a study carried out in Maxico, the black and white (both opaque) coloured mulch produced better effect on production of red pepper (*Capscicum annum L.)* while the development of plants with blue and red mulch was poor because of high ground temperature, but did not have appreciable yield reduction (Quezada-Martin, *et al.,* 2004). The transparent or clear plastic film has no herbicidal effect, but soil heating is better with marginal heat retention. Hence the clear film mostly recommended for cold areas where heating is required along with use of herbicides to control the weeds. While the black opaque film does not require application of herbicide and it has pronounced herbicidal effect to control the weeds. But soil heating is poor with better heat retention as no radiation is returned back. But it needs careful use as the film temperature increases and if any fruit is touched, it may be damaged. White / silver opaque film has better light reflection and aid in higher vegetative growth. In order to achieve better results, co-extruded double layer film of black and white combination may be used which have combined effect e.g. better herbicidal effect, more heat retention and more light reflection.

Horticultural production with plastic mulch needs drip irrigation since other means of water application cannot meet out the crop water demand. Plastic mulch with drip irrigation enhanced the strawberry productivity by 36% in open field and 22% in walk in tunnel type greenhouse as compared to without mulch i.e. 7.0t/ha and 18.4 t/ha, respectively in two conditions in Srinagar, J&K. On the other hand, if the plastic mulched crop is irrigated with other methods e.g. sprinkler irrigation, the yield has been reduced. In Meghalaya, a sprinkler irrigated cauliflower yield was reduced by 38% with plastic mulching, while the reduction was only 13% for Broccoli. Less water penetration in the soil was the reason for reduced yield under sprinkler irrigation.

Conclusion

There is lot of scope for improving the agricultural production scenario in the South Asia which will reduce the effect of drought to a great extent. Harvesting of rainwater in small ponds and then using it for agricultural production to supplement the crop water requirement during long dry spells as well as irrigation to crops as per need. However, such harvested water remains in a limited quantity and needs to be saved against unproductive losses such as seepage and evaporation and should be used judiciously and in an effective manner so that each drop can be used to its maximum production. Few strategies for use of the limited harvested rainwater has been explained which have variations due to prevailing topographical and other conditions. The plasticulture techniques including micro-irrigation and plastic mulching are also becoming popularized and gaining momentum among the farmers to benefit water saving and improving the production. But, still there are some bottlenecks like high initial cost for micro-irrigation, skillfull maintenance, labour requirement in plastic mulch laying and poor mechanization, etc which need to be given proper attention.

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Potentials of Rainwater Harvesting in different Hydrological Regimes: Practical and Policy Implications for South Asian Countries

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Monsoon rains from June to September are the largest source of precipitation in South Asia. Many countries in South Asia, particularly, India, Sri Lanka and Pakistan have long tradition of water harvesting. In India, many of the traditional water harvesting systems have either gone under disuse due to a variety of physical, social, economic, cultural and political factors which have caused their deterioration and decline of institutions which have nurtured them or have lost their relevance in the modern day context due to their inability to meet the desires of the communities. While the first dimension of the decline in water harvesting tradition has been well researched and documented, the second dimension is much less understood and appreciated. The lack of resistance to appreciate the fact that different periods in history are marked by genesis, rise and fall of some new water harvesting tradition, is also very clear.

In India's water sector history, the past two decades are characterized by a boom in water harvesting. They are markedly different from the traditional ones in two ways; first from the context; and second from the purpose. As regards the context, they are able to use recent advancements in soil, geosciences and hydro-sciences; and modern day techniques and technologies in survey and investigation, earth moving and construction; and management tools such as hydrological and hydraulic modeling. While the traditional ones represented the best engineering feat of those times, in terms of water technology used for water harnessing and distribution; and the volume of water handled, the modern water harvesting systems are at best miniatures of the large water resource systems that use advances in civil engineering and hydrology. As regards the purpose, they are employed as resource management solution, and not as resource development solutions. For instance, many water harvesting structures were built for improving aquifer storages and groundwater quality.

The limited research on rainwater harvesting (RWH)/artificial recharge so far had focused on engineering performance of individual structures (see Muralidharan and Athawale, 1998). While a lot of anecdotal evidences on the social and economic gains exist, there is little understanding based on empirical work of: 1] the impacts of water harvesting activities on local hydrological regime in terms of net water gain; 2] basin level impacts on overall basin water balance; and 3] economic imperatives from a long term perspective. Of late, researchers had raised questions of the possible unintended impacts of water harvesting (see Bachelor *et al*., 2002), and its economics. One of the reasons for the little or lack of empirical research on the hydrological and economic aspects of water harvesting systems is the lack of ability to generate accurate scientific data on various parameters, mostly hydraulic, hydrological and meteorological, governing the performance and impact of water harvesting. The problem mainly stems from the fact that these systems are very micro in nature, thereby making it difficult to obtain data on the variables from conventional sources. Analysis of water harvesting systems also misses the influence of "scale factor".

The paper would attempt the following: 1] discuss the physical—hydrological and meteorological, socio-economic and purely economic considerations that need to be involved in decision-making with regard to water harvesting investments; 2] discuss how these considerations limit the scope of or provide opportunities for water harvesting in South Asia; and, 3] make practical suggestions for improving the effectiveness of rainwater harvesting. This is achieved through the analysis of micro and macro level hydrological, geological and socio-economic data for the Indian sub-continent, which is representative of the different hydrological regimes that exist in South Asia.

Rainfall and other physical characteristics of major South Asian Countries

India

The lion's share of the precipitation in India is from rainfall, and the occurrence of snowfall is limited to the sub-Himalayan region. Indian monsoon is characterized by high degree of spatial and temporal heterogeneity. The mean annual rainfall varies from less than 100mm in the western part of Rajasthan to around 11,700mm in Chirapunji in Meghalaya. The magnitude of annual rainfall is large in north eastern states and south western regions, which experience both south west and north-east monsoons. The unique characteristics of rainfall are as follows: the regions which receive low mean annual rainfall experience high year to year variation, whereas the regions which receive high mean annual rainfall experience low year to year variation. The number of rainy days is large in high rainfall regions, and small in low rainfall regions. The coefficient of variation in rainy days shows more or less the same spatial pattern as the mean annual rainfall.

India has diverse climates, and varies from hyper-arid to arid to semi-arid to sub-humid to humid. It has mountainous regions, middle mountains, plateaus, plains, deserts, and coastal plains and deltas.

Sri Lanka

Annual rainfall in this island country is 2540 mm to over 5080 mm in south west of the Island. The rainfall is less than 1250mm in the north-west and south-east of the island. Hence, there are two rainfall zones in the country, viz., the dry zone and the wet zone. The South West monsoon is from May to August, whereas the North East monsoon is from November to February. Rainfall pattern in Sri Lanka is influenced by orographic features. Being an Island country, Sri Lanka has coastal climate in many parts. It also has mountain in the central and south central regions with cold climate, and the remaining low lying regions have humid tropical climate.

Pakistan

There is significant spatial variation in the rainfall in this sub-tropical country, though most of the country receives very low rainfall. The whole of Sindh, most parts of Baluchistan, the major part of the Punjab and central parts of Northern areas receive less than 250 mm of rainfall in a year. Northern Sindh, southern Punjab, north-western Baluchistan and the central parts of Northern Areas receive less than 125 mm of rainfall. True humid conditions occur after the rainfall increases to 750 mm in plains and 625 mm in the highlands. There are two sources of rainfall: the monsoon from July to September, and the western depression from December to March.

Nepal

The monsoon season in Nepal is from June to September. Autumn, from September to November, is cool with clear skies. In winter from December to February, it is cold at night and can be foggy in the early morning but afternoons are usually clear and pleasant, though there is occasional snow in the mountains. Rainfall in Nepal varies from region to region. The annual rainfall in Katmandu generally exceeds 1300mm. The mean annual precipitation ranges from more than 6000mm along the southern slopes of the Annapurna range in central Nepal to less than the 250mm in the north central portion near the Tibetan plateau. Rainfall amounts ranging from 1500mm to 2500mm is predominant over most parts of the country. On an average, about 80% of the precipitation is confined to the monsoon period from June to September.

Vast areas of Nepal fall in high altitude mountainous region. High mountains cover nearly 35% of the geographical area, followed by middle mountains covering nearly 42% and Tarai region covering nearly 23 per cent. The climate varies from Alpine to sub-Alpine in the higher Himalayas to temperate in the lesser-Himalayan region to sub-tropical in the Terai and Siwalik regions of the south within a distance of 200km.

Afghanistan

Precipitation in Afghanistan has a very pronounced annual cycle with a dry period in summer, generally from June to September, except for the western region where dry season starts in May and lasts till October. Annual precipitation is ranging from 50mm in the southwest to 700mm in the region of Salang and about 300mm in the capital Kabul, and therefore shows a significant variation. The areal average of annual precipitation is less than 300mm. Towards the eastern part of the country, the total annual precipitation decreases to about 100mm. It has the central highlands, which are part of the Hindukhush Himalayan range, northern plains and south western plateau, which consists of sandy desert and semi desert.

Bangladesh

Bangladesh has tropical monsoon climate characterized by high seasonal rainfall, high temperature and high humidity. The average annual rainfall varies from a maximum of 5,690 mm in the northeast of the country to minimum of 1,110 mm in the west. The groundwater, however, provides adequate storage to compensate for annual variations in rainfall and stream flow. Most of Bangladesh is alluvial plains formed by the delta of Ganges, Brahmaputra and Meghna river systems, except the south eastern and north eastern hills.

Critical issues in Rainwater Harvesting

One of the most important underlying values in rainwater harvesting is that it is a benign technology (Bachelor *et al*., 2002) and cannot create undesirable consequences. Water harvesting initiatives are driven by firm beliefs and assumptions, some of which are: 1] there is a huge amount of monsoon flow, which remain un-captured and eventually ends up in the natural sinks, especially seas and oceans, supported by the national level aggregates of macro hydrology; 2] local water needs are too small that exogenous water is not needed; 3] local water harvesting systems are always small, and therefore are cost effective; 4] since the economic, social and environmental values of water is very high in regions hit by water shortages, water harvesting interventions are viable, supported by the assumption that cost-effective alternatives that can bring in the same amount of water do not exist; 5] incremental structures lead to incremental benefits; and 6] being small with low water storage and diversion capacities, they do not pose negative consequences for downstream uses.

Lack of Emphasis on Local Water Demand and Potential Supplies

Rainwater harvesting ignores a few critical parameters that govern the potential of RWHS in meeting local water demand. First is the hydrological regime of the region/locality. Second is the reliability of the supplies, governed by the reliability of rainfall. Third is the constraint imposed by local geological and geo-hydrological settings on recharge potential. Fourth is the aggregate demand for water from various sectors within the local area.

Some basic hydrological phenomena, which make the above mentioned parameters very critical in deciding the scope of rainwater harvesting and groundwater recharging, are:

- For runoff harvesting, the rainfall has to exceed a threshold to generate runoff, though the threshold would vary according to the nature of soils and land cover. The estimated runoff based on regression equation arrived at from observed flows in Hathmati sub-basin of Sabarmati basin ($R=0.00193*X^{2.022}$) in western India (source: GOG, 1994) shows that for the runoff to cross 100mm, the minimum rainfall required is 682 mm. Whereas in the case of Kabani sub-basin of Cauvery, runoff starts when the rainfall crosses 366 mm. However, the actual runoff rates would depend on how strong is the correlation between rainfall and runoff in a given basin, and this relation weakens if year to year change in rainfall intensity and pattern is major.
- Regions with lower mean annual rainfall experience higher variability and *vise versa* (Pisharoty, 1990). Hence, in regions with lower mean annual rainfall, rainwater harvesting as a dependable source of water is likely to be low.
- Generally, it has been found that larger magnitude of annual rainfall means more number of rainy days and smaller magnitude of annual rainfall means less number of rainy days spread over the rainy season (Pisharoty, 1990). Lesser rainy days also means longer dry spells and thus greater losses from evaporation for the same region.
- High intensity rainfalls are common in semi-arid and arid regions of India (Garg, 1987 as cited in Figure 24; Athawale, 2003). Higher intensity of rainfall can lead to high intensity of runoff occurring in short durations, limiting the effective storage capacity of rainwater harvesting systems to almost equal to its actual storage size.
- High evaporation during rainy season means losses from surface storage structures. It also means faster rate of soil moisture depletion through both evaporation from barren soils and evapo-transpiration, increasing the rate and quantum of soil infiltration. This reduces runoff generation potential. Among the seven locations in Gujarat for which ET_0 data are available, ET_0 during monsoon varies from a lowest of 543mm in Vadodara to 714mm in Rajkot. As percentage of annual ET_0, it varies from a lowest of 33% in semi-humid Surat to 37.3% in Bhuj, Kachchh (source: authors' analysis based on data from IMD, Ahmedabad). In the case of Rajasthan, ET_0 during monsoon ranges from 433mm in the hill station of Mt. Abu to 967.7 mm in Jaisalmer in the Thar Desert. In percentage terms, it varies from a lowest of 32% of the total annual ET_0 in Sawaimadhupur to a highest of 49.3% in Anupgarh (GOR, 1992). Among the 10 locations selected along Narmada basin in Madhya Pradesh, the values range from 429mm to 600mm, with it as a percentage of total ET_0 ranging from 31.3% in Betul to 35% in Mandla (source: GOMP, 1972).

- Soil infiltration capacity can be a limiting factor for recharge. In sandy and sandy loam soils, the infiltration capacity of the recharge area can be sustained through continuous removal of soils. But clayey soils have inherent limitation (NGRI, 2000). If the infiltration rate approaches to zero fast, it will have negative affect on the recharge efficiency of percolation ponds. As thin soil cover has low infiltration (Muralidharan and Athawale, 1998), the extent of the problem would be larger in hard rock areas with thin soil cover. Dickenson (1994) based on several infiltration studies shows that rate of infiltration declines to a minimum value within 4-5 days of ponding. This also will have adverse effects on the performance of structures built in areas experiencing flash floods and high evaporation rates, solutions for which would be wetting or drying of pond beds through regulation of inflows.
- For artificial recharge, the storage potential of the aquifer is extremely important. The storage potential of an aquifer *vis-à-vis* the additional recharge is determined by the geological formation characteristics, and the likely depth of dewatered zone.
- In hilly watersheds, the area available for cultivation is generally very low, keeping agricultural water demand low. At the same time, the surface water potential available for harvesting is generally high due to high rainfall and runoff coefficients. On the contrary, towards the valleys and plains, the area available for cultivation increases, raising agricultural water demand. At the same time, the surface water potential available for harnessing is generally low due to the lower rainfall, and low runoff coefficients owing to mild slopes, high PE and deeper soil profiles.

The implications of some of these factors on the potential of rainwater harvesting systems are analyzed in the following two sections.

Limitations Imposed by Hydrological Regimes

Local water management interventions are often based on very little understanding of the local hydrological regimes, which govern the potential supplies of water for harvesting. They are rather based on deep-rooted belief that higher the size of water impounding structure, higher would be the hydrological benefit in terms of water storage and recharge. The government implemented large-scale work of excavation of thousands of village ponds, irrespective of the nature and size of catchments. Part of the reason is the lack of availability of data on inflows, determined by stream-flows; and outflows, determined by evaporation rates, for small rainwater catchments. While runoff harvesting is most suited to areas with high “runoff catchment area” to “run on” area ratio (Lalljee and Facknath, 1994), this is also ignored. Higher the aridity, larger would be the required catchment area to the cropped area required for the same water yield (Prinz, 2002). Often, encroachment of catchments of water harvesting systems for crop cultivation is very rampant, reducing the runoff prospects.

The states, which have taken up rainwater harvesting and groundwater recharge programmes on a large scale, are Gujarat (north Gujarat, Saurashtra and Kachchh), Rajasthan, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Madhya Pradesh, Orissa and Chattisgarh. A major part of these regions is covered by six water-scarce river basin systems, namely, Sabarmati, rivers of Kachchh and Saurashtra, Pennar, Cauvery, east-flowing rivers between Mahanadi and Godavari, east flowing rivers between Pennar and Kanyakumari, which have less than 1,000 m^3 of renewable water per annum (Gupta, 2000: pp 116). Now let us look at the hydrological regime existing in these regions.

For this, we first examine the percentage area of each state falling under different rainfall regimes (<300mm, 300-600mm, and 600-1000mm, 1000-1500mm, 1500-2500mm and >2500mm); and different PE regimes (< 1500mm, 1500-2500mm, 2500-3500mm and >3500mm). It is understood that regions with relatively low rainfall have higher potential evapo-transpiration due to relatively low humidity, higher number of sunny days (Pisharoty, 1990). Lower rainfall, coupled with higher PE reduces the runoff potential and high evaporation from the impounded runoff, thereby increasing the dryness (Hurd *et al*., 1999). The analysis shows that Gujarat and Rajasthan have 11% and 42% area, respectively, fall under extremely low rainfalls (< 300mm); and 39% and 32%, respectively under low rainfall (300-600mm). The other states by and large fall in the medium rainfall (600mm-1000mm) and high rainfall (1000-1500mm) regimes. In the case of Maharashtra, MP, AP, Karnataka and Tamil Nadu, a lion's share (85% and above) falls in medium rainfall regime, and in case of Orissa and Chattisgarh, 45% and 40% respectively fall in high rainfall regime (**see Map 1**).

As regards PE, lion's share of Gujarat and Rajasthan fall under high evaporation (2500-3000mm); nearly 35-56% of the geographical area of other states (except Orissa and Chattisgarh) fall under high evaporation regimes; the area of these states falling in the medium evaporation regime (1500-2500mm) is in the range of 38-65%. The entire Orissa and Chattisgarh fall in medium evaporation regime. Overall, a large section of the area (of the 9 states considered) has medium rainfall, and medium to high evaporation. A significant portion of the area (of Gujarat and Rajasthan) has very low to low rainfall and high evaporation (**see Map 2**).

In the next step, we analyze: the proportion of the geographical area from each of these regions/states falling under different rainfall variability classes like > 25%, 25-30%, 30-40%, 40-50% and 50% and above. Higher the magnitude of PET during monsoon, higher will be the negative impact on hydrological variables such as surface storage and recharge. While it reduces surface storage through evaporation, higher PET during monsoon also means higher crop water requirement during the season and increased soil moisture depletion leading to reduced recharge from rainfall. In barren soils, higher evaporation rates leads to faster soil moisture depletion perpetuating higher rate of infiltration of the incoming precipitation and lower runoff.

A large percentage of the total geographical area of Gujarat and Rajasthan (72% and 68%, respectively) has high to very high (30-40% and above) variability in rainfall. Significant parts of the geographical area of the states viz., Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu (37% to 92%) experience medium variability in rainfall; the rest of the area experiences low variability. The entire Orissa and Chattisgarh experience only low variability in rainfall. In nutshell, more than 50% of the total geographical area of all the states put together experience medium variability; nearly 25% experience “high to very high variability”; and nearly 20 per cent experience “low variability” in rainfall (**see Map 3**). They coincide with “medium rainfall-medium to high evaporation”, “low rainfall-very high evaporation” and “high rainfall- medium evaporation” regimes, respectively.

It can be seen from **Maps 1, 2 and 3** that regions with high variability in rainfall coincide with those with low magnitudes of rainfall and high PE, which also have high dryness ratio. In such areas, a slight variation in precipitation or PE can substantially magnify the water stress on biological systems as compared to humid regions (Hurd *et al*., 1999). Higher the variability in rainfall, lower would be the reliability of local water harvesting/ recharge systems. This is because chances of occurrence of low rainfall and extremely low runoff would be higher under such circumstances, and at the same time, the demand for water would be high due to environmental stress caused by poor soil moisture storage, low runoff and high temperature.

In the third step, we analyze the average number of rainy days and its variability across regions. We attempt to find out the percentage of geographical area of each region, falling under different rainy days (say <20 days, 20-30 days, 30-40 days, 40-50 days, 50-75 days, and 75 and above days). We also analyze the implications for the quantum of rainfall in each rainfall event and the maximum and minimum daily rainfall under different rainfall regimes.

The analysis shows that Gujarat and Rajasthan fall in regions which experience monsoon rains in a fewer days. To elaborate: nearly 21% of Gujarat and 45% of Rajasthan states receive less than 20 days of annual rains; nearly 51% of Gujarat and 70% of Rajasthan fall in areas which experience less than 30 days of rain in a year; nearly 1/3rd of both the states receive 30-40 days of rain. As regards the states viz., Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu, the area which receives 30-40 days of rain ranges from 9 to 27%; 40-50 days of rain ranges from 29-39%; 50-75 days of rain ranges from 27-58%. The Western Ghat in Maharashtra and Karnataka receive heavy rains spread over many days (> 75). As regards Orissa and Chattisgarh, both the states receive 50-75 days of rain in a year. To sum up, the regions which receive fewer days of rain (erratic rains) coincide with those experiencing low rainfall and high evaporation and high variability in rainfall. The regions which experience many wet days coincide with those which experience high and reliable rainfall and medium evaporation (**see Maps 1, 2, 3 and 4**).

Synthesizing the results of the spatial analysis of rainfall, PE, rainfall variability and number of rainy days that are provided in **Maps 1-4**, the following trends can be established: the inter-annual variability in rainfall increases with reducing rainfall; the number of wet spells reduces with lowering magnitude of rainfall; the PE increases with lowering magnitude of rainfall. The implications of this trend on the potential of water harvesting in a region needs to be understood. Lower the rainfall, coupled with higher potential evaporation and inter-annual variability in rainfall and fewer rainy days, lower would be the potential of water harvesting. This is due to the following processes. First: the runoff potential by and large would be low in low rainfall regions with high dryness ratio. Second: evaporation from surface storage would be high due to high PE. Third: the probability of occurrence of very low rainfalls, causing heavy reductions in runoff, would be high, with consequent hydrological stresses.

Limitations Imposed by Socioe-conomic System

Water harvesting arguments totally misses on the water demand-availability perspective at micro level. Ideally, the RWHS would work if the area which has uncommitted flows to harness has "un-met demand" or *vice versa.* This is unlike large water resource systems where provisions exist for transfer of water from "surplus" areas to deficit areas.

The water demand of an area is determined by the agro-climate and existing socio-economic system, which, in fact, gets adjusted by the natural resource environment of the village, the available technologies for accessing them and the institutional and policy environments over a period of time. Regions which were heavily into irrigated agriculture in the past, supported by good water endowments, institutional support and favourable policies, might continue demanding large quantities of water for irrigation even when they run out of water. This is because communities take quite some time to devise coping and adaptive strategies to manage with conditions of water deficits.

Studies in a village in Mandvi taluka of Kachchh, which is one of the most arid districts in India, showed that the annual water withdrawal from aquifers for irrigating corps is 25.42 MCM. The entire water requirements in the village were being met by groundwater, which is experiencing severe over-draft conditions (Kumar, 1997). The total amount of rainwater falling in the village is nearly 10.14 MCM (source: based on data provided in Kumar, 1997 on geographical area and the mean annual rainfall of Kachchh). With a surface water potential of 0.014 MCM/sq. km (IRMA/UNICEF, 2001), the amount of runoff water that would be available for replenishment through natural and artificial recharge from within the village is only 0.40 MCM. The runoff is, therefore, a small fraction of the total consumptive use. This means that the village has to depend on exogenous sources of water for making water use sustainable. What is presented is representative of almost the entire peninsular India excluding Kerala, central India and western India.

On the other hand, there are many regions in India where the economic demand for water is far below what the natural endowment can provide. The entire Ganga-Brahmaputra basin area can be put in this category. The region has enormous amount of static groundwater, estimated to be 8787.6 BCM, apart from having high rainfall and cold sub-humid climate that generate sufficient surface flows. Cheaper access to water might increase the demand for irrigation water slightly. But, there are significant limits to it imposed by the cold and humid climate and very low per capita arable land, and therefore would continue to be below what the water endowment can provide. Already, the irrigation intensities are high in Uttar Pradesh and Haryana. Though irrigation intensity in Bihar is low, the sub-humid and cold climate reduce the irrigation requirement significantly. In most part of this region, the issue is not of the physical availability of water, but the ability of communities to access it for irrigation (Kumar, 2003). Water harvesting anyway does not offer any economic solution here for the poorer communities to access water.

Issues in Evaluating Costs and Economics

In the planning of large water resource systems, cost and economics are important considerations in evaluating different options. But unfortunately, the same does not seem to be applicable in case of small systems, though concerns about economics of recharge systems in certain situations were raised by scholars.

Part of the reason for lack of emphasis on "cost" is the lack of scientific understanding of the hydrological aspects of small scale interventions, such as the amount of stream flows that are available at the point of impoundment, its pattern, the amount that could be impounded or recharged and the influence area of the recharge system. Even though simulation models are available for analyzing catchment hydrology, there are great difficulties in generating the vital data at the micro level on daily rainfall, soil infiltration rates, catchment slopes, land cover and PET which determine the potential inflows; and evaporation rates that determine the potential outflows. Further for small water harvesting project, implemented by local agencies and NGOs with small budgets, cost of hydrological investigations and planning is hard to justify. Often, provision for such items is not made in small water harvesting projects.

That said, the amount of runoff which a water harvesting structure could capture, depends not only on the total quantum of runoff, but also on how it occurs. A total annual runoff of 20 cm occurring over a catchment of one sq. km. can generate a surface flow of 0.20 MCM. But the amount that could be captured depends on the pattern. As Garg (1987) points out, in arid and semi-arid regions in India, high intensity rainfalls of short duration are quite common (source: Garg, 1987 as cited in Athawale, 2003: Figure 24). These runoffs generate flash flood. If the entire runoff occurs in a major rainfall event, the runoff collection efficiency would reduce with reducing capacity of the structures built. If large structures are built to capture high intensity runoff thereby increasing the runoff collection efficiency, that would mean inflating cost per unit volume of water captured. Oweis *et al* (1999) have argued that runoff harvesting should be encouraged in arid area only if the harvested water is directly diverted to the crops for use.

Given the data on inflows and runoff collection efficiencies, predicting the impacts on local hydrological regime is also extremely complex, requiring accurate data on geological and geo-hydrological profiles, and variables.

In lieu of the above described difficulties in assessing the effective storage, unit costs are worked out on the basis of the design storage capacity of the structures and thumb rules about number of fillings. Shri Vivekananda Research and Training Institute, Mandvi, Kachchh, which had done pioneering work in the field of artificial groundwater recharge in India, often resorts to this thumb rule to evaluate the cost effectiveness of recharge structures they built in Kachchh. The recent book by Dr. R. N. Athawale on rainwater harvesting in India though had covered a gamut of technical aspects of water harvesting in different regions of India, does not deal with economics issues (Athawale, 2003).

Scale considerations are extremely important in evaluating the cost and economics of water harvesting/groundwater recharge structures because of the hydrological integration of catchments at the level of watershed and river basins. The cost and economics of water harvesting systems cannot be performed for individual systems in isolation, when the amount of surplus water available in a basin is limited. This is because incremental structures do not result in proportional increase in the hydrological benefits (Kumar, 2000a), as interventions in the upper catchments reduce the potential hydrological benefits from the lower systems. What is important is the incremental hydrological benefits due to the new structure. A system in itself may be cost-effective and economically viable if evaluated independently, but, if evaluated as a part of a large-scale water-harvesting intervention at the level of river basins, the system may not be justifiable from cost angle when compared against the additional benefit it brings in.

In any basin, the marginal benefit from a new water harvesting structure would be smaller at higher degrees of basin development, while the marginal cost is higher (**Fig.1**). The reason being: 1] higher the degree of basin development, lower would be the chances for getting socially and economically viable sites for building water impounding structures, increasing the economic and financial cost of harvesting every unit of water; and 2] with higher degree of development, the social and environmental costs of harvesting every unit of water increases (Frederick, 1992), reducing the net economic value of benefits.

Therefore, the cost and economic evaluation should move from watershed to basin level. As **Figure 1** indicates, the level at which basin development can be carried out depends on whether we consider the flows in a wet year or dry year or a normal year. Nevertheless, there is a stage of development (marked by O in the chart) beyond which the negative social, economic and environmental benefits start accruing, reducing the overall benefits. Here, O is the optimum level of water resource development.

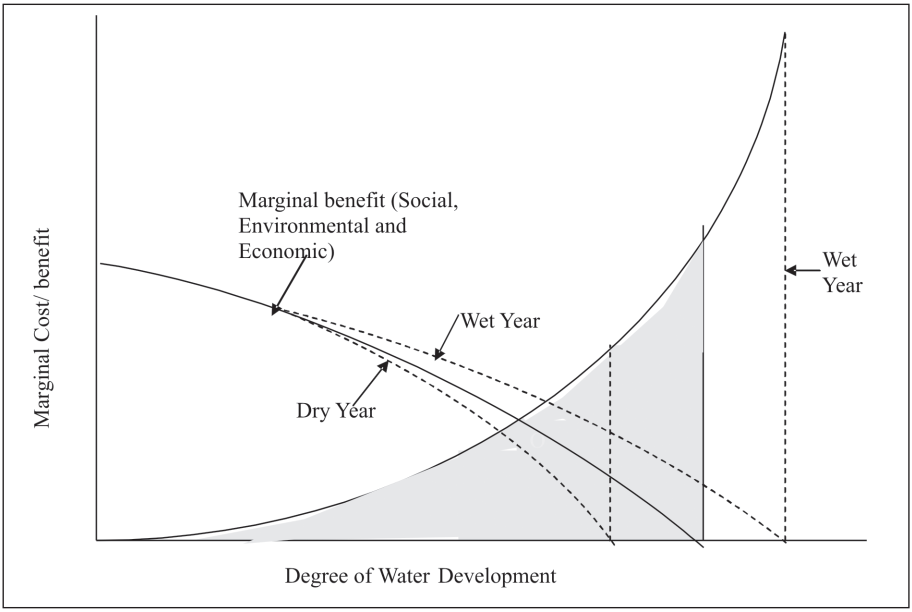


Fig. 1 : Marginal Cost and Benefits of Water-harvesting with different degrees of Basin Development

But, it is important to keep in mind that the negative social and environmental effects of over-appropriation of basin's water resources may be borne by a community living in one part of the basin, while the benefits are accrued to a community living in another part. Ideally, water development projects in a basin should meet the needs and interests of different stakeholders living in different parts. Therefore, optimum level of water development should not aim at maximizing the net basin level benefits, but rather optimizing the net hydrological and socio-economic benefits for different stakeholders and communities across the basin. Hence, it is basin-wide optimization. That said, in certain situations, the local economic benefits from RWH against the economic costs themselves may be questionable. But, such interventions could be justified if there are potential social benefits of changing patterns of water availability and use, in terms of increasing water availability to poorer farmers with low capability land holdings. But such decisions should be based on evaluation of alternative strategies to meet the local water needs of the poor.

Now the ability to derive economic benefit of recharge depends on where the recharged water ends up. In regions underlain by hard rock geology, the groundwater flow patterns are quite complex. Often, the benefits are recharge structures extend up to a few kilometers downstream or upstream depending on the pattern of occurrence of geological structures such as lineaments, fractures and dykes (Muralidharan and Athawale, 1998). Tracing the recharge water in such situations would require sophisticated studies involving isotopes. This is a common problem in the hard rock areas of Saurashtra, Kachchh, north Karnataka and Tamil Nadu where large-scale water harvesting/groundwater recharge interventions are taken up through check dams, ponds and percolation tanks. Often the communities, for whom investment for recharge system are made, do not get the benefit (Moench and Kumar, 1993). In certain other situations, the recharge water could end up in saline aquifers.

The economics of RWH would also be a function of the incremental value of benefits accrued from the use of newly-added water. Apart from the recharge volume, the value of the use to which the additional water is put is extremely important in determining the incremental benefits, an issue often ignored in the project planning. Often, the benefits of RWHS are not clearly identified or understood. While the cost of water harvesting is significant, it is critical to divert the new water to high-valued uses. Phadtare (1988) pointed out that recharge projects would be economically viable in alluvial north Gujarat if the water is diverted for irrigation, as structures are expensive. Yield losses due to moisture stress are extremely high in arid and semi-arid regions and that providing a few protective irrigations could enhance yield and water productivity of rain-fed crops remarkably, especially during drought years (Rockström et al., 2003). The available extra water harvested from monsoon rains should therefore be diverted to supplementary irrigation in drought years.

There are regions where human and cattle drinking become high priority demands. North western Rajasthan, which is arid and dominated by pastoral communities, named *Gujjars*, is one such example. The social and economic value realized from the use of water for human drinking and livestock use, respectively, would be much more than the economic value realized from its use in irrigating crops. In such situations, water should be diverted for such uses where the opportunity costs are low and net value products are high. But proper water use planning to realize maximum value from the added water is largely missing in water harvesting efforts.

Lack of Integrated Approach

In many river basins, the surface water systems and groundwater systems are often inter-connected. Any alterations made in one of them could change the availability of water in the other (Sohiquilo, 1985; Llamas, 2000). In many hilly areas, especially in the Western Ghats, the water levels rise steeply after monsoon, and groundwater contributes significantly to the stream flows downstream during lean seasons due to the steep groundwater flow gradients. In that case, any water harvesting intervention to store water underground may not make much sense as it would get rejected and appear as surface flows (Mayya, 2005). On the other hand, in regions with deep water table conditions like in north Gujarat, the runoff directly moves into the groundwater systems of the plains through the sandy river bed as dewatering of the upper aquifers increases the rate and cumulative percolation.

With 2/3rd of the country's geographical area underlain by hard rock formations, storage capacity of aquifers poses a major challenge for artificial recharge. Most parts of water-scarce states, viz., Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, Orissa, Chhattisgarh and Tamil Nadu are underlain by hard rocks ranging from basalt, crystalline granite, hill aquifers and sandstone. A small areas in Gujarat has extensive alluvium, Narmada valley and (Cambay basin) (**see Map 5**). The hard rock aquifers have no primary porosity and have only secondary porosity. The constraints imposed by hard rock geology in recharge efforts through percolation tanks are: high depth to water table below and around the recharge structure due to occurrence of recharge mount and shallow bed rocks, which prevent percolation of water (Muralidharan, 1990 and Muralidharan and Athawale, 1998); and low infiltration capacity of the thin soils overlaying the hard rock formations. Due to low specific yield (0.01-0.03), sharp rise in water levels is observed in aquifers during monsoon, leaving little space for infiltration from structures. While harnessing water for recharge is extremely important during normal and wet years, the natural recharge in hard rock formation is high during such years as it is a function of seasonal rainfall (Athawale, 2003), further reducing the scope for artificial recharge.

In Saurashtra, in spite of the poor potential offered by low rainfalls, high variability, and high evaporation rates (**see Map 1-3**), significant recharge efforts were made. But, the biggest constraint in storing water underground during high rainfall years is the poor storage capacity or specific yield of the basalt formations. During good rainfall years, the aquifers get saturated with natural recharge immediately after the rains, leaving no space for entry of water from the recharge systems (Kumar, 2000a). An estimated 20,000 check dams built in the region to capture the rainwater and recharge the aquifers are able to store only small fraction of the surplus runoff. In such situations, proper water use programming is required to achieve effective utilization of the available surplus water, wherein water from aquifers is pumped out and used during the rainy season itself thereby creating storage space for the incoming flows (Muralidharan and Athawale, 1990).

The groundwater level fluctuation data obtained from Ghelo river basin in Saurashtra illustrate this. The basin had experienced intensive water-harvesting since 1995. The data were collected from open wells located inside the basin periodically during and after the monsoon rains. The wells located close to the water harvesting structures and those away from the structures are demarcated. Analysis of time series data on water level fluctuation in the wells in relation to the rainfall events shows that the wells close to water harvesting structures get replenished faster than those located away from the structures. But, these wells start overflowing after the first major wet spell, while the second category of wells show similar trends after the second wet spells. Another interesting observation is the steep rise in water levels in wells located both close to and away from the water harvesting structures soon after the first wet spells. It is in the order of 35-40 feet. The steep rise in water levels is indicative of the poor specific yield of the aquifer in the area, as the magnitude of cumulative rainfall that had caused this fluctuation is quite small (nearly 200 mm).

Trade off between Local Vs Basin Impacts in Closed Basins

Due to lack of integration between plans for water harvesting at the local level and basin level water resource development, RWH often leads to over-appropriation of surface water in river basins. While planning of conventional water development projects is based on dependable yields from the catchments, the plans for WH which happen subsequently do not take into account the "committed flows" for downstream reservoir/ water diversion systems.

Also, there is an increasing tendency to believe that because these structures are too small that they are benign (Batchelor *et al*., 2002) though present in large numbers in most cases. The primary reason for this is that the agencies which are concerned with small water harvesting (in the upper catchment) and those which are concerned with major head- works are different and they do not act in coordinated fashion at the level of the basin. Building of small water harvesting systems such as tanks, check dams is often the responsibility of minor irrigation circles of irrigation department or district arms of the rural development departments of the states concerned. This ad hoc approach to planning often leads to over-appropriation of the basin water, with negative consequences for large schemes downstream.

Data collected from Ghelo river basin shows that the inflows into Ghelo-Somnath reservoir had significantly reduced after intensive water harvesting work was undertaken in the upper catchment. **Figure 2** shows the catchment rainfall and runoff in Ghelo-Somnath. After 1995, the year which saw intensive water harvesting work, the reservoir overflowed only in 2005 when the rainfall recorded was 789 mm. While reduction in runoff could be attributed to rainfall reduction as well, rainfall-runoff regressions were carried out for two time periods i.e., 1969-1995 and 1995-2005. The regression equations clearly show that the relationship between rainfall and runoff had changed after water harvesting interventions (**see Fig. 3**). For the same amount of rainfall, the runoff generated is now low. Or in other words, the amount of rainfall required for filling the reservoir had now increased from 320 mm to 800 mm. While this is theoretically true, the actual runoff received by the station might actually differ as there are many factors other than just rainfall magnitude which determines the runoff rates. Though the curves intersect, at high magnitude of rainfall, this is not a problem as such high rainfall does not occur in the basin, and the curve needs to be considered only for the rainfall regime of the basin.

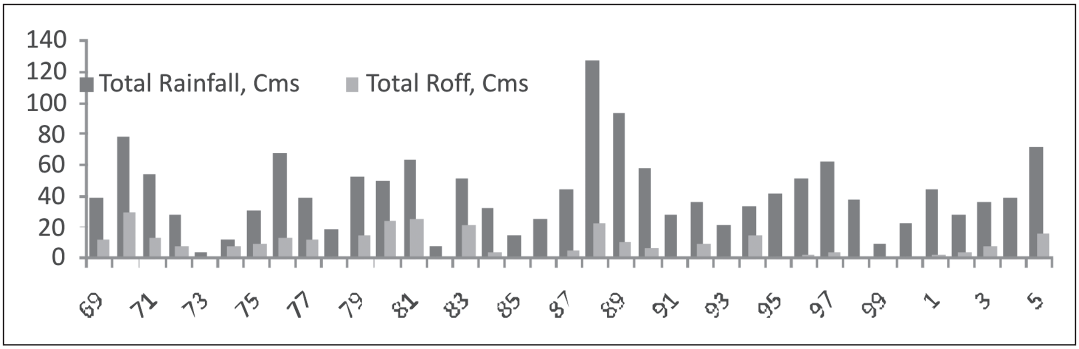


Fig. 2 : Ghelo-Somnath Rainfall and Reservoir Inflows

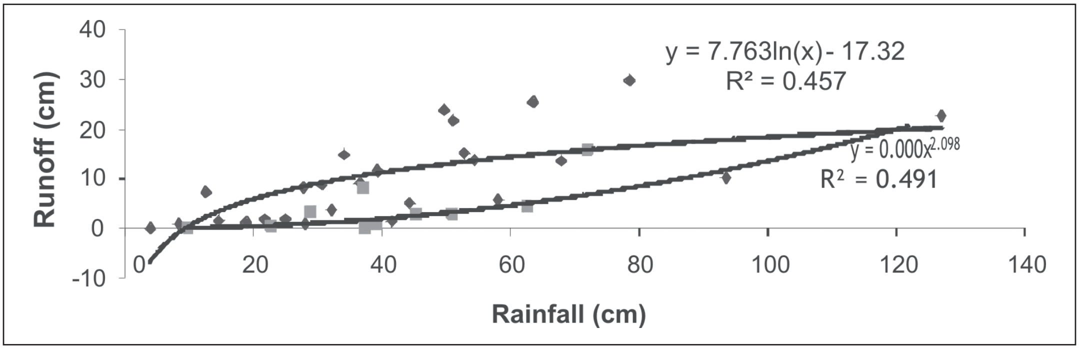


Fig. 3 : Impact of Water Harvesting on Inflows in Reservoir: Ghelo-Somnath

Many large and important river basins in India, which are also facing water scarcity, are now "closed" or do not have uncommitted flows that are utilizable through conventional engineering interventions. Some of them are Pennar, Cauvery and Vaigai in the South (based on GoI 1999: pp 472-477), and Sabarmati, Banas in the west, which are closed. In addition to these, all the west-flowing rivers in Saurashtra and Kachchh in Gujarat are also closed. While Krishna basin is on the verge of closure, some of the basins which are still "open" are Godhavari and Mahanadi in the east (based on GOI 1999: pp 466-469).

It is hard to judge whether a basin is closed or open on the basis of the storage capacity of reservoirs and the dependable flows, as many reservoirs also divert a lot of water during monsoon season, making the effective water utilization more than the live storage capacity. The estimated ratio of total live storage of reservoirs in 17 major river basins in India against the dependable runoff in these basins shows that for many basins, the ratio is far less than 100 per cent, leaving the impression that there is much more uncommitted flows in the basin for future harnessing. But this is not correct. Take for instance Narmada basin. The total live storage volume of all terminal dam built in Narmada, i.e., Sardar Sarovar, is 5800 MCM, where as the total water utilization from this reservoir is 11, 200 MCM. All the 30 large and 135 medium reservoirs together would divert a total of 30,588 MCM of water for irrigation and various other purposes (NWDA, 2004). But the total live storage of these reservoirs would be much less, i.e., 23,790 MCM (GoI, 1999: pp 36). This is because a significant amount of water would be diverted from these reservoirs for kharif irrigation within the basin and outside, particularly from Sardar Sarovar reservoir.

Trade off between Economics and Hydrological Opportunity

Regions with semi-arid and arid climate experience extreme hydrological events (Hurd *et al*., 1999). High inter-annual variability in rainfall is a common phenomenon in most parts of these water-scarce regions. Rainfall variability induces higher degree of variability in runoff. Such high variability is found even in the high rainfall regions as well as low rainfall regions. We take the example of the upper catchment area of Cauvery basin in peninsular India and one of the catchments of Sabarmati River basin in North Gujarat of western India.

In Banaskantha district in north Gujarat, which has semi-arid to arid climatic conditions, the rainfall records show a variation from a lowest of 56mm in 1987 to 1584mm in 1907. The runoff estimated on the basis of regression equation developed for a sub-basin, named, Hathmati of Sabarmati basin in north Gujarat, which is physiographically quite similar to Palanpur area of Banaskantha, shows that the runoff can vary from a lowest of 0.6mm to 541mm. But the occurrence of actual runoff could be different from this based on how other variables that are not considered in the regression viz., the intensity and pattern (over space and time) of rainfall, influence the runoff intensity. Thus the lowest runoff is close to 1/1000th of the highest runoff. Though what can occurs at the sub-basin level may not be representative of that in small upper catchments, the difference cannot be drastic. Even for a humid, high rainfall region of Wayanad district in Kerala, the runoff estimated for a small catchment of Karappuzha on the basis of the rainfall-runoff relationship developed for Kabani sub-basin (catchment area of 7040 sq. km) of Cauvery river basin, to which the area falls, and the observed rainfall of the area, ranged from 528mm in the lowest rainfall year (2002) to 1458mm in the highest rainfall year (1994) in a 31-year period from 1973-2003.

When there is a high inter-annual variability in the runoff a catchment generates, a major planning question which arises is “for what capacity the water harvesting system should be designed”. When scarcity is acute, highest consideration is given to capturing all the water that is available. If all the runoff which occurs in a high rainfall year is to be captured, then the cost of building the storage system would be many hundred times more than what is required to capture the one which occurs during the lowest rainfall.

But, the system would receive water to fill only a small fraction of its storage capacity in the rest of the years. This could make it cost-ineffective. The issue of variability is applicable to the design of large head works as well. But, in large systems, the water in excess of the storage capacity could be diverted for irrigation and other uses to areas which face water shortages during the same season, thereby increasing the effective storage.

In order to illustrate this point, we use the data generated from Ghelo river basin in Saurashtra. The basin has a total catchment area of 59. 20 sq. km. It had a medium irrigation reservoir with a storage capacity of 5.68 MCM and has been functional since 1966. On the basis of inflow data of the reservoir for the period 1969-95 showed that the total runoff generated in the basin varied from zero in the year corresponding to a rainfall of 39 mm to a maximum of 17.78 MCM in the year corresponding to a rainfall of 1270 mm. Today, the total capacity of water harvesting systems built in the upstream of Ghelo reservoir is 0.15 MCM. During the period from 1969 to 2005, the reservoir showed overflow for 13 years with a total quantum of 60.936 MCM. If one million cubic metres of runoff had to be captured in addition to the 5.89 MCM that would be captured by the medium irrigation reservoir, it would cost around 0.09 X/m^3 of water, while capturing 3 MCM would cost 0.11 X/m^3 of water. If the maximum runoff observed in the basin, i.e., 17.785 MCM has to be captured, the total volume of water captured would be only 60.91 MCM, in which case the unit cost of water harvesting would be around 0.21 X/m^3 of water. Here, "X" is the cost of storage structures for creating an effective storage space of one MCM. Here, again, we are not considering the incremental financial cost of the special structures for capturing high magnitudes of runoff, which cause flash flood.

Maximizing Local Benefits Vs Optimum Benefits for Basin Communities

Generally, in any river basin, the upper catchments are rich in terms of their ability to contribute to the basin yields. This is mainly because of the unique physiographical features, and partly because of the climatic conditions—such as steep slopes, high rainfall in the mountains, and high humidity—, which provide favourable environment for runoff generation. The upper catchments also provide good source of base flows due to forest cover which causes favourable conditions for water storage and infiltration. On the demand side, these regions generally are less endowed in terms of availability of arable land. Over and above, the demand rates for irrigation are generally low. On the other hand, the lower catchments are generally characterized by lower rainfalls and higher levels of aridity (rainfall deficit to meet ET demands) and better access to arable land, increasing the aggregate demand for irrigation.

There are numerous examples for this. A few to cite are: the upper catchment of Cauvery basin in the south, Narmada basins in central India, Sabarmati basin in western India, tributaries of Indus in the north western India, Krishna basin in Central India and Mahanadi basin in eastern India. Some parts of Kabani sub-basin of Cauvery river basin have cold and semi-humid climate, and parts of this sub-basin receives the second highest rainfall in India after Chirapunji with the mean annual rainfalls crossing 4000 mm. Irrigation demands in these regions are low owing to high precipitation and low reference evapo-transpiration, and low per capita availability of arable land**.** On the other hand, the lower parts of Cauvery in Tamil Nadu are hit by scarcity of water for irrigation owing to lower rainfalls and high evapo-transpiration.

We have defined the agricultural water demand as a function of per capita net sown area and the ratio of ET_0 and rainfall; and water availability as a function of rainfall. It is assumed that: higher the ET_0/R ratio, higher would be the irrigation requirement for a unit of land; higher the per capita (rural population) net sown area, higher would be the aggregate demand for irrigation per capita. **Table 1** shows the estimated values of two selected agricultural water demand variables, viz., ET_0/R and per capita arable land; and one water availability variable, i.e., rainfall. It also shows that the irrigation demand is much higher in the lower catchment areas, and availability higher in upper catchments in all these six important basins.

Major water resource/irrigation projects undertaken in the past tap stream flows generated from the upper catchments, but cater to either the lower parts of these basins or other less water endowed regions outside these basins (Verghese, 2001 and 2002). Bakhra reservoir and Nangal diversion projects located in the high rainfall Shivalik hills of Himachal Pradesh essentially cater to the ravenous low rainfall and drought prone regions of Punjab and scanty rainfall regions of Rajasthan (Verghese, 2002); the Sardar Sarovar dam harnesses water from ample rainfall areas in Narmada valley and takes it to the drought-prone areas of north Gujarat and Saurashtra which are characterized by low and erratic rainfall (Verghese, 2001). Similarly, the large reservoir projects in Cauvery transfer water to the drought-prone regions in Tamil Nadu and Karnataka. As such the water demand for irrigation is extremely low in the upper catchments.

Moreover, as irrigation water use efficiency and water productivity are likely to be high in areas with variability in rainfall and high drought- proneness (Rockström *et al*., 2003), with transfer of water from the well-endowed regions to the poorly-endowed regions, the economic value of water in agriculture increases. The recent research carried out by IWMI in water-scarce and land-rich western Punjab and water-rich and land-scarce eastern Uttar Pradesh showed that the value of water realized from irrigation is much higher in Punjab than in eastern UP. The economic value of water was Rs. 14.85/m^3 in western Punjab, where as it was Rs. 11/m^3 in eastern Uttar Pradesh. Due to scarcity of water, the farmers in Punjab make better economic use of water by choosing cropping systems that are economically more efficient and doing agronomic practices to obtain higher yields, higher physical productivity and economic efficiency (Kumar *et al*., 2008).

But, often water harvesting initiatives, especially those by NGOs, are driven by considerations other than economic efficiency, most important of which are social equity and environmental justice. Impounding water in the upper catchments might serve social objectives of meeting drinking water requirements.

As evident from the above illustrations, there is a clear trade off between meeting economic efficiency objectives, and these developmental goals. Therefore, any water resource intervention in the upper catchment areas which reduce the downstream uses should be done with due consideration to the net change in "gross value product" of water in the basin due to the interventions. The "gross value product" can be defined as the sum total of the incremental value product from the economic uses, environmental services and social uses the basin's water resources meet. The amount of water to be captured upstream through RWH interventions should also be optimized to derive maximum regional social equity, environmental value and overall output from the economic uses of water. In basins where the available water resources are already committed (closed basins), the challenge is bigger as maximizing the gross value product might mean reallocating some water from one low valued use to a high valued use.

Table 1 : Comparison of agricultural water demand variables in upper and lower catchment districts of selected indian river basins

Name of basin	Name of upper catchment district (UCD)	Name of lower catchment district (LCD)	Mean annual rainfall (mm) in		Mean annual potential evapo-transpiration (mm) in		PET/R		Per capita net sown area (Ha)	
			UCD	LCD	UCD	LCD	UCD	LCD	UCD	LCD
Sabarmati	Dungarpur	Ahmedabad	643.7	821.0	1263.0	1788.8	1.96	2.18	0.14	0.47
Indus	Shimla	Ludhiana	1597.0	525.0	986.60	1698.6	0.62	3.24	0.14	0.25
Narmada	Shahdol	Jhabua	1352.0	792.04	1639.0	2127.0	1.21	2.69	0.35	0.35
Cauvery	Wayanad	Nagapattianan	3283.0	1337.0	1586.9	1852.5	0.48	1.39	0.18	0.13
Krishna	Raigarh	Guntur		1029.0		1785.9		1.74	0.13	0.22
Mahanadi	Raipur	Puri	1388.0	1440.0	1667.0	1667.0	1.20	1.16	0.18	0.06

UCD: Upper catchment district; LCD: Lower catchment district
Source: (1) Agricultural Statistics of India and (2) FAO data on precipitation (R) and reference evapo-transpiration (PET)

Major findings

Following are the major findings vis-à-vis the critical issues in rainwater harvesting from the point of view of hydrological opportunities, economic viability and socio-economic impacts.

- Macro level hydrological analysis shows that rainwater harvesting solutions offers extremely limited potential in terms of its ability to reduce the demand-supply imbalances and provide reliable supplies in naturally water scarce regions. The reason being: a] significant part of these regions are characterized by low mean annual rainfalls, high inter-annual variability in rainfall, with high potential evaporation and larger share of evaporation occurring during rainy season, reducing the runoff potential and increasing the occurrence of hydrological stresses; and b] another significant part is characterized by medium rainfalls, with medium inter-annual variability, but "medium to high evaporation", making surface storage difficult.
- A large part of the water-scarce regions, which fall under the "medium rainfall-medium to high evaporation" regime are underlain by hard rock formations such as basalt, crystalline rocks and other consolidated formations such as sandstones. The percolation tanks, the most preferred recharge structures, are likely to have low efficiency in these hard rock areas and also areas having silty clay and clayey soils.
- In high rainfall, and medium evaporation regions which experience high reliability in rainfall such as parts of Orissa, western Ghat and north eastern hilly region, the overall potential and reliability of water supplies from RWHS would be high.
- Inefficient recharging in hard rocks, as illustrated by data from Ghelo river basin, is due to lack of integration of groundwater and surface water use. In these regions, planning of recharge schemes should consider surface water impoundment of all the available excess flows, than direct recharge. This should be followed by water use programming to create underground storage for incoming surface flows. However, this is not followed.
- Many water-scarce regions have water demands which far exceed the supplies, with vulnerability to hydrological stresses, that they would require exogenous water.
- Economic evaluation of water harvesting/groundwater recharge systems poses several complexities due to the difficulty in quantifying the inflows, the storage and recharge efficiency, and the economic value of the incremental benefits, which are social, direct economic and ecological or environmental. Data for water harvesting structures constructed in the upper catchment of Ghelo shows a storage capacity of 0.15 MCM. At the same time, the estimated inflow reduction in the reservoir downstream (Ghelo-Somnath) was not found to be constant, but a function of the rainfall itself. At below normal to normal rainfall, the flow reduction was highest where as at higher levels of rainfall, the difference appear to be reducing.
- Scale considerations are extremely important in evaluating the cost and economics of water harvesting/groundwater recharge structures because of the integration of catchments at the level of river basins. The economics of water harvesting cannot be

performed for structures based on their individual benefits and costs, when the amount of surplus water available in a basin is limited; but on the basis of incremental benefits. Further, higher in degree of basin development, higher will be the marginal cost and lower would be the marginal benefit.

- In the basins which experience high inter-annual variability in the stream flows, the trade-off between hydrological impacts of water harvesting and economic benefits is likely to be large. With increasing storage capacity of RWH systems, the economic viability becomes poorer as the average cost of water harvesting per unit volume of water increases. The historical data on reservoir inflow obtained for Ghelo river catchment illustrate this.
- In "closed basins", there is apparent trade off between local benefits and downstream benefits. U/S diversions reduce the prospects of storage and diversion systems d/s. Examples of closed basins in India are river basins in north Gujarat, Saurashtra, Kachchh, western Rajasthan and basins in Peninsular India, such as Cauvery, Pennar and Vaigai. Narmada is another basin which in immediate future would join this category of river basins. The detailed hydrological data collected from Ghelo river basin in Saurashtra also illustrate this.
- In many important basins, there is an apparent trade off between maximizing overall benefits for basin communities in terms of enhancing the gross value product of water, and maximizing the local benefits of water harvesting. This is owing to the fact that in these basins, water from well-endowed regions with low water demands is being diverted to poorly-endowed regions with high water demands, enhancing its social and economic value. Noteworthy examples are Indus in India and Pakistan, Cauvery and Krishna in the southern Peninsula of India, Narmada in central India and Sabarmati basin in western India.

Practical Suggestions for Efficient Water Harvesting

1. *Enhancing Knowledge of Catchment Hydrology*: In water harvesting, what is least understood is the catchment hydrology. Most small rivers in developing countries of south Asia are not gauged for stream flows and siltation. Example is Narmada river basin. It has a total of 56 gauging sites of which 25 collect data on siltation load. Data on siltation rates are often available for large reservoirs from siltation studies done by Central Board of Irrigation and Power (CBIP). But applying this to small catchments can lead to either under-estimation of siltation rates as siltation rates are generally high for hilly upper catchments. On the other hand, applying rainfall-runoff relationships of large basins for small upper catchments would result in under-estimation of runoff, as small upper catchments would normally have steeper slopes. The scale problems in hydrology are well documented (Sivanappan and Kalma, 1995).

Though runoff data can be generated for streams which otherwise are not gauged, through runoff modeling, scientific data on hydrological parameters such as soil infiltration rates, land use characteristics, catchment slopes are essential to arrive at reliable results (Jakeman *et al.*, 1994). Managing hydrological data for small catchments is still a major challenge in south Asian countries.

2. *Research to Focus on Green as well as Blue Water*: The central focus of any rainwater harvesting project is about capturing the excess water which flows out of the domain of interest, storing and subsequently diverting it for beneficial uses. But, green water is an important component of the hydrological system and the harvested water in traditional systems such as tanks and *Khadin*. The focus has never been on improving the efficiency of utilization of this green water. For any basin, it is crucial to know how much of the total precipitation falling on the basin is available as green water and how much of it gets used up in crop production; how much of it is lost in non-beneficial evaporation from the soil.

   In high rainfall regions, the utilizable surface water resources are much less in comparison to the runoff generated. Here, effective strategies to capture runoff *in situ* for crop production through proper land use planning—including increasing area under paddy, would help improve green as well as blue water use, and alter the hydrology positively.

3. *Basin Water accounting and Water Balance*: For any water scarce river basin, water accounting is the first and the most important step to begin with before planning any water harvesting and recharge project. It is important to know whether the basin has any surplus flows, which goes into the natural sink, or significant amount of water that is lost in evaporation from natural depressions. This can be followed by water balance studies to examine what percentage of the water could be captured without causing negative effects on the downstream uses. Needless to say, both water accounting and water balance studies should be carried out for typical rainfall years so as to capture hydrological variability. Such studies can provide critical inputs to basin-wide water resource planning for optimal water harvesting to ensure sound economic viability.

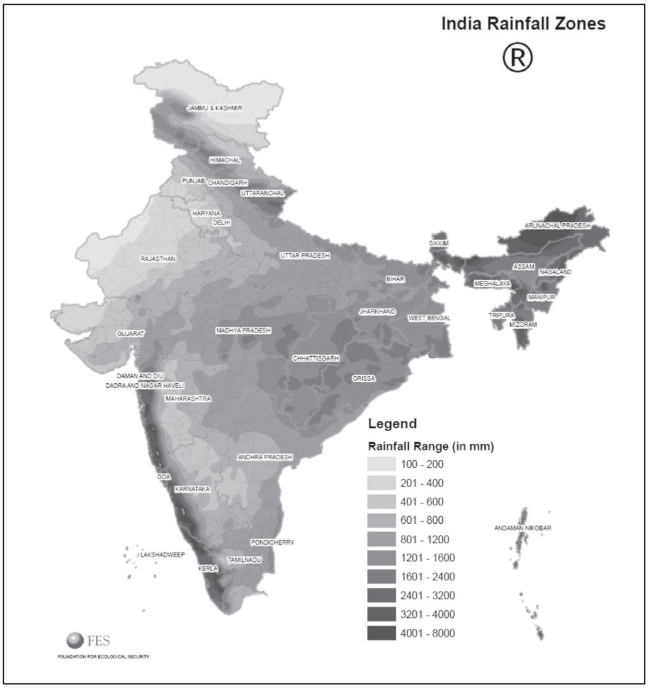
4. *Wet Water Saving*: In river basin which experience high aridity during the summer months, the water stored in tanks, pond and other small reservoirs can lead to heavy losses through evaporation. If this is prevented, it can lead to wet water saving, through increase in output per unit of evaporated water. Directly diverting the harvested water from the RWH system to the crop land is critical to maximizing the net hydrological gain, especially in areas with poor groundwater storage or areas experiencing high inter-annual variability in runoff (Oweis *et al.*, 1999). Allocation of blue water

harnessed to rain-fed crops to avoid moisture stress during critical stages of crop growth would increase the yield of crops remarkably (Seckler, 1996; Rockström *et al*., 2003), thereby increasing the productivity of green as well as blue water. In the case of sub-Saharan Africa, Rockström et al. (2003) showed that yield could be doubled in certain cases through hydro-climatic alterations.

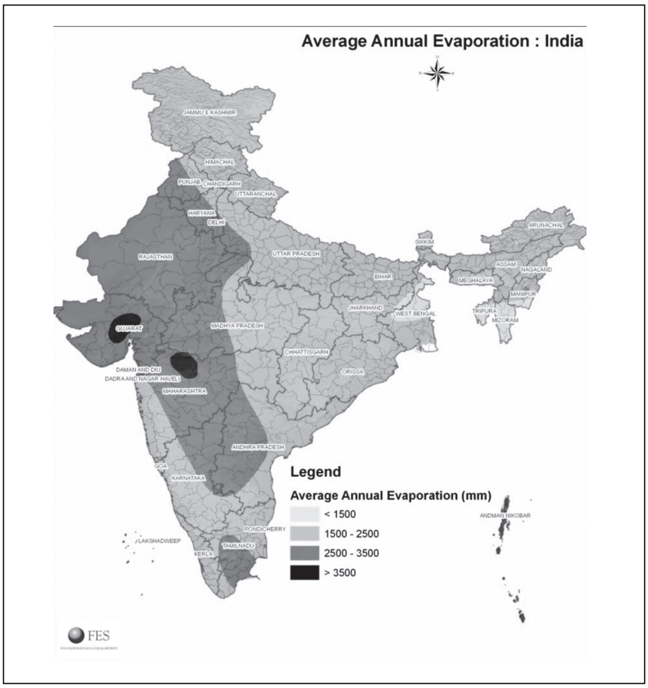
Practical and Policy Suggestions for Efficient Water Harvesting

In the most naturally water-scarce regions, RWH offers limited potential. In many other regions, which have medium rainfalls, but experience "medium to high evaporation", the poor groundwater potential of hard rock which underlie these regions pose a constraint for recharging. In high rainfall regions with moderate evaporation, rainwater harvesting offers good potential. Economic evaluation of water harvesting systems poses several complexities due to the problems in quantifying the hydrological impacts, and the various benefits. Economics of water harvesting cannot be worked out for structures on the basis of individual benefits, but on the basis of incremental benefit. In many water-scarce basins, there is a strong trade-off between maximizing the hydrological benefits from RWH and making them cost-effective. In many water-scarce basins, RWH interventions lead to distribution of hydrological benefits, rather than augmentation. There is an optimum level of water harvesting which a basin can undergo which can help optimize the gross value product of water vis-à-vis economic, social and environmental outputs basin-wide.

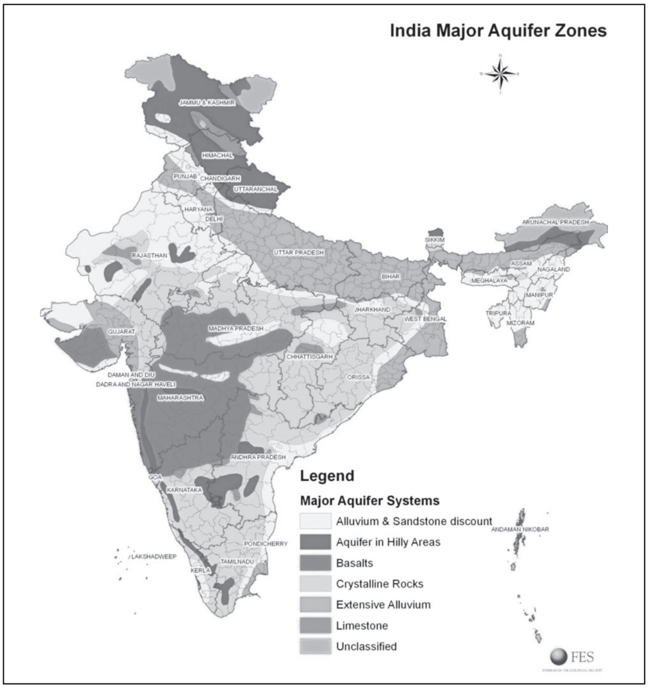
Unlike India, many countries in South Asia where water scarcity has begun to hit populations over large areas, RWH still hasn't become the part of mainstream water programme of governments. Those countries can draw remarkable learnings from the experience of India, particularly the analysis presented in this paper, to frame their water harvesting policies. The following should be the key elements of water harvesting policy. 1. River basins, instead of watersheds, should be the unit for planning water harvesting systems, to allow integration of upper and lower catchments and groundwater and surface water systems in the drainage basins. 2. In allocation of funds for water harvesting, priority should be given to "open basins". 3. Water accounting and water balance studies would therefore be mandatory before embarking on water harvesting projects in any river basin, to find out how much of un-utilized and un-committed flows are there in the basin. 4. In "closed basins", the economics of water harvesting should consider the downstream effects, to capture the overall effect of building of the system. 5. In situations where equity considerations compel building of water harvesting systems in upper catchments of "closed basins", financial support should be contingent upon the agencies investing in productivity improvements in the use of harvested water.



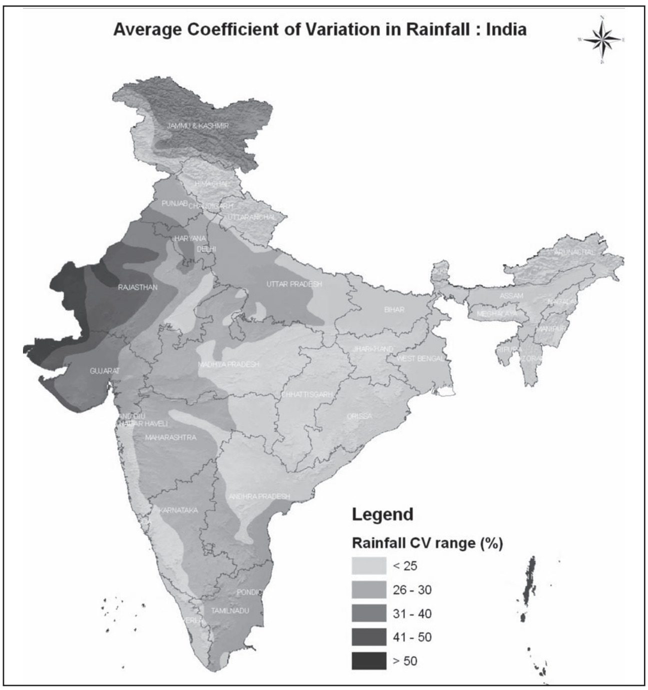
Map 1 : Rainfall in India



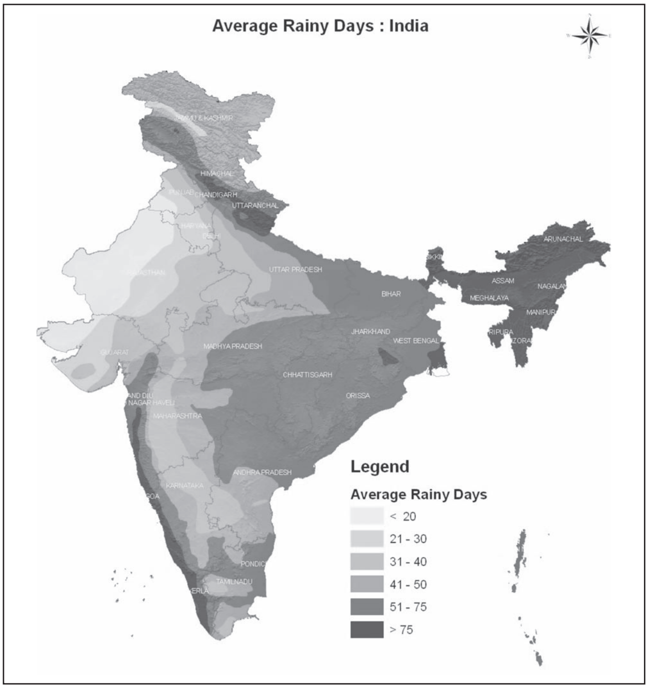
Map 2 : Average Annual Evaporation in India



Map 3 : Major Aquifer Systems in India



Map 4 : Coefficient of Variation in Rainfall in India



Map 5 : Number of Rainy Days in India

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Water Resource Management for Generation of Employment in SAARC Country' Perspective

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Efficient management of water resources is among the critical policy issues across the continents. The need for action in this direction is growing by day, as countries and communities across the globe are increasingly experiencing the water stress in various contexts. This water stress especially, has come about with the acceleration of groundwater based irrigation due to different governance structures are in operation depending on the nature of the water sources. For, surface water mostly comes under state ownership/ management while groundwater is managed mainly by private people. Imbalances in allocation, distribution and usage of water are creating conflicts in general across the globe and in India particularly.

Water Availability and Withdrawals (Supply and Demand for Water):

Global Scenario

Different estimates show the intensity of the water stress across the globe. The rainfall that is stored in the soil and evaporates from it is the main source of water for natural eco systems and for rainfed agriculture, which produces 60 per cent of the world's food. Renewable surface water runoff and ground water recharge is the main source for human withdrawals and the traditional focus of water resource management. Asia (15 per cent) and Europe 16 per cent) are the major renewable surface water resource continents available across the globe **(Table 1).**

Table 1 : Global Water Withdrawals (1990)

Continent	Annual Withdrawal		% of Renewable Water Resources
	Km3	%	
Asia	2007	58.8	15
Africa	149	4.4	4
Europe	476	13.9	16
N.America	617	18.1	8
S.America	141	4.1	1
Oceania	24	0.7	1
Total	3414	100.0	8

Source: World Resources 2000-01.

Table 2 : Three Largest Water Users (1990)

Country	Annual withdrawal (km^3)	% World withdrawal	% of availability	Per capita (cubic metre)
China	525	18.3	19	439
India	500	14.6	40	588
USA	448	13.1	18	1677
Sub-total	1473	46.0	-	648

Source: World Resource 2000-01

Table 2 gives the major water withdrawal countries across the globe.

- India and China account for one third of global withdrawal
- India, China and USA nearly halved the global withdrawal
- China and USA use less than 20% of their renewable water resources; India uses 40% (may be an underestimate)
- Agricultural withdrawal -China (77%) India (91.2%) USA (27%)
- Per agricultural withdrawal- Lower in India and China.

Precipitation in the form of rain and snowfall provides over 4000 km^3 of fresh water to India, most of which returns to the oceans via the many large rivers which flow across the subcontinent. A portion of this water is absorbed by the soil and is stored in underground aquifers. A much smaller percentage is stored in inland water bodies both natural (lakes and ponds) and man-made (tanks and reservoirs).

Water Resources Availability in India:

Over the years, there have been many estimates of the water resources available to India. The most recent (as shown below) are those given in the Report of the high-level National Commission for Integrated Water Resources Development Plan (hereafter NCIWRDP) set up by the Government of India, Ministry of Water Resources, (September , 1999) (Figures in cubic km) (extracted from Raju, K. V. 2005).

Precipitation over the Indian landmass————4000

Available surface water resources ————1953

Available groundwater resources ————432

Usable surface water resources ————690

Usable groundwater resources ————396

Total usable water resources ———1086

Present quantum of use around ———580-650

There are wide variations, both temporal and spatial, in the availability of water in the country. Much of the rainfall occurs within a period of a few months during the year, and even during that period the intensity is concentrated within a few weeks. Spatially, there is a wide range in precipitation – from less than 200 mm (or even 100 mm) in parts of Rajasthan to 11000 mm in Cherapunji in the north-east of the country. This has (or is felt to have) implications for water-resource policy and planning and leads to certain responses. As against the above figures of availability, there are projections of water demand for various uses. Many variables and assumptions enter into these estimations, and multiple projections may have to be made with reference to different assumptions and estimations in regard to some of the factors involved (Extraced from Raju, K. V. 2005). In addition, there can be different expectations ('scenarios') as to the likely course of future developments. Some of the studies on the subject try to project water needs under three scenarios: (a) things go on as before and no significant changes are made in policies and practices (the 'Business As Usual' or BAU scenario): (b) some incremental improvements are attempted in policies, procedures, patterns of use and technologies ('Improved Management' scenario); and (c) significant and radical changes are brought about with a view to ensuring economy in water–use, resource-conservation and long-term environmental 'sustainability' ('sustainable water world' scenario). Some others adopt BAU, High Growth (HG) and Sustainable (SS) scenarios. Based on their respective assumptions and scenarios, different studies give their projections of future water requirements (for all uses): ('Precipitation' includes rainfall and snowfall; 'available surface water resources' are measured in terms of annual flows at sites close to the terminal points of the river systems; 'available groundwater resources' means 'dynamic' groundwater or 'groundwater potential', i.e., the quantity that can be extracted annually, having regard to the rate of annual replenishment ('recharge') and economic considerations; 'usable water resources' means that part of the notionally 'available' water resources which is actually available for use through impoundment or other means. (There is a view that the quantum of available surface water resources of 1953 BCM includes the groundwater availability of 432 BCM, as much of 'dynamic' groundwater eventually joins surface water flows into the sea and the quantum of groundwater that independently flows into the sea is not significant; but this view is not accepted by all.) Water is also available in the form of atmospheric and soil moisture, and as stored in wetlands; there are also possibilities of local augmentation of availability through rainwater harvesting or additional runoff-capture. However, these availabilities are not generally taken note of (at any rate not adequately) in the conventional estimations of water engineers; similarly, 'usable' water resources can also have a wider meaning than the conventional engineering sense.

(i) The Working Group (WG) of the NCIWRDP and NCIWRDP itself: 973 to 1180 BCM in 2050.

(ii) India Water Vision (IWV) of India Water Partnership: 1027 BCM in 2025.

(iii) Study by Kanchan Chopra and Biswanath Goldar of the Institute of Economic Growth (KC/BG): 920.92 BAU, 1004.72 HG, and 964.9 SS in 2020.

WG and NCIWRDP assume that certain steps to ensure economy, efficiency and conservation will be taken, and predict a fragile balance between supply and demand on that basis. IWV and KC / BG also seem to adopt a similar position of a cautious but not an alarmist view of the future. Is such a position warranted? There are two divergent views on this question. One is that this is a complacent view and that a crisis is imminent. The other view, questioning the prediction of a crisis, is that of the Centre for Science and Environment (CSE): they argue that if there is proper water management, and if local, community-based water-harvesting is undertaken extensively all over the country (wherever it is feasible), there will be no crisis.

Demands

Access to adequate water is one of the leading factors limiting development in India. Agricultural, industrial and domestic uses are competing more and more for a limited supply. The agricultural sector continues to dominate water use owing to its continued importance to the Indian economy, while industrial demands are increasing as the sector continues to grow. Domestic needs claim only a small portion of the annual water withdrawals as access to adequate water and sanitation supplies remains low throughout most of the country. Greater access and an improvement in the socio-economic situation in rural India will likely result in higher demand for water from this sector in the coming years.

Agricultural

Agriculture remains central to the Indian economy and it therefore receives the greater share of the annual water allocation. According to the World Resources Institute (2000), 91.2% of India's utilisable water is devoted to this sector, mostly in the form of irrigation (**Table 3**). The necessity of irrigation for agricultural production is great due to the

Table 3 : Total Water Availability in India

Annual Withdrawals (cubic kilometer per year)				
Total (km^3/ per year)	Per capita (m^3 per person)	Withdrawals by sector (per cent)		
		Agriculture	Industry	Domestic
645.8	635	91.2	4.0	4.8

Source: World Resources, 2005 (FAO, 2000).

unpredictable nature of the monsoon. In regions completely dependent on rainfed agriculture, a weak monsoon season can result in drought conditions that can lead to reduced yields or even total crop failure. Even during normal monsoon seasons, farmers are usually able to produce only one crop per year and yields are generally much lower than in irrigated areas. Indeed, the productivity of irrigated agriculture per unit of land has been estimated at seven times that of rainfed agriculture (World Bank, 1999). Massive investment in irrigation in the past fifty years has resulted in an expansion of the gross irrigated area from 23 million hectares in 1951 to over 90 million hectares in 1997, and plans exist to continue developing irrigation infrastructure over the coming years (World Bank, 1999). This growth in irrigated area, along with improvements in farming technologies and plant genetics, has been responsible for the incredible growth in crop production over this period. The increase in production has also contributed greatly to the national economy and to India's food security. However, irrigation expansion has also placed greater demands on surface and groundwater resources. Groundwater alone accounts for 39% of the water used in agriculture and surface water use often comes at the expense of other sectors such as the industrial and domestic supply. At the other extreme, flood conditions can be equally devastating to the agricultural sector and requires careful planning in terms of drainage and the construction of flood control structures. Development projects such as dam and canal construction were devised to help mitigate the effect of the monsoon on rivers and seasonal streams. For the most part, they have been successful at reducing the impact of flooding in some areas, although their effectiveness is limited in the face of exceptional rainfall events.

Industrial

In the past several decades, industrial production has increased in India owing to an increasingly open economy and greater emphasis on industrial development and international trade. Water consumption for this sector has consequently risen and will continue growing at a rate of 4.0% per year (World Bank, 1999). According to the World Bank, demand for industrial, energy production and other uses will rise from 67 billion m^3 to 228 billion m^3 by 2025. Hydroelectric generation already accounts for a large percentage of the water demand from this sector. The potential in India has been estimated at 84,000 MW, of which only 22,000 MW is currently being harnessed (MOWR, 2001). The large untapped potential, particularly in the northern regions of India, and the growing demands for electricity from a larger population and industrial sector, will ensure that development of this activity continues in the coming years.

Domestic

Demand from the domestic sector has remained low and accounts for only 4.8% of the annual freshwater withdrawals in India (World Resources Institute, 2000). Domestic water use will increase as the population continues to grow and access to water is improved. Recent data from the World Bank indicates that demand over the next twenty years will double from 25 billion m^3 to 52 billion m^3.

Only 85% of the urban and 79% of the rural population has access to safe drinking water and fewer still have access to adequate sanitation facilities (World Resources Institute, 2000). The central government made a commitment to improve access to water in rural and urban areas in the National Water Policy adopted in 1987. The original goal of providing water to 100% of all citizens of India by 1991 had to be revised and now stands at 90% access to urban and 85% access to rural areas. Drinking water and sanitation nevertheless remains high priorities on the government agenda.

Most urban areas are serviced by a municipal water distribution system. Usually, the municipal water supply originates from local reservoirs or canals, but in some cases water may be imported through inter-basin transfer. Although the major cities in India enjoy access to central water supply systems, these schemes often do not adequately cover the entire urban population and are notoriously inefficient and unreliable. In rural areas, access to water is even more precarious. Over 80% of the rural domestic water comes from groundwater sources since it is more reliable in terms of water quantity and quality. Still, in areas where water is scarce, rural women must travel long distances to wells or streams to fetch water for their daily needs.

Irrigation Development in India

Tank Irrigation

Surface structures or formations collecting and storing rainwater, runoff and seepage from the surrounding areas are known as tanks or ponds. Over the centuries, locally built water storage systems (e.g, tanks in South India, *Johads* in Rajasthan), have acted as insulation against droughts, helped in recharging groundwater, provided crucial irrigation for crop production, functioned as a source of multiple uses for the village community (drinking water, washing, bathing, water for livestock and wildlife, fishing, water for cultural and ritual purposes), and played a role in the maintenance of a good natural environment. Because of these benefits, the Indian kings, *Jagirdars*, religious bodies and philanthropists built large numbers of tanks all over their domains. These rainwater-harvesting structures in various forms were known by different names in different parts of the country, e.g., k*ere* in Karnataka, c*heruvu* in Andhra Pradesh, *erie* in Tamil Nadu, *johad* and *bund* in Rajasthan, *ahar* and *pyne* in Bihar.

Tanks were meant not only for agriculture, but also served as a resource-base for many other activities such as the collection of fodder, fuel, the making of bricks, pots, baskets, etc, with women offering their assistance in these processes. Tanks were also part of the socio-religious and economic system in villages. The location of the tank and its physical conditions were a matter of much significance to the people, particularly women, in carrying out their economic activities. The tank and its surroundings used to be the common property of the village and its people. The reverence for water as a life-sustaining element and the tradition of respect for water-sources ensured the proper maintenance of tanks for use by all, mitigating to some extent the prevalent caste-discrimination in work and access to and control over tank-based resources. The maintenance of natural resources through a continuous process of use and conservation meant not merely the assurance of livelihoods to the people of the village, but also the preservation of the ecological balance.

The years after Independence witnessed the abolition of *Inamdari* landholding patterns and hereditary village offices, and there were also changes in the land-use patterns affecting the catchments of the tanks. These processes, whatever their other merits, had negative effects on tanks. In the post-Independence era there was a decline in the tank irrigated area and the emphasis shifted to major and medium irrigation projects. The share of net irrigated area under tanks declined in the country from 17.3 per cent in 1950-51 and to 6.8 per cent in 1990-91 (GoI 1994). The decline of tank-irrigated area is common throughout the country. The reasons for this will be gone into later.

Major and Medium Irrigation

Reference was made earlier to the shift from the community to the state and to the emergence of large state-built irrigation works. In pursuance of the recommendations of the first Irrigation Commission, a number of projects on a truly large scale began to be constructed. In the early 20th century, the aim was to provide protective rather than productive irrigation works (Reddy, 1998).

After Independence, the Government of India launched an ambitious programme to improve agricultural production through the extensive development of the irrigation infrastructure. Development works in irrigation were taken up in all five-year and annual plans. Aside from China, the irrigation system in no other country is as extensive as in India.

Passing over the earlier Plans and confining ourselves to the recent ones, the position is that from the Sixth five-year Plan onwards, emphasis has been laid on the completion of on-going projects and consolidation of gains, rather than on ‘new starts’. However, new projects continued to be undertaken.

Present Status of Irrigation

Surface Water

Twelve major river systems drain the subcontinent along with a number of smaller rivers and streams. Of these twelve, the Ganges - Brahmaputra and the Indus systems are the most important in terms of water provision and their impact on Indian society. Together, these systems drain almost half of the country and carry more than 40% of the utilizable surface water from their source in the Himalayas to the ocean. Over 70% of Indian rivers drain in the Bay of Bengal, mostly as part of the Ganges-Brahmaputra system. The Arabian Sea, on the western side of the country, receives 20% of the total drainage from the Indus system as well as a number of smaller rivers down the western coast. The remaining 10% drains into interior basins and the few natural lakes scattered across the country (Encyclopedia Britannica Online 2000). The flow regime of India's rivers is strongly influenced by the monsoon climate. The advent of the monsoon rains results in an annual peak in stream flow in most rivers and streams across the subcontinent. Rivers with sources in the mountains see an additional peak in stream flow during the spring snowmelt. In many cases, water levels increase dramatically and flooding is common. During the dry season, the stream flow diminishes in most large rivers and even disappears entirely in smaller tributaries and streams. To regulate the flow in these rivers and distribute water more evenly throughout the year, a number of large dams have been built on the principal river systems. However, even these measures have been inadequate to control water availability in the country, especially during the dry season.

The gross irrigated area (GIA) of the country increased from about 23 million hectares (Mha) in the triennium ending (TE) 1952–53 to about 72 Mha in TE 1996–97, an increase of 2.62 percent per annum. During the same period the net irrigated area (NIA) had increased from 21 Mha to nearly 54 Mha, an increase of 2.16 percent per annum. By 1999-2000 NIA increased to 57 Mha (IASRI, 2004). This is elaborated below in terms of category of irrigation.

Canal irrigation: In absolute terms, the net canal-irrigated area increased from about 8.61 Mha in TE 1952–53 to about 17.25 Mha in TE 1996–97 and to 17.55 Mha by year 1999-2000. This increase was not commensurate with the magnitude of the investments on the 'major and medium' irrigation sector in the Plans. The rate of growth of the area under canal irrigation tended to decelerate after the Sixth Plan despite increased investments mainly because of three reasons. First, the relatively easier potential had already been utilized, and further development was more difficult, with the result that there was inevitably a decline in the rate of growth of the area under irrigation. Secondly, the investment costs of the irrigation projects that were taken up from the Seventh Plan onwards were much higher, and a given order of investment could create only a lower order of irrigation potential than was possible in earlier Plan periods. Thirdly, budgetary allocations could not be made in adequate measure for the large number of major and medium irrigation (MMI) projects taken up, and this inevitably resulted in the slower completion of projects and therefore the slower creation of irrigation potential. There is every possibility that the growth of canal-irrigated area may decelerate further in future for these reasons. Further, while the area under canal irrigation did increase in absolute terms in almost all the States, the share of canal-irrigated area in the net irrigated area either declined or did not increase very much between the early sixties and late nineties, because of the significant role played by groundwater irrigation during the last 40 years.

Tank Irrigation: Tank irrigation has gradually declined over the last 50 years both in absolute terms and also in relation to NIA. Among the three major sources of irrigation, the tank is the only source where this phenomenon is observed. Tank-irrigated area started declining continuously from the 1960s, though some improvements have been noticed during the nineties. Interestingly, this reduction in area under tank irrigation happened despite the construction of thousands of new tanks during this period (Vaidyanathan, 1994 and 2001). Tanks are mostly concentrated in areas where other sources of irrigation are limited or absent. The worst affected group because of the continuous decline of tank irrigation is that of poor farmers (small and marginal) for whom an alternative source of irrigation is costly or not available. Ten Studies (Janakarajan, 1993; Narayanamoorthy, 1993; Palanisami et al. 1996; Sivasubramaniyan, 1997; Dhawan, 2000; Palanisami and Easter, 2000; Vaidyanathan, 2001; Raju et al., 2001) have identified many reasons for the decline of tank irrigation:

a) Encroachments in the tank foreshore and along the feeder channels have reduced the supply of water to the tanks;

b) the accumulation of silt in the tank basin/bed has reduced the waterholding capacity of the tanks;

c) the construction of dams/reservoirs in the upper watershed or catchment area has prevented the water supplies from reaching downstream tanks;

d) the rapid development of groundwater irrigation in the tank command areas has reduced the participation of farmers in tank-related works, which ultimately reduced the area under irrigation;

e) the poor design of new tanks has resulted in low levels of performance;

f) there has been a breakdown in village institutions because of caste and other conflicts, while community participation which was part and parcel of tank irrigation development has declined drastically; and finally (but importantly)

g) there has been inadequate attention on the part of the government.

The reliability of official data showing a decline in area irrigated by tanks has been questioned on the basis of field studies of a large number of tanks in Tamil Nadu – in most of the tanks surveyed, the effective command area is more or less the same or even increased in some cases, compared to the figures recorded in the tank memoirs.

The effect of spread of well irrigation is to weaken the collective activity in maintenance and regulation of tank water distribution; not necessarily to a reduction in area irrigated directly or indirectly by tank water, there is a strong presumption that the decline reflects misclassification of areas getting well irrigation in the tank commands as well irrigated area. There is no mention of demographic pressure leading to increase in number of ayacutdars or of the shift in focus of land control and changes in the configurations of local power structure. The literature on the tank irrigation points to a far more complex and nuanced picture than suggested by the author.

Several research studies have indicated reduced focus of government agencies to rejuvenate tank systems (Vaidyanathan, 1994 and 2001; Sivasubramaniam, 1995; Palanisami, 1990; Palanisami and Easter, 2000, Raju, et al, 2001). Considering its cost and other advantages, adequate attention needs to be given to the improvement of the performance of tanks. A few southern states – Andhra Pradesh, Karnataka and Tamil Nadu have indicated new projects to revive tank systems on community-based management. Other factors that have been identified (Raju et al, 2003) include: (a) the abolition of *zamindari* and the tanking over the rights of ownership of *zamindari* or other private tanks by the government, (b) the involvement of multiple governmental agencies and a lack of coordination among them, (c) political interference compounded by poor technical capabilities in the location and construction of new tanks and their size, (d) which hampered the water regulation and capacity of centuries-old upstream/downstream tanks in recent decades, (e) a widening conflict of interests between tank-bed cultivators (including unauthorized ones) and command farmers, (f) especially in the absence of institutional mechanisms to safeguard the interests of the resource, (g) increased control by the government agencies without accountability, (h) the absence of accountability to, or control by local communities, and (i) the lack of governmental policy and programme support for traditional water management institutions.

Groundwater

Groundwater representss one of the most important water sources in India and accounts for over 400 km^3 of the annual utilizable resource in the country. Due to the highly variable nature of the climate, groundwater has become a popular alternative for irrigation and domestic water use across India. Reliance on groundwater resources is particularly strong where dry season surface water levels are low or where wet season flows are too disruptive to be easily tapped. In addition to being accessible, groundwater quality is generally excellent in most areas and presents a relatively safe source of drinking water for Indians in rural and urban centres. The presence and availability of groundwater varies greatly with changes in topography, subsurface geology and the prevailing climate in the region. In some areas, groundwater exists in deep aquifers while in others the water is stored near the surface. The location of the aquifer also affects its recharge rate and its susceptibility to pollution and overuse. In general, the mountainous and hilly regions in the north and west do not allow adequate infiltration and as a consequence, groundwater is mostly limited to valleys and other lower lying areas. In the peninsular part of the country, the underlying geology limits the formation of large continuous aquifers. Groundwater is therefore scattered where fissures permit adequate storage or is found in shallow depressions near the surface. As a result, the overall yield potential in this region is low although some areas may see medium to high potential depending on the local hydrogeology. Coastal regions are usually rich in groundwater owing to the largely alluvial terrain, but the aquifers risk being easily contaminated by saltwater ingress due to over pumping. The alluvial tract of the Gangetic plain, which extends over 2000 km across central and northern India, has the best potential for groundwater extraction in the country. This large area possesses many favourable characteristics for groundwater storage and recharge, and the yield over most of the region has been estimated at moderate to high. The importance of groundwater in the national life is evident: around 59% of irrigated agriculture, and 85% of rural drinking water comes from groundwater. Even after all the major and medium irrigation projects (under construction or contemplated) are implemented, a substantial part of irrigation (not far below 50%) will still depend on groundwater.

One of the biggest developments that have taken place in Indian irrigation after Independence is groundwater irrigation. This source is predominantly owned and managed by farmers (Shah, 1993). Groundwater-irrigated area has increased to 34 Mha in 1999-2000. It was about 29.81 Mha in TE 1996–97 from 6.39 Mha in TE 1952–53, its share in NIA increased 59 percent by 1999-2000. Unlike tank and canal irrigation, the area under groundwater irrigation grew at a rate of 3 to 5 percent during different sub-periods from the 1960s onwards. The main factor in the growth of groundwater irrigation is tube-well irrigation, which grew at an impressive rate of 9.90 percent per annum during the period 1960–61 to 1996–97. The area under tube-well irrigation, which accounted for less than one percent of NIA up to 1960, increased to about 37 percent by 1999-2000. The development of the rural electrification programme and the availability of credit at highly subsidized rates have helped the farmers to increase the area under groundwater irrigation significantly (Shah, 1993; Vaidyanathan, 1994). The rapid development of groundwater irrigation not only helped the well-owning farmers but also the non-well-owning farmers through water markets (Narayanamoorthy, 1994; Saleth, 1996; Shah, 1993; Shah and Raju, 1987). However, there are problems associated with tubewell/borewell irrigation and with water markets, which will be referred to later.

Irrigation by Other Sources: Over the last 40 years, changes have also taken place in areas under other sources of irrigation. While the share of this category in the total net irrigated area declined consistently in the majority of the States between TE 1962–63 and TE 1996–97, the absolute area has increased moderately in many States during this period. During TE 1962–63 and TE 1996–97, Madhya Pradesh registered the highest growth rate of over 9 percent per annum, where its share of NIA also increased impressively from 6.31 percent to 12.95 percent during this period. At all India level, other sources contributed five percent of the net irrigated area during 1999-2000.

Regional Variations: The development of irrigation is not the same across different States and sources of irrigation from TE 1962–63 to TE 1996–97. Between TE 1962–63 and TE 1996–97, the highest growth in the area under irrigation, (from canals or from other sources) registered in the western region as compared to the other three regions (Extracted from Raju, 2005). This was because of the higher irrigation potential and the higher level of investments on irrigation development made by the States forming part of the western region. The growth rate of irrigation (both NIA and GIA) is found to be very low in the southern region as compared to other regions during the period mentioned above. There are two reasons for this: first, most of the surface irrigation potential had been harnessed before Independence by the southern region and therefore further growth was bound to be low; secondly, tank irrigation, which is an important source in the southern region, declined at a rate of 1.31 percent per annum between the sixties and late nineties, which affected the growth of both NIA and GIA.

Agro-Climatic Zones: From an agro-climatic perspective, India is divided into 15 zones. Water-resource availability and the circumstances of water-utilization vary considerably in the different agro-climatic zones. The area of irrigated land varies from 64% of the net sown area in the Trans-Gangetic Plain zone (States of Punjab and Haryana) to 6.3% in the Western Dry Region. Broadly, the level of irrigation (and consequently the use of water) is high in the Gangetic Plain region and in the Eastern Coastal Plain zone. A related point is the unquestioning reliance on canal/groundwater-based irrigation for all areas and regions and the tendency to assume that in the absence of this no 'development' is possible. Many areas in the country practice types of irrigation (usually classified in statistical tables under the category 'Other Sources') that are suited to the local terrain conditions. It would be myopic to dismiss these systems as anachronistic. They have their place. Modern knowledge and technology can be utilized for improving and modifying the traditional systems so as to make them more relevant to present conditions (Sengupta, 1985). Institutional means of reviving those systems by synthesizing traditional technology with modern knowledge could rejuvenate the development of irrigation in these areas.

Finally, there are regions with modest or limited irrigation development. These are classified as 'rainfed' areas. Rainfed agriculture is usually associated with images of deprivation and underdevelopment. However, recent research conducted on the divide between irrigated and rainfed agriculture has provided some unexpected results. Fan and Hazell (2000) have conducted an analysis on the productivity of irrigated and rainfed districts in the country from 1970 to 1995. They utilized Indian Council of Agricultural Research classification of 20 agro-ecological zones for their analysis. They categorized the districts (the ultimate unit in this method) into irrigated and rainfed areas with reference to the level of irrigation in the districts. Districts with irrigation levels greater than 25% were denoted as irrigated and those with levels less than 25% were rainfed (Fan and Hazell, 2000). Districts with poor irrigation development (hence 'rainfed' according to this nomenclature) were further defined as having poor or high potential depending on whether the zones within which these districts lie, have poor or rich soils, low or high rainfall and short or long growing seasons. Their analysis by considering a number of factors such as public and private irrigation, high-yielding varieties of crops, fertilizer application, literacy rates as well as rural markets, reach the conclusion that investment in rainfed areas including many low-productivity regions is at least as productive as in irrigated areas, and also has a much larger positive impact on poverty (Fan, Hazell and Thorat, 2000).

Irrigation: its multifarious uses for irrigation, problems and deficiencies:

Canal Irrigation

The huge and growing public investments (about Rs. 1,556,250 millions, from 1950-51 to 1999-2000) over the last five decades do not reflect in the expansion of area under public irrigation systems. Major and medium irrigation received about 2/3rds of the total sectoral investments. While the area under public canals more than doubled its share in the overall irrigation has declined from 34 per cent to 31 per cent **(Table 5).** Area under tank (another public source) has declined both in absolute and relative terms. On the other hand, area under well irrigation, which is a private source, has record five-fold increase over the years. Presently, well irrigation is the single largest source of irrigation accounting for 34 million hectares and 59 per cent of the share in the total irrigated area. These imbalances in water resource development are resulting in resource degradation (Reddy, 2004). This is mainly due to the imbalance in the distribution of and access to water resources across regions. With the surface systems canal irrigation has been the most favoured sector to the neglect of minor systems such as tanks. Interestingly, most of the tanks are located in the fragile resource regions, where groundwater is the major source of irrigation. The inter linkages or complimentarily between these two sources coupled with the policy neglect have resulted in ecological problems, equity and sustainability of water resources.

Table 5 : Changes in Net Irrigate Area under Different Sources, All India from 1950/51 to 1999/2000 (in Million ha.)

Year	Canals			Tanks	Groundwater	Other Sources Irrigate	Total Net Area	Gross Irrigated Area
	Govt.	Private	Total					
1950-51	7.2 (34.4)	1.1 (5.3)	8.3 (39.7)	3.6 (17.2)	6.0 (28.7)	3.0 (14.4)	20.9 [17.6]	22.6 [17.2]
1955-56	8.0 (34.9)	1.4 (6.1)	9.4 (41.8)	4.4 (19.2)	6.7 (29.3)	2.2 (9.6)	22.9 [17.7]	25.6 [17.4]
1960-61	9.3 (37.6)	1.2 (4.9)	10.5 (42.4)	4.6 (18.5)	7.3 (29.5)	2.4 (9.6)	24.7 [18.6]	28.0 [18.3]
1965-66	9.9 (37.6)	1.1 (4.2)	11.0 (41.4)	4.3 (16.1)	8.7 (33.1)	2.5 (9.1)	26.3 [19.3]	30.1 [19.9]
1970-71	12.0 (38.6)	0.9 (2.9)	12.9 (41.4)	4.1 (13.2)	11.9 (38.2)	2.3 (7.3)	31.1 [22.1]	38.2 [23.0]
1975-76	13.0 (37.7)	0.9 (2.6)	13.9 (40.3)	4.0 (11.3)	14.4 (41.4)	2.4 (7.0)	34.5 [24.3]	43.2 [25.3]
1980-81	14.5 (37.4)	0.8 (2.1)	15.3 (39.4)	3.2 (8.3)	17.7 (45.6)	2.6 (6.7)	38.8 [27.7]	49.6 [28.6]
1985-86	15.1 (35.5)	0.5 (1.2)	15.6 (37.0)	3.0 (7.4)	20.8 (49.0)	2.7 (6.7)	42.5 [30.2]	54.0 [30.4]
1990-91	16.9 (35.2)	0.5 (1.0)	17.4 (36.3)	3.0 (6.3)	24.7 (51.4)	2.9 (6.0)	48.0 [33.6]	62.2 [33.5]
1995-96	16.6 (31.1)	0.6 (1.1)	17.2 (32.2)	3.1 (5.7)	29.7 (55.6)	3.5 (6.5)	53.4 [37.6]	71.3 [38.1]
1999-2000	17.6 (30.8)	0.5 (0.9)	18.1 (31.6)	2.7 (4.7)	33.6 (58.7)	2.9 (5.0)	57.2 [40.5]	76.3 [40.2]

Note: figures in '()' are relative shares to net area irrigated. Figures in '[ ]' are respective percentage to the net and gross sown areas.

Source: Statistical Abstracts of India, CSO (various years).

(i) Canal-irrigation efficiency in India (around 35 to 40%) is very low. But "efficiency" of water use has to be assessed in at least three ways: (a) "Irrigation" efficiency, (b) "Productive" efficiency, and (c) "Economic" efficiency (for details see Vaidyanathan and Subramaniyan, 2004). It is true that what is lost from canals through seepage is partly recovered as groundwater recharge and as `return flows' further down, but that is not a reason for inefficient conveyance. (In any case, it is the actual application of water on the ground in irrigation that contributes more to recharge and return flows than seepage from canals. This depends on the size of the command and the distances over which water has to be transported and whether or not the distribution network is lined? That again is not a justification for the excessive use of water in irrigation).

(ii) Injudicious canal-irrigation without regard to soil conditions, over-application of water, failure to take the groundwater table into account, and inadequate attention to drainage, have led to the emergence of conditions of water-logging and salinity in many areas, resulting in valuable agricultural land going out of use. The reclamation of such lost lands is not always possible, and where feasible, it often requires large investments. A 1991 Report of a Working Group of the Ministry of Water Resources estimated the extent of waterlogged land in the country at 2.46 Mha and that of salt-affected land at 3.30 Mha.

On an average, the yields of irrigated agriculture in India have been relatively low in comparison with what has been achieved in other countries, or even in some parts of this country; and there has been inadequate attention to increasing productivity in rainfed areas. Even the NCIWRDP's projections for the future seem fairly modest as shown in **Table 6.**

Table 6 : NCIWRDP's projections of yields (tonnes per ha)

Average Yield (projected)	**Year 2010**	**Year 2050**
Irrigated food crops	3	4
Unirrigated	1.1	1.5

Higher yields, which ought to be achievable, will mean a reduction in the demand for water.

(iii) The source of canal irrigation is generally a major project, and the cost of creating irrigation potential through such projects has been steadily increasing: from Rs. 12000/ha in the first Plan (1951-56) to Rs. 66570/ha in 1990-92 in current prices; and from Rs. 8620/ha to Rs. 29587/ha in constant 1980-81 prices. The figures today must be much higher. (Rough figures of Rs. 80000/ha to 100000/ha (in current prices) have been mentioned).

(iv) Further, there is a persistent gap between the irrigation potential created at such cost and the extent of its utilization **(Table 7).** This problem, which was earlier presumed to occur only in the case of major and medium projects, was later found to be present in the context of minor irrigation also.

Table 7 : Gap between irrigation potential created and utilized (end of 1995-96) (in Mha)

Category	Ultimate	Created	Utilized	Gap	Actually irrigated (land-use statistics)
Major/medium	58.46	32.20	27.45	4.75	
Minor(surface)	17.38	12.10	10.72	1.38	
Minor(groundwater)	64.05	44.42	40.83	3.59	
Total	139.89	88.72	79.00	9.72	70.64

The Command Area Development Programme which was formulated as the answer to this problem is considered in the ensuing section on reforms.

(v) Resource constraints, an unsound Plan/Non-Plan distinction, and an in-built preference for new construction over the efficient running of what has been built, have together resulted in the under-provisioning and neglect of maintenance. Systems built at great cost fall into disrepair, and there is a failure to provide the planned service. Canal irrigation is thus dependent on an inefficient and unreliable supply. Signs of improper operations and inadequate upkeep of systems are plentiful. Canals are silted up or eroded, and breach. Water is unevenly distributed between head and tail of distributaries, minors, and even field channels, with tail-enders often receiving no water, while areas adjacent to the canals are becoming waterlogged. Where water is supplied, timings are often unreliable. The contrast between public surface systems, over which farmers have little control, and private groundwater systems that provide water virtually on demand, makes the situation more acute. Although farmers spend considerable amounts to invest in private wells and pump groundwater, they have not been willing to pay as much for the less adequate service from surface systems. Those who do not receive irrigation “opt out” of paying, driving cost recovery lower still, thus feeding into a vicious circle of poor maintenance and growing financial crisis in Indian canal irrigation.

While parts of this analysis are certainly accurate, it is not complete or fully accurate. First, it assumes a structural relationship between fees and operation and maintenance funding that does not, in fact, exist. It is only in the context of fiscal deficits and declining indirect revenue from irrigation that low irrigation charges have become a serious factor in under funding operation and maintenance. Moreover, it is not clear that more funding would necessarily improve performance because of the incentive structure within irrigation agencies. Indeed, most analyses have neglected the role of farmers' political opposition to irrigation fees (which stems, in part, from dissatisfaction with service as well as from populist appeals by politicians).

(vi) Canal irrigation in India has been marked by a number of inequities. As waters begin to rise in the reservoir, and canal systems for taking them to the tail-end are not yet ready, the head-reach farmers have plenty of water available and tend to plant water-intensive crops. This establishes a pattern of water-use that cannot easily be changed at a later stage. It is also a matter of unwillingness and inability of managements. by the time the full canal system is ready, much of the water stands pre-empted in the head-reach areas and there is little left for conveyance to the tail-end. This is a familiar problem in most project commands.

(vii) Irrigation water from canals is supplied to farmers at very low prices in most States. This leads to the wasteful use of water and is not conducive to the promotion of resource-conservation. Even at the prevailing low rates, the collection of irrigation charges is poor in most States. The result is that the revenues accruing to the government from the provision of irrigation do not even cover the operation and maintenance costs of the systems, and there is no contribution towards capital-related charges, much less any generation of resources for further investments. This subject is dealt with further in the section on reforms.

(viii) Finally, most of the inter-State river water disputes arise in the context of canal irrigation (existing or desired) from major projects. Examples, among others, are the Ravi-Beas, Telugu Ganga, Alamatti and Cauvery disputes.

Sharing of interstate waters was handled reasonably smoothly in the initial phases but have become more acute and contentious in more recent times reflecting the growing demand for water and limited scope for expansion of supplies. Unfortunately, that such disputes are rampant even within states and that there are hardly any institutions or due process to resolve them on the basis of clear principles).

Groundwater Iirrigation

(i) There has been over-extraction (mining) of groundwater leading to depletion in some areas, and salinity ingress in coastal zones (e.g., in Gujarat). On the other hand, there is a situation of rising water tables and the emergence of water-logging and salinity in other areas (e.g., in the Sharda Sahayak command in Uttar Pradesh).

(ii) Water markets tend to emerge in the context of groundwater extraction through tubewells and borewells, and they serve some useful purposes, but there are dangers of unsustainable extraction as also of inequitable relationships between sellers and buyers. Water markets are not limited to tubewells and borewells; that apart, their extent is relatively limited except perhaps in the deep alluvial aquifers of the Gangetic plain and north Gujarat. Free or highly subsidized pricing of energy has become major reason for groundwater over-extraction.

(iii) The answer to both (i) and (ii) above may be claimed to lie in regulation, but this has so far not been found feasible because of political factors and the legal problem of easement rights. Under the directions of the Supreme Court, the Central Groundwater Authority has been established, but it is not yet clear how it will evolve and operate, what kind of regulation it will attempt, and with what success.

Since mid sixties, through encouragement through institutional finance and rural electrification the number of groundwater resources and its exploitation has increased tremendously **(Table 8).** In India, while 76 percent of the operational holdings are small and marginal farms of less than 2 ha. They operate only 29 percent of the area. They constitute 38 percent of net irrigated area by well and account for 35 percent of the tube wells fitted with electric pump sets (World Bank, 1998, p. 4). Thus, in relation to operational area, small and marginal farmers are well represented in groundwater irrigation in greater proportion than their representation in landholdings.

Table 8 : Changes in Groundwater sources during 1951-1997 (Numbers in Millions)

Source	**1951**	**1997**	**% Change**
Dug wells	3.86	11.28	192
Shallow tube wells	0.3	6.52	2073
Public tube wells	0.24	1.68	600
No. of Electric Pump sets	0.21	11.36	5309
Diesel Pump sets	0.66	4.99	656

Source: GOI, 1999: p.506.

Another reason for acceleration of groundwater resources is that the productivity of canal irrigated areas is not the same as productivity of groundwater irrigated areas.

Water Harvesting Systems

The unequal distribution of water resources over time and geographic area have necessitated the development of water harvesting systems. These structures are designed to help capture and store rainwater during the monsoon season and serve as a source of drinking and irrigation water during the rest of the year. In India, tanks, ponds and reservoirs cover a total of 5 million hectares, the majority of which lies in the southern portion of the country (MOWR, 2001). Although they do not make a significant contribution to the total freshwater water resource in India, water harvesting systems do have a strong impact in terms of drinking water and irrigation provision on a local scale.

Many of the water harvesting structures used in India are based on ancient models and are therefore highly adapted to the prevailing climatic and hydrologic conditions of the area. The potential of these systems to supply adequate freshwater to all areas and sectors is high. However, since colonial times, these systems have been increasingly abandoned and neglected in favour of large dam and canal irrigation projects. So far, these 'modern' structures have been successful in providing water to portions of rural and urban India, yet high economic, social and environmental costs have reduced their overall benefit. As a result, development and civil society organisations have been advocating the return to local water harvesting systems for domestic and irrigation purposes. As awareness and public opinion continue to grow, water harvesting systems will become increasingly more important source of water in India.

Participatory Irrigation Management

If the 'utilization gap' problem led to the CAD Programme, the failure of the major and medium projects to provide satisfactory irrigation service to the farmers led to the idea of PIM. The dysfunctionality of the system and a growing feeling even within the government that it could not really run these huge, far-flung irrigation networks efficiently and render proper service, combined with the dissatisfaction of the farmers, led to the idea of transferring parts of the system to the farmers themselves for management. It became fashionable to talk about "farmers' participation", though the 'participation' envisaged was limited, was being reluctantly invited under the pressure of circumstances, and at a late stage in the operation of projects earlier planned and executed by the state in an essentially non-participatory manner. (Underlying this line of thinking in recent years has also been the ideological consideration on the part of some, particularly the international financial institutions, of reducing the role of the state.) Be that as it may, the entrustment of the management of the system below a certain level to the users themselves was a necessary and desirable proposition in the given circumstances, and PIM has become an important measure of reform in the major / medium irrigation sector.

There were early anticipations of what is now called 'PIM'. Passing over earlier history we may note that the National Water Policy 1987 stressed the involvement of farmers in various aspects of the management of the irrigation system, particularly in water distribution and the collection of water rates. The Committee on the Pricing of Irrigation Water (Government of India, 1992) recommended not merely the revision and rationalization of water rates but also improvements in the service as a necessary accompaniment, and for bringing this about, it strongly advocated farmers' participation in the management of irrigation systems. The Eighth Plan, recommending "greater user participation in major and medium projects both at system level and the local level", observed: "Local initiatives by users or non-government organizations to set up users' organizations to manage water below government outlets will be actively supported by the Government." The Working Group on PIM for the Ninth Five-Year Plan identified legal, institutional, and financial aspects as being crucial to the effective implementation of PIM programmes. It concluded that the efforts made so far had been tentative, and that in the absence of clear legal provisions Water Users' Associations (WUAs) remained weak. It suggested that legislative backing for PIM should be provided as early as possible. By the beginning of 2002, several States - Andhra Pradesh (which played a pioneering role in this regard), Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, and Rajasthan – had enacted laws to promote PIM and the formation of WUAs. Turnover 'below a certain level' will not accomplish much unless the users representatives were on decision making and monitoring bodies at all levels right upto the system level with power to decide, through mutual consent, matters relating to allocations and delivery schedules. This was the thrust of the recommendations of the pricing committee (1992). And a view voiced in several other writings.

Turning to actual implementation, fourteen States have pilot or full-scale PIM programmes: Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, and West Bengal (Navalawala 1995; Raju and Brewer 1996; INCID 1996a). These ranges from minimal changes proposed in Haryana to more ambitious programmes in Maharashtra and Gujarat. The proposed WUA functions include O & M functions in seven States, dispute-settlement in only one State and the collection of water charges in seven States. Perhaps the most dramatic changes are proposed in Bihar, where farmers are to assume maintenance responsibility for distributary commands of up to 10,000 ha, and can retain 70 percent of the irrigation charges. Here again, severe fiscal crises which precipitated a clear breakdown of the Government's ability to deliver irrigation service has been responsible for the most sweeping changes (Brewer *et al.* 1997). Several NGOs, over the years have demonstrated successfully, on how to build up water users associations linking them with critical functions, in different parts of the country. Some of them are, SOPPECOM in Maharashtra, DSC in Gujarat, IRDAS in Andhra Pradesh.

Andhra Pradesh is the first and leading state in India to bring about overall institutional reforms in the irrigation sector at the state level (Peter, 2000; Raju, 2000). The main components of the reform process are: (a) introduction of a suitable policy and legal framework; (b) formation of Water Users' Associations across all types of irrigation systems in the state; (c) implementation of large-scale training on the issues related with the irrigation reform programmes both for farmers and the staff of the irrigation department; (d) bringing in significant financial reforms to influence quality performance of Users' Associations. Despite the range of policies, cases can be classified according to two critical dimensions: level of water users' organizations and changes in the collection of irrigation charges. The first is important because some form of farmers' organization is necessary if users are to take over O&M activities, thereby contributing to the objectives of improving efficiency of management and/or reducing government costs. The second is aimed at reducing financial deficits, either by increasing the collection of charges or reducing state expenditure on collecting water charges. The level of organization indicates the level at which users are expected to take on an active role. Haryana proposes to have water users' organizations only below the outlet (as is currently found in most States). A number of States (Andhra Pradesh, Madhya Pradesh, Karnataka, Rajasthan, Bihar, Gujarat, and Maharashtra) propose transferring O&M responsibilities to WUAs at distributary or minor level. This approach implies a somewhat greater degree of change, as it generally requires the formation of new organizations to co-ordinate between outlet-level groups, and a greater level of responsibility for farmers in O&M. This could reduce marginally the fiscal deficits of the States if the State agency withdraws from O&M at the distributary level, and it can improve performance if farmers do the work more effectively than the government agency had done. However, in many cases the Government does not fully withdraw, so any 'farmer involvement' often becomes a supplement to the agency. The transfer of O&M responsibilities to a three-tiered structure of WUAs and joint management committees (JMC) with the Government is proposed in Tamil Nadu, Andhra Pradesh and Kerala.

Water, Employment and Poverty

Water is an important input for enhancing agricultural growth. It is found that water abundant region has higher level of crop production. Increasing agricultural productivity creates more opportunities for employment and poverty reduction. More irrigation means fewer people below the poverty line (Shah and Singh, 2003). Irrigation as an input for agricultural production if available at lower cost helps increasing income to the farmers. This also strongly works for generation of employment. More water creates more employment. The annual average employment growth for 2000–2007 was higher for Asian women than for Asian men, and the employment-to-population ratio for Asian women was also higher than the world average for women. Asian women have certainly been an engine of the region's economic dynamism. But 45 per cent of working-age Asian women were inactive compared to 19 per cent of men, and differentials persist in the types of jobs women and men have access to, the level and regularity of their earnings, the opportunities for mobilizing and organizing, and the ways in which women's and men's productive and reproductive roles are coordinated and protected through policies. In developing Asian countries, women still make up the "buffer workforce" – both within labour markets as flexible and expendable workers concentrated in informal employment and within households as “secondary earners” or “added workers”. However, women themselves had few buffers against economic crises and the range and effectiveness of their buffers were inadequate.

Recent data on growth of output confirm that developing Asia is leading the world in a strong recovery from the global economic crisis. Other key macroeconomic indicators: private consumption, gross fixed investment and trade had also recovered by 2010, in some cases surpassing pre-crisis levels. But the recovery in economic growth has not been matched by labour market recovery, and the employment outlook is uncertain (ILO 2011). In some developing countries particularly in East Asia, job growth is back but the quality of jobs is a major concern. Overall, in developed and developing countries in Asia, unemployment rates remain elevated; high youth unemployment together with a growing number of discouraged youth poses a serious challenge. Progress in reducing vulnerable employment has stagnated, and progress in reducing working poverty has slowed. Moreover, gender-based inequities in the labour market persist, in part due to the expansion and feminization of informal employment. The poor labour market recovery exacerbates the tremendous human costs of the crisis and threatens sustained economic recovery and future socio-economic development. Although, some of the regions/countries which are water abundant simultaneously have more poverty and unemployment. Bangladesh and India have the same unemployment trends **(Table 9).** Some of the study done in Punjab says that poverty reduction and employment increase is due to perennial sources of irrigation.

Table 9 : Percentage Distribution of Unemployment Rate in SAARC

Sl.No	Name of the Countries	Percentage (%)	Year
1	Afghanistan	100	2008
2	Bangladesh	5	2009
3	Bhutan	4	2009
4	India	9.4	2010
5	Maldives	NA	NA
6	Nepal	46	2008
7	Pakistan	4	2009
8	Srilanka	5.9	2009

In 2005, India has launched a massive programme of employment generation by act called National Rural Employment Act (NREGA). The programme stands as strong support to alleviate rural poverty in the country. There were many leakages reported. However, it was found that the progarmme is more effective where the irrigation potential is strong. In the box below, one can see its effectiveness.

Box 1

India's National Rural Employment Guarantee and gender equality

The National Rural Employment Guarantee Programme (NREGP), renamed in October 2009 as Mahatma Gandhi National Rural Employment guarantee (MGNREGP) makes 100 days of work per household a legal entitlement in rural areas and stipulates the reservation of at least one third of jobs for women, equal wages for work of equal value and the provision of a crèche when there are more than five women on a programme. A recent study found that (a) women's participation ;in the NREGA has been increasing; (b) state-wise women's participation in the programme is positively correlated with women's participation in rural areas, though women's participation in NREGAis often higher than women's participation in other forms of recorded work so far; and (c) women's participation is negatively correlated with the existing gender wage gap in unskilled agricultural labour. The latter implies that where women's actual wages as a share of men's is lower in the private sector, women are flocking to work in this government administered programme. This will inevitably raise women's bargaining power, and is potentially a critical factor in reducing gender disparities in the labour market. The question of course is to what extent the implementation of the programme will adhere to the Guidelines and to what extent other considerations would influence the actual roll out of the programme in different State Governments. The paper also finds that the achievements or outcomes of the NREGA as far as women are concerned are – as with any other Government programme – mediated by the intervening institutions including both the gendered nature of the labour market and the efficacy or otherwise of the local Government.

Source: Dasgupta an sudarshan 2011 (forthcoming)

Key Challenges in the water sector

- There is a need to concentrate on the availability or quality of drinking water is often jeopardized by overuse of pollution in other sectors.
- The demands for municipal and industrial needs are on the increase, only option is to save water for agricultural use. Hence, efficient use of water in agriculture is therefore a top priority.
- Equally important, the harvesting and efficient use of rainfall is necessary.
- Rapid contamination of water -Proactive measures are therefore a priority to control or contain such pollution threats.
- Water actions are therefore urgently required in many critical areas -that encourage wasteful water use (with special attention to rice, which is a high-water-requirement crop);

- protecting drinking water sources

The sustainable development of water resources in the country will depend on four key activities, (water conservation mission in Andhra Pradesh):

a) Securing drinking water demands in terms of quantity and quality,

b) Development of water planning, river basin management and prioritizing for sustainable water extraction,

c) Water resources development with respect to other state priorities in Vision –2020 of the India and of respective states,

d) The development of an efficient and well-managed water sector.

This approach to sustainable development requires a significant change in governance, involving policy development, organizational reform, use of economic measures, strengthening of legal frameworks and development of monitoring and regulation procedures. This approach needs to be supplemented with research and development, and capacity building (both community and government) through education and training.

Integrated Water Resources Management (IWRM) is the preferred approach to water management. But IWRM requires a range of inputs like:

a) State-level policy decisions,

b) Initiatives at the district level,

c) Legal and institutional frameworks,

d) Capacity building, research and development,

e) Engaging wider society.

Central to IWRM is the coordinated development and management of water, land and related resources to maximize social development and economic growth while safeguarding important ecological values. The preferred approach for using IWRM includes:

- Managing all available water and determining sustainable limits of use.
- Using stakeholder participation at all levels of decision-making.
- Reorienting government services to deliver coordinated action at district and village levels.
- Moving water to its most efficient use.
- Developing water policy and a state IWRM plan.
- Facilitating resources for research and development.
- Improving water information in order to achieve effective water management.

As part of the action plan strategy requires to design:

a) Short-term recommendations

a. constituting water conservation missions at state level
b. developing a state-level action plan for the next one/two years
c. initiating several district level pilot projects
d. initiating river basin level pilot projects
e. establishing a monitoring and learning procedures to assess the implementation of water vision.

b) Long-term recommendations

a. Develop
i. State water policy
ii. Integrated water resources management plan
iii. River basin management plan
b. District action plans
c. Water research programme

Institutional strengthening

For the Institutional strengthening -Vaidyanathan and Oudshoorn (2004) suggest the following:

a) The existing legal framework, and its underlying concepts needs to be clear.
b) The elements of a framework of laws and institutions to facilitate and promote negotiated settlement among claimants for water;
c) the structure and functioning of existing irrigation and water management institutions in selected systems, the perceptions of concerned interests (different user groups, managers, those adversely affected) regarding defects and their attitudes to alternative ways of organization needs to be studied.
d) A critical assessment of the experiments with user participation and their lessons.
e) Collate and evaluate experiences of participatory, integrated management in other countries and their lessons for design of better institutional arrangements in India.

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Water Harvesting Programme: Need for Holistic Approach with attention to Socio-Economic and environmental dimensions

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If the objectives of any water conservation project or a natural resource conservation project have to be in the true sense achieved successfully, it is imperative that the socio-economic and environmental aspects of the project are given equal importance along with the implementation of new technology and scientific knowledge. This has to begin right from the conception and design stage of the project. Numerous studies as well as our experience in the past shows that if, a project is to be successful it needs to be approached holistically.

Similarly, in case of rainwater harvesting systems, it takes more than engineering and agronomy to make a project successful. Socio-economic and ecological factors with a holistic view are particularly important because when we decide to plan interventions such as rain water harvesting, the intervention is not only about water for drinking and irrigation for a particular region. The entire ecosystem in which these interventions are planned gets affected by it either directly or indirectly. As the ecosystem gets affected human beings who are very much an integral part of this ecosystem also get affected. Consequently everything that is manmade; be it the socio- economic structure such as the socio- economic institutions, the services they provide, or the interconnections among them - everything gets impacted in varied degrees and levels due to this one single act. How that happens is explained below.

"..What hasn't been addressed sufficiently in the lead up to the MDG (Millenium Development Goals) review is the fact that some of the biggest constraints to achieving these global development objectives - the impacts of climate change and other environment-related threats — continue to be routinely sidelined in development policies and practice. Until this changes, there is little hope of permanent gains in many of the areas covered by the MDGs…

…A more coherent approach also requires much greater attention and action to address the particular challenges facing women and girls and their role in advancing sustainable development." —Wangari Mathai & Mary Robinson Sep 20, 2010

What is an Ecosystem?

Below is a working definition of an ecosystem. "An ecosystem is a biological environment consisting of all the organisms living in a particular area, as well as all the nonliving, physical components of the environment with which the organisms interact, such as air, soil, water and sunlight. It is all the organisms in a given area, along with the nonliving (abiotic) factors with which they interact; a biological community and its physical environment."

Any intervention in an ecosystem will have repercussions for other constituents of the same. More often than not, it is extremely difficult to tell what those repercussions are going to be.

There are many reasons why this difficulty exists. Ecological timescales are vastly different than human timescales. A plant or animal that is introduced to aid humans may do so for decades, before it turns into a menace. So also with human alteration of a landscape, a dam may be apparently beneficial for many years, after which the damage it has been causing becomes apparent. This is one reason for this lacuna. A second reason is that the interventions up until the 20th century were largely scattered and small. This reduced size and scale diminished the opportunity for us humans to draw the connections.

To delve a bit deeper into the second reason, an ecosystem consists of Networks. Intervention in Networks cause ripples. Ripples cause disturbances. These disturbances can either get dampened or amplified over time and space. Initial conditions of the Ecosystem, and the kind of intervention influence the direction and intensity of the disturbance.

As an example, take the case of a mountain stream. The network consists of the forests of the mountains; the kind of trees, shrubs and grasses that constitute the biodiversity; the micro and macro fauna that inhabit the mountain; the soil and so on. Even when humans intervene with good intentions in such a situation for example it has invariably led to unforeseen negative impacts. For example, a dam built in such a situation alters the landscape and impacts the life of the mountain denizens. Soil erosion ensues; groundwater levels can get impacted either way depending on the area under study; tree cover gets impacted in terms of extent and biodiversity; downstream water levels in streams and rivers get impacted – in terms of the timing of release of water and the levels of flow; aquatic life gets impacted, and so on.

It is useful to recognize the components of an Ecosystem and then plan interventions. Not that such recognition will necessarily avoid the negative impacts of intervention, but, the level of awareness will be higher and the warnings will likely be perceived earlier than otherwise.

Fritjof Capra's description of Ecological Systems Concepts is a good starting point to provide a framework for better understanding of the possible impacts of any intervention. This provides an introduction to a Systems Theory Approach. By changing how we view the system, it is hoped that our interventions will be more effective. This will also reduce the chances and occurrences of collateral damage and unintended negative consequences will be minimized.

Networks

All living things in an ecosystem are interconnected through networks of relationship. They depend on this web of life to survive. For example: In a garden, a network of pollinators promotes genetic diversity; plants, in turn, provide nectar and pollen to the pollinators.

Nested Systems

Nature is made up of systems that are nested within systems. Each individual system is an integrated whole and — at the same time — part of larger systems. Changes within a system can affect the sustainability of the systems that are nested within it as well as the larger systems in which it exists. For example: Cells are nested within organs within organisms within ecosystems.

Cycles

Members of an ecological community depend on the exchange of resources in continual cycles. Cycles within an ecosystem intersect with larger regional and global cycles. For example: Water cycles through a garden and is also part of the global water cycle.

Energy Flows

Each organism needs a continual flow of energy to stay alive. The constant flow of energy from the sun to Earth sustains life and drives most ecological cycles. For example: Energy flows through a food web when a plant converts the sun's energy through photosynthesis, a mouse eats the plant, a snake eats the mouse, and a hawk eats the snake. In each transfer, some energy is lost as heat, requiring an ongoing energy flow into the system.

Keeping the above Concepts in mind, it is useful to change our perspective and method of viewing ecosystems. Planners and policymakers have until now mostly followed a 'Reductionist Approach'. This implies looking at individual components of our ecosystem and 'fixing' whatever seemed to be the problem. For example; when a water shortage arose in a city, water pipelines were laid and water was brought from many tens of miles away. Nowadays, that distance has increased to ten times that in some cases. Such solutions cannot obviously continue to serve our ever-expanding demands. We need to redesign human socio-economic-political systems and policy making, so that, our demands are realigned to be in harmony with our ecosystem. We have to utilize what our ecosystem can provide on a consistent and long-term basis, without getting compromised, and often irreversibly damaged in the process of providing for us. Such a realignment of our designing methodology calls for a different perspective. The main changes to way we currently view systems will include the following:.

From Parts to the Whole

With any system, the whole is different from the sum of the individual parts. By shifting focus from the parts to the whole, we can better grasp the connections between the different elements.

From Objects to Relationships

In systems, the relationships between individual parts may be more important than the parts. An ecosystem is not just a collection of species, but includes living things interacting with each other and their nonliving environment. In the systems view, the "objects" of study are networks of relationships. This perspective emphasizes relationship-based processes such as cooperation and consensus.

From Structure to Process

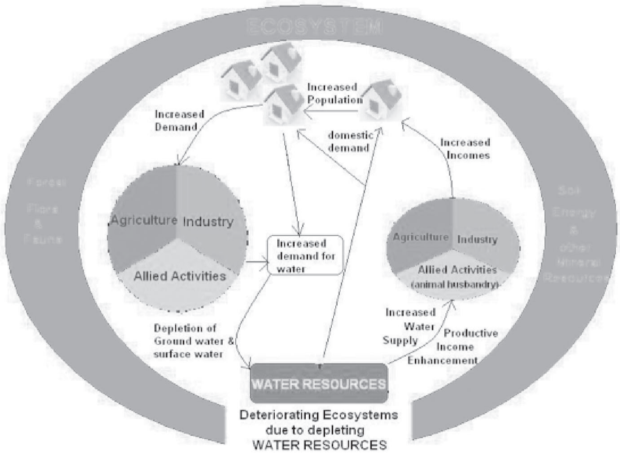
Living systems develop and evolve. Understanding these systems requires a shift in focus from structure to processes such as evolution, renewal, and change. Mapping of relationships that often cannot be quantified but are nevertheless vital needs to be given due attention. Such relationships have to be understood in their relevant context as their behavior is dynamic over space and time.

From Contents to Patterns

Within systems, certain configurations of relationship appear again and again in patterns such as cycles and feedback loops. Understanding how a pattern works in one natural or social system helps us to understand other systems that manifest the same pattern.

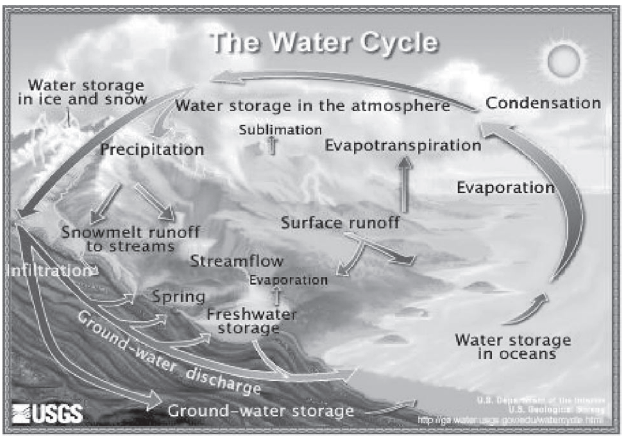
A better understanding of flows of energy and matter in an ecosystem and a holistic way of thinking rather than a compartmentalized approach will enable us to design more appropriate interventions. Any human-social system is a subset or nested cycle of an ecosystem. A Systems Thinking Approach will also provide us more wholesome information as to how any intervention is going to impact human society from an economic, social, cultural and political angle. This in turn will enable us to design more sustainable interventions that will serve us not just well, but for longer periods.

Below is a simple Diagrammatic Representation of a well intentioned intervention that can go awry over time.



Coming to the issue at hand – Rainwater Harvesting In a World of Changing Climate let us first have a quick diagrammatic look at the Hydrological Cycle.

Diagram of Hydrological Cycle



Today, Rainwater Harvesting has become an issue of high importance as water is becoming increasingly scarce. This is true in both urban and rural areas. The importance of water in both our production processes and for us humans to carry on our daily activities cannot be overemphasized. Clearly water plays a vital role in our personal lives as well as our economic, social, cultural and political life. In the past, and increasingly today, when water shortages have arisen, in different parts of the globe, conflicts have invariably ensued. At times these have even led to wars, but almost always, human lives have been lost.

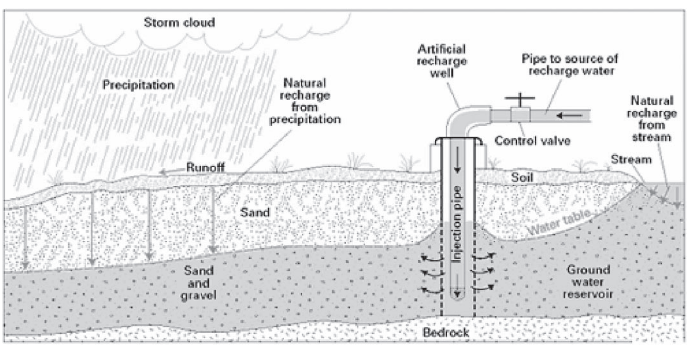
Rainwater Harvesting gives us an opportunity to more effectively tap water at the Post-Precipitation stage of the Hydrological Cycle. This is an attempt to improve upon nature's already existing tapping and storage mechanisms of rainwater. As already outlined above, we have to be cautious in our attempts at doing so, and using a Systems Approach will help us do that. What we are essentially trying to do is to reduce the runoff so that we can have localized storage of water as well as raise the level of groundwater table in the surrounding areas.

There are three broad determinants of Surface Water Runoff.

- Meteorological Factors
- Physical Characteristics
- Human Factors

Meteorological factors affecting surface (over soil) runoff	**Physical characteristics affecting surface runoff**	**Human factors affecting surface runoff**
Type of precipitation - Rainfall intensity - Rainfall amount - Rainfall duration - Distribution of rainfall over the drainage basin - Direction of storm movement - Precipitation that occurred earlier and resulting soil moisture - Meteorological conditions that affect evapotranspiration	- Land use - Vegetation - Soil type - Drainage area - Basin shape - Elevation - Topography, especially the slope of the land - Drainage network patterns - Ponds, lakes, reservoirs, sinks, etc., in the basin, from continuing downstream	Urbanization — more impervious surfaces reduce infiltration and accelerate water motion. Removal of vegetation and soil — surface grading, artificial drainage networks increases volume of runoff and shortens runoff time to streams from rainfall and snowmelt

The diagram below depicts some interventions for groundwater recharge.



In the light of Climate Change, it is today a known fact that the timing, intensity, duration and amount of rainfall is going to break from past steady patterns around which human socio-economic-cultural and political systems have evolved and been built. With weather patterns in general and rainfall in particular becoming more erratic, water availability will become more unreliable.

Rainwater Harvesting is a proactive measure that we can take to increase the reliability and certainty of water availability at a local level, without reliance on energy-dense water transport infrastructure. When implementing these measures though, we should take more than sufficient cognizance of the fallout of such changes that we make, lest we make a bad situation worse. This is where taking a holistic view via Systems Thinking Approach will help.

How systems approach with a holistic view can be translated into action while actually implementing project is illustrated through the following steps.

Stakeholders' needs and priorities analysis

In order to fulfil the objectives of the rainwater harvesting programme the first step would be to assess the water needs of the potential beneficiaries and various stakeholders in the programme affected region. If the local priority is drinking water supply, for example, the response to water harvesting systems for crop production will be poor.

Participation of various stakeholders

It is widely accepted that unless diverse stakeholders are actively involved in the development projects which are aimed to help them, the projects are doomed to failure. Hence it is important that the beneficiaries participate in every stage of the project right from the needs assessment to designing the project and it's actual implementation.

Throughout the course of the season it is helpful to involve people in monitoring, such as; rainfall and runoff measuring and recording tree mortality. A further participatory role in maintenance and contribution towards maintenance in cash and kind is also very desirable. This creates a sense of belonging/ ownership for the project amongst the various stakeholders. Hence, it is a good strategy to get the beneficiaries involved in monitoring and evaluation, and also get their suggestions and contribution towards evolution of the water harvesting systems.

Scaling Up of The Project and Customizing as Per The Needs or The Region

Widespread adoption of water harvesting techniques by the local population is the only way that significant areas of land can be treated at a reasonable cost on a sustainable basis. Although the basic planning needs to be done in consultation with hydrologists, ecologists, irrigation engineers and other technical experts, the systems proposed need to be simple enough for the people to implement and to maintain to ensure sustainability in the long run.

To encourage adoption, apart from incentives in the form of tools for example, there is a need for social mobilization through motivational campaigns, demonstrations, training and extension work. It is also important to keep in mind that over appropriation of a basin's resources can lead to negative social and environmental effects/ negative externalities to the people in another part of the river basin. Hence the project needs to be viewed holistically and it's suitability in the larger scheme of things needs to be examined right at the planning stage.

Area Differences

It is tempting to assume " One size fits All", that a system which works in one area will also work in another, superficially similar, zone. However there may be technical dissimilarities such as availability of stone or intensity of rainfall, or distinct socio-economic differences. For example a system which is best adapted to hand construction may not be attractive to people who normally till with animals. If a system depends on a crop well accepted in one area - sorghum for example - this may be a barrier to acceptance where maize is the preferred food grain.

Gender and Equity

If water harvesting is intended to improve the lot of the poorer, it is important to consider the possible effects on gender and equity. In other words, will the introduction of water harvesting be particularly advantageous to one group of people, and exclude others?

The concept of gender in development recognizes that men and women often hold different positions and have different responsibilities and decision-making authorities within the household and in the community, play different roles in society, have dissimilar control over and use of resources, and often have different views and needs. An adequate integration of a gender perspective into development programmes considers the division of labor and sharing of benefits between men and women, so as to consciously distribute work and benefits and to facilitate equal access to, and control of, resources and community decision-making processes.

Gender equality is defined in various ways, but tends to refer to five main components: rights, opportunities, value, situation and outcome, and agency. Throughout the world, there are gender-specific differences in consumption patterns, lifestyles, access to and control of resources and power, and vulnerability to climate change.

A growing body of literature discusses the connection between gender and the effects of water scarcity and environmental degradation. For example, today, drought exacerbated by climate change is contributing to chronic crop failures, deforestation and water shortages, with devastating impacts for girls and women. The primary food producers and procurers of water and fuel for cooking are women. Environmental changes are resulting in women being forced to travel farther to secure food, water and fuel for their families. This has been shown to have negative impacts on nutritional levels, educational attainment and work opportunities, to say nothing of quality of life issues overall. Hence it is very essential that specific attention is paid to the role of women at every stage in the process ensuring that their voices are heard and their needs and concerns are addressed effectively.

Land tenure and Lands under Common Property Regime

Political economy is an extremely important aspect of any developmental project. In case of water harvesting, land tenure issues can have a variety of influences on water harvesting projects. On one hand it may be that lack of tenure means that people are reluctant to invest in water harvesting structures on land which they do not formally own. Where land ownership and rights of use are complex it may be difficult to persuade the cultivator to improve land that someone else may use later. On the other hand there are examples of situations where the opposite is the case - in some areas farmers like to construct bunds because it implies a more definite right of ownership.

Some studies have shown that many a times decisions regarding construction water harvesting structures are based on political considerations and the interests of the most influential in the region and not on scientific or hydrological knowledge and data. Such situations are definitely, a recipe for disaster and hence need to be strictly avoided. 'Rain Water Harvesting' in this respect can be especially sensitive with regard to upstream down stream issues. Another difficult situation is land under common property regimes, or controlled by the community, particularly, where no well defined management tradition exists. Villagers are understandably reluctant to treat areas which are communally grazed. Such community controlled degraded land in and around villages can only be improved if land use management issues are taken up by the communities themselves. Water harvesting can be one of the opportunities for conserving and rehabilitating such degraded lands. However, it requires a lot of will on the part of the community. For example, unless grazing controls are implemented, there is little point in spending money on water harvesting structures for re-seeding in such degraded lands.

Conclusion

Finally, the experience of related to water conservation in the past has shown that there is no better substitute for participatory approach and dialogue with the diverse stakeholders and a continued close relationship throughout the project. Project needs to learn from the people of the target area continuously and be open to their ideas and suggestions, in particular about local traditional knowledge regarding water conservation. It is essential that project authorities keep in mind the importance of people's priorities and participation. It is also important that the benefits of the new initiatives are made apparent to the stakeholders as early as possible.

For new techniques there is often a need for demonstration before people understand and envisage their effectiveness. Motivation and promotion of awareness among the people with regard to the project objectives and how to achieve them are very important issues. It is sad but true that very often the people simply do not understand what a project is trying to achieve, or even what the meaning of the various structures is! Hence, demonstration through a first successful pilot project is always a good option.

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Drought Scenario in South Asia & An Overview of Integrated Water Resources Development & Management Techniques for Drought Management in South Asia

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Drought is a natural, recurring climatic feature which stems from the lack of rainfall over an extended period of time (i.e. a season or several years resulting in severe shortage of water resources). It occurs almost in all climatic regions of the world. Drought is a normal phenomenon in arid zone areas, a common phenomenon in semi- arid zone areas and a rare to very rare phenomenon in dry humid and humid areas. It is a natural disaster, which can be anticipated and also expected on the basis of rainfall pattern, temperature etc. Drought connotes a situation of water shortage for human, cattle and agriculture consumption resulting in economic losses, primarily in agriculture sector.

South Asia comprises some of the world's most drought prone regions. Majority of area in the South Asian region is under rainfed agriculture with large portions of arid and semi-arid zones, which continues to face more challenges in terms of droughts. Though the region has diversified economy with significant improvements in Agriculture and irrigation, periodic droughts have affected millions of people in rural areas of South Asia, causing much damage to the economy of the region. Although the region has rich fresh water resources, countries like Afghanistan, India, Pakistan and Sri Lanka are experiencing periodic and continuous droughts as a result of which, agriculture and food security in these countries is getting affected.

Drought management measures are always related to efficient water resources management measures. Efficient Drought Management measures include integrated water resources development and management with appropriate rain water harvesting and water conservation mechanisms with improvements in water use efficiency and irrigation efficiency.

The South Asian region has rich fresh water resources. But there is a lack of an efficient water supply, storage, distribution and supply systems, coupled with lack of adequate rain water harvesting and conservation mechanisms in the region. With the rise in population and consequent increase in demands due to bringing more and more areas under cultivation and the requirements of water for Agriculture, domestic, horticulture, power and industrial purposes, the demand for water in the South Asian region is increasing continuously. Hence, the need of the day is to conserve the available water ,reduce wastage of water and use it more efficiently.

The Drought Scenario in SAARC Region

South Asia comprises some of the major drought affected countries of the world. Approximately 40% of the world's poor live in the South Asia and the drought disasters are of recurring type in this region. Approximately 23% of the world's population live in SAARC region comprising Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka . SAARC region also sustains the world's poorest people since it contributes less than 5% of world's GDP. Agriculture is the main source of livelihood in the region and failure of monsoon or deficient rain cycles often lead to drought. Recurrent droughts in the region are severely affecting the economies of the countries. Large parts of Southern Afghanistan, the province of Baluchistan in the remote south-western region of Pakistan and several States of India have been experiencing drought, caused by poor rainfall. The lack of rains means that local water sources getting dry up and there is very little vegetation for grazing. This has led to substantial loss of livestock and distress selling of livestock by the poor farmers in these regions. This adds to the existing problem of poverty in these countries and causes considerable strain on the natural resources. Because of successive droughts, the general health of the population has also declined, with rising levels of malnutrition due to the poor diet and subsistence living. The scenario of drought in each of the SAARC countries is briefly discussed below:

Afghanistan

Afghanistan is a mountainous country with snow covered mountains of high altitude, up to 7500 m above the sea level. The presence of mountains causes lot of variations in terms of climate and rainfall & snowfall. Over 80% of the annual precipitation falls as snow in the mountain ranges of central Afghanistan. Afghanistan has been one of the countries that has faced resource crisis over the years. The extreme poverty and underdevelopment in Afghanistan makes the population more susceptible during disaters. During the last decade, the country had faced acute food shortage induced by drought in some parts of the country. Crop production was decimated and agricultural livelihood came to a standstill and these cascaded a chain of adverse events like acute food grain shortage, mass migration, conflict among the people and draining the economy that was already crippled. Water shortage and its aftereffects pose a threat of severe food crisis and migration in Afghanistan. The hardest drought hit provinces in Afghanistan are Nangarhar, Takhar and Laghman.

Bangladesh

Bangladesh is a country, located in a deltaic plains of river basins and sea shore. The country is one of the most densely populated countries in the world and susceptible to all types of disasters. Majority of the population in Bangladesh live below poverty line at subsistence level, thereby making them more vulnerable to disasters. Though Bangladesh is a water rich country, drought is also a common hazard in Bangladesh. During the last 50 years, Bangladesh experienced drought situations in more than 20 times. Despite recurrent and devastating droughts in Bangladesh, it has attracted less attention than floods and cyclones, for which Bangladesh is more prone. Nevertheless, drought is also a serious problem in Bangladesh and the Government and scientific community in Bangladesh are paying due attention to drought. In Bangladesh, westernmost and easternmost parts are prone to drought while the menace is less manifested in the central part of the country.

Bhutan

Bhutan is a small Himalayan kingdom with rich forest coverage. Bhutan does not suffer from Drought. Climate Change & Global Warming have adverse impacts on climate and weather patterns across the world as they cause average temperatures to increase. As temperatures rise, so do other environmental problems in countries like Bhutan and people, animals, communities and ecosystems are at risk of being exposed to these adverse climate conditions.

India

Among all the SAARC countries, India is the most affected on account of drought both in terms of total number of people and area affected. In India, drought occurs mainly due to the failure of South-West monsoon (from June to September). Country's Irrigation Potential is 140 Million Ha (76 MHa through surface water irrigation and 64 MHa through Groundwater). In India, the demand for water has increased significantly and the rate of withdrawl of ground water has increased exponentially as it is being used for agricultural and horticultural purposes. Because of over exploitation of ground water in many parts of the country, the ground water table is vastly depleting. Depletion of ground water and limitation of surface water imply that not all net sown area is amenable to irrigation.

In India, there is lot of variation of rainfall both in terms of area, extent of occurrence, precipitation, intensity and also time of occurrence. Sixteen percent of the country's total area is drought prone. Annually about 50 million people in the country are exposed to the drought disaster. A total of 68% of sown area is subject to drought in varying degrees. More than 73% of annual rainfall in India is received during the South- West Monsoon. Hence, areas, which have received less rainfall during this period and affected by drought need to wait till the next monsoon. The data on rainfall in India indicates that

- Rainfall is erratic in every 4 out of 10 years. Annual average rainfall is 1160 mm in India. However, 85% of it is concentrated in 100-120 days (SW monsoon)
- 35% of area receives rainfall between 750 mm 1125 mm and is drought prone
- 33% of area in the country receives less than 750 mm rainfall and is chronically drought prone. Most of drought prone areas lie in the arid (19.6%), semi-arid (37%) and sub—humid (21%) areas of the country that occupy 77.6% of its total land area of 329 Mha.

Maldives

Maldives consists of a group of around 1200 islands in the Indian Ocean, out of which around 200 islands in the southwest of India and south-southwest of Sri Lanka only are inhabited. The average elevation of these islands is only 1.2 m above MSL. The average size of these islands are 40-60 hectares, the largest being 500 hectares. The climate is warm round the year with little variation in temperatures with two distinct seasons i.e., dry season (northeast monsoon) and wet season (southwest monsoon). Maldives does not suffer from drought problem. Maldives is not an agricultural country. Delay in onset of monsoons is not considered as drought. But when the duration of northeast monsoon (dry season) exceeds a certain limit, many islands may fall shortage of fresh water for drinking and other domestic purposes since ground water in these islands is not suitable for drinking and domestic usage.

Nepal

Nepal is a land locked country, exposed to various types of natural and man- made disasters. Though a vast network of rivers in Nepal created good ground water conditions, drought conditions are prevailing in Nepal. Uneven, low and irregular rainfall is the main factor for occurrence of droughts in Nepal. The western part of Nepal, mid and far western terai are more vulnerable to droughts. The entire mountainous region is generally dry. Out of the 75 districts of Nepal, approximately 40 districts are food deficient as a result of drought. The most affected summer crops are maize (in the hills) and rice (in the terai). Lack of irrigation facilities in the country makes the problem more serious. Nepal is also facing problems due to high poverty, low literacy rate, poor public awareness, difficult and undeveloped physical infrastructure, lack of political commitment, policy support at the top level, lack of cooperation and coordination among various government agencies, slow decision making process etc, coupled with lack of modern technology, fore-warning systems. Now, the Government of Nepal is giving due importance to drought risk management and has undertaken agriculture and irrigation development plans and programmes to ensure food security.

Pakistan

Drought frequently occurs in Pakistan. The Punjab Province, North-West Frontier Province and Sindh experienced some of the worst droughts. According to the Economic Survey of Pakistan, the drought was one of the most significant factors responsible for the less than anticipated growth performance and also for negative agricultural growth. Since 70 percent of the entire population of Pakistan is rural based and dependent on agriculture for its livelihood, negative agricultural growth has not only impacted agro-based industry, but displaced a large number of the rural poor. Due to drought in Pakistan, massive migratory trends have been witnessed to irrigated and urban areas. The most severe drought at the national scale occurred during 1999-2000, prolonging up to 2002 in many areas of the country, as a result of which, the agriculture growth suffered a major setback and also causing acute shortage of food, fodder and water. In Pakistan, migration of population due to drought is a regular phenomena. In Pakistan, though massive canal network was available, the effect of droughts has not been controlled. During the current decade, droughts have occurred in the Thar Desert of Sindh Arid Zone. Massive migratory trends have been witnessed continuously from severe drought affected areas to irrigated and urban areas. In places like Tharparkar where the economy is largely dependent on livestock, the impact of drought was very harsh. The pastures had dried up and fodder availability was restricted, in some extreme cases non-existent. Many of the livestock population had to subsist on toxic bushes which had made them vulnerable to diseases like pest des petites, enterotoxaemia, diarrhea etc.

Sri Lanka

Sri Lanka, though is an island nation, with average annual rainfall around 1860 mm, has experienced several severe droughts from the ancient times. The main causes for droughts in Sri Lanka are failure of monsoon rains, less than average annual rainfall, high temperature, humidity, and evaporations etc. Data on occurrence of droughts in Sri Lanka during the last three decades reveal that some parts of the country have experienced drought regularly. Almost all parts of Sri Lanka have experienced drought in the last thirty years. An average of 11,000 hectares of paddy land gets destroyed every year due to unavailability of water in sufficient quantities. A vast extent of other crops get affected by drought every year in Sri Lanka, resulting in huge economic losses. In terms of frequency of occurrence and the total number of people affected, drought can be classified as a major disaster in Sri Lanka.

From the above discussion, it is evidently clear that majority of South Asian region is prone to periodical and continuous droughts. A severe drought will exacerbate existing problems of poverty, and have a devastating effect on the lives of the most vulnerable people. Hence, there is an acute need of long term assessment of the drought prone areas in the region for formulation and implementation of drought mitigation programs. One of the most effective ways of tackling the problems of drought is to ensure adequate water for agriculture sector through improved irrigation and reduced losses using better agricultural practices and avoiding wastage of water and conserve water by employing various water harvesting and conservation methods and techniques. The water resources of any country are fixed. In fact, there is no more fresh water on earth today than there was 2000 years ago, when the population of the earth was only 3% of the present population. With increase in population and bringing more and more areas under agriculture, the fresh water demands all over the world has increased enormously. In the past 100 years, the world population has increased by three times but the water use by the humans has increased by six times. The demands for fresh water resources will depend upon the water consumption methods, population, area under cultivation, requirements of water for agriculture, domestic, industrial, energy, horticulture, animal husbandry, recreation and other needs. It also depends upon how effectively the available water is being used. Since we cannot increase the availability of water in any region, the only option is to conserve the available water and use it effectively through an efficient water supply, storage and distribution mechanisms and avoiding wastage of water.

Impact of Climate Change on South Asia

Climate Change and global warming has become a serious threat to all the countries in the world. It is estimated that by the middle of the current century, the global temperatures are likely to be increased by 2.0 to 2.5^{0}c. This rise in temperature will adversely affect the productivity, crop yield, human & animal health, way of life, water-supply etc. These changes will have more adverse impact on agriculture through direct and indirect effects on crops, soils, livestocks and livelihoods of the people. It will also have significant adverse impact on agricultural land use, irrigation, soil erosion and soil organic transformation etc.

The impact of Climate Change will be felt more by the developing countries because of their high vulnerability. South Asia, though it is contributing less to global warming and Climate Change will be the worst affected. Water, food and energy security in the South Asian region is closely linked to Climate Change and its impact is likely further aggravate water crisis in South Asia. Due to Climate Change, there will be wide spread variation of precipitation both in intensity, area and time of occurrence and extreme events like long dry spells, followed by intense rainstorms, heat waves, cold waves etc will become more frequent and rainfall in the region may be concentrated in shorter and more intense durations and wet areas may get wetter and dry areas more drier as a result of which, the region may witness more frequent and intense floods and droughts.

In a Climate Change scenario, surface runoff is projected to decrease drastically in arid and semi-arid regions of South Asia. This will significantly affect the total volume of water available in the region and water management will witness more challenges. With the projected Climate Change scenario, the areas suitable for agriculture, the length of growing seasons and yield potential of crops are expected to decrease. Maturity time of crops like maize may be reduced from one to four weeks. This will have serious long term implications on the yield of all types of crops. Even the high yielding varieties of crops may also result in giving low yields. This will pose a major challenge to the food security in the region. This will have significant adverse impact on the economy of the South Asian region since it is predominantly dependent on agriculture sector.

Integrated Water Resources Development and Management

Fifty years ago, the population in South Asia was less than forty percent of the present population. People were not as wealthy as today and therefore, consumed fewer calories and ate less meat, so less water was needed to produce their food. Today, the demand for water resources in South Asia is much more intense. This is because there is increase in the population and also their lifestyles and their consumption of water-thirsty meat and vegetables is rising, and there is increasing demand for water from industry, urbanization, energy and recreation needs. In future, the demand for water in the South Asian region will further increase. Hence, there is an urgent need to follow an efficient management of water resources through an integrated approach.

Successful management of any resources will depend upon accurate knowledge of the resource available, its correct estimates based on scientific tools and models, the uses to which it may be put, the demands for the resource, prioritization of the demands based on the needs, keeping in view the riparian rights and pressing demands of the people, policies of the Governments and systems and mechanisms to translate policy decisions into actions on the ground. Integrated Water Resources Development and Management approach addresses these issues and provides for development and efficient management of water resources.

Integrated Water Resources Development and Management approach is a comprehensive, participatory planning and implementation tool for managing and developing water resources in a way that balances social and economic needs, and that ensures the protection of ecosystems for future generations. It has been defined by the Technical Committee of the Global Water Partnership (GWP) as " A process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." The Integrated Water Resources Development and Management approach is an open, flexible process, bringing together decision-makers across the various sectors that impacts water resources, and bringing all stakeholders to the table to set policy and make sound, balanced decisions in response to specific water challenges faced.

Water Harvesting and Conservation

Water Harvesting and Conservation is an effective drought mitigation measure. It reduces soil erosion, augments soil moisture and improves water use efficiency. It refers to the processes and structures of rainfall and runoff collection from large catchment areas and channeling them for human consumption. Rainwater harvesting is the accumulating and storing of rainwater. It can be used to provide drinking water, water for livestock, water for irrigation or to refill aquifers for groundwater recharge. Water collected from the ground, sometimes from areas which are specially prepared for this purpose, is called Storm water harvesting. In some cases, rainwater may be the only available or economical water source. Rainwater harvesting systems are simple to construct from inexpensive local materials, and are potentially successful in most habitable locations. In many parts of South Asia, particularly in Afghanistan, India, Pakistan and Sri Lanka, these processes and structures have been in existence for a long time.

Water Conservation

Water conservation can be defined as any beneficial reduction in water loss, use or waste as well as the preservation of water quality. A water conservation measure is therefore, an action, behavioral change, device, technology, or improved design or process implemented to reduce water loss, wastage, or use. Water efficiency is a tool of water conservation. A reduction in water use is accomplished by implementation of water conservation and water efficiency measures or improved water management practices that enhance the beneficial use of water. The goal of water conservation is to ensure availability of water in sufficient quantities when required. The withdrawal of fresh water from an ecosystem should not exceed its natural replacement rate. Under no circumstances, over exploitation of water should be permitted. Available water should be sparingly used, wastage of water should be totally avoided and water should be optimally utilized. Minimizing human water use helps to preserve fresh water habitats for local wildlife and migrating waterfowl, as well as reducing the need to build new dams, reservoirs, storage structures and other water diversion infrastructure. Many SAARC countries are using various tools and techniques for conserving water.

Water conservation techniques include conservation of water available in the soil (as soil moisture), improved irrigation efficiency and water use efficiency, reduced conveyance losses, reduced evaporation (from water surface), reduced transpiration and evapo-transpiration, recharge of ground water and conjunctive use of surface and sub-surface water etc. Emphasis should also be on increasing the Dam / Reservoir Efficiency, Conveyance Efficiency & water delivery system efficiency, On-Farm Application Efficiency, and Drainage Efficiency etc. Water use in most socioeconomic activities can vary widely, depending upon the interplay of many factors. Water use efficiency includes any measure that reduces the amount of water used per unit of any given activity, consistent with the maintenance or enhancement of water quality. Water use or evapo-transpiration (E) is expressed in terms of mm or kg of water m^{-2}, Water use efficiency = g C m^{-2} mm^{-1} or g C kg^{-1} water

Water use efficiency = GPP/E or NEP/E
GPP = gross primary productivity, i.e., C uptake by photosynthesis (~twice of NPP)
NEP = net ecosystem productivity (net C sequestration)
= GPP – R

Dam / Reservoir Efficiency (R.E) :

$$\textbf{R.E} = \frac{\text{The Maximum live storage attained during a year}}{\text{Designed live storage}}$$

Conveyance Efficiency (E_{C1}) & Water Delivery System Efficiency (E_{C2})

$$E_{C1} = \frac{\text{Total water delivery at inlet to the block of fields}}{\text{Water released at the project head work canal conveyance efficiency}}$$

$$E_{C2} = \frac{\text{Actual water carrying capacity of all canals}}{\text{Designed Capacity of all Canals}}$$

- For main canal & Distribution-discharge >150 C/S.
- For Distribution network-discharge < 150 C/S.
- For both lined & unlined canals.
- Sample representing from head / middle / tail ends.

On-Farm Application Efficiency (F.E) :

$$\textbf{F.E} = \frac{\text{Water used by crop to meet evapo-transpiration needs.}}{\text{Water delivered to the field.}}$$

Drainage Efficiency (D.E) :

$$\textbf{D.E} = \frac{W_d}{(W_s + R_e - E_t)}$$

W_d = Total water drained from the system
W_s = Total water supplied to the system.
R_e = Effective rainfall during the period under consideration.
E_t = Water used by crops to meet evapo-transpiration needs.

The first step in water conservation starts with the estimation of the requirement and availability of water (from all sources) in a given geographical area i.e., a revenue/ irrigation division, mandal or a district. The measures for conservation and augmentation of water could be organized only after estimating the demand and availability of water. The state irrigation departments, rural water supply and rural development departments, public health engineering, relief and revenue departments in coordination with the district administration should undertake such exercise scientifically on the basis of the consumption needs of the population and water requirements of the crops in the area and water demands from industrial, service, domestic, horticultural and agricultural needs. Availability of water depends upon many factors like rainfall, area, extent of precipitation, runoff conditions, percolation and ground water recharge, water storage and water withdrawal, etc. Areas with high rainfall may also severe scarcity if run-off is very high and the level of percolation is poor.

Measures needed to be taken for managing water situation in drought affected areas include:

- Artificial recharge of Ground Water
- Traditional Water Harvesting and Conservation Methods
- Recharge of dried up Open Wells / Dug Wells
- Efficient Reservoir Management
- Repairs and Augmentation of Existing Water Supply Systems
- Better Agricultural Techniques and Practices
- Rain water harvesting
- Improvement in irrigation efficiency
- Increase in water use efficiency
- Better water supply, storage and distribution mechanism

Expanding the availability of water during drought seasons through the various engineering and non-engineering measures will reduce the impact of droughts. Necessary measures should be taken to ensure that water is conserved as much as possible and also to ensure that sufficient water is kept in reserve through various types of storage structures. Diverting flood flows in a good year to delineated aquifer zones to store water underground in extremely dry areas and high temperature zones will reduce evaporation losses. In any river basin, both the surface water and ground water should be exploited in an integrated and holistic manner so that the ecology and environment of the basin supports the flora and fauna.

Artificial Recharge of Ground Water

Depending upon the topography, shape, configuration, and slope of the land, nature and depth of soil cover, type of rocks, and their formation and layout, water absorbing capacity of land, rainfall intensity etc, artificial recharging measures shall be devised and implemented. These measures include: Contour Bounding, Contour Trenching, Contour Cultivation, Gully Plugging, Check Dams, Gabion Structures, Stream bank Protection, Farm Ponds, Percolation Tanks,Sub-surface Barriers, Injection walls, Anicuts etc. Most parts of South Asia are facing water crisis. Climate Change, overuse, misuse of water, pollution etc. are the principle causes of water crisis in South Asia. Added to this are pumping ground water faster than aquifers can recharge and using ground water for irrigation purposes.

Traditional Water Harvesting and Conservation Methods

In most parts of South Asia, traditional Water Harvesting and Conservation systems were in existence since ancient times. Over a period of time, people in the South Asian region have developed the coping mechanisms and traditional knowledge to deal with recurrent droughts. But in recent times many of these traditional Water Harvesting and Conservation systems which were low cost, community oriented and environment-friendly were abandoned. These traditional structures and water conservation practices need to be studied at micro level and suitably modified if necessary and implemented. Many minor irrigation and major irrigation tanks that were dried up were occupied by human settlements. Many open wells, step wells and village ponds etc were also abandoned. There is an urgent need to revive them. Realizing the importance of these traditional Water Harvesting and Conservation structures, the national and provincial/state governments in the SAARC region have initiated various measures to revive them. They include recharging dried up dug wells, Village Ponds/ Tanks, Khadin, Tankas/ Kundis, Vavdi / Bavadi / Jhalara etc. In many parts of South Asia, thousands of open wells and minor irrigation tanks were dried up because of declining water levels due to over exploitation of the ground water for irrigation and other purposes. These can be used to recharge ground water. Storm water can be diverted in to these dried up open wells/ tanks/ponds to directly recharge them. Many of them were deposited with silt. Hence, de-silting has to be taken up on priority to enable them to recharge. By doing so, we can not only recharge the dried up aquifers but also reduce the soil moisture losses since more water can percolate and can be retained by the soil.

Farming Techniques for Water Conservation

As populations grow, and as demand for food increases in a world with a fixed water supply, there are efforts under way to learn how to produce more food with less water, through improvements in irrigation methods and technologies, agricultural water management, crop types, and water monitoring. Agriculture is the largest water user in the SAARC region. Agriculture takes 69% of all the water withdrawn for human use. Productivity of water in agriculture sector in South Asia is very low. On an average, in South Asia, 1000 tons of water is being used for producing one ton of grains. Approximately one to three cubic meters of water is being used for producing one kg of rice. Majority of agricultural water use in SAARC countries comes from groundwater supplies, and existing groundwater supplies are expected to decrease at least by 18 to 20 % by 2050 in all these countries (if present rate of exploitation of ground water is continued). Therefore, conservation and optimum utilization of water is very important for meeting agricultural water demand in these countries. We can no longer afford to waste water any more. A depleting water table and a rise in salinity due to overuse of chemical fertilizers and pesticides has made matters serious in most of the SAARC countries. Various methods of water harvesting and recharging have been and are being applied all over the SAARC region to tackle this problem. In areas where rainfall is low and water is scarce, the local people have used simple techniques that are suited to their region and reduce the demand for water. Accurate water measurement and soil moisture monitoring are key components of efficient on-farm water management practices.

Water measurement and monitoring soil moisture are key components for efficient farm management practice. On-farm water use can be reduced substantially without decreasing productivity through improved irrigation technologies and efficient water management practices. Water is critical for sustaining the food security also. Training farmers in agricultural techniques which extend the range of crops they can grow and which make more efficient use of scarce water resources should be given top priority. Strengthening of the capacities of local village committees to manage and develop agricultural and water projects is of utmost importance. Simple techniques can be used to reduce the demand for water. The underlying principle is that only part of the rainfall or irrigation water is taken up by plants, the rest percolates into the deep groundwater, or is lost by evaporation from the surface. First of all wastage of water should be avoided. By improving the efficiency of water use, and by reducing its loss due to evaporation, by following efficient and appropriate irrigation systems we can also reduce water demand.

Irrigation

There are three basic types of irrigation i.e., surface (gravity), sprinkler, and drip irrigation. Using surge flow valves and reusing tail water can increase water use efficiency of gravity irrigation systems. Drip irrigation is a very water efficient method of irrigation that can be effective with certain crops and on uneven terrain. Use of efficient watering systems such as drip irrigation and sprinklers will reduce the water consumption by plants. Irrigation Efficiency (I.E) needs to be improved. Irrigation flow meters can be used to help calculate the efficiency of irrigation systems, identify water loss from leaks in conveyance systems, and to accurately apply only the necessary amount of water based on soil moisture levels and weather conditions. Soil moisture monitoring is used in conjunction with weather data and crop evapo-transporation requirements to schedule irrigation. Fields should be designed for efficient water use by grading land with laser equipment, creating furrow dikes to conserve rainwater, and by retaining soil moisture through conservation tillage. Irrigation sector is caught in a vicious cycle. Inadequate funding for O&M over years has resulted in the neglect of maintenance and upkeep of the irrigation system leading to deterioration in the quality of irrigation service. Physically, the irrigation and drainage system is not able to receive and deliver the planned quantity of water matching with the demand pattern. Poor irrigation service, often not matching with the crop water requirements over space and time, results in low productivity of crops.

Irrigation Scheduling

Irrigation scheduling involves managing the reservoirs so that water is available when the plants need it. Soil moisture and weather monitoring are used to determine when to irrigate, and soil capacity and crop type are used to determine how much water should be applied during irrigation. Soil moisture monitoring regardless of the irrigation system used, scheduling irrigation should be based on the crop's water needs. Crop water need is often assessed by monitoring soil moisture. There are many ways to measure soil moisture, each method is having its own advantages and disadvantages, and varying degrees of accuracy. The most obvious and common method of soil moisture monitoring is to observe the soil feel and appearance at various soil depths within the crop root zone.

Drip and Sprinkler Irrigation

Various irrigation methods involve different trade-offs between water consumption, crop yield, and associated cost (i.e., fixed cost, cost of equipment and structures and variable cost i.e., cost of labor and time of employment etc). Some of the irrigation methods like sprinkler irrigation and furrow irrigation are less expensive but are also less efficient as much of the water evaporates, runoff or drains below the root zone. Some types of sprinkler irrigation systems, where the sprinklers are operated near ground level are more effective. Drip irrigation applies small amounts of water frequently to the soil area surrounding plant roots through flexible tubing with built in or attached emitters. Subsurface Drip Irrigation (SDI) delivers water underground directly to roots. Since water is applied directly to individual plant roots, SDI minimizes or eliminates evaporation, provides a uniform application of water to all crop plants, and applies chemicals more efficiently. These systems, though more expensive, offer greater potential to minimize runoff, avoid drainage and evaporation and wastage of water and also facilitate appropriate irrigation timing and management. Drip irrigation also reduces plant stress and increases crop yield. A carefully managed amount of water is applied, thereby avoiding deep percolation and runoff, while reducing salt accumulation. Since a constant level of moisture is maintained around the root zone, with less surface moisture present in between rows, weed growth is reduced. Water contact with crop leaves and fruit is also minimized, making conditions less favorable for disease. Drip irrigation systems also increase the yield very significantly and save water up to 70% and increase fertilizer use efficiency by 30 to 40%. They facilitate consistent and healthy growth of crops and therefore, enable them to mature fast, which results in higher and faster return on investments. Through drip irrigation, plant protection chemicals can also be given and since fertilizer can be applied to the root of the plant, there is no wastage and hence, the costs of fertilizers, interculture and labor use also gets reduced. Drip and sprinkler irrigation systems also reduce farm operation and maintenance costs through energy savings and automation. Also, drip systems are the only type of irrigation that can use water efficiently on steep slopes, odd-shaped areas, and problem soils.

Conclusion

Drought in South Asia can be managed effectively through an integrated water resources development and management with an efficient water supply, storage, distribution and supply systems. Central all the drought mitigation programs is rain water harvesting and water conservation techniques and improving the water use efficiency and irrigation efficiencies and also by using innovative, low cost, small scale irrigation technologies.

All the countries of South Asia have lot of experience in dealing with droughts. In fact disaster management in the SAARC region started with the management of droughts only since the days of the colonial period in the region. Countries in the SAARC region have formulated their national policies on disaster management and put in place various mechanisms and systems through legal and administrative actions to ensure an appropriate disaster management strategy in place. In conformity with these measures, all the member countries of the SAARC have initiated several measures for an effective drought management through strengthening preparedness for drought, reducing underlying factors of drought risk, and knowledge management, institutional structures, active research programs, community based approach etc. With integrated water resources development and management systems and through the water conservation techniques and practices discussed above, with development of improved irrigation systems, with the SAARC member countries government's commitment for implementing the frameworks for drought risk reduction, through mutual cooperation and coordination among all the SAARC countries and with a proactive approach of all the governments of the SAARC region, it is quite possible to ensure that droughts in the region are events in the past.

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Characterization of droughts and development of forewarning system

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Drought is one of the natural disasters that have plagued mankind on many occasions throughout the history. Despite tremendous technical advances mankind is unable to combat this broad scale and formidable natural disaster. Drought is a climatic anomaly, characterized by deficient supply of moisture resulting either from sub- normal rainfall, erratic rainfall distribution, higher water need or a combination of all the three factors.

Drought is affecting large parts of South Asian regions. With the nonstructural nature of its damage and impact covering larger geographical areas, drought affects the largest number of people in South Asia. The agrarian economies of the South Asian countries are therefore more vulnerable. In fact, drought has been one of the primary reasons for widespread poverty and environmental degradation in SAARC countries. The South Asian regions have been among the perennially drought-prone regions of the world. Afghanistan, India, Pakistan and Sri Lanka have reported droughts at least once in three years in the past five decades, while Bangladesh and Nepal also suffer from drought frequently. What is of concern is its increasing frequency. Since the mid-1990s, prolonged and widespread droughts have occurred in consecutive years in Afghanistan, India and Pakistan while the frequency of droughts has also increased in Sri Lanka, Nepal and Bangladesh (FAO, 2002). Further, the latest IPPC report and other climate model predictions indicate that the global change is likely to increase the vulnerability of tropical countries to drought, more so in South Asia. (IPCC, 1996 and 2001). In view of frequent occurrence and severity of droughts in countries of South Asia, it is necessary to understand their characteristics and forewarning for taking better management options.

Categorization of Droughts

Although drought is a commonly occurring natural disaster associated with prolonged deficiency of rainfall, there is no unique definition of drought. Several definitions of drought are available in literature (Thornthwaite, 1948; Ramdas, 1960; Van Bavel, 1953; Palmer, 1965). Thornthwaite (1948) characterized four types of droughts viz., permanent, seasonal, contingent and invisible.

Permanent drought: Permanent droughts are associated with inadequacy of soil moisture/ rainfall to meet the water requirements of the crop during most of the years. It is a characteristic of driest climates. Agriculture is possible only by irrigation.

Seasonal drought: It occurs mostly in climates having well defined rainy and dry seasons. Planting dates and crop duration should be synchronized with rainy season and residual moisture storage (Arid and semi arid regions).

Contingent drought: It is dependent upon irregularity of rainfall and so is not regular to occur in any definite season.

Invisible drought: This can occur even when there is frequent rainfall in an area. This type of drought results when rains do not supply enough water to counteract water loss by evapotranspiration. This occurs usually in humid areas.

National Commission on Agriculture (1976) has categorized drought into three types viz., meteorological drought, hydrological drought and agricultural drought based on the concept of its utilization. They are defined as below :

Meteorological drought: When rainfall over an area is less than 25 percent of its normal rainfall, it is called meteorological drought.

Hydrological drought: Meteorological drought, if prolonged, results in hydrological drought with marked depletion of surface water and consequent drying up of reservoirs, lakes, streams and rivers.

Agricultural drought: It occurs when soil moisture and rainfall are inadequate to support a healthy crop growth during growing season.

Some even try to classify a fourth category of drought called socio - economical drought (Appa Rao, 1992), as drought affects adversely the economy and progress of a region.

Drought Assessment

Rainfall is the major controlling factor determining the availability of water for meeting the various needs of vegetation, human and livestock population. Most of the studies concentrate on the precipitation deficit as an indicator of severity. It is always preferable to substitute a variable more closely aligned to the water problem. A drought index value is a single number used for assessing drought severity. Some of the drought indices that are mostly used are described here:

Meteorological Drought

Normalized deviation is the departure of actual precipitation to average amount of monthly, seasonal or annual rainfall.

Normalized deviation (ND) = $(P_{tot} - P)/P$

Where P_{tot} is the total annual precipitation in mm for a particular year and P is the average rainfall for the area.

India Meteorological Department (IMD) uses normal deviation method for declaration of droughts. According to IMD, drought is said to have occurred over a region when total seasonal rainfall is less than 75 percent of the normal value of the region. Rainfall deficiency of 26 to 50 percent from normal over a region is termed as moderate drought and a deficiency of more than 50 percent of the normal as severe drought. IMD (1971), based on 500 selected stations, identified drought-prone areas as:

Moderate drought

Annual or seasonal departure from normal rainfall between -26 and -50%	Rajasthan, Saurashtra and Kutch, parts of Gujarat, Punjab, Haryana, West Uttar Pradesh, Maharashtra, Rayalaseema, and Interior Karnataka.

Severe Drought

Annual or seasonal departure from normal rainfall less than -50%	Western parts of West Rajasthan and Kutch

For this purpose, areas where the frequency of drought, as defined above, is 20% of the years of data examined were classified as 'Drought areas' and areas having drought frequency more than 40% of the years as chronically drought affected areas. The areas included in the categories by them are:

(i)	Drought Areas	Rajasthan, Saurashtra and Kutch, Gujarat, Punjab, Haryana, West Uttar Pradesh, Madhya Pradesh and North Maharashtra
(ii)	Chronic Drought Areas	Western parts of Rajasthan and Saurashtra and affected areas of Kutch

Aridity Anomaly Index (AI)

Aridity anomaly index of Thornthwaite (1957) described the expression of water deficiency by plants.

Aridity Index (AI) = ((PE-AE)/PE)* 100

Where PE is the water need of plants (also known as potential evapotranspiration), AE actual evapotranspiration and PE – AE denotes the deficient. AE is computed from water balance procedure, which considers water-holding capacity of soil. Based on Aridity Index, drought can be classified as moderate, large, severe and disastrous. The drought classification procedure adopted by Subrahmanyam and Sastri (1969) is as follows:

Departure of Aridity Index from mean	Drought Intensity
$<1/2\sigma$	Moderate
1/2ó to σ	Large
σ to 2σ	Severe
$>2\sigma$	Disastrous

India Meteorological department estimates the difference between actual AI and normal AI for a week (percentage) and groups drought into mild (0 – 25), moderate (26 – 50) and severe (>50).

Standardized Precipitation Index (SPI)

The SPI was used for drought classification by Komuscu (1999) and Mc Kee et al. (1995). The SPI can be written as

SPI = $(X- X_m)/ \sigma$
Where X = Precipitation for the station.
X_m = Mean Precipitation
σ = Standardized deviation.

Drought classification based on SPI (Mc Kee et al. (1995)

SPI	Drought class
Less than – 2.0	Extreme drought
-1.50 to - 1.99	Severe drought
-1.0 to -1.50	Moderate drought
-0.99 to 0	Mild drought

Palmer Drought Severity Index (PDSI)

PDSI is a soil moisture algorithm. The basic concepts and steps for computing the PDSI are described by Palmer (1965). Classification of droughts based on PDSI is :

PDSI Values	Drought Classes
-4.0 and less	Extreme drought
-3.0 to -3.99	Severe drought
-2.0 to -2.99	Moderate drought
-1.0 to -1.99	Mild drought
-0.5 to -0.99	Incipient dry spell
-0.49 to -0.049	Near Normal

Agricultural Droughts

As an agricultural drought affects most as compared to a meteorological or hydrological drought, it is the agricultural drought, which is of common concern. In fact, when the word drought is used, it commonly connotes agricultural drought.

Main characteristics agricultural drought are:

i. It builds over a period of time (may be even a year or two) with increased scarcity of water -generally due to insufficient or erratic monsoon rains.

ii. It does not have a well-defined start. It is a creeping phenomenon.

iii. Generally, it does not have a sharp ending although sometimes a prolonged spell of drought can come to a sudden end through a fairly long spell of specially heavy rainfall as in case of depression or cyclone.

iv. Drought can be localized covering a district or a group of districts. On the other hand, it can be widespread covering a few states.

v. Area affected by a drought usually takes an elliptic shape instead of a circular coverage.

Various approaches were followed to quantify the intensity of agricultural drought. Appa Rao et al. (1981) utilized the departures of aridity index week by week as criteria for classifying agricultural droughts. Victor et al. (1988) used water requirement satisfaction Index (WRSI) for identifying agricultural drought.

For agrometeorological works, IMD monitors the drought index (I) operationally on a weekly basis for over 2500 station in terms of:

$$1 = \frac{(PE - AE) \times 100}{PE}$$

AE is estimated using a water balance technique. According to their criterion, drought intensities are classified as

Aridity Index Anomaly (I)	Drought intensity
< 25%	Mild drought
26% to 50%	Moderate drought
>51%	Severe drought

Moisture Adequacy Index (APET/PET) as Index of Drought

Studies at CAZRI categorized drought based on Moisture adequacy index which is the ratio of actual evapo-transpiration (AET) to potential transpiration (PET).

Drought free period	AET > PET/2
Moderate drought period	PET/2 > AET > PET/4
Severe drought period	AET < PET/4

A novel method of classification of agricultural droughts was attempted at this Institute (Sastri et al., 1981: Ramana Rao et al., 1982) by considering the effect of drought (in terms of AE/PE) during different phenological stages of a crop. The classification is as follows:

AE/PE(%) during different Phenophases	Drought Intensity	Code		
		Seedling	Vegetative	Reproductive
76 to 100	Nil	S_0	V_0	R_0
51 to 75	Mild	S_1	V_1	R_1
26 to 50	Moderate	S_2	V_2	R_2
25 to Less	Severe	S_3	V_3	R_3

Depending upon the values of AE/PE during different phenophases, the drought code varies as $S_1 V_3 R_2$, $S_0 V_1 R_1$ etc. This is a generalized classification without specification on any crop. After introducing the crop factor, drought code in three syllables can be unified into a single drought code (A).

Characterizing Areas Prone to Agricultural Drought

To assess the agricultural drought, it is necessary to measure the extent to which rainfall and soil moisture are falling short of the water requirement of crops during the cropping season. Moisture Adequacy Index (MAI) is a better measure for assessing the degree of adequacy of rainfall and soil moisture to meet the potential water requirement of crops. Hence, to identify the mandals that can be vulnerable to agricultural drought, weekly MAI was worked out for the mandals of Andhra Pradesh.

Methodology for Calculating MAI

Moisture Adequacy Index (MAI) is the ratio of actual evapotranspiration (AET) to the potential evapotranspiration (PET). AET can be obtained as an output parameter from water balance calculations. Thornthwait and Mather (1955) weekly water balance model was used for estimating water balance of mandals. In each district, water balance of mandals was worked out. The weekly water balance parameters like weekly AET, surplus, deficit etc. for weeks 1 to 52 were worked out. Weekly MAI for weeks 1 to 52 were worked out as ratio of weekly AET and PET values. As Agricultural droughts occur during the cropping season only, average MAI during the cropping season has been taken as the yardstick for assessing the intensity of agricultural droughts. Agricultural droughts during different seasons (years) were classified into four groups based on average MAI during the season **(Table 1)**.

Table 1 : Drought classification based on MAI

Drought severity	MAI
No drought	MAI > 0.75
Mild drought	MAI <0.75 and >0.50
Moderate drought	MAI <0.50 and >0.25
Severe drought	MAI <0.25

Frequencies of all the categories of agricultural drought like mild, moderate and severe were added to work out the drought frequency of a mandal. Districts having drought frequency less than or equal to 20% were classified as safe, more than 20 or less than or equal to 40% as moderate and more than 40% as severe. Based on the above classification, districts were categorized as safe, moderate and severe.

Drought Severity Index (DSI): Considering the agricultural drought frequency (number of years of different types of drought like mild, moderate and severe) and the severity based on MAI, an index called drought severity index has been devised (Eqn.1). The formula for working out drought severity index (DSI) is as follows:

$$DSI = \frac{(0.0 * \text{No drought} + 0.25 * \text{Mild droughts} + 0.50 * \text{Moderate droughts} + 0.75 * \text{Severe droughts}}{\text{Total number of years}} \text{X100} \quad ....(1)$$

Based on drought severity index, mandals were classified into 4 categories viz. safe, less vulnerable, moderately vulnerable and highly vulnerable. This categorization was made using the mean (M) and standard deviation (s) of drought severity index over all the mandals of the state. The methodology for categorization of mandals and the limits of DSI are presented in (**Table 2**).

Table 2 : Drought classification based on DSI

Category	DSI
Safe (SF)	$\leq (M - \sigma)$
Less vulnerable (LV)	$> (M - \sigma)$ and $\leq$ Mean
Moderately vulnerable (MV)	> Mean and $< (M + \sigma)$
Highly vulnerable (HV)	$> (M + \sigma)$

Accordingly, mandals with DSI ≤ 3 were marked as safe (SF); DSI > 3 and ≤ 13.5 as less vulnerable (LV); DSI > 13.5 and ≤ 24 as moderately vulnerable (MV) and DSI > 24 as highly vulnerable (HV).

Drought Monitoring

Monitoring by technical/ scientific means is necessary to provide early warning of drought and to provide an objective and transparent definition of drought to be used in the allocation of resources. Drought information network is to be established to provide data and interpretation on all aspects of previous and future droughts including time of occurrence, location, intensity, duration and impacts in different sectors.

Some of the national and international organizations involved in monitoring and issuing early warning of droughts are

- WMO's World Weather Watch (WWW)
- World climate program
- Food and Agriculture Organizations Global information and Early Warning System on Food and Agriculture (FAO/GIEWS)
- USAID's Famine Early Warning Systems (FEWS)
- South African Development Community (SADC) regional and national early warning system in South Africa.
- African Centre for Meteorological Applications Development (ACMAND)
- National Agricultural Drought Assessment and Monitoring system (NADAMS) under Indian conditions. Besides, National Remote sensing agency makes vegetation cover monitoring and crop stress area demarcation.

Early Warning System

Early warning empowers individuals and communities threatened by natural hazards to act in sufficient time and in an appropriate manner so as to minimize the risk of droughts. Technologically oriented early warning, integrated with field data on crop and livestock conditions, price movements, human welfare etc. is crucial for tracking drought, its onset, its impact and farmers response to it. Primary policy decision makers, resources generators, and relief and mitigation workers need information about early warning on onset of drought event, estimation of area, intensity and duration, long term and short term plan for drought management etc.

A definition of warning stages (e.g. normal, alert, alarm, emergency) should be generated by the early warning system to trigger responses from government. The effective warning system should have meteorological/ agricultural information, production estimates, price trends of food and feed, availability of drinking water and household vulnerability, so that a variety of indices related to production, exchange and consumption could be addressed (Ayalew, 1994). Further, information on the spatial extent and duration of drought, time of occurrence with reference to crop calendar and severity of drought would help in the management.

Software for Drought Detection, Monitoring and Early Warning

The information about the onset of drought conditions in a timely and reliable manner is useful in many ways to organize corrective steps for drought mitigation. Drought is a creeping phenomenon, the extent of which appears gradually, thus offering the possibility of monitoring it and issuing early warning. There are two ways to monitor drought. One is based on network system of stations, and the other is by remote sensing. Though the latter offers fast and wider area characteristics, available data at smaller scale like mandal level is not reliable and it has some limitations. Hence, former way of monitoring droughts through network of stations was adopted.

A monitoring and early warning system should be established to provide timely information on formation, development, persistence, and alleviation of drought till its end, to those responsible for mitigation and relief measures. To meet this objective, the following steps should be undertaken:

(i) Building a system that can capture, analyze, and transfer drought information in a timely fashion

(ii) Monitoring the present status and estimation of future available water/soil moisture

(iii) Special department to enforce the criteria and issue / cancel drought warnings

Considering three components, viz., (i) atmospheric parameters (ii) agricultural parameters (iii) hydrological parameters, a ***software*** for monitoring agricultural drought and issuing early warning has been developed. In this software, moisture adequacy index and water requirement satisfaction index are used. A crop-specific water balance model is used for obtaining these indices. The input and output for the model is given below:

INPUT
1. Rainfall
2. Maximum and minimum temperature for calculation of potential evapo-transpiration.
3. Crop coefficient
4. Yield response factor
5. Available water holding capacity (AWC) of the soil
6. Latitude and longititude of the mandal for estimation of radiation for calculating PET.
7. Maximum yield of crop
8. Duration of the crop.

OUTPUT
1. Runoff
2. Deep drainage
3. Drought signals
4. Relative yield

The input and output frames are given in **Figs. 1 & 2.** The program is written in Visual Basic. The software that was developed, not only provides drought signals during the crop-growing period, but also estimates yield at the end of the season. The software is so designed that a technical officer at mandal level can use it. Provision is also made in the software to identify the sowing date (date of onset of monsoon) based on daily rainfall. The date of onset of rainy season is defined as that date after 3rd week of May, when rainfall accumulated over two consecutive days is at least 20 mm. Based on the onset date, the appropriate crops and crop varieties that are to be grown for a particular date will be displayed for different soil types of the State.

The software will assess the water requirement of a crop from the library in which weekly water requirement of all the major crops is stored.During the crop-growing period, whenever the signal of drought appears, the software will estimate the water requirement from that date till the end of crop. It will also estimate the amount of rainfall likely to occur at 50% probability till the end of crop (stored in the library). The amount by which the likely occurrence of rainfall is going to fall short of the water requirement of the crop will also be displayed. Water requirement during different phenological stages of some major crops have been worked out. Besides evapo-transpiration losses, runoff and deep drainage losses have to be accounted which amounts to approximately 30% of total rainfall. Provision has also been made in the software to record and update at weekly intervals the information on the total area sown in different mandals. A library of the normal crop area (total of all crops) in each mandal is stored in the software and percentage of area sown

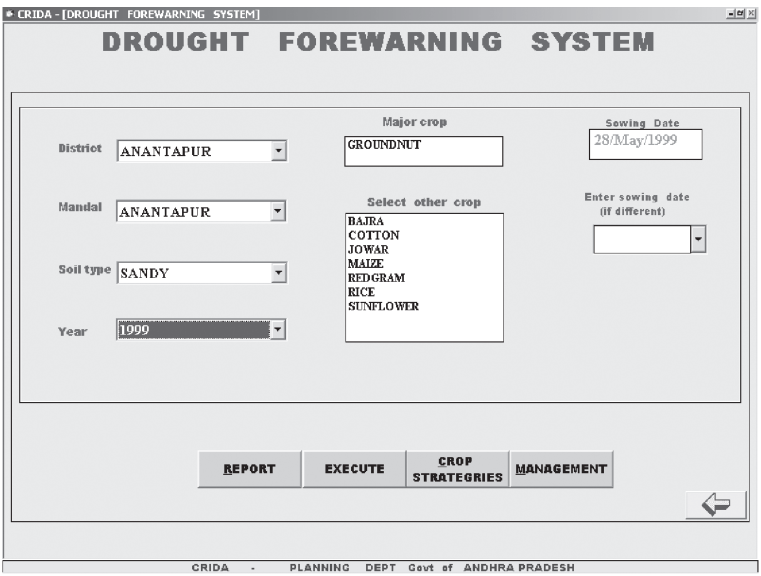
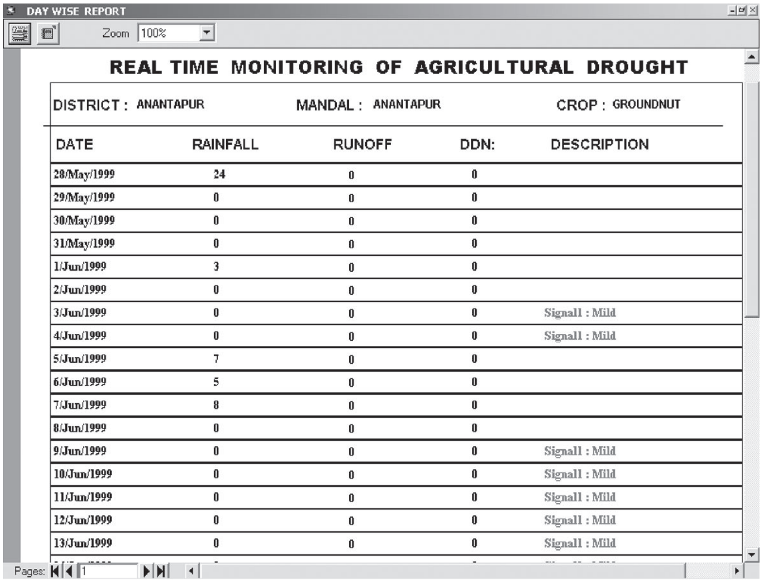


Fig. 1 : Drought forewarning system (sample input)



REAL TIME MONITORING OF AGRICULTURAL DROUGHT

DISTRICT : ANANTAPUR MANDAL : ANANTAPUR CROP : GROUNDNUT

DATE	RAINFALL	RUNOFF	DDN:	DESCRIPTION
28/May/1999	24	0	0	
29/May/1999	0	0	0	
30/May/1999	0	0	0	
31/May/1999	0	0	0	
1/Jun/1999	3	0	0	
2/Jun/1999	0	0	0	
3/Jun/1999	0	0	0	Signal1 : Mild
4/Jun/1999	0	0	0	Signal1 : Mild
5/Jun/1999	7	0	0	
6/Jun/1999	5	0	0	
7/Jun/1999	8	0	0	
8/Jun/1999	0	0	0	
9/Jun/1999	0	0	0	Signal1 : Mild
10/Jun/1999	0	0	0	Signal1 : Mild
11/Jun/1999	0	0	0	Signal1 : Mild
12/Jun/1999	0	0	0	Signal1 : Mild
13/Jun/1999	0	0	0	Signal1 : Mild

Fig. 2 : Drought forewarning system (sample output)

will be displayed at weekly intervals for declaring drought or no drought situation. Mandal may be declared, as drought affected, if the total cropped area does not exceed 50% of the normal by July 31 as this is considered as one of the norms followed by Government of India.

Methods Employed

For calculating PET from maximum and minimum temperature, the method suggested by Campbell (1977) was used. The PET estimated with the model was compared with the actual PET to arrive at correction factor for reliable estimation of PET.

- For yield estimation, WRSI values as reported by FAO water balance model of Frere and Popov (1979) was used.
- Provision is also made to display management strategies whenever a drought signal appears depending upon the timing of drought, early (June-July), mid season (August) and late (September and beyond).
- For drought signals, MAI values estimated by the water balance model were used. The criteria followed for declaring mild, moderate, and severe drought based on MAI values and their duration is illustrated as under:

MAI range	Duration (days)	Drought category
>0.75	-	No drought
0.75 - 0.5	10-20 21-30 >30	Mild Moderate Severe
0.5 – 0.25	1-10 11-20 >20	Mild Moderate Severe
<0.25	1-7 8-14 >15	Mild Moderate Severe

Conclusion

In this chapter categorization of drought was discussed and indices for assessing severity of drought were presented. Author has developed novel methodology for characterizing and classifying areas prone to drought. The classification will help the planners in taking different types of long-term and short-term measures for combating droughts. A software was developed for real time monitoring of agriculture droughts at mandal or county level in Andhra Pradesh. There is a need to develop a network to monitor agricultural droughts across all the SAARC countries for effective implementation of long and short term drought mitigation measures and establishing regional cooperation for exchange of real-time drought information.

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Coping with Climate Change : Strategic Initiatives in India

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Climate change impacts on agriculture are being witnessed all over the world, but countries like India are more vulnerable in view of the high population depending on agriculture and excessive pressure on natural resources. The warming trend in India over the past 100 years (1901 to 2007) was observed to be 0.51^0 C with accelerated warming of 0.21^oC per every10 years since 1970 (Krishna Kumar 2009). The projected impacts are likely to further aggravate yield fluctuations of many crops with impact on food security and prices. Climate change impacts are likely to vary in different parts of the country. Parts of Western Rajasthan, Southern Gujarat, Madhya Pradesh, Maharashtra, Northern Karnataka, Northern Andhra Pradesh, and Southern Bihar are likely to be more vulnerable in terms of extreme events (Mall *et al.* 2006).

Rainfall and Temperature Trends

Rainfall is the key variable influencing crop productivity in rainfed farming. Intermittent and prolonged droughts are a major cause of yield reduction in most crops. Long term data for India indicate that rainfed areas witness 3-4 drought years in every 10-year period. However, no definite trend is seen on the frequency of droughts as a result of climate change so far. For any R&D and policy initiatives, it is important to know the spatial distribution of drought events in the country. A long term analysis of rainfall trends in India (1901 to 2004) using Mann Kendall test of significance by CRIDA indicates significant increase in rainfall trends in West Bengal, Central India, coastal regions, south western Andhra Pradesh and central Tamil Nadu. Significant decreasing trend was observed in central part of Jammu Kashmir, Northern MP, Central and western part of UP, northern and central part of Chattisgarh. Analysis of number of rainy days based on the IMD grid data from 1957 to 2007 showed declining trends in Chattisgarh, Madhya Pradesh, and Jammu Kashmir. In Chattisgarh and eastern Madhya Pradesh, both rainfall and number of rainy days are declining which is a cause of concern as this is a rainfed rice production system supporting large tribal population who have poor coping capabilities.

Due to increase in CO_2 levels the earth is warming up. In the last 15-20 years, there has been a sharp rise in the global temperature. While there are varying projections of temporal variations in temperature, there is a near unanimity in its direction and trend **(Fig. 1).** In India too, the overall mean temperature is showing an increasing trend in most parts of the country. The central and western parts showed decreasing trend in maximum temperature while increasing trend of minimum temperature was observed in east, north & southern parts. Until last year, 2009 was the warmest year on record since 1901 (+0.913 ^{0}C) above the normal of 24.64 ^{0}C) and now 2010 has surpassed it (+0.93 ^{0}C). The other warmer years on record in order are 2002 (0.708), 2006 (0.6), 2003 (0.560), 2007 (0.553), 2004 (0.515), 1998 (0.514), 1941 (0.448), 1999 (0.445), 1958 (0.435), 2001 (0.429), 1987 (0.413) and 2005 (0.410).

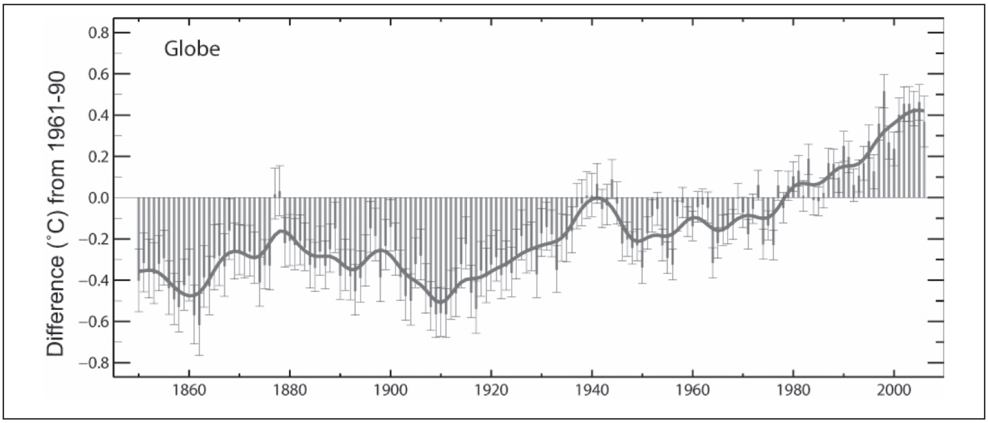

Fig.1 Changes in global temperature trends over the last century

As far as Indian agriculture is concerned, temperature rise during rabi is of more significance. For minimum temperatures, most of the locations in India are showing an increasing trend. This is a cause of concern for agriculture as increased night temperatures accelerate respiration, hasten crop maturity and reduce yields. The increasing trend is more evident in central and eastern zones where rainfall is also showing a declining trend which makes this area more vulnerable and requiring high attention for adaptation research.

Impact on Agriculture, Livestock and Fisheries

The impact of climate change on agriculture may accentuate at regional level creating more vulnerability in food security rather than global level as a whole. The potential impact will be shifts in sowing time and length of growing seasons, which may necessitate adjustment in sowing and harvesting dates, change in genetic traits of cultivars and sometimes total adjustment of cropping system itself. With warmer environment associated with erratic rainfall distribution the rate of evapotranspiration will increase and quick depletion of soil nutrient reservoir would call for much greater efficiency in use of water and nutrients to sustain crop productivity. Apart from these, tackling with frequent and more intense extreme events like heat and cold waves, droughts and floods may become norm of the day for common farming community (IPCC, 2001). Such phenomena will impact agriculture considerably through their direct and indirect effects on crops, livestock, and incidences of pest-disease-weeds, increasing deterioration of soil health in totality and thereby threatening the food security like never before.

Crop production

The Indian Council of Agricultural Research (ICAR) initiated an all India Network project in 2004 to study the possible impacts of climate change on major crops, livestock, fisheries, soils and other biotic factors as well as to understand natural adaptation capabilities of both flora and fauna. The possible interventions to increase the adaptability of crop-livestock systems and mitigation measures to minimize the adverse impacts were studied across different agro-ecosystems of India. The output of the studies (Agarwal, 2009) so far indicated that a marginal 1 ^{0}C increase in atmospheric temperature along with increase in CO_2 concentration would cause very minimal reduction in wheat production in India if simple adaptation strategies like adjustment of planting date and varieties are adopted uniformly. But in absence of any adaptive mechanism, the yield loss in wheat may go up to 6 million tones. A further rise by 5 ^{0}C may cause loss of wheat production up to 27.5 million tones. Similarly, rice yields may decline by 6% for every one degree increase in temperature (Saseendran *et al.* 2000). In addition to direct effects on crops, climate change is likely to impact natural resources like soil and water. Increased rainfall intensity in some regions would cause more soil erosion leading to land degradation. The study on wheat and rice suggested that high temperature around flowering reduced fertility of pollen grains as well as pollen germination on stigma. These effects are more pronounced in *Basmati* rice as well as *Durum* wheat cultivars. A positive finding of the study was that the *Aestivum* wheat cultivars are more or less tolerant to such adverse affects. But differential impact of increasing temperature is observed with respect to grain quality of wheat where it is found that *Aestivum* wheat cultivars are more prone to reduced grain quality due to increasing temperature during the fruit setting stage than *Durum* cultivars. Field experiments using advanced 'Temperature gradient tunnels' with different dates of sowing to study impact of rising temperature on growth and development of different crops revealed that an increase of temperature from 1 to 4 ^{0}C reduced the grain yield of rice (0-49%), potato (5-40%), green gram (13-30%) and soybean (11-36%). However, one of the important pulse, chickpea, registered 7-25% increase in grain yield by an increase in temperature up to 3 ^{0}C, but was reduced by 13% with further 1 ^{0}C rise in temperature.

Horticulture

A significant decrease in average productivity of apples in Kullu and Simla districts of Himachal Pradesh have been reported which is attributed mainly to inadequate chilling required for fruit setting and development. Reduction in cumulative chill units of coldest months might have caused shift of apple belt to higher elevations of Lahaul-Spitti and upper reaches of Kinnaur districts of Himachal Pradesh. However results from simulation models suggest that climate change could benefit coconut crop. Coconut yields are likely to increase by 4, 10, and 20% by 2020, 2050 and 2080, respectively, in the western coastal areas of Kerala, Maharastra, Tamil Nadu and Karnataka. But the impact may be negative in east coast areas as they are already facing a much warmer atmospheric thermal regime than western coast.

Insect and pest dynamics

The impact of rising temperature and CO_2 are also likely to change insect pest dynamics. Dilution of critical nutrients in crop foliage may result in increased herbivory of insects. For example, Tobacco caterpillar (*Spodoptera litura*) consumed 39% more castor foliage under elevated CO_2 conditions than controlled treatments (Srinivasa Rao *et al*. 2009). The advancement of breeding season of major Indian carps as early as March has been reported from West Bengal which is extended from 110 to 120 days due to increase in environmental temperature, which stimulates the endocrine glands of fish and helps in the maturation of the gonads. This brings about a possibility to breed these fishes twice a year at an interval of 30 to 60 days. Increased heat stress associated with rising temperature may, however, cause distress to dairy animals and possibly impact milk production. A rise of 2 to 6 ^{0}C in temperature due to climate change is expected to negatively impact growth, puberty and maturation of crossbred cattle and buffaloes. As of now, India loses 1.8 million tonnes of milk production annually due to climatic stresses in different parts of the country. The low producing indigenous cattle are found to have high level of tolerance to these adverse impacts than high yielding crossbred cattle.

Soil and water resources

Besides, the nutrient loss from soil through high rate of mineralization and CO_2 emissions from soil could be accelerated as a result of increase in temperature. Low carbon soils of mainly dryland areas of India are likely to emit more CO_2 compared to high or medium carbon temperate region soils. Simulation of water balance using Global and Regional Climate Models revealed likely increase in annual as well as seasonal stream-flows of many Indian river basins pointing to the need for adoption of more effective runoff and soil loss control measures to sustain crop production across the country. At the farm level increased temperatures will also increase crop water requirement. A study carried out by CRIDA (unpublished) on the major crop growing districts in the country for four crops, viz., groundnut, mustard, wheat and maize indicated a 3% increase in crop water requirement by 2020 and 7% by 2050 across all the crops/locations. The increase in water requirement for major crops like maize, cotton and groundnut in different agro-climatological zones of AP by 2020 is given **Table 1**. The crop duration is also likely to be reduced by 1-2 weeks.

Table 1 : Crop water requirements to rise: crop duration to decrease (eg. AP in India)

Station	Crop	Increase in water requirement in mm (2020-2025)	Reduction in crop duration (weeks)
Anankapalli	Maize Groundnut	51.7 61.3	1 1
Anantapur	Groundnut Redgram	70.1 174.3	1 1
Jagityal	Cotton Maize	60.5 49.0	2 1
Rajendranagar Tirupathi	Red gram Groundnut Groundnut	114.5 73.0 73.0	2 1 1

(Source : NPCC, CRIDA, 2007)

Managing Weather Risks in Agriculture

A comprehensive strategy of utilization of existing knowledge, strengthening R&D in key areas and evolving a policy framework that builds on risk management and providing incentives to sustainable use of natural resources will be required for successful adaptation by farm sector to climate. The goal of this strategy is to minimize as risks associated with farming and enable farms to cope with these risks (Singh *et al.*, 2009).

Technology options

Small changes in climatic parameters can often be managed reasonably well, by altering dates of planting, spacing, input management, new cultivars adapted to drier conditions, salt water resistant varieties of crops in the areas where drainage is poor development of irrigated agriculture and farming systems like mixed cropping, crop-livestock and that are more adapted to changed environment can further ease the pressure. In addition to these, improving technology to increase production in climate favourable sites in order to offset uncertain production in marginal areas, better adaptation of agricultural calendar, crop diversification to spread risks and setting up processing and storage facilities.

World over, crop diversification is regarded as the most common and effective risk management strategy that is employed by farm households. Multiple cropping system is another strategy that even if a particular crop does not do well, the loss will be compensated by gains in another crop. Optimum use of fertilizers and ecologically clean agro technologies would be another risk management strategy. There are some limitations of this strategy however. First, diversification is clearly a feasible strategy to the extent that crop risks are independent, however, if returns are strongly correlated across crops, the risks facing farmers are similar to systemic risks and crop diversification will not be effective in reducing producer risk. Second, crop diversification calls for spreading resources across crops even when a particular crop offers higher average net returns than other crops. Therefore, the price of diversification is the income foregone, on average, by not growing the remunerative crop. Third, if there are fixed costs in the cultivation of a particular crop, then there is a minimum efficient scale and that may conflict with the requirements of crop diversification. Farmers with smallholdings are likely to run into this constraint. The major impact of climate change in arid and semi-arid regions is likely to be an acute shortage of water resources associated with significant increases in surface air temperature. Some of the management strategies in semi-arid and arid region are as follows:

Semi-arid regions

1. Shift to drought tolerant cultivars
2. Enhancement and maintenance of soil fertility and protection of soils from degradation
3. Development of complementary irrigation
4. Development of early warning system on drought and other climate induced natural disasters
5. Implementing crop-livestock integration
6. Implementing agroforestry systems

Arid regions

1. Shifting from agriculture to other less climate sensitive activities (Livestock, Agroforestry)
2. Use of short duration varieties
3. Optimize planting dates

Policy Options

Apart from the use of technological advances to combat climate change, there has to be sound and supportive policy framework. The framework should address the issues of redesigning social sector with focus on vulnerable areas/ populations, introduction of new credit instruments with deferred repayment liabilities during extreme weather events, weather insurance as a major vehicle to risk transfer. Governmental initiatives should be undertaken to identify and prioritize adaptation options in key sectors (storm warning systems, water storage and diversion, health planning and infrastructure needs). Focus on integrating national development policies into a sustainable development framework that complements adaptation should accompany technological adaptation methods.

In addition, the role of local institutions in strengthening capacities e.g., SHGs, banks and agricultural credit societies should be promoted. Role of community institutions and private sector in relation to agriculture should be a matter of policy concern. There should be political will to implement economic diversification in terms of risk spreading, diverse livelihood strategies, migrations and financial mechanisms. Policy initiatives in relation to access to banking, micro-credit/insurance services before, during and after a disaster event, access to communication and information services is imperative in the envisaged climate change scenario.

Some of the key policy initiatives that are to be considered are:

Mainstreaming adaptations by considering impacts in all major development initiatives. Facilitate greater adoption of scientific and economic pricing policies, especially for water, land, energy and other natural resources. Consider financial incentives and package for improved land management and explore CDM benefits for mitigation strategies. Establish a “Green Research Fund” for strengthening research on adaption, mitigation and impact assessment. (Venkateswarlu and Shanker 2009).

Globally, weather insurance plays an important role in mitigating climatic risks. In several developed countries this strategy has worked successfully as these countries have excellent long term weather data, farmers have large holding and have a business approach for farming. In India, the small holders are generally more prone to risks but they are averse to buy insurance policies. The crop insurance scheme has made some progress but it is a long way to go. Considering the climate trends being witnessed in recent years all over the country, weather based insurance appears to be a better alternative for mitigating risks in agriculture for Indian farmers. The research institutes and insurance companies jointly should develop crop-wise data on the weather sensitivity so that appropriate policies can be designed which are friendly to farmers, at the same time keep the insurance companies viable. The Government also should share the premium burden. Instead of spending huge amounts of money on rehabilitation after the disaster, it is prudent to spend on premium subsidy.

Finally, there is a need to make climate change adaptation and mitigation measures as an integral part of overall planning and development strategy of the country on long term. (Venkateswarlu and Shanker, 2009).

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Countering Climate Change- Strategy to Adaptation

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Climate change is no more a hypothesis. The scientific analysis of trend in global temperature and other climatic indicators leave no doubt that the earths' climate is changing at an alarming rate. The fact is that climate change is a reality that is happening. As recorded in the Fourth Assessment Report of Inter-governmental Panel on Climate Change (IPCC) (2007), global warming is very much evident with the increase in global average air and ocean temperatures, irregular precipitation and extreme rainfall, widespread melting of glaciers, increase in intensity and frequency of storms/ storm surges/coastal flooding and rising global mean sea level. Rising in the sea level and increase in the average global temperature are the direct evidences in support of climate change. Eleven of the twelve years between 1995 and 2006, rank among the twelve warmest years in the instrumental record of global surface temperature since 1850. Global average sea level rose at an average rate of 1.8 (1.3 to 2.3) mm per year between 1961 and 2003 and at an average rate of about 3.1 (2.4 to 3.8) mm per year from 1993 to 2003. Research by scientists have clearly indicated an increase in earth's temperature by about 0.7^0 C. It is also agreed in general that this increase is mainly due to concentration of Green House Gases (GHG) mainly CO_2 which today stands at 380 ppm.

Climate Change and its Impact

General observations about the impacts of climate change

The impact of global warming is evident in the form of increase in intensity and frequency of hydro-meteorological disasters i.e. droughts, cyclones, floods,etc. Observational data clearly indicates increase in tropical cyclones in North Atlantic since 1970. The increase in drought prone areas and frequency of drought incidences is quite common in many countries of the world. Change in rainfall pattern and its duration are also very common observations in most of the tropical countries.

Though climate change is a global phenomenon and every region and sector will be affected by this phenomenon, yet impact of global warming is not going to be uniform. The changes will differ from one location to other; for example, the global warming will be more at higher latitudes than in the tropics. The social implications of climate change will mainly be decided by development, socio-cultural conditions, etc. The population directly depending on natural resources for their livelihood will be the worst sufferer, like communities dependent on agriculture and fishing, the ethnic groups, etc. The impact of global warming is decided mainly, based on prevailing geo-climatic conditions, hydrology and socio-economic factors. The developing countries, including the SAARC countries due to their specific geo-physical characteristics, climatic and socio-economic conditions are supposed to be worst sufferers of the climate change. The extreme weather conditions and unprecedented frequent incidences of hydro-meteorological disasters in these countries during the last decade show that the parts of these countries are already reeling under the impact of climate change. Impact of climate change has been depicted in **Fig.1**. Some other common observations about impact of climate change in some SAARC countries are as follows:

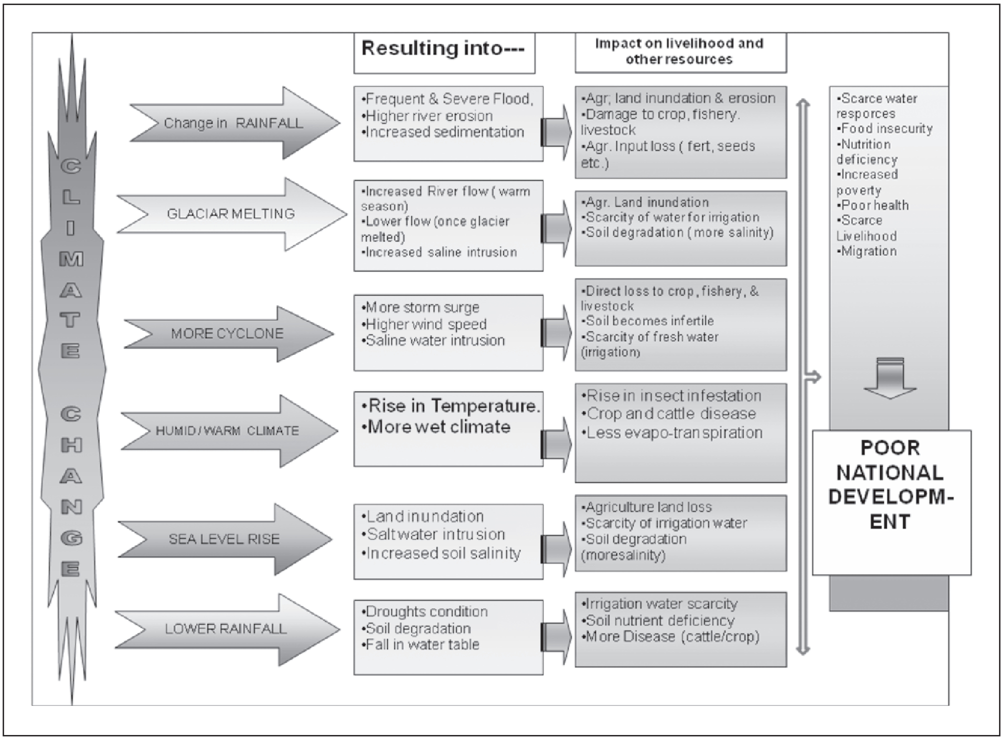

Fig. 1 : Impact of climate change on livelihood and other resources

- Glaciers in Himalayan region are receding due to global warming by 16 meters per year, causing major implication for water availability in glacier fed rivers. As per an estimate 750 million people living in downstream region of such rivers are at risk due to decreasing water availability.
- Water level fall in glacier fed rivers is common observation, especially in Kashmir valley of India; where water levels in almost all streams have fallen by 2/3rd and ground water level is also showing falling trend.

- Frequent floods and droughts have become a common feature in India, Pakistan, Nepal and Afghanistan. Even regions which were supposed to be drought prone observed severe floods in recent past. Floods in desert district of Barmer in Rajasthan in 2006 and historical flood of Pakistan are main examples of extreme weather behaviour.
- Frequent disastrous cyclones in Bay of Bengal hitting east coast of India including West Bengal and Orissa and Bangladesh. In 1999 two cyclones hit Orissa in quite close succession affecting 15 million people.
- Sunderban delta region has been affected by sea level rise; increase in water and soil salinity and disappearance of few islands has clearly established the fact. Four islands in Sunderban delta named Bedford, Lochahara, Suparibhanga and Kabasgadi disappeared due to sea level rise in last twenty years, rendering thousands of families homeless. As per the recent estimates, another island named Sagar may lose five percent of its land mass in next decade. Similarly, increase in soil salinity has adversely affected the agriculture production and resulted in scarcity of fresh water in coastal region of Bangladesh and India.
- Severe heat waves have become a frequent phenomenon, even in coastal regions. In 1998 heat wave conditions in coastal Orissa killed about 1500 people. Similarly, in 2002 severe heat waves conditions recorded in coastal Andhra Pradesh.
- Adverse impact on crop production has been observed in many regions. In India, a shortfall has been observed in apple production in Himachal Pradesh, pearl millet in Rajasthan, paddy and maize production in Kashmir valley, etc.

Impact of climate change on water resources

Among all sectors, the worst impact of climate change is expected to be on water resources. In future, water resources may come under increasing pressure due to changing climatic conditions. The unprecedented increase in temperature will result into severe damage to hydrological cycle. This impact will be disastrous in developing countries, where livelihood of large portion of the population is dependent on agriculture and allied sectors. The climate change will likely affect water supply and its quality and demand. There may be fluctuations in water availability through precipitation, humidity, and temperature, which will result in increasing the level of uncertainty. Such conditions will increase recurrence of hydro-meteorological hazards such as floods, cyclones and droughts. The river system deriving its water from glaciers will be the worst sufferer due to climate change. Studies have shown that an increase in temperature by 1.5^0C will increase the risk of flood in such rivers. A warmer climate may cause reduction in water availability, particularly in arid and semi-arid regions, leading to frequent severe drought conditions.

Climate Change Mitigation and Adaptation

The threat of climate change has aroused widespread international concerns. Keeping in view the severity of the problem and its impact on society and environment, numbers of initiatives are being taken at different levels. To assess the extent of the problem the IPCC has been issuing a series of reports detailing the extent of the GHG emission and potential consequences based on different models. Based on the inputs from the IPCC reports and other researches, the United Nations Framework Convention on Climate Change (UNFCC) came into force in 1994. The UNFCC basically emphasised two main strategies to tackle climate change i.e. mitigation and adaptation. Mitigation in context of climate change refers to finding ways to slow the emission of GHG or to store them in various carbon sinks; while adaptation involves enhancing coping mechanism to climate change i.e. taking measures to reduce the negative impact or exploit the positive ones by making appropriate adjustment (UNFCC).

Mitigation is essential but adaptation is imperative: As per UNFCC policy, both mitigation and adaptation are essential to reduce the climate change risks and increase the vulnerability of the society to resist the impact. Mitigation and adaptation are not alternatives; but both to be pursued actively side by side. Mitigation is essential, but it will not be enough on its own to achieve the desired results, because the rigorous efforts as mitigation today will not be able to prevent climate change in future.

Adapting to climate change is one of the approaches targeted to reduce the impacts due to low frequency long-term changes in climate variables. Adaptation is a process by which strategies to moderate, and cope with the consequences of climate change, including climate variability are enhanced, developed, and implemented. Many structural/physical and institutional adaptation mechanisms have been implemented in the past through conventional top-down approach. However, they lack community participation and livelihood focus. Developing adaptation strategy also requires a vision that balances the need to reduce climate change impacts with any constraints in policy-making processes.

Adaptation often needs employing different forms of technology, whether "hard" forms, such as new irrigation systems or "soft" technology such as insurance or crop rotation pattern. Whatever the level of technology, its application needs systematic and planned approach and the process is likely to be iterative process rather than a one off activity. Ignorance of this approach may lead to mal-adaptation i.e. the adaptation which may create further implications and may lead to increase in vulnerability of the society and environment to climate change risks.

Planned Adaptation to Climate Change

Identifying a suitable adaptation option, its implementation and further ascertain its adaptability to the present as well future climate change risk needs a systematic approach. **Fig. 2** shows different stages involved in developing ideal adaptation strategy. The stages and various sub-components involved in it are discussed in the succeeding text:

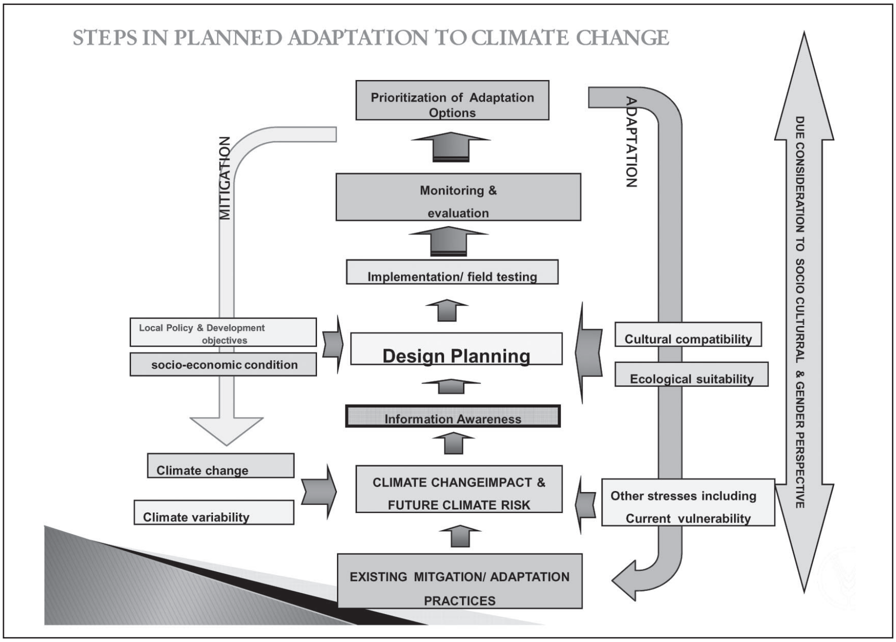

Fig. 2 : Stages in Systematic and Planned adaptation option to climate change

I. Assessment of current vulnerability and existing response practices- This includes:

- assessing natural and socio-economic conditions,
- assessing current climate risks,
- assessing local perceptions about climate risks and impacts,
- documentation of available response mechanism,
- assessing institutional frameworks.

II. Assessment of future climate risks – This includes activities focused on future climate change scenarios, vulnerability and environmental trends as a basis for considering future climate change risks. The main steps are:

- downscaling of climate change scenarios,
- collecting and monitoring local meteorological data,
- undertaking climate impact assessment and outlooks on various sectors (mainly livelihood sector).

III. Identification and testing of adaptation options –This is undertaken with the goal of establishing an adaptation option menu of good practices, identified through stakeholder consultations. The major steps involved are:

- identifying adaptation options including local technologies and science-based knowledge,
- mobilizing communities and raising local awareness,
- building institutional and technical capacity,
- identifying the most suitable extension strategies to introduce and communicate adaptation options to community and other stakeholders,
- validating selected adaptation options at various levels and consolidating them into a menu of good practice options.

The adaptation options menu, thus, developed contains viable technologies for managing climate risks. It synthesized adaptation practices that could catalyze long-term adaptation processes. The adaptation options need to be validated against a set of key criteria before implementation and field testing.

IV. Design location-specific adaptation strategy – It involves identification and selection of viable adaptation options and measures, and the formulation of these options into community-friendly adaptation menus. The key components are:

- undertaking field-based demonstrations for applying adaptation options,
- undertaking economic feasibility studies,
- Increasing advocacy, broader awareness raising and networking.

V Mainstreaming and up-scaling good adaptation practices: For up-scaling and mainstreaming the good field tested adaptation option steps included :

- Advocacy, broader awareness raising and networking
- Economic feasibility studies

Evaluating Adaptation Option

Different criteria and indicators may be used to evaluate the field tested adaptation options and prioritize them as ideal, highly recommended, recommended, recommended in changed conditions in future, not recommended and so on. Thus a Climate Change Adaptation (CCA) option, if applied in the short-term, i.e. under current climatic and socio-economic conditions, has to meet the following four criteria:

i. Ecological suitability
ii. Economical and social feasibility
iii. Capability to reduce climate hazard risk exposure
iv. Control on GHG emissions

Following the above mentioned criteria the field tested CCA options may be prioritized in different following categories (**Fig. 3** indicates prioritization of field tested adaptation options based on these criteria):

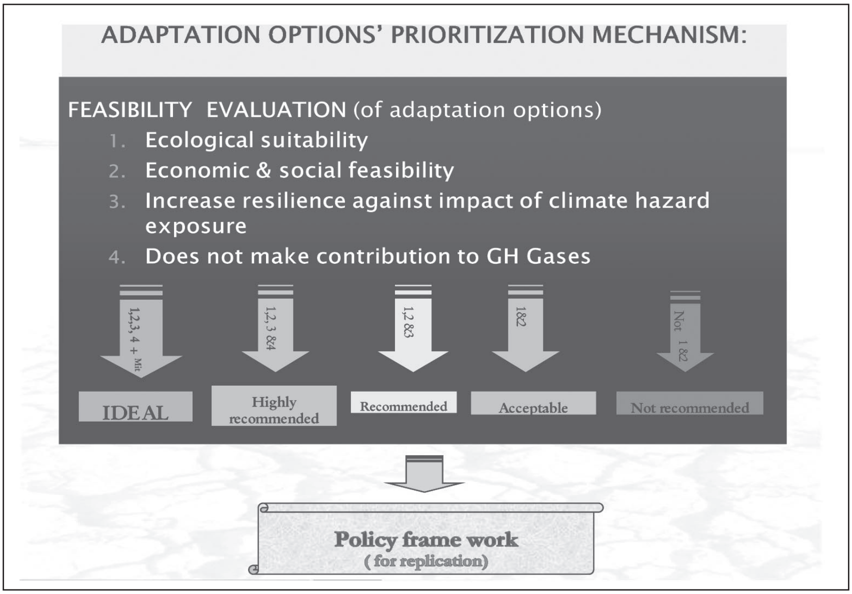

Fig. 3: Evaluating adaptation options to climate change

Recommended- A Climate Change Adaptation option is recommended for replication if it at least fulfils the first two criteria (agro-ecological suitability and economic and social feasibility), along with reducing exposure to hazard risks. This is based on the assumption that any measure that reduces general livelihood vulnerability is also valuable in the broader Climate Change Adaptation (CCA) context, since it reduces overall vulnerability. If an option increases climate hazard exposure, it is not recommended; even if it may seem economically and socially feasible in the short run.

Highly recommended- A Climate Change Adaptation option is highly recommended, if in addition to meeting the first three criteria it does not contribute to GHG emission.

Ideal- a Climate Change Adaptation option is considered ideal, if in addition to meeting the first three criteria, it serves the aim of mitigation by limiting or reducing Green House Gas (GHG) emissions. However, in the context of developing countries this is not a knock-out criterion, given their comparatively high vulnerability to climate change impacts and the resulting urgent need for adaptation.

Recommended in changed framework conditions: If an option reduces climate hazard exposure, but is not economically and/or socially feasible under current conditions, it may currently be not attractive, in particular for the poor with little pre-investment capacities. In that case it is necessary to assess if under changing framework conditions it might qualify later. Therefore, it should not be immediately ruled out, but remain known for the medium to longer term context in which the socio-economic conditions may have changed towards enabling the most vulnerable to make use of the Climate Change Adaptation (CCA) option.

Conclusion

Climate change is putting pressure on all developing countries due to obvious problems of increasing population pressure and high growth and development. In SAARC Region, climate change can bring additional pressure on ecological and socio-economic systems that are already under stress due to rapid urbanization, industrialization, and economic development. This region is highly vulnerable to the impacts of changing climate due to its huge and growing population, a very long and densely-populated and low-lying coastlines, and an economy that is closely tied to its natural resource base.

The impact of climate change can be controlled by proper mitigation techniques as well as through appropriate adaptation. Mitigation is essential but adaptation is imperative and inevitable because even if the most rigorous efforts at mitigation will not be able to prevent climate change and therefore the only alternative left is adaptation. The adaptation to climate change needs a systematic approach to identify and select suitable adaptation mechanism or option that suit the local needs and conditions (natural and socio- economic both) and also can sustain with the future climate change risks. It is advisable that before introducing adaptation option in new environment, it should be properly field tested and evaluated, using appropriate criteria.

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Water Demand Management- A Drought Coping Mechanism

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The initial efforts for agricultural development in the post-Independence era concentrated more on huge irrigation projects. Harnessing of riverine flow through dams built across major rivers provided copious water to boost agricultural production which hastened the Green Revolution supported by the high yielding varieties. The post-Green Revolution scenario is much complex and much more challenging. While the yield levels in the Green Revolution belt are tapering down due to second generation problems, the second Green Revolution is expected to come out of the other half, which is not irrigated by any major irrigation project. Thus, with nearly two thirds of agricultural area cultivated under the influence of monsoons, the key to increasing food production depends on how well rainwater is utilized. Despite best efforts, one half of the total cultivated area in India will remain rainfed forever (Singh *et al*., 2000).

Providing water for irrigation in the large dry tracts of the country is going to be environmentally and socially an expensive proposition. Groundwater irrigation has been expanding at a very rapid pace in India since the 1970s with the growing numbers of groundwater irrigation structures (wells and tube wells) in the country. Their number stood at around 18.5 million in 2001, of which tube wells accounted for 50% and it has been estimated that, the number of groundwater irrigation structures is now around 27 million with every fourth rural household owning at least one such irrigation structure (Shah, 2009). Development and the share of groundwater in the net irrigated area has also been on the rise. Of the addition to net irrigated area of about 29.75 million hectares between 1970 and 2007, groundwater accounted for 24.02 million hectares (80%). On an average, between 2000/01 and 2006-07, about 61% of the irrigation in the country was sourced from groundwater. The share of surface water has declined from 60% in the 1950s to 30% in the first decade of the 21st century.

Groundwater Vulnerability

Though groundwater overuse was recognised as a serious problem for quite some time (Dhawan, 1995; Moench, 1992 and Macdonald *et al*., 1995), conventional approaches to groundwater in India until the mid-1990s have involved a clear focus on the “development” of groundwater resources.

Available data shows that there has been a remarkable change in the groundwater scenario in the country even within a short span of nine years (1995-2004). On the basis of their stage of groundwater development, the districts are classified as "safe" and "unsafe" (districts in the "semi-critical", "critical" and "overexploited" categories). The proportion of "unsafe" districts in India has grown from 9% in 1995 to 31% in 2004 and the area under "unsafe" districts has risen from 5% to 33% and population affected from 7% to 35% within this short span of nine years. The main issue concerning the groundwater use is to create a balance between the water use and recharge in the system and also enhance the sustaibnability of production and to reduce extreme overexploitation of the resource in some parts of the country.

Groundwater Sustainability

Emphasising the need to maintain groundwater balance, the Planning Commission's Expert Group has spoken about the need for "adopting all groundwater management units for a sustainable yield management goal, which means that average withdrawals should not exceed long-term recharge" (Planning Commission 2007: 47). This would be more important in typical rainfed areas where groundwater recharge is largely dependent on rainfall. If groundwater source is used in a judicious way, it becomes imperative to identify the priorities for water use and also to optimize the water use with a view to enhance the total productivity. This involves working out the requirements for water use at local within the user community for sustainable use of water. Sustainable use of groundwater involves adoption of norms related to enhancing recharge through protection of the recharge area, controlling the depth and spacing of wells, regulating capacity and efficiency of pumps used, water-saving irrigation methods and overall regulation of cropping pattern to rationalise water use in agriculture. These rules are facilitated and supported by a scientific understanding of the characteristics of the resource (Kulkarni and Shankar, 2009).

Groundwater Recharge

Contrary to this, investments made on building check dams, percolation ponds, farm ponds, gully plugs and other soil and water conservation measures which are spread across the length and breadth of a watershed lack the spectacular view of a huge dam, but help distribute the benefits of investment more equitably across parched lands. A series (over 13,000) of check dams and farm bunds built all over the drought prone areas of Yavatmal district of Maharashtra has brought hundreds of acres into double cropping by impounding a whopping 56 m cu m of water (ibid). There were several hidden benefits to this effort as well. The water table went up in open as well as tube wells. People migrating during dry seasons stayed back to tend their second crop. Above all, there was no displacement of any household from this area. These accomplishments are no less engineering feats. These are perhaps much more challenging as they pose a variety of situations for augmenting water resources for aiding enhancement of agricultural productivity.

Similarly the study (Ravindranath *at el*., 2011) revealed that the construction of percolation tanks and check dams under the NREGA in Chitradurga district enhanced environmental services through recharging shallow aquifers, increasing the water available for agriculture, and locally reducing soil erosion by trapping soil in check dams. The percolation potential of the villages studied improved by 1,000-28,000 cubic metres a year. In Koverahatti, the construction of percolation tanks improved recharge by 24% in the watershed considered and two check dams increased it by about 1% to 2%. Nagaramgere showed up to a 6% increase in recharge of the region. The Kallahatti check dam and one of the Koverahatti check dams showed a 3% increase in recharge.

Desilting has provided several sustained environmental services, including a rise in the groundwater level, an increase in irrigated area and better soil fertility, thereby increasing food production, and contributing to water and food security in the villages of drought-prone Chitradurga district. Loss of vegetation cover, over-grazing and inappropriate cultivation practices in water catchment areas have led to silting of water bodies such as tanks and dams, resulting in a loss of water storage capacity and reduction of groundwater recharge.

Need for Irrigation in Rainfed Areas:

Agriculture in rainfed areas depends on the vagaries of weather, especially of the rain. The dry areas are characterized by low annual rainfall, the distribution of which varies in space and time. Without doubt, the greatest climatic risk to sustained agricultural production in these areas is rainfall variability, which unfortunately is usually greater in zones of lower mean annual rainfall.

Major constraint in crop production in rainfed is insufficient soil water in the root zone to meet crop water requirements because of unpredicted and uneven distribution of rainfall. Periods of severe water stress are very common and often coincide with the most sensitive stages of plant growth. Therefore, water supplied through supplemental irrigation, if applied in the right amount and at the right time, can make a crucial difference in the yield potential of common crops. It has also been said that supplemental irrigation aims to increase the total farm yield and water use efficiency by maximizing the area that benefits from the water available (Caliandro and Boari, 1992). These two objectives are often contradictory: maximizing the cultivated area usually comes at the cost of providing an optimal amount of water to the crops during the sensitive stages. The preferred objective of supplemental irrigation is to optimize yield per unit of water, which implies the effect of water stress on crop yield during the various stages of crop growth.

Supplemental irrigation is a *temporal* intervention, designed to influence when water is made available to augment natural evapotranspiration. It is irrelevant when daily rainfall is often adequate to support crop growth, but there are frequent periods of shortage, during which the crop would die, or yields would be substantially depressed by moisture shortage. Such a state clearly requires either surface storage, or exploitation of groundwater. Where water is limited in relation to land, supplemental irrigation will be desirable because the productivity of rainfall (which would otherwise evaporate straight back from the bare soil, or would be transpired by non-economic crops) is increased by the addition of relatively small amounts of water which assures the survival of an economically valuable crop.

Groundwater which is less vulnerable to climate change may be the alternative source of irrigation in rainfed areas in the context of climate change scenario. Occurrence of rainfall is more unpredictable in the climate change era which is key source of moisture particularly in rainfed agriculture.

Groundwater Use in Watersheds

Participatory watershed development has proved as an attractive approach for rural development and is seen as a win-win solution as it simultaneously promises natural resource conservation and increase in agricultural productivity. The programme basically consists of bringing cultivable areas under crops according to principles of contour-based cultivation and erosion-prone, less favourable lands under perennial vegetation. This proposition aims at *in-situ* moisture conservation thus increasing the productivity, reducing soil erosion and land degradation. Excess surface runoff water is harvested in irrigation or percolation tanks either for supplementary and/or critical irrigations and sub-surface lateral flow recharging of underground aquifers. The intended impacts of watershed development are, among others, to increase groundwater recharge and increase overall water resource availability. Towards this, soil and water conservation measures (especially bunds), drainage-line treatments such as check-dams, and tree planting aim at reducing runoff and increasing percolation. It has been assumed that increased water availability would be used judiciously for rainfed crops to ensure sustainable yields.

However, in the absence of proper strategies for management of augmented water resources at local level, the resource augmentation increases the competition for the resource itself. This can happen in two ways: switching to water intensive crops and expansion of area under irrigation. As population increases and per capita demand rises for food and water, competition and conflicts over water resources are going to get a lot worse unless radical steps are taken. Both irrigated areas and the total amount of groundwater abstracted have increased substantially, associated with policies to increase food production, subsidies and increased access to loans for farmers to sink wells and purchase pumps, and incentives such as free or cheap electricity. Open-access policies have also led to widespread declines in groundwater levels. In large parts of semi-arid India extraction is exceeding recharge, except during years with rainfall patterns that are conducive to high rates of recharge but almost constant water use across years. In the process, a shift has taken place from traditional large-diameter dug wells to deeper borewells for sustainable sources but without much success.

The most fundamental problem is high levels of water use for irrigation (and inefficient use of irrigation water) with available water sources for limited area resulting in lower water productivity from watershed areas. It has been reported (Lobo & Palghadmal, 1999) that Watershed development projects may actually contribute to increased competition between water use for irrigation and available water sources because extending the irrigated area is often an explicit objective or an unintended outcome.

Demand Management

Demand management of water involving enhancement of water availability and productivity through adoption of improved management practices at a community/group level would be one of the solutions for realizing the potential benefits from increased water resources.

The proposed solution should aim at:

- covering more number of farmers,
- reducing the cropping area under more water consuming crops
- efficient scheduling through critical /protective irrigation for rainfed crops,
- diversification of crops
- sharing of available resources among community members,
- sharing of investment for water distribution mechanism etc.

The above approach envisages providing assured water supply to rainfed crops to overcome intermittent dry spells within rainy season with equitable distribution of water to every farmer within the group/community by harnessing the augmented water resources under watershed programmes. Further, more number of farmers can also be beneficiaries for other subsidies such as free electricity, supply of micro irrigation systems, etc. under these programmes.

Case Study:

Malkaipet Tanda, a small village in Ibrahimpur cluster located in Parigi Mandal of Ranga Reddy district where National Agricultural Innovation Project (NAIP) Component – 3 sub-project on sustainable rural livelihoods is chosen for implementation of the concept of water demand management through sharing of groundwater resources. Most of the farmers belong to the tribal community with possession of drylands with the limited or no irrigation support. They seasonally migrate to nearby towns to meet their livelihoods during frequent droughts. NAIP team visited the village and interacted with the villagers. During the discussion it was found that seventeen farmers share their *pattas* on a 50 acre stretch which had three functioning bore wells and one defunct. Of these 50 acres, only seven acres of paddy was being cultivated while the remaining land was kept fallow during *rabi* season. NAIP team conducted a meeting with farmers and discussed the concept of water sharing through a pipeline network and use of sprinklers for improved application of water among bore well owning farmers and others who did not own bore wells. After several rounds discussions, bore well owing farmers came forward to share the water with others by cutting down the acreage under paddy. They formed a group under the block named as *Lavunipatta Water User Association*. The existing bore well water was not sufficient for all 50 acres, so local anchoring partners (WASSAN) approached District Water Management Agency with a proposal requesting their assistance to dig two community or common bore wells under Comprehensive Land Development Programme. The defunct bore well was also repaired in the meantime. The six bore wells were now ready to provide protective irrigation to the entire block of 50 acres, provided they are networked and water is applied through sprinklers.

The whole block was surveyed with Total Station survey equipment and a layout was drawn for linking of all bore wells to irrigate the block with sprinkler irrigation. The pipeline network work was funded by NAIP and carried out and monitored by beneficiary group with technical support of NAIP team. After completion of work, NAIP team organized a training programme for the user group and trained them in operation and maintenance of pipeline and sprinkler system. User charges were fixed for bore well and non bore well owners. The group of farmers sat together and worked out rabi crop action plan for year 2009. Farmers agreed to cultivate groundnut in 25 acres in the season. The group was further divided into eight sub-groups and assigned a set each of sprinklers and pipes for use and maintenance. Irrigation schedule and irrigation calendar were also prepared based on crop requirement. The mobilization of the community to share groundwater by networking pipeline and installing water sharing system has resulted in increase of irrigatable area to 30 acres (including 5 acres paddy for home consumption) from a meager seven acres.

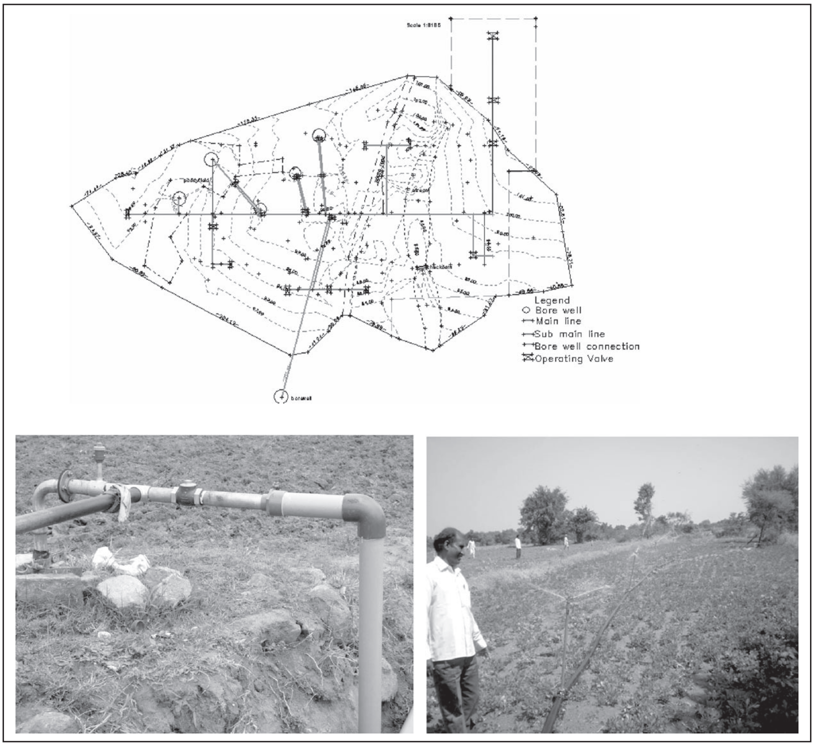
Process of Design and Planning

- Discharge of each bore well was measured in summer to ensure minimum yield of the bore well through out the year.
- Based on the available discharge, the maximum irrigable area was deduced

- A grid survey was conducted by Total Station in order to make a contour map of the study area. Contour map of 0.5 m interval was made from the survey without considering the sub-plots of the farmers so that the total area was considered as single unit for laying the network of pipelines for interconnecting of bore wells and providing of out lets.
- Design of underground pipeline network and sprinkler irrigation using Pythagoras software.
- Pipe line network was first divided in to two sections in order to minimize the cost of the main line as all the six bore wells were located on one side of the area to be served.
- Sub-mains were laid out in such a way that the out lets on the sub-mains are close enough to irrigate the surrounding area with sprinkler irrigation.
- More out lets were provided to cover the entire area with sprinklers.
- The system was designed in such a way that farmers have flexibility to irrigate their lands using five to ten sprinklers at a time from the out lets.
- Optimization of number of operating sprinklers (1500-1800 lph) at a given time (50 to 60) to match with water yield from all the bore wells
- Formulation of a user group consisting of all the beneficiaries. Later the group was divided in to six sub-groups with two to three farmers for easy operation and maintenance of sprinkler system
- Developing of irrigation cycle for promoting consensus among the user group to agree for adopting efficient crop plans
- Capacity building of farmers for operation and maintenance of pipe line network and sprinkler system

Planning of Protective Irrigation from a Community Managed Groundwater Resources

After proper design and lay out (**Fig. 1**)of the pipeline which connected all the bore wells under two different sections, a trail run was conducted to mitigate the leakages and assured sprinkler water reaches the most remote area in other hand all the boundaries of the area. Some technical details were given in **Table 1**. The probability of occurrence of dry spell of more than two weeks in August and September is 18% whereas in October it is 48 %. Therefore, provision was made to irrigate once each in August and September and twice in October. As rainfall during *rabi* season in this area is generally negligible, the entire *rabi* crop needs to be cultivated with irrigation support. Keeping this in view a crop like groundnut which has modest irrigation requirement was chosen for *rabi* cultivation. An irrigation calendar was prepared which depicted the rotation of irrigation cycle among the farmers.



An irrigation calendar for *rabi* groundnut was arrived at for 45 acres representing 18 farmers through a participatory process during the beginning of the season. The farmers were divided in to six groups that enable each with one set of sprinklers to share among them. It was decided to give a 3 cm of water in each irrigation involving in two and quarter hours of sprinkler operation (**Table 1**). Each irrigation cycle was of seven days that cover all the 18 farmers' fields after every seven days the cycle would be repeated. The detailed irrigation calendar was shown in the **Table 2**.

Table 1 : Irrigation design and system particulars

Particulars	**Magnitude**
Total discharge available	30 lps
Main line size	140 mm
Sub mains size	90/70mm
Sprinkler discharge	1800 lph
Sprinkler pipe size	75 mm
Spacing	12 m x 12 m
Power availability	8 hr
One shift time	2 hr 15 min
No of shifts per day	3
Depth of irrigation per shift	3 cm
Irrigation interval	One week

Table 2 : Irrigation calendar of water sharing among the farmers in the network

S. n	Farmer code	Area, ac	no. of shifts	Mon			Tus			Wed			Thu			Fri			Sat			Sun		
1	1	3	8	1	2	3	1	2	3	1	2													
2	2	2.5	7									3	1	2	3	1	2	3						
3	3	4	11	1	2	3	1	2											1	2	3	1	2	3
4	4	3	8						1	2	3	1	2	3	1	2								
5	5	3	8														1	2	3	1	2	3	1	2
6	6	2.5	7	1	2	3	1	2	3	1														
7	7	3	8								1	2	3	1	2	3	1	2						
8	8	2	6																1	2	3	1	2	3
9	9	3	8	1	2	3	1	2	3	1	2													
10	10	2	6									1	2	3	1	2	3							
11	11	2	6															1	2	3	1	2	3	
12	12	3	8	1	2	3	1	2	3	1	2													
13	13	3	8									1	2	3	1	2	3	1	2					
14	14	3.5	10	1	2	3	1	2												1	2	3	1	2
15	15	3.5	10						1	2	3	1	2	3	1	2	3	1						
16	16	2	6																1	2	3	1	2	3

Water Sharing Norms

The following are the water sharing norms:

- The bore well owners have entered in to agreement that each member would contribute Rs 100 per acre of irrigated land and other water users from the pooled water resources will pay Rs 1000 per acre per year.
- The amount thus collected will be pooled in to separate bank account for expenses towards maintenance of the pipeline network.
- The bank account will be operated by the elected body of water user association.
- Every month meetings will be held and the expenses made and deposits received will be reviewed.

Impact of the Intervention:

Cropping area has been increased in *kharif* season from 31 acres in the year 2008-09 to 45 acres in the year 2010-11 (**Fig. 2**). There is 45 percent increase in cropped area with assured supplemental irrigation that ensured sustainable crop production in kharif season even in abrupt climate condition. The area under water intensive crop like paddy was reduced by 30 percent which enabled to provide the supplemental irrigation to other ID crops. Green gram was introduced in the project area in 2009-10 with an extent of 5 acres

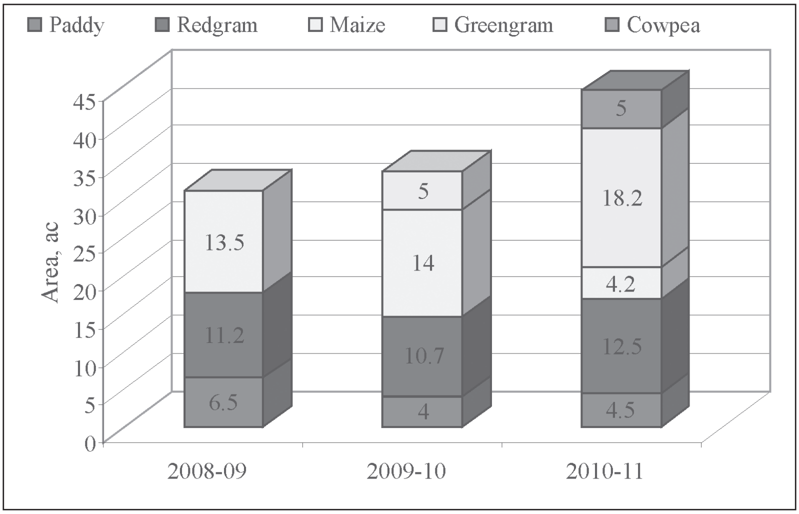


Fig. 2 : Development of cropping area and crop diversification in kharif season under network

and further it was extended to 18.5 acres due to higher yield accrued comparative to maize which could tolerate midterm drought in place of maize. The area under redgram had remained constant. Cowpea was introduced in the year 2010-11 on an experimental basis.

- The study area experienced a tremendous increase of 118 percent in total cropped area from 12.7 acres in 2008-09 to 27.5 acres in 2010-11. The bench mark of groundnut area in 2008-09 was 11.2 acres and which was increased to 21 acres in 2010-11 (**Fig. 3**). Area under cultivation of paddy was also increased because of sufficient rainfall and increase in groundwater.

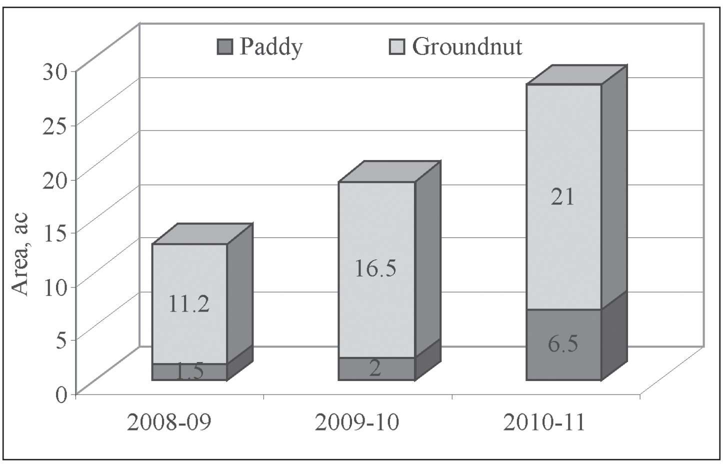


Fig. 3 : Development of cropping area in Rabi season under network

- It was also noticed that the total area under crops in case of non-bore well farmers was doubled from 13.2 acres in 2008-09 to 27.2 acres in 2010-11 in kharif season while no significant change registered in case of bore well farmers (**Fig. 4**). The area under maize crop was reduced in case of both bore well and non-bore well farmers and it was replaced by green gram. The area under redgram was also increased from 7.2 to 11 acres in case of non-bore well farmers.

- In *rabi* season, It was noticed that the area under cultivation of groundwater in case of non-bore well farmers varied from zero in 2008-09 to 8 acres in 2010-11 while it was increased from 12.7 to 19.5 acres in case of bore well farmers (**Fig. 5**). No change in the cropping pattern in the *rabi* season. Moreover the area under paddy crop was also increased from 1.5 to 6.5 acres in case of bore well farmers for the same period (from 2008-09 to 2010-11).

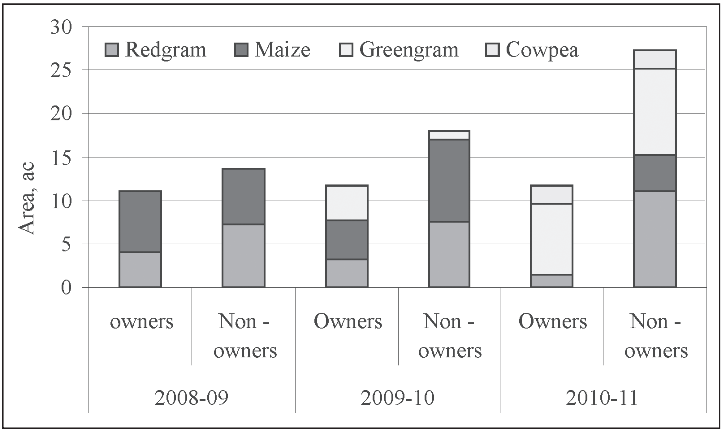


Fig. 4 : Development of irrigation security with bore well and non borewell owners in Kharif season

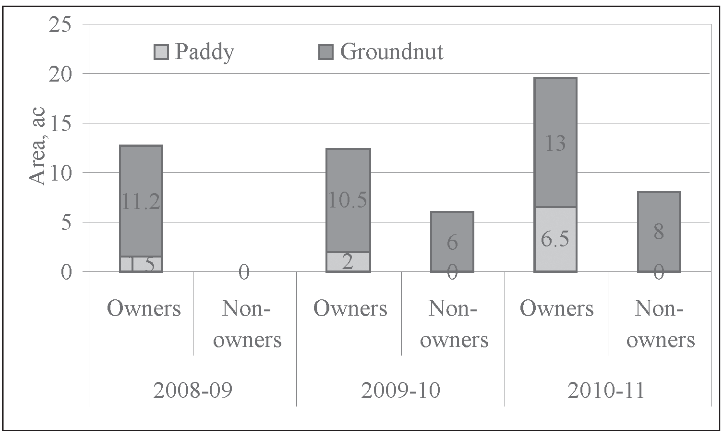


Fig. 5 : Development of irrigation security with bore well and non borewell owners in Rabi season

Lessons learnt so far:

- Bore wells are the individual property and it is difficult to convince the owners unless institutions effectively function with broader mind.
- Careful crop planning is essential for equitable distribution of available water.
- Proper design of network system is essential to ensure proper supply of water within reasonable cost.

Scope for improvement

- Existing development programmes such as micro irrigation systems can be dovetailed to support this type of programs
- Differential subsidy programs can be devised with community/group as focus point rather than individual farmers in rainfed areas
- Existing policy/regulations on water extraction such as WALTA need modification with a view to ensure minimum irrigable area under each dug/bore well
- Large scale awareness programs for farmers and critical support in terms of Human Resource Development for these interventions need to be developed.

Conclusion

It is easier to conceptualize that the available groundwater be better used for cultivating water efficient crops rather than water consuming crops like paddy so that larger area can be brought under the realm of protective irrigation. At the micro level, a farmer lacks both willingness and facilitation to see that the groundwater he owns is shared with his neighbours. This is due to lack of complete understanding of the hydrological behaviour and resource (groundwater). This study has clearly brought out that it requires sustained efforts in engaging with the community and educating the members of the community on prudent resource use in order to harness the benefits of technology. Thus, social engineering needs to be pursued as a much needed tool along with good resource management practices.

Further, the study also underlines that careful crop planning with a practical irrigation calendar is essential for equitable distribution of available groundwater. Proper design of network system is essential to ensure supply of water within reasonable cost. Farmers' participation plays crucial role in equitable distribution of groundwater resources and water management.

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Effect of Climate Change on Water Availability and Demand of Rainfed Rice in a Sub-Tropical Region

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Climate change is a change in the "average weather" that a given region experiences. Climate change refers to changes in the climate of the Earth as a whole, including temperature increase (global warming) or decrease, and change in rainfall distribution. The term "climate change" is sometimes used to refer to all forms of climate inconsistency. Many observations indicate that the world's climate has changed during the 20th century. The average surface temperature has increased by about 0.6°C (1°F), snow cover and ice extent has decreased, and the sea level has risen by 10 to 20 cm .The warming of the climate system is now unambiguous, as proved by observation of increase in global average air and ocean temperatures, widespread melting of snow and ice and rising of global average sea level (IPCC, 2007).

Mall et al. (2006) provided an excellent review of climate change impact studies on Indian agriculture, mainly from the perspective of physical impact. The available evidence shows a significant drop in yields of important cereal crops like rice and wheat under climate change scenarios. However, bio-physical impacts on some of the important crops like sugarcane, cotton and sunflower are yet to be studied adequately. In the Indian context, Kumar and Parikh (2001) estimated the macro level impacts of climate change using distinct approach. They showed that under doubled carbon dioxide concentration levels in the later half of twenty-first century, the gross domestic product would decline by 1.4 to 3% due to climate change.

The IPCC 4th Assessment Report states that South East Asia (SAARC nation) is expected to be seriously affected by the adverse impacts of climate change since most economies are relying on agriculture and natural resources. South East Asia is annually affected by climate extremes, particularly floods, droughts and tropical cyclones, while large areas of the region are highly prone to flooding and influenced by monsoon. Such climatic impacts will severely threaten the livelihood of poor people living in rural areas with limited adaptive capacity.

Climate change is expected to affect the agriculture in South East Asia in several ways. For example, irrigation systems will be affected by changes in rainfall and runoff, and subsequently, water quality and supply. Yet the region already faces water stresses, and future climate change effects on regional rainfall will therefore have both direct and indirect effects on agriculture. Facing with temperature rise of 2-4 °C, studies suggest the potential for both gains and losses. For example, for less than 2°C rise, agricultural losses are experienced in the Philippines, while rice yields in Indonesia and Malaysia are projected to increase. In fact, although climate change impacts could result in significant changes in crop yields, production, storage, and distribution, the net effect of the changes around the region is uncertain because of local differences in growing season, crop management etc. However, climate studies generally indicate increasing rainfall in most part of the region. But even with rainfall increases, temperature increase may threaten agricultural productivity, stressing crops and reducing yields. In particular, scientific studies document a high sensitivity of major cereal and tree crops to changes in temperature, moisture, and carbon dioxide concentration of the magnitudes projected for the region. For example, projected impacts on rice and wheat yields suggest that any increases in production associated with CO_2 fertilization will be more than offset by reductions in yield resulting from temperature and/or moisture changes. Such agricultural impacts particularly affect low-income rural population that depend on traditional agricultural systems or on marginal lands.

Agriculture is always vulnerable to unfavourable weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are important factors, which play a significant role in agricultural productivity. The impacts of climate change on agricultural food production are of global concern and for that matter sub-tropical region, where lives and livelihoods depend mainly on agriculture, is exposed to a great danger, as India is one of the most vulnerable countries due to climate change.

The impacts of an increase in mean seasonal temperature on crop are now reasonably well understood. However, the magnitude of changes in mean precipitation and in sub-seasonal and inter-annual climate variability in future climates is less certain, and the resulting impacts on crop production are also uncertain. Large impacts on food production can occur when climate thresholds, such as temperature, are transgressed for short periods (Wheeler et al., 2000). Temperature will increase in near future in most parts of world due to higher concentration of CO_2 and other green house gases (IPCC, 2000). Higher temperatures can negatively impact on crop production directly through heat stress. Changes in rainfall patterns can have both negative and positive effects on agricultural production. It is felt that global warming will affect agricultural production directly because of alternations in temperature and rainfall and indirectly through changes in soil quality, pests and diseases. It is likely that the currently observed trend of global warming, which has been 0.6°C ± 0.2°C since 1900, will continue and that the average global temperature will increase by 1.4°C to 5.8°C over the period 1990 to 2100. The impact of this type of climate change will probably lead to a decrease in crop productivity, but with important differences between regions (McCarthy et al., 2001).

The uneven seasonal distribution of rainfall may expose the crop to a range of mild to severe intra-seasonal dry spells, which may subsequently affect the yield adversely. Actual crop water stress will depend on rainfall partitioning, water holding capacity of the soil, crop water demand, antecedent soil water and crop water uptake capacity, and requires at least a simple water balance analysis to assess. The addition of rainfall partitioning and timing of dry spells to growth stages, would make dry spell analyses more relevant to farm management. The approach to dry spells applied in this study was directly linked to crop management, where a dry spell was defined as a period of consecutive dry days resulting in a soil water deficit causing crop water stress.

Rice (*Oryza sativa* L.) is the staple food for more than two-third of the world's population. Stable and high yields of rainfed lowland rice are important for food security in many of the subsistence farming system in Asia. About 7.5% of the total rice production comes from irrigated lowland production (Bouman and Toung, 2001). Phenological development of plants is generally related to temperature. At higher temperatures, crops develop faster and their potential production will be generally lower. This does not apply to plants that are mainly photoperiod sensitive. Rainfed rice production is largely dependent on the supply of water during rainy season, with the timing and amount of rainfall playing a critical role. An early arrival of the monsoon and excessive rainfall can cause flooding, which is harmful to young rice seedlings. On the other hand, a late arrival of monsoon usually leads to severe water stress. Ample rainfall during growing season is also essential for attaining optimum yield. Often,higher intensity of rainfall during the monsoon season results in severe flooding and loss of crops. To overcome the loss of crops during flooding, farmers occasionally re-plant rice seedlings in an attempt to avoid food shortages.

Maintaining the security of water resources is a key priority for the South East Asian poor rural population. The region already faces water stresses, and many areas are often dependent upon limited groundwater and rainfall conditions. Climate change will further aggravate water shortage by extreme events such as droughts which undermine food security, or extreme rainfall events which increase the risk of flooding. Challenges to water resources management will therefore be exacerbated by sea-level rise which contributes to salt-water intrusion into available freshwater resources. Scientific assessments of changing patterns of runoff and river flows in the region in the next decades, as well as increase in water management costs and increases of poor rural people affected by water stress is essential.

Large population and increasing demands on the agricultural, industrial, and hydro-power sectors will put additional stress on water resources. Pressure will be most evident on drier river basins and those subject to low seasonal flows. Hydrological changes in island

and coastal drainage basins are expected to be small, apart from those associated with sea-level rise. However, national studies suggest both gains and losses due to projections of increased runoff in some river basins in response to increasing rainfall. For example, water stress in the Mekong Delta will rise, and water shortages in the Philippines may rise of fall.

Materials and Methods

Study area

To evaluate the demand of water for rainfed crop under climate change scenarios, a study was conducted in a few locations namely Kharagpur, DumDum and Purulia, situated on the eastern part of India. The climate of Kharagpur (22.33° N latitude and 87.33° E longitude), Dumdum (latitude 22.38° N, longitude 88.38° E) and Purulia (latitude 23.20° N, longitude 88.28° E) are classified as sub-humid, sub-tropical **(Fig 1).** It is characterized by hot and humid summer in April and May, rainy during June to September, moderately hot and dry autumn in October and November, cool and dry winter in December and January and moderate spring in February and March. The Kharagpur region receives an

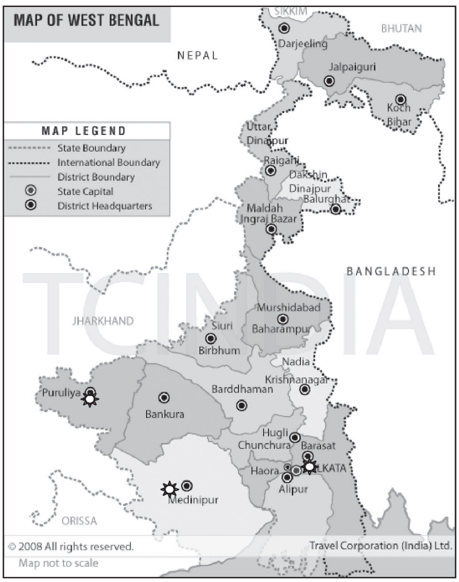
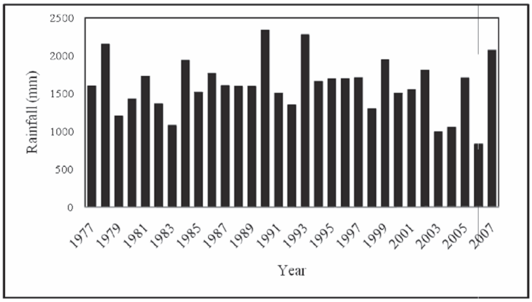


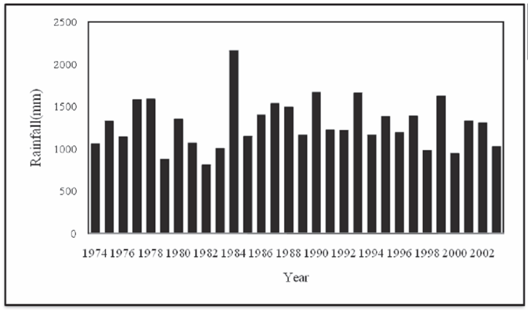
Fig. 1 : The study area (Kharagpur, Purulia and Dumdum)

average rainfall of 1200 mm with an occurrence of 70-75% of the total rainfall in the monsoon season during June to October and the average temperature varies between 21 °C and 32 °C. The Dumdum and Purulia regions receive an average rainfall of 1600 and 1300 mm with an occurrence of 75-85% of the total rainfall in the monsoon during June to October and the average temperature varying between 21.5 °C-32 °C and 26 °C-46

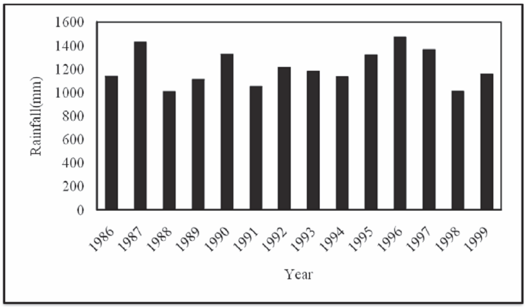
°C. Variation in rainfall for Kharagpur during 1977 to 2007 and for DumDum (1974 to 2003) and Purulia (1986 to 2000) are shown in **Fig. 2.** The soil of this region is of lateritic type with sandy loam texture, which is taxonomically grouped under the group 'Alfisol'.



(a) Kharagpur



(b) DumDum



(c) Purulia

Fig. 2 : Cumulative rainfall during the growth period of rice at (a) Kharagpur, (b) DumDum and (c) Purulia for the years 1977-2007, 1974-2003 and 1986-2000, respectively .

Field Layout and Experimental Details

Field experiments were conducted on rice crop in the experimental farm at IIT Kharagpur under both irrigated and non-irrigated (rainfed) conditions. Thus there were two treatments (rainfed and irrigated) with two replications each. Area of each plot was 40×20 m and was surrounded by raised dikes of 30 cm all around. A short duration (101 days) rice (*Oryza sativa* L.) Variety of MW-10 in rainy (wet season) was grown in all the plots during the experimental period. Rice variety, MW-10 was chosen because it is a high yielding drought resistant variety suited to upland ecosystem (Mandal, 1990). Under irrigated condition, supplemental irrigation (SI) was applied to the crops using harvested rainwater. The area of each tank was 96 m^2, i.e.12% of the total field plot area of 800 m^2. Rice seeds @ 100kg/ha was sown on dry tilled soil with 20 cm spacing between the rows on the day of onset of monsoon in all the plots. Before sowing, farmyard manure@ 5 tons/ha was applied to the soils in all the plots. Seeds were pre-treated before sowing. Nitrogen (N), phosphorus (P) and potassium (K) fertilizers were applied in the form of urea, single super phosphate and muriate of potash, respectively with 60, 45 and 45 kg/ ha.

Weather Data

Daily values of the weather variables such as: maximum, minimum, mean temperature and rainfall for the experimental period were obtained from an automatic weather station installed close to the experimental crop field. Thirty one years of weather data (1977-2007) of Kharagpur were collected for use in the Aqua-crop v.3.1 model. The climatic data for Dumdum (1974-2003) and Purulia (1986-2000) were collected from the India Meteorological Department, Pune. The evapo-transpiration was estimated from temperature by the Hargraves method. By default, Aqu,acrop obtains the atmospheric CO_2 concentration for a particular year from the 'MaunaLoa.CO_2' file in its database which contains observed and expected concentrations at Mauna Loa Observatory.

Crop Data

Crop parameters were measured during different stages of growth. The crop data included days from sowing to emergence, full cover date, maturity date, and harvest date, start of senescence date, maximum rooting date, and maximum root depth. The data on grain yield, above ground actual evapo-transpiration and crop water use efficiency were recorded at different stages of crop growth during each crop experiment.

The Aquacrop v.3.1 Model

Aquacrop v.3.1 (crop growth simulation as well as water balance model) relates its soil-crop-atmosphere components through soil and water balance, the atmosphere (rainfall, temperature, evapo- transpiration and carbon-di-oxide concentration) and crop conditions (phenology, crop cover, root depth, biomass production and harvestable yield) and field management (irrigation, fertility and field agronomic practices) components (Raes et al.,2009a and Steduto et al.,2009).

Aquacrop calculates the daily water balance and separates its evapotranspiration into evaporation and transpiration. Transpiration is related to canopy cover which is proportional to the extent of soil cover whereas evaporation is proportional to the area of soil uncovered. The crop responds to water stress through four stress coefficients (leaf expansion, stomata closure, canopy senescence and change in harvest index). The model reproduces the canopy cover from daily transpiration taking into account leaf area expansion and canopy development, senescence and harvest index. In Aquacrop v.3.1, yield is obtained by multiplying biomass by harvest index. Harvest index (HI) is simulated by a linear increase with time starting from flowering up to physiological maturity. The adjustment of HI in relation to available water depends on the timing, severity and duration of water stress (Hsiao et al., 2009). HI is adjusted for five water stress coefficients namely coefficients for inhabitation of leaf growth, for inhibition of stomata, for reduction in green canopy duration due to senescence, for reduction in biomass due to pre-anthesis stress and for pollination failure (Stedutu et al., 2009). A further detailed conceptual description of Aquacrop is available in Raes et al., (2009a.b).

Calibration and Validation of Crop Model

Soil water in Aquacrop v 3.1 was calibrated using the measured data set of 1998 whereas it was validated using 1999 datasets. Canopy cover was calibrated under nearly optimal growing condition (rainfed) in 1998 (planting on June 21). The main calibration parameters for CC include the canopy growth coefficient (CGC), the canopy decline coefficient (CDC), water stress (P_{upper}, P_{lower}) and the shape factor affecting leaf expansion and early senescence. The measured canopy cover was reproduced by adjusting the stress coefficients. Canopy cover per seedling was estimated based on a general knowledge of the crop characteristics. After calibrating CC, suitable threshold for stomata closure was chosen to reproduce the periodically observed biomass.

The validation of the model for biomass and grain yield was done using independent data sets of the cropping seasons of 1998 (rainfed and irrigated, planted on June 21); 1999 (rainfed and irrigated, planted on June 11) and 2000 (rainfed and irrigated, planted on June 10). During the validation of the model, the observed data were compared with the corresponding simulated grain yield or above ground bio-mass data. Best fit of the simulated data were evaluated graphically and statistically.

Results and Discussion

Long-Term Trend in Variation of Rainfall at the Study Locations

Trend is a long term variation in a time series. It tells whether a particular data set is increasing or decreasing over a period of time. A time series is a sequence of observations which are ordered in time or space. The Mann-Kendall non-parametric test was used to analyse the trend of variation in climatic parameters such as: rainfall, maximum temperature and minimum temperature at Kharagpur, Dumdum and Purulia.

The temporal plots of monthly rainfall **(Fig. 3)** showed the existence of the inter-annual variability in the time scale of 31 years. The thick solid lines indicated the linear trends. The analysis showed that the rainfall for the months of July-September did not exhibit noticeable trend during the period of 1977-2007 except for the month of June which showed a negative trend of 3.95 mm,3.95mm/ year. The results showed that there was no significant trend during June-August at Purulia **(Table 1)** except September where there is a very weak increasing trend. At Dumdum **(Table 2)** there was no significant trend during June and August but a decreasing trend during the month of July and September.

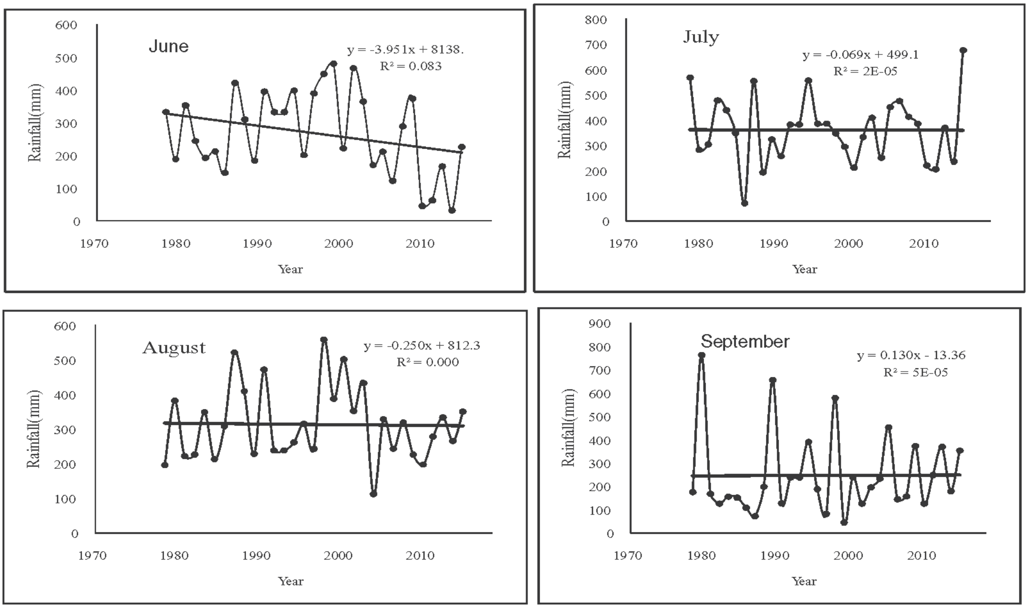


Fig. 3 : Temporal plots of rainfall (mm) from 1977-2007 for the months June-September at Kharagpur. The thick straight lines indicate the best-fit linear trend of rainfall.

Table 1 : The trends of annual rainfall at Purulia (1986-2000)

Month	Rainfall(m value)	R^2
June	-0.02	3E-07
July	1.23	0.00
August	-1.36	0.00
September	8.04	0.09

Table 2 : The trends of annual rainfall at Dumdum (1974-2003)

Month	Rainfall(m value)	R^2
June	0.20	8E-05
July	-1.97	0.02
August	2.05	0.02
September	-0.69	0.00

Figs. 4, 5 and 6 show the temporal distribution of total monsoon rainfall for June-September, which depicts that the rainfall exhibited inter-annual variations in the time scale of 31 years with standard deviation (σ) of 344.88 mm at Kharagpur, 30 years with standard deviation (σ) of 289.40 mm at Dumdum and 15 years with standard deviation (σ) of 151.60 mm at Purulia. The years 1978, 1984, 1990, 1993, 2007 at Kharagpur; 1978, 1984,1990,1993,1999 at Dumdum and 1987, 1996 at Purulia had strong positive

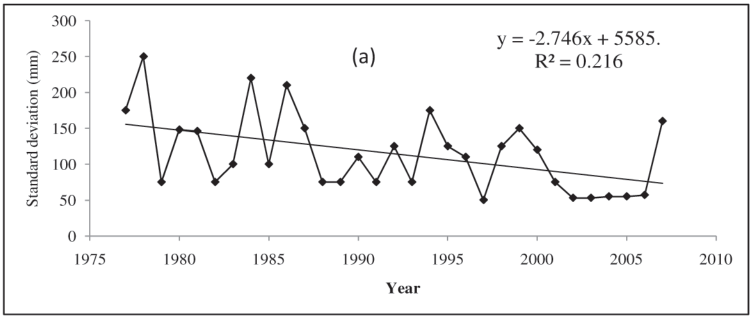


Fig. 4 : The distribution of monsoon rainfall (mm) for the period 1977-2007 at Kharagpur. The thick solid line indicates linear trend.

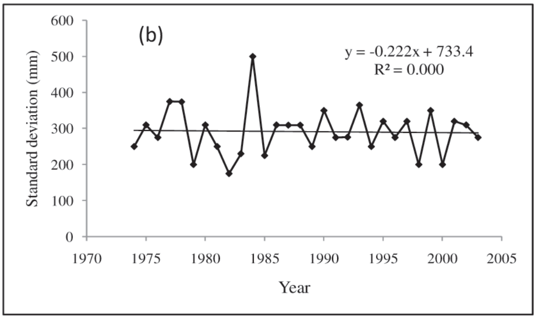


Fig. 5 : The distribution of monsoon rainfall (mm) for the period (1974-2003) at Dumdum. The thick solid line indicates linear trend.

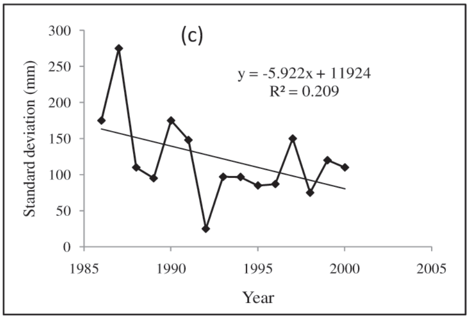


Fig. 6 : The distribution of monsoon rainfall (mm) for the period (1986-2000) at Purulia. The thick solid line indicates linear trend.

anomaly of monsoon rainfall which was close to or higher than +σ. The monsoon rainfall for Kharagpur showed a very weak decreasing trend at the rate of 2.2mm/day. The monsoon rainfall for Dumdum and Purulia showed no significant trend. The dotted horizontal lines in fig: 4, 5 and 6 show the positive and negative standard deviation (σ) of rainfall. The results showed that the monsoon rainfall over Kharagpur, Purulia and Dumdum does not have a definite nature of variation. The impact of such variations on the rice yield is complex. The years 1983, 2003, 2004, at Kharagpur and 1982, 1998, 2000 at Dumdum and 1988,1991,1998 at Purulia had been identified as the drought years with rainfall anomalies equal to or lower than -σ. Since there was no significant trend in the rainfall, the inter-annual variability would mainly be responsible for the climatic impacts on the variation of rice yield. Fig.7 a, b, c shows the temporal variations of rainfall data obtained by using 31 years rainfall data for Kharagpur, 30 years rainfall data for Dumdum and 15 years rainfall data at Purulia. It was indicated that the variability of monsoon rainfall exhibits decreasing trend during the whole period. The decreased variability depicts fluctuation of higher amplitudes in the future resulting in less severe droughts and floods over Kharagpur, Purulia and Dumdum. The years 1993, 2007 at Kharagpur 1984 at Dumdum and 1987, 1996 at Purulia were the flood years with high rainfall anomaly and the crops were severely affected in these years due to the floods.

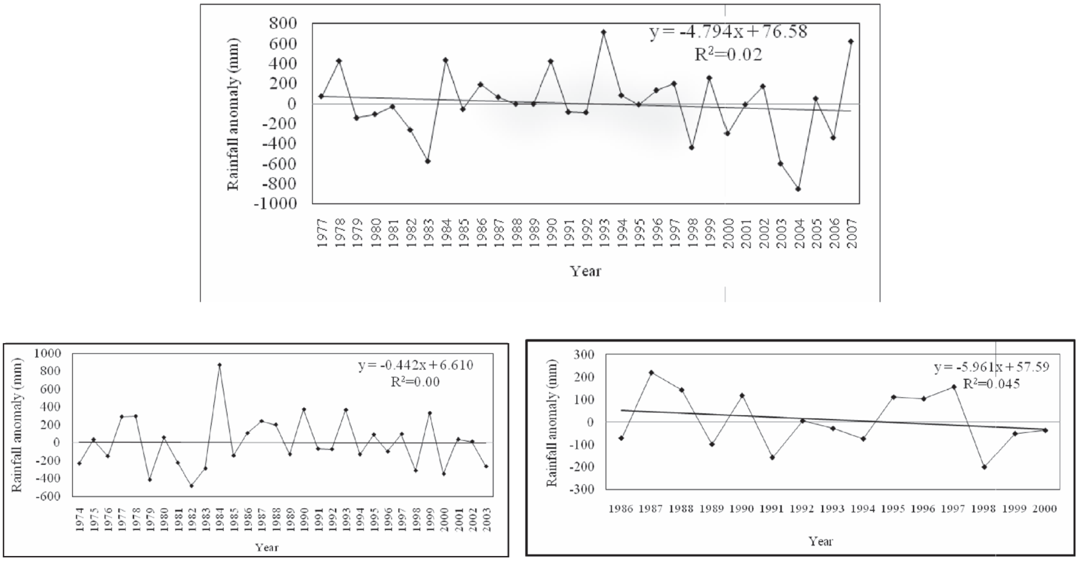


Fig. 7 a, b, c : Variation of rainfall of monsoon rainfall at (a) Kharagpur (1986-2000), (b) Dumdum (1974-2003) and (c) Purulia (1986-2000). The Thick solid line shows the linear trend of σ.

Appropriate Agro adaptation measures

Stochastic dominance (SD) rules were used to evaluate crop management such as date of sowing, planting density (in terms of number of hills and number of plants per hill) and irrigation application in terms of rate and time of application. These fairly simple management options were chosen to illustrate the methodology of combining crop modeling with stochastic dominance.

(i) Adjustments in sowing date:

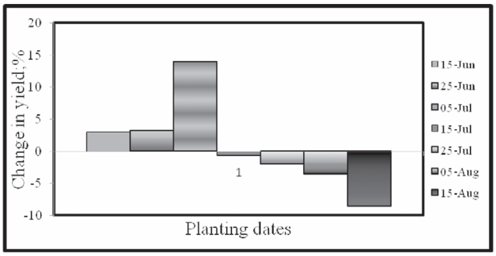
The grain yield was simulated for various planting dates starting on 15th June at 10 days interval up to 15th August to find the optimum planting dates of the variety MW-10 at the three locations in Eastern India. The planting date evaluation of the variety was done using developed climate change scenarios. The results obtained at the 3 regions are given below.

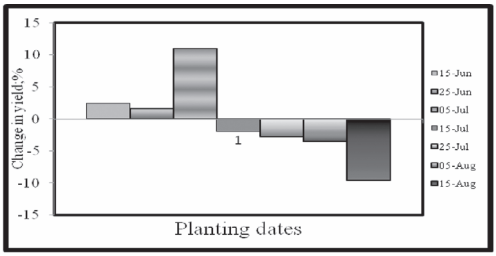
Among the different planting dates the planting on 15th June had highest simulated grain yield of 2500.87 kg ha^{-1}, 2435.06 kg ha^{-1}, 2413.12 kg ha^{-1},2325.37 kg ha^{-1} whereas planting on 15th August simulated the lowest grain yield of 2018.25 kg ha^{-1},1996.31 kg ha^{-1},1974.37 kg ha^{-1},1952.44 kg ha^{-1} for MW-10 rice for the fixed scenarios under the elevated CO_2 (200 ppm over the ambient) and rise in temperature (1°,2°,3° and 4° C over the ambient) at Kharagpur (Fig 8). The lowest reduction in grain yield was noted for the 15th June planting for different scenarios.

The simulated cumulative probability curves showed the best planting time of 5th July for the fixed scenarios under the elevated CO_2 (200 ppm over the ambient) and rise in temperature (1°,2°,3° and 4 °C over the ambient) for rainfed rice. Higher yields were simulated for 5th July and lower grain yields for all other planting dates (Fig 8).

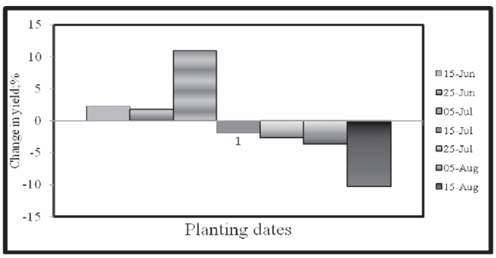
Among the different planting dates 15th June planting was noted to be the best planting time in Purulia. With the fixed scenarios of 200 ppm rise in CO_2 concentration and rise in temperature of 2°, °3 °and 4° C over the ambient, the simulated grain yield was decreased for all planting dates. There was a marginal rise in yield for the elevated CO_2 and rise in temperature of 1 °C. Increase in yield of 1% was found for 15th June planting for elevated CO_2 and rise in temperature of 1° C. With elevated CO_2, lowest reduction in yield was found for 15th June,25th June and 15th July planting for rise in temperature of 2 °C,3 °C, and 4 °C respectively **(Fig: 8 a, b, c).**

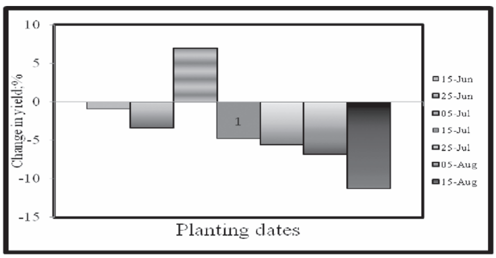
(T1) (a) (T2)



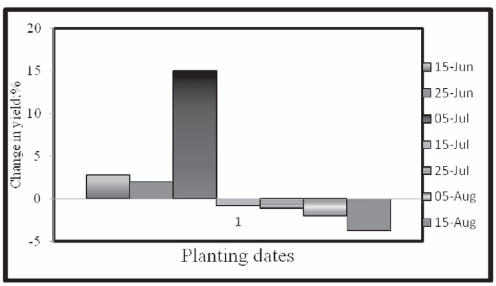


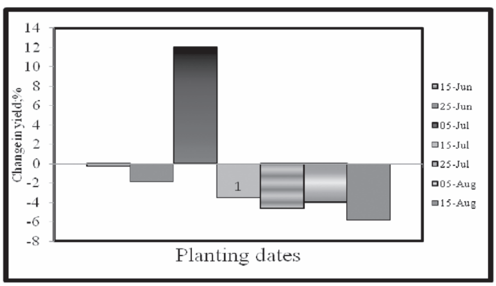
(T3) (T4)





(T1) (b) (T2)





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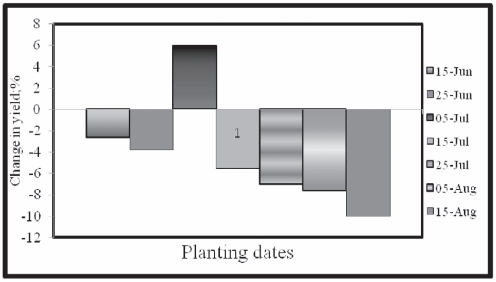
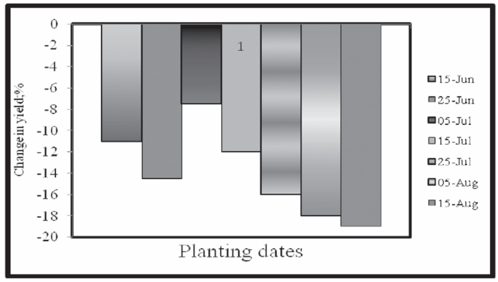
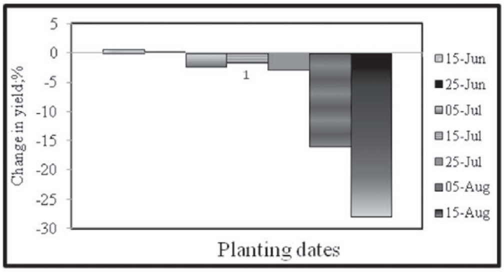
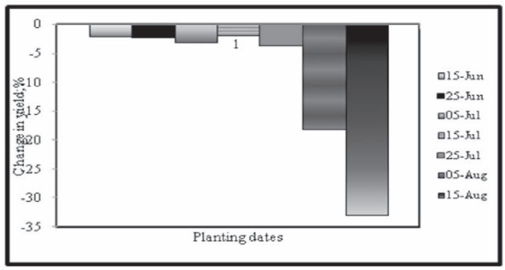




(T1) (c) (T2)





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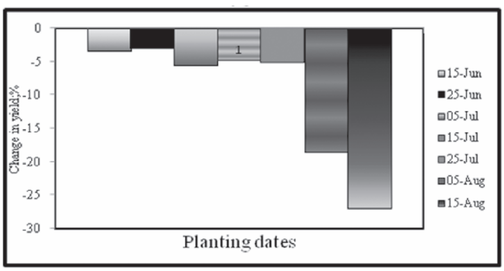
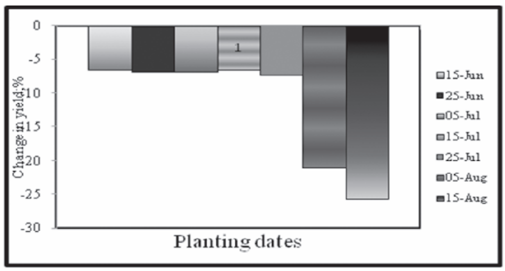




T1=1°C T2=2°C T3=3°C T4=4°C

Fig. 8 a, b, c : Change in yield under the elevated CO_2 (200 ppm over the ambient) and rise in temperature for the variety MW-10 for different sowing dates at (a) Kharagpur (b) Dumdum and (c) Purulia

(ii) Crop yield in relation to radiation use efficiency:

Growth and yield of rice in response to plant densities and irrigation (optimum to stress) were analyzed in terms of interception and utilization of photo-synthetically active radiation (PAR) and water use efficiency (WUE). The amount of solar radiation intercepted by a crop is a major determinant of the total dry matter (TDM) produced. Therefore analysis of crop growth should consider TDM as a product of the amount of photosynthetically active radiation (PAR) intercepted by the crop, multiplied by an efficiency factor (Monteith, 1977, & Gallagher & Biscoe 1978). Such analysis suggests that radiation utilization efficiency is a conservative quantity (Monteith & Elston 1983), whilst the amount of radiation intercepted is the variable that determines the crop yield.

At present, very few studies with rice have analyzed crop performance in terms of radiation interception and utilization. During the crop growth period, the total amount of incident PAR received during the growing season was 2077 MJ m^{-2}, of which only 47.81 % was intercepted in Kharagpur (Table 4); PAR was 2115.4 MJ m^{-2}, of which only 38.80 % was intercepted in Dumdum (Table 5); and the PAR was 2088.3 MJ m^{-2}, of which only 43.33 % was intercepted in Purulia (Table 6). The amount of PAR intercepted differed significantly with plant densities. The plant density of 112 plants m^{-2} resulted in the interception of more radiation than other plant densities during both the seasons. For the plant density of 16 plants m^{-2} the yield was high in the three regions, at plant density 48 plants m^{-2} the yield decreased and at plant density 112 plants m^{-2} the yield again increased. Generally higher irrigation regimes with changing plant densities, intercepted significantly more PAR as compared to lower levels of irrigation .The values of PAR and yield increased continuously for I1, I2, I3, I4 and I5 treatments respectively. Plant density significantly affects the radiation utilization efficiency for TDM and grain yield during both the seasons. Overall mean RUE for TDM and grain yield was 5.56 g MJ^{-1} and 0.2.41 g MJ^{-1}, for three regions respectively.

Table 4 : Simulated water and radiation use efficiencies as affected by plant density and irrigation regimes during rice growth season at Kharagpur.

Treatment	Total intercepted PAR (MJ/m^2)	TDM (kg/ha)	Grain yield (kg/ha)	RUE_{TDM} (g/MJ)	RUE_{GY} (g/MJ)	WUE ($_{TDM}$) (kg/ha /mm)	WUE ($_{GY}$) (kg/ha /mm)	CUMULATIVE ET (mm)
Plant density								
D1(16plants/m^2)	1085.15	6194	2806	5.70	2.58	24.61	11.15	251.6
D2(64plants/m^2)	1080.47	6497	2903	6.01	2.68	25.36	11.33	256.1
D3(112plants/m^2)	1089.81	6410	2875	5.88	2.63	25.07	11.24	255.6
Irrigation regimes+ Plant density								
I1(62mm+ 16 plants/m^2)	1037.34	10652	5014	10.26	4.83	29.52	13.89	360.8
I2(78mm+ 48plants/m^2)	1022.55	11203	5276	10.95	5.16	30.16	14.20	371.4
I3(93mm+ 80 plants/m^2)	1017.58	11492	5420	11.29	5.32	30.49	14.38	376.8
I4(108mm+ 112 plants/m^2)	1010.57	11694	5523	11.57	5.46	30.71	14.50	380.7
I5(123mm+ 134plants/m^2)	1007.55	11809	5583	11.72	5.54	30.82	14.57	383.1

Table 5 : Water and radiation use efficiencies as affected by plant density and irrigation regimes during rice growth season at Dumdum.

Treatment	Total intercepted PAR (MJ/m^2)	TDM (kg/ha)	Grain yield (kg/ha)	RUE_{TDM} (g/MJ)	RUE_{GY} (g/MJ)	WUE ($_{TDM}$) (kg/ha /mm)	WUE ($_{GY}$) (kg/ha /mm)	CUMULATIVE ET (mm)
Plant density								
D1(16plants/m^2)	1294.44	6766	2622	5.22	2.03	27.13	13.12	265.6
D2(64plants/m^2)	1323.91	7443	2737	5.62	2.07	27.85	13.31	267.2
D3(112plants/m^2)	1336.95	7303	2697	5.46	2.02	27.42	10.12	266.3
Irrigation regimes+ Plant density								
I1(62mm+ 16 plants/m^2)	1182.39	11336	5475	9.58	4.63	31.37	15.15	361.3
I2(78mm+ 48plants/m^2)	1167.81	11897	5747	10.18	4.92	32.03	15.47	371.4
I3(93mm+ 80 plants/m^2)	1167.81	12211	5899	10.45	5.05	32.40	15.65	376.8
I4(108mm+ 112 plants/m^2)	1157.26	12436	6008	10.74	5.19	32.66	15.78	380.7
I5(123mm+ 134plants/m^2)	1151.93	11809	6070	10.25	5.27	30.82	15.84	383.1

(iii) Crop yield in relation to water use efficiency:

Efficient use of water or water use efficiency in rice production is of paramount importance in view of projected boost in rice production to meet the growing population (Ahmad et al., 2005a). Previous studies have demonstrated that grain yield increases proportionally with water supply, particularly higher under flooded irrigation (Sharma, 1987). Heenan & Thompson (1984) found that delaying flooding until two weeks before panicle initiation reduced water use by 30% without incurring any significant loss in yield of rice crop. During crop growing season, the D1 and D3 densities significantly increased crop ET over D2. Cumulative crop ET of D1 and D3 were statistically at par. Generally for higher irrigation regimes, in both seasons, evapotranspiration was significantly higher as compared to lower levels of water depths in three regions (Tables 4, 5 and 6). Plant density significantly affects the WUE for TDM and grain yield during both the seasons. Overall mean WUE for TDM and grain yield were 31.91 kg ha^{-1} mm^{-1} and 4.92 kg ha^{-1} mm^{-1} respectively.

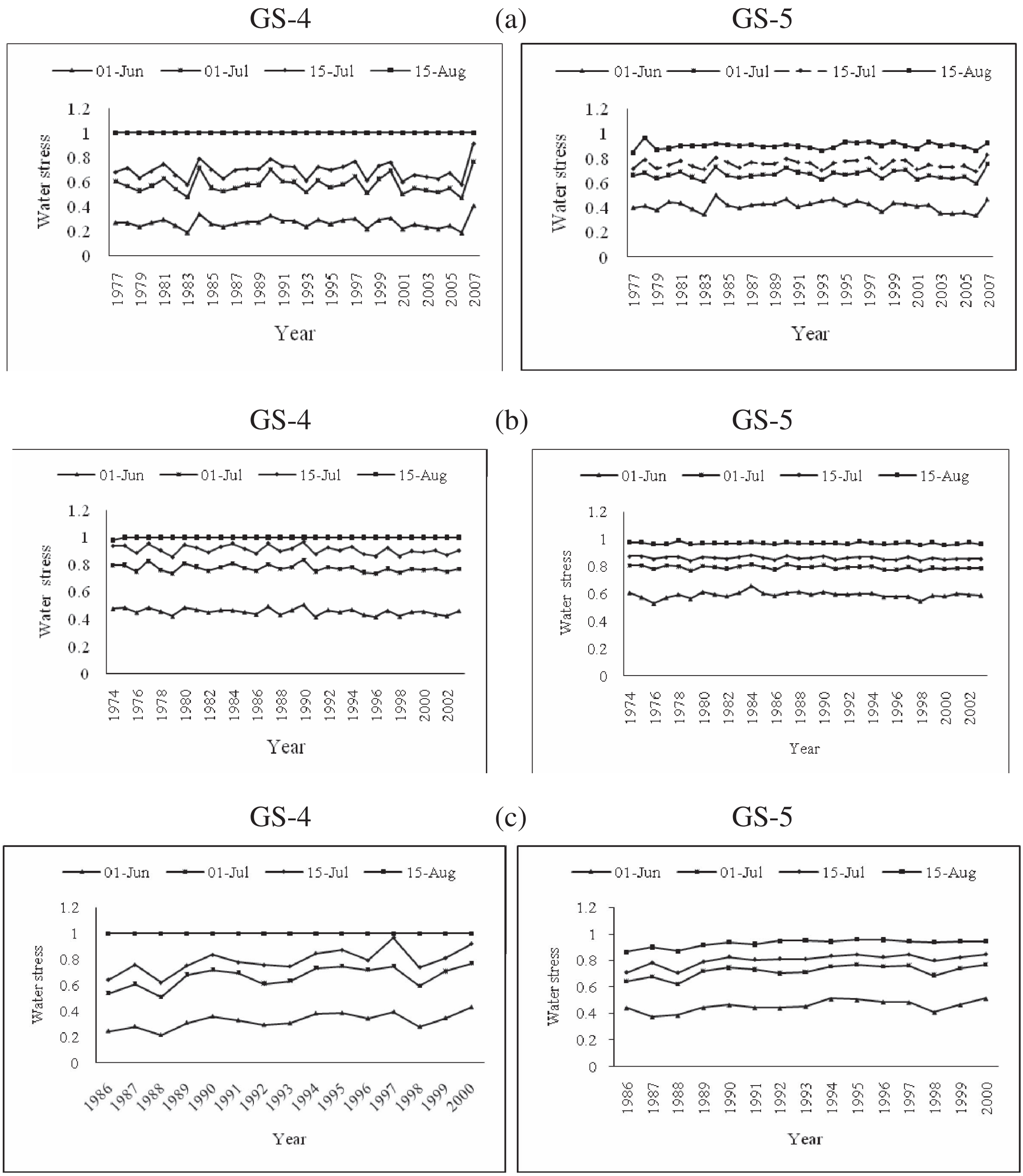
Table 6 : Water and radiation use efficiencies as affected by plant density and irrigation regimes during rice growth season at Purulia.

Treatment	Total intercepted PAR (MJ/m^2)	TDM (kg/ha)	Grain yield(kg/ha)	RUE_{TDM} (g/MJ)	RUE_{GY} (g/MJ)	$WUE_{(TDM)}$ (kg/ha/mm)	$WUE_{(GY)}$ (kg/ha/mm)	CUMULATIVE ET (mm)
Plant density								
D1(16plants/m^2)	1183.42	6471.35	3106.25	5.46	2.62	43.99	21.11	147.1
D2(64plants/m^2)	1183.42	6335.22	3066.25	5.35	2.59	43.30	20.95	146.3
D3(112plants/m^2)	1198.33	6410.31	3098.25	5.35	2.58	42.50	20.54	150.8
Irrigation regimes+ Plant density								
I1 (62mm+16 plants/m^2)	1183.42	12390	6195	10.46	5.23	49.22	24.61	251.7
I2 (78mm+48plants/m^2)	1158.02	12824	6412	11.07	5.53	50.15	25.07	255.7
I3 (93mm+80 plants/m^2)	1152.85	13580	6790	11.78	5.88	52.47	26.23	258.8
I4 (108mm+112 plants/m^2)	1142.43	14239	7120	12.46	6.23	54.59	27.30	260.8
I5 (123mm+134plants/m^2)	1137.18	14384	7192	12.64	6.32	54.96	27.48	261.7

The study demonstrated a linear relationship between yield (TDM, seed yield), accumulated PAR and Cumulative ET in the three regions. With the increase in PAR, the TDM yield decreased and with the increase of cumulative ET the TDM and yield increased in three regions.

(iv) Effect of Transplanting and moisture stress on yield

Late transplanting causes moisture stress during the flowering and maturity stages, resulting in lower yield. Rice plant productivity and yield are most sensitive to water stress during the flowering and maturity stages (De Datta, 1981; Yoshida, 1981). A soil water deficit factor, SW_{DEF} that ranges from 0.0 to 1.0 is used in the aquacrop model to determine the relationship between water availability and yield **(Fig. 4.35 a, b and c)**. Fig. 9 shows declining yields due to increasing water stress during flowering and maturity stages at Kharagpur,Dumdum and Purulia. As farmers move the transplanting date to the later part of the monsoon, the possibility of water stress during the flowering and the maturity stage increases. However, if farmers in subtropical regions sowed short variety MW-10 rice on 1st June, the occurrence of water stress during flowering and maturity stage was minimal **(Fig. 9)**. For a 1st July sowing date, however, rice plants mostly experienced low levels of water stress during the maturity stage. Although water stress



GS-4=Flowering stage GS-5=Maturing stage

Fig 9: Water stress under flowering and maturing stages at (a) Kharagpur (b) Dumdum and (c) Purulia.

was very occasional during the flowering stage, for a 15th July sowing date, it became significant during maturity stage and thus adversely affected the simulated yield. For the 15th August sowing, high water stress reduced yield noticeably. All locations experienced high to severe water stress during the flowering and maturity stages with this sowing date. The crop loss for the 15 August sowing date resulted from the combined water stress that occurs during the last two growth stages. Thus, water stress played a key role in determining the yield of rainfed short season MW-10 rice. During the monsoon season, soil water availability is not limited. As a result, the intra-seasonal rainfall variability does not play a major role. By sowing rice seedlings at the appropriate time, however, farmers can ensure an optimum yield. Water stress at the end of the rice-growing season caused by a late sowing date can significantly reduce yield.

For future agricultural and socio-economic planning, quantitative estimates of potential MW-10 rice yield under water stress during flowering and maturing stages are essential. To fulfill this objective, the results were interpreted to determine a critical value over which yield declines noticeably. It was found that when SW_{DEF} is 0.7 during flowering and or maturing stage potential yield reduced significantly. Thus, $SW_{DEF} < 0.7$ and >0.7 were designated as indication of low and high water stress, respectively. The model estimated that the average yield for the subtropical region was 2267 kg ha^{-1} under low water stress during both flowering and maturity stages for the 1st June sowing date. Potential yield declined 56% for high water stress during maturity stage only (Fig. 4.36 a, b and c). For a 1st July sowing date, potential yield in the subtropical region was 2158 kg ha^{-1} under low water stress during flowering and maturity stages. However, this region losses 30% and 70% yield when high water stress occurred during maturing stage and both flowering and maturity stages, respectively . For a 15th July sowing date, Subtropical region would produce 1842 kg ha^{-1} rice under low water stress during both flowering and maturing stages. Potential yield declined 43%, 52%, and 67% for high water stress during maturing stage, flowering stage, and both flowering and maturing stages, respectively. For a 15th August sowing date, a similar trend in yield loss was observed for high water stress during flowering and maturity stages. High water stress during the maturity and flowering stages resulted in 32% and 69% yield loss compared to low water stress conditions for this sowing date (Fig. 10 a, b, c). Frequency of high water stress during the flowering stage only is higher compared to the high water stress during both flowering and maturing stages. Analysis of the data suggests that high water stress during the flowering stage is usually associated with dry conditions for the growing season.

Therefore, greater potential yield reduction under high water stress during the flowering stage only, as compared to the water stress during both flowering and maturing stages, is a result of highly anomalous hydro climatic conditions.

Rice yield comparison for different cultivars using two crop growth models

Comparison of simulated rice yield was done using aquacrop and DSS_AT software for three rice cultivars MW-10 (104d), Lalat (110d) and Swarna (150d). The results from two software showed that swarna had a higher yield for the three regions and MW-10 had a lower yield in all the three regions. The reason was mainly due to the fact that Swarna is a long duration variety of rice and MW-10 is a short duration variety of rice. Lalat variety has a medium yield as simulated by two software. Moreover the results from the two software presented a negligible difference between the results **(Fig: 11).**

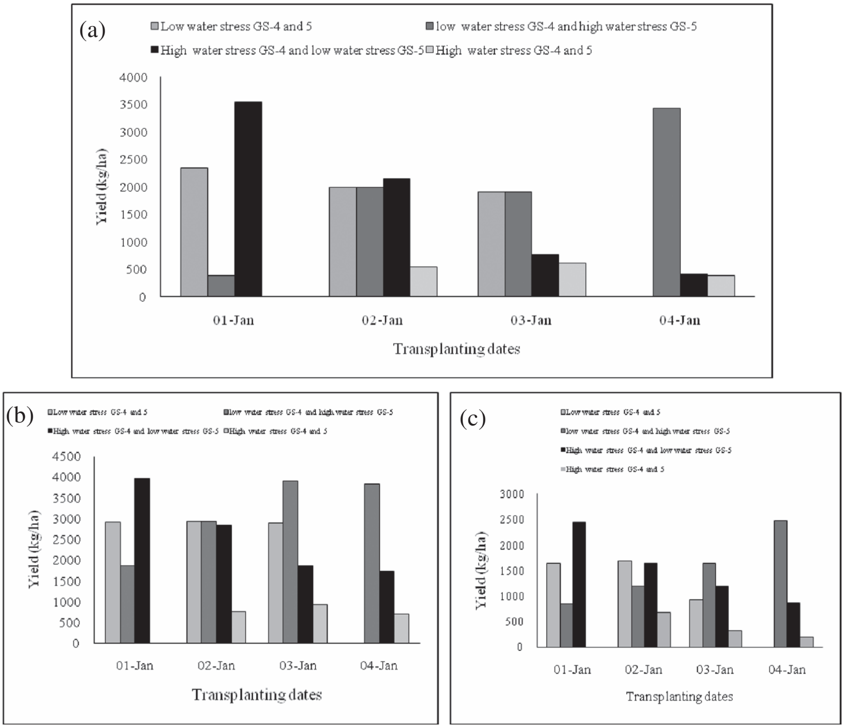


Fig. 10 a, b, c : Water stress and regional potential yield at Kharagpur under four transplanting dates at (a) Kharagpur (b) Dumdum and (c) Purulia.

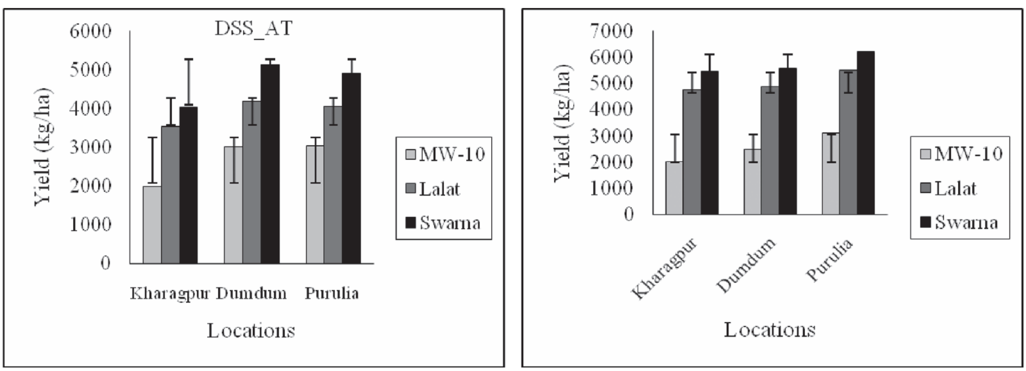


Fig. 11 : Comparison of yield by DSS AT and Aquacrop software for (short duration, medium duration and long duration) different cultivars of rice varieties in subtropical region. The vertical line indicates the standard deviation.

Conclusion

The aquacrop model is able to simulate the seasonal gross crop water requirement, irrigation water requirement and yield response to water for mw-10 short season rice at the three locations of the subtropical region in eastern India. Climate variability leads to large annual fluctuation in the grain yield. Increase in temperature will affect rice yield negatively, while increase in CO_2 concentration and quantum of rainfall will have positive effect on yield. Alternative management practices such as proper sowing date, planting density and various irrigation regimes in terms of rate and time of application will help to mitigate negative effects of climate change. A soil water deficit factor $sw_{def} < 0.7$ and >0.7 were designated as indication of low and high water stress respectively by the aquacrop model. 1st June and 1st July sowing date experienced a minimal water stress; whereas 15th July and 15th August sowing date experienced high water stress resulting in reduction in the yield noticeably. Comparison of the rice yield using Aquacrop and DSS_AT software revealed a negligible difference between the simulation results obtained from them.

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Ecological Forecasting using TOPS for Weather Risk Management in SAARC Countries

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Over the past three decades population is nearly doubled, resulting in enormous pressure on natural resources, particularly water in the semi-arid regions. Climate projections indicate that the situation will only get worse, with a projected possible 30-50% reduction in runoff (Gosain et al., 2006). Therefore, it is beneficial to start planning for the next few decades so that increased food demands can be met with shrinking supplies of water. Several barriers will prevent SAARC countries from significantly expanding access without technological innovation. Installing weather stations is costly, and operations and maintenance in remote areas adds greater cost and complexity. Expansion of existing surface meteorology networks requires significant capital for deployment (over Rs. 3 lakh per weather station) and maintenance expenses (~ Rs. 30,000 per year per weather station), as over few thousands of weather stations are potentially required to cover all the notified villages in the country[1] . Technological innovation will be required to exploit existing infrastructure and inform future deployment strategy to reduce capital expenditure requirements.

Terrestrial Observation and Prediction System (TOPS)

The Terrestrial Observation and Prediction System (TOPS) is designed to integrate weather and land surface information from satellites with simulation models to understand and predict ecosystem states and activity, including the risk of drought and floods, crop water requirements, and crop yields (Nemani et al., 2009). As described above, one of the key functions of TOPS is to collect, process and grid surface weather observations to generate spatially continuous fields of meteorology that are, in turn, used in modeling ecosystem and agricultural water and carbon budgets (**Fig 1**). TOPS has been producing data (including interpolated meteorological surfaces) operationally for California and the United States on a daily basis since 2004, and has also been applied to create daily meteorological surfaces for multiple regions around the world extending from 1950 onwards to till date. By providing a comprehensive suite of environmental measures in consistent formats, TOPS also facilitates the development and support of a wide range of applications for environmental resource monitoring and management at a range of spatial and temporal scales. A number of U.S. Federal agencies are currently collaborating with NASA on the development of applications of TOPS, including use by the National Park

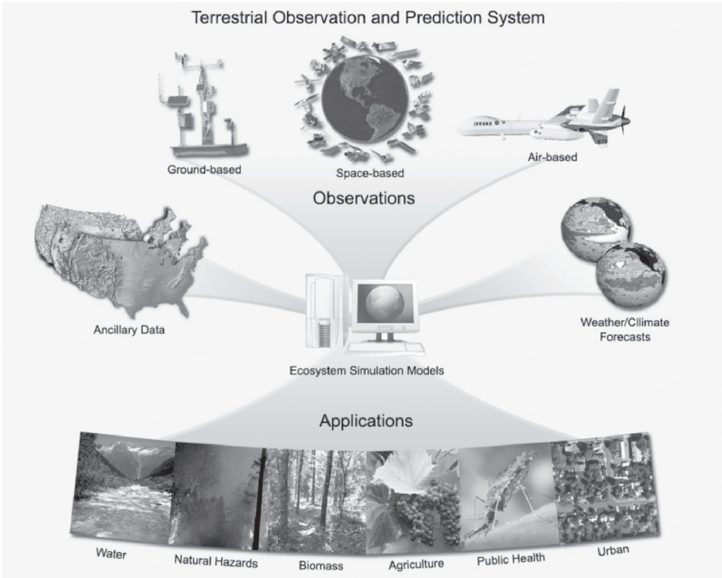


Fig. 1 : TOPS framework showing data-model integration and various application domains where TOPS data have been used.

Service and the U.S. Fish and Wildlife Service to monitor and forecast environmental conditions in national parks and protected areas; use by the California Department of Water Resources to monitor and forecast irrigation demand; use by the NOAA National Marine Fisheries Service to forecast stream temperatures to improve habitat managed for endangered salmonid species; use by the California Department of Public Health to monitor meteorological conditions associated with increased risk of West Nile virus; and experimental use by the USDA Risk Management Agency to improve forecasting of crop yields. Development of these applications has relied on the meteorological surfaces produced by TOPS, which can be used to drive mechanistic models or develop new statistical models relating land surface conditions to a range of related biological processes and agricultural metrics.

Surface Observation and Gridding System

TOPS utilizes the Surface Observation and Gridding System (SOGS) (Jolly et al., 2005) to ingest daily observations of maximum temperature, minimum temperature, precipitation, dew point temperature and other fields from more than 6,000 meteorological stations globally. An implementation of TOPS has also been tested for Tamil Nadu State, India at spatial resolutions of 4 km^2 and 1km^2 using publicly available data from approximately 30 stations throughout the state (**Figs. 2 a to e**). Daily maximum temperature, minimum temperature, and cumulative precipitation observations are

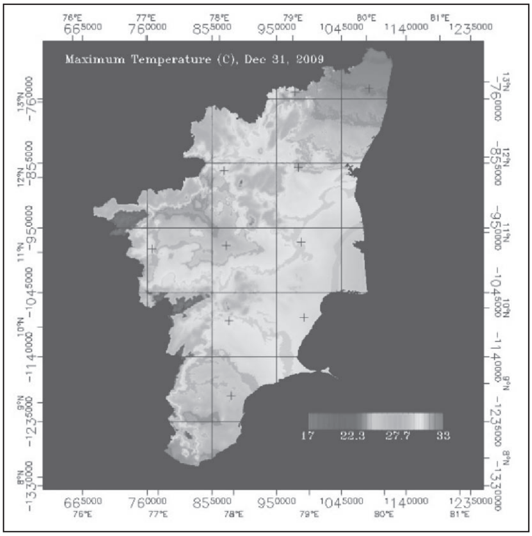
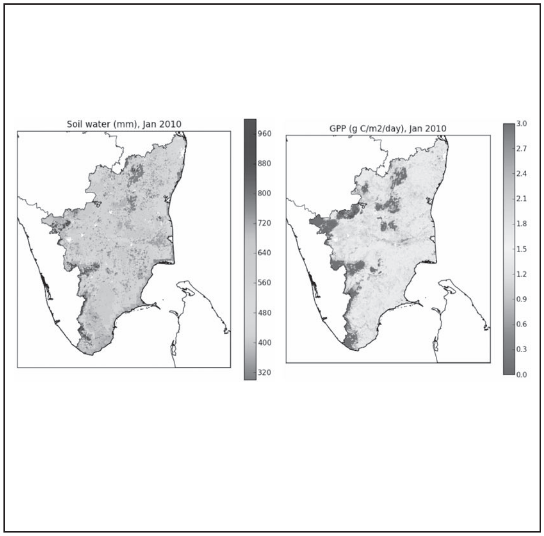
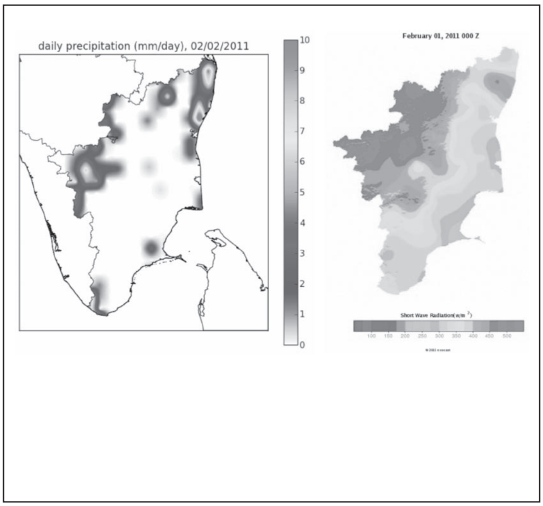


Fig. 2 a : Spatially continuous fields of maximum air temperatures derived using SOGS and TNAU observations at 1 x 1 km resolution.



Figs. 2 b : Daily rainfall fields over Tamilnadu from SOGS using TNAU and Satellite data at 1 x 1 km resolution



Figs. 2 c and d : Spatial distribution of soil moisture and gross primary production or photosynthesis over Tamil Nadu derived using TOPS.

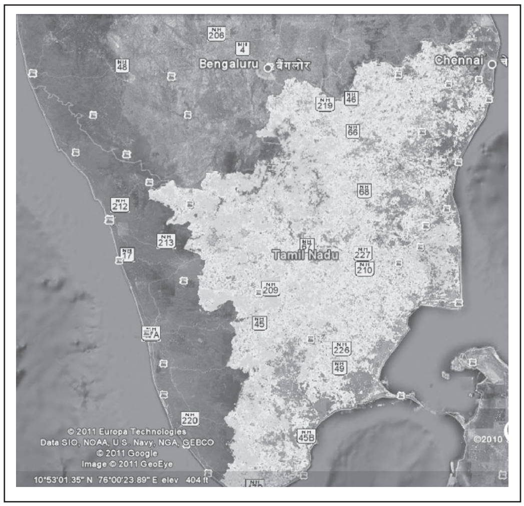


Fig. 2 e : An example showing NDVI anomalies from TOPS displayed on Google-Earth for fast visualization.

interpolated from the station observations to spatially continuous grids following Thornton et al. (1997), and applying a method based on the spatial convolution of a truncated Gaussian filter to perform the interpolation. The interpolation algorithm also accounts for the effects of elevation differences on temperature and precipitation using an empirical relationship calculated for each daily grid from observations using a weighted least squares regression (Thornton et al., 1997).

In addition to surfaces derived from direct observations of temperature and precipitation, TOPS also provides interpolated average saturation vapor pressure deficit (VPD) and shortwave radiation surfaces derived from the temperature and precipitation observations. To generate the VPD surfaces, the average daytime VPD is first estimated at each meteorological station from observations of daily average, minimum, and dew point temperature. For stations where observations of dew point temperature are unavailable, minimum temperature observations are used as a surrogate for dew point temperature (Thornton et al., 1997).

Approach

Past analysis of the gridded fields over various locations in the world showed errors in air temperatures to be within 1°C, and rainfall to be within 10%. Initial analysis of surfaces produced from only 100-200 stations within India indicates errors in air temperatures of 1-2 °C, and rainfall within 10-20%. Incorporation of data from additional surface stations should further improve the accuracy of these estimates, and new research suggests that errors can be even further reduced by integrating satellite data such as observations from TRMM and MODIS (**Figs. 3 a to f**).

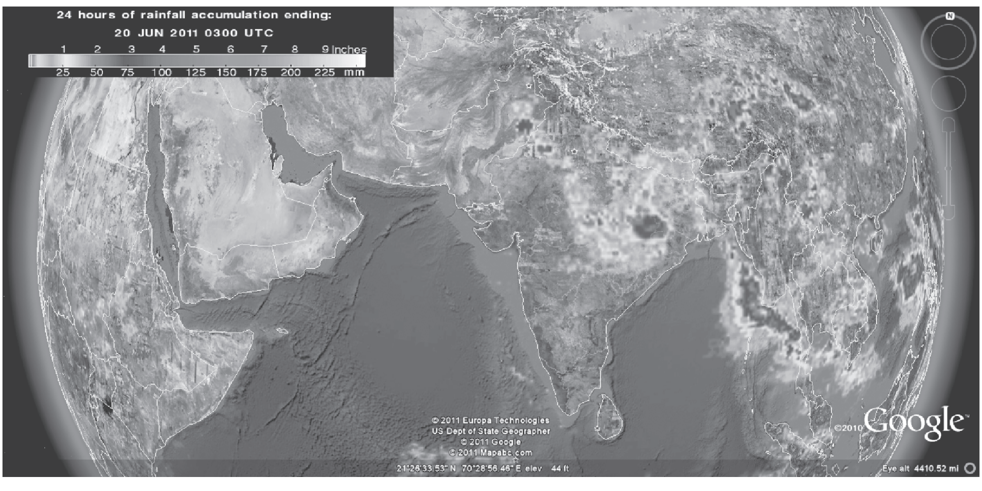


Fig. 3a : An example showing past 24 h rainfall (on 20th June) over SAARC Countries from TOPS displayed for fast visualization.

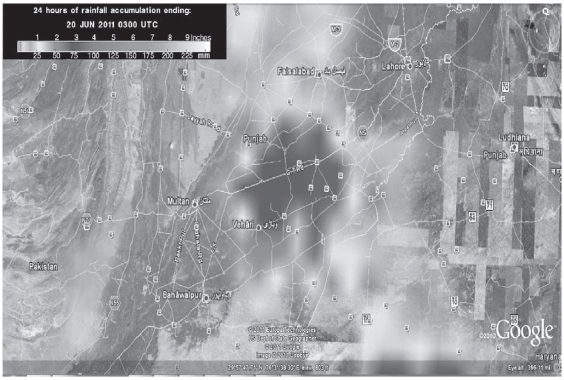


Fig. 3b : An example showing past 24 h rainfall (on 24th June) over Parts of India and Pakistan from TOPS displayed for fast visualization.

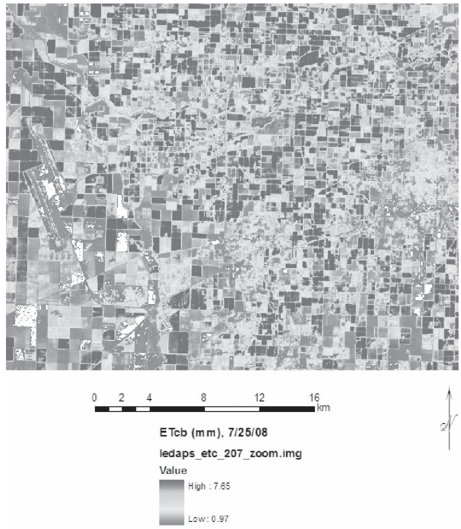


Fig. 3c : Map of daily evapotranspiration over a 30x30km region at 30m resolution.

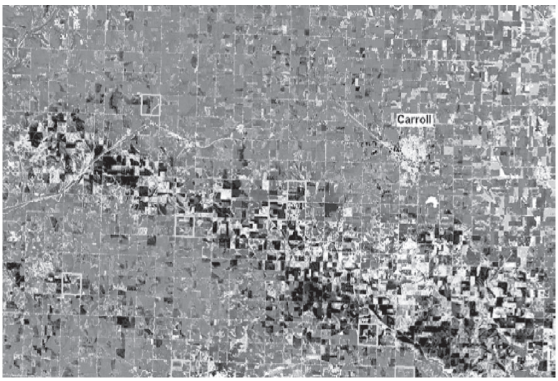


Fig. 3d : Map showing hailstorm damage over a 30x30 km region at 30 m resolution.

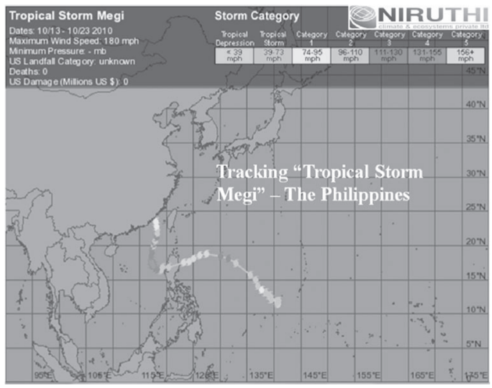


Fig. 3e : Map showing tracking of Typhoon: Tropical Storm "Megi" over The Philippines in the year 2010.

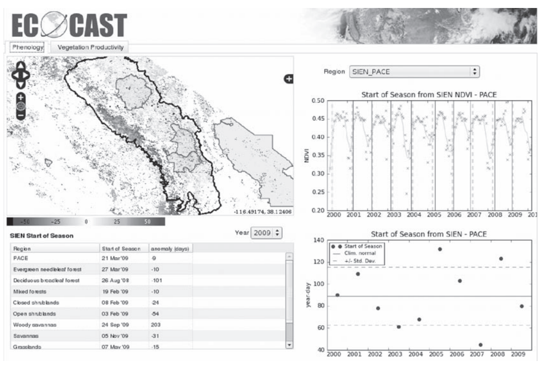


Fig. 3 f : TOPS-Gateway for user community to easy access to data

Niruthi, Climate & Ecosystems Private Limited

Niruthi is one of very few companies worldwide to offer end-to-end solutions in weather/climate business. We are a group of accomplished scientists and engineers with two decades of experience in atmospheric modeling, weather forecasting, satellite remote sensing, climate analysis and forecasting, climate change, information technology and a variety of applications. We are experts at what we do and our claims are backed by our publications in major scientific journals. Our key strength, and one that sets us apart from others in the field, is rooted in our ability to integrate all facets of this complex issue on behalf of our clients. We thrive on taking the best of science to solutions. Founding members of Niruthi include scientists and engineers who worked on the development of the NASA Terrestrial Observation and Prediction System, and have extensive experience in developing applications of satellite and meteorological data to support management of natural and agricultural resources.

Potential Area of Applications

Agriculture

Our services for the agricultural sector include:

- Access to real time weather data including temperatures, wind speed, rainfall, humidity, and soil moisture conditions
- Crop health status, crop monitoring and yield forecast
- Tracking of approaching storms from remote locations
- Efficiency improvement in irrigation, fertilization, and weed control
- Identification of potential fishing zones, etc.

Media

Niruthi serves the media with:

- Access and display of real time weather data
- Advanced warnings of severe weather
- Posting of real time weather data on web site
- Promoting community awareness and brand building
- Helping increases non-traditional revenue

Construction Industry

Niruthi can help the construction industry become weather-wise offering services to:

- Monitor weather conditions to improve productivity
- Track approaching storms and secure contractor sites
- Provide information to insure property in case of damage due to weather
- Identify sites where to build
- Build to meet standards

Energy

The energy sector is highly sensitive to weather and climate. Niruthi provides custom services to:

- Gather real time weather data from remote sites
- Maintain a more efficient power grid
- Protect sensitive equipment
- Position service and repair crew
- Assist in power plant citing

Transportation

A weather-wise transportation sector takes advantage of weather information to plan for rerouting, penalties, spoilage, sun kinks, derailment, blow over and hail damage. Niruthi assists the transportation sector by gathering live weather data from multiple remote sites (highways, intersections, railroads, bridges, and waterways) and setting alarms for specific weather parameters.

Health

Public health is highly sensitive to weather events, as these affect morbidity, mortality, and vector spread. Niruthi provides information to hospitals and health agencies about current and forecast weather conditions and potential impacts on the health of the community.

Hospitality

Niruthi enhances the experience of guests offering services to:

- Provide live weather conditions to guests
- Show local seasonal climatic conditions
- Organize guest activities based on weather
- Broadcast weather information on in-house cable network

Other areas of Services

Research Services

Niruthi provides state-of-the-art research services to develop instrumentation and application models in the areas of climate change and adaptation. These services assist in:

- Risk assessment and strategic planning
- Decision support modeling in multiple formats
- Development of "climate friendly" products for the retail market
- Formulation of climate change policy
- Climate change mitigation and technology options
- Renewable energy policy and markets

Data Services

We offer processing, analysis, and reporting of weather and climatic data for any region around the world, such as:

- Meteorological data processing and analysis for scientific reporting
- Local to national customized terrestrial/marine weather forecasts
- On site consultation services such as weather forecasts, real time monitoring and updating of conditions, to provide a comprehensive report for the required period
- Dissemination of forecasts via the various media
- Analysis of short and long term climate trends

Analysis of extreme weather probabilities using statistical methods

Software and Hardware Services

Niruthi can help with data monitoring and processing needs through:

- Database development for storing and accessing weather and climate data
- Set up of regional models
- Development, installation, and maintenance of atmospheric monitoring systems

Conclusion

TOPS can produce and deliver daily historical and current data on maximum temperature, minimum temperature, dew point temperature, daily total rainfall, daily average humidity and daily total solar radiation at 1 x 1 km resolution for selected regions of SAARC countries, which will be useful for weather index insurance settlement at village level by reducing the basic risk. Furthermore, this information platform would provide guidance to weather station operators on how to optimally site future deployments. Daily weather forecast at village level along with agro-advisory will help farmers to act well in time to mitigate various production risks they encounter.

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Agromet Advisory Services to Minimize Weather Risk in Agricultural Planning

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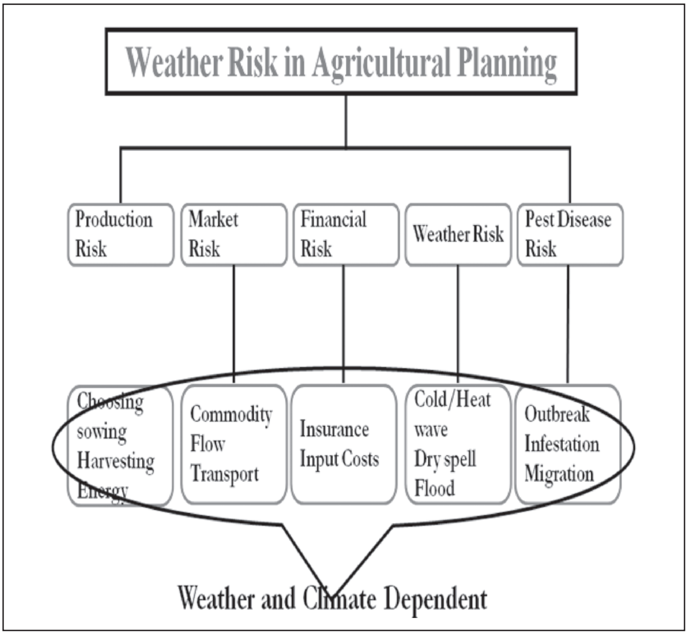
Agriculture is a gamble with weather, which is most unpredictable in space and time. Unfavorable weather conditions affect almost all sectors in varying degrees. However, food and fiber production is perhaps most sensitive and vulnerable to such fluctuations. South Asian Association for Regional Cooperation (SAARC) Region is broadly classified as low-income or, low-middle income category in global parlance. While poverty and hunger remain one of the major challenges before the region, Agriculture remains the predominant sector of the region's economies. A vast majority of population in the region lives in rural areas and depends upon agriculture for livelihood and sustenance. Region-wise agriculture is facing several challenges, threatening its growth and sustainability. This necessitates preparedness to face upcoming challenges and unfolding new reality. Many changes affecting agriculture transcends geography and are trans-boundary in nature: climate change, animal and plant diseases pose formidable challenges. These challenges can be faced and agricultural productivity can be increased, costs reduced and impending crop shortfalls mitigated or avoided through the judicious use of information and knowledge about climate and weather, including early warning through agrometeorological advisories. Communication Technology, institutional innovations, globalization, better technologies and efficient ways of managing water and farm inputs are now available to make farming decision-making easier than before. These can be very helpful to save water and energy, reduce cost and increase farmers' income.

Indian Agriculture

Indian agriculture has traditionally been tied strictly to South West Monsoon rainfall. Rainfall variability at sub-seasonal scale during monsoon makes the agriculture more vulnerable to natural disasters such as drought, floods, cyclone, heat and cold wave, hail etc. Weather and climatic information plays a major role before and during the cropping season and if provided in advance can be helpful in inspiring the farmer to organize and activate their own resources in order to reap the benefits. Hence, the Agro-meteorological information may help the farmer make the most efficient use of natural resources, with the aim of improving agricultural production; both in quantity and quality. It becomes more and more important to supply agrometeorological information blended with weather sensitive management operations before the start of cropping season in order to adapt the agricultural system to increased weather variability. Subsequent to this, short and medium range weather forecast based Agro-meteorological advisories become vital to stabilize their yields through management of agro-climatic resources as well as other inputs such as irrigation, fertilizer and pesticides. Agro-meteorological service rendered by Indian Council of Agriculture Research (ICAR), India Meteorological Department (IMD), Ministry of Agriculture, Ministry of Earth Sciences is a step to contribute to weather information based crop/livestock management strategies and operations dedicated to enhancing crop production and food security.



Weather based agro-advisory service, has been functioning since 1993 and effectively serving the farming community of villages. It receives weather forecast from the IMD (Earlier from NCMRWF) twice a week on Tuesday and Friday for five days period based on which the expert committee prepares the agro-advisory needed for that week.

National Agromet Advisory Bulletin

The bulletin is prepared for national level agricultural planning & management and is being issued by National Agromet Advisory Service Centre, Agricultural Meteorology Division of India Meteorological Department. Prime users of this bulletin are Crop Weather Watch Group, (CWWG), and Ministry of Agriculture. Bulletin is also communicated to all the related Ministries (State and Central), Organizations, Non Governmental Organisations (NGOs) for their use.

State Agromet Advisory Bulletin

This bulletin is prepared for State level agricultural planning & management. These bulletins are issued from 22 AAS units at different State capitals. Main user of this bulletin is State Crop Weather Watch Group (CWWG). This is also meant for other users like fertilizer industry, pesticide industry, irrigation department, seed corporation, transport and other organizations which provide inputs in agriculture.

District Agromet Advisory Bulletin

The Government launched District-level Agrometeorological Advisory Service (DAAS) in June 2008 as one of the flagship programme of Ministry of Earth Sciences. The DAAS aims to generate agro-meteorological information (weather forecast and agromet advisories) and develop suitable dissemination system, to the farming community in order to improve crop/livestock productivity.

The DAAS is multidisciplinary and multi-institutional project. It involves all stakeholders such as State Agricultural Universities (SAUs), Indian Council for Agriculture Research (ICAR), Krishi Vigyan Kendras (KVK), Department of Agriculture and Cooperation, State Departments of Agriculture/ Horticulture/ Animal Husbandry/ Forestry (up to District level offices), NGOs, Media Agencies, etc. This project is implemented through a five tier structure to set up different components of the service spectrum. It includes meteorological (weather observing and forecasting), agricultural (identifying weather sensitive stress and preparing suitable advisory using weather forecast), extension (two way communication with user) and information dissemination (Media, Information Technology, Telecom) agencies. The organizational structure and functions of DAAS are shown in **Fig. 1.** The critical components of DAAS system is discussed in the following sections:

Weather Observing System

District-level service needs meteorological observations at sub-district levels. The current observation forms the basis for running the Numerical Weather Prediction (NWP) models and also refining the weather forecast generated at district scale. Also, the historical climate data are needed to support the crop planning. The India Meteorological Department (IMD) has a network of 125 Automatic Weather Station (AWS) and a large number of manual observatories. IMD is in the process to set up 550 additional AWS and 1350 Automatic Rain Gauge (ARG) stations in the first phase of its modernisation plan. With this, every district in the country will have at least one AWS and two ARG stations. In the second phase the network density of AWS/ARGs will be further enhanced so as to automatically record meteorological observations at near block level. In addition to this, a network of 55 Doppler Weather Radar has been planned of which 12 are to be

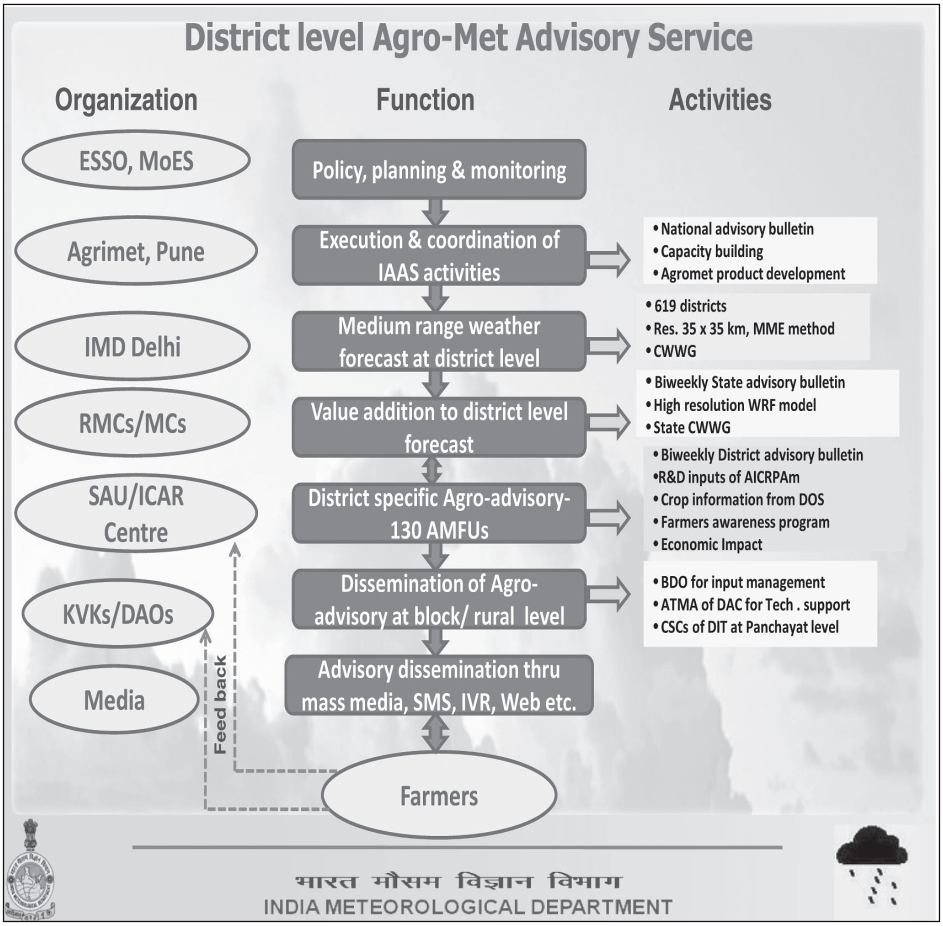


Fig. 1 : DAAS organizational structure and their functions

commissioned in the first phase. Techniques have been developed to assimilate large volumes of satellite-derived information. A new satellite INSAT-3D was launched in the year 2009. Through improvement in observing systems, there will be further improvement in defining the initial conditions to run the numerical weather prediction models which may lead to higher accuracy in weather forecast.

Weather Forecasting System

IMD has started issuing quantitative district level (612 districts) weather forecast of up to 5 days from 1st June, 2008. The products comprise of quantitative forecasts for 7 weather parameters viz., rainfall, maximum and minimum temperatures, wind speed and direction, relative humidity and cloudiness, besides weekly cumulative rainfall forecast. IMD, New Delhi generates these products based on a Multi Model Ensemble technique using forecast products available from a number of models of India and other countries. These include: T-254 model of NCMRWF, T-799 model of European Centre for Medium Range Weather Forecasting (ECMWF); United Kingdom Met Office (UKMO), National Centre for Environmental Prediction (NCEP), USA and Japan Meteorological Agency (JMA). The products are disseminated to Regional Meteorological Centres and Meteorological Centres of IMD located in different states. These offices undertake value addition to these products twice a week on Tuesday and Friday and communicate to 130 AgroMet Field Units (AMFUs) located with State Agriculture Universities (SAUs), ICAR etc. The value addition is based on the inputs from very high resolution meso-scale model (WRF) model, synoptic knowledge, bias correction of district forecast etc. These Centres run the WRF model using initial conditions generated from global model for detailed analysis of rain-bearing systems at higher resolution (9*9 Km grid). Data used in these numerical weather modeling are upper air soundings, land surface (including network of automatic weather stations and automatic rain gauge at sub-district scale), marine surface buoys, aircraft observations, wind profilers, and satellite-data (wind, radiance, rain-rate, etc.). Besides district level medium range forecast, IMD is also providing weather forecast in short, extended and long range. IMD's operational weather observation and forecasting systems has 4 components such as observations, dedicated communication, analysis and forecasting and dissemination.

Weather Insurance

As the name suggest, weather insurance is an insurance coverage against the vagaries of weather. Many agrarian economies owe their strength to favourable weather parameters, such as rainfall, temperature, relative humidity etc. An analysis of Indian Crop Insurance Program between 1985 and 2003 reveals that rainfall accounted for nearly 95 percent claims – 85 percent because of deficit rainfall and 10 percent because of excess rainfall (AIC, 2006). Reducing vulnerability to abnormal weather in developing countries may very well be the most critical challenge facing development in the new millennium. One of the most obvious applications of weather risk management product is weather insurance or weather derivatives.

The basic idea of weather insurance is to estimate the percentage deviation in crop output due to adverse deviations in weather conditions. There are statistical techniques to work out the relationships between crop output and weather parameters. Techniques like multivariate regression could explain the impact of weather deviations / variations on productivity. This gives the linkage between the financial losses suffered by farmers due to weather variations and also estimates the indemnities that will be payable to them. The analysis could also include contingencies associated with the timing and the distribution of weather parameters, particularly over the season.

Weather based insurance is an upcoming strategy that has proven its worth in places such as India and it is important and deserves the attention as it improves the food securities of communities especially the resource poor. At the farm level, weather based index insurance allows for more stable income streams and could thus be a way to protect people's livelihood and improve their access to finance.

Agro-meteorological Field Units (AMFUs) and Agromet Advisory

Based on the above forecast products and the crop information available from districts, the AMFU prepares district-wise agromet advisories. The Ministry of Earth Sciences has set up a network of 130 AMFUs covering the agro-climatic zones of the country. These are operated at State Agriculture Universities (SAUs), Indian Council of Agricultural Research institutions (ICAR), Indian Institute of Technology (IIT) by providing grant-in-aid from IMD. These units are responsible for recording agro-meteorological observations, preparing medium range weather forecast-based Agromet advisories for the districts falling under precinct of concerned agroclimatic zone and dissemination of the same. Concerned universities/institutes have appointed Nodal Officer and Technical Officers, who prepare the advisory bulletins in consultation with the panel of experts already created at these units. The Agromet bulletins include specific advice on field crops, horticultural crops and livestock etc., which farmers need to act upon. Its frequency is twice a week i.e. Tuesday and Friday. Also in case of untimely development of weather, these units prepare the weather based advisory and warnings and issue to different users in a timely manner.

Agro-meteorological Inputs for AAS

Agricultural Meteorologists are trained to deal with soil, water, weather, crops and meteorological principles to agriculture. As the success or failure of agriculture depends upon the chains of five factors viz, a seed, soil, weather, technology and farmer's skills, any weak link in the chain finally determines the agricultural production.

Advisory content shall vary with location, season, weather, crop condition, and local management practices. This may include:

1) Crop-wise farm management information tailored to weather sensitive agricultural practices like irrigation scheduling, pest and disease control operations, fertilizer application etc. It should also contain special warnings for taking appropriate measures for saving crop from malevolent weather, if any information on crop planning, variety selection, selection of proper sowing, harvesting time etc. may also be provided. Also provide location-specific package and practices for cultivation of different crops suitable for the agro-climatic zone etc.

2) Spraying conditions for insect, weed, or disease problems
3) Problems related to animal health and their products
4) Wildfire rating forecasts in wildfire prone areas, and
5) Livestock management information for housing & health and nutrition etc.

Wherever possible, outputs from crop and pest & disease models may be used to increase the timeliness of spraying operations, irrigation applications, fertilizer applications, etc. The advisories should also serve an early warning function, alerting producers to the implications of various weather events such as extreme temperatures, heavy rains, floods, and strong winds.

For effective utilization of agromet advisory services, the following points are to be kept in view :

Identification of Weather Sensitive Field Operations

i. Field preparation (summer ploughing)
ii. Time of seeding
iii. Emergence of seedlings
iv. Fertilizer application
v. Irrigation
vi. Spraying of pesticides
vii. Harvesting
viii. Marketing
ix. Outbreak of pests and diseases

Preparation of Crop Weather Calendars

There is need for structuring crop weather calendars depending upon the date of sowing and variety with major emphasis on vulnerability of the crops to the changing weather conditions.

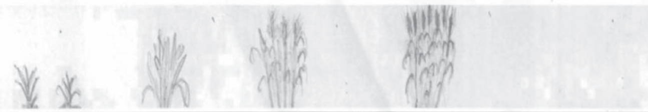
These calendars should specify the forecasting needs in terms of weather parameters and days in advance so that the forecast will be more appropriate. The furnished crop-weather calendar gives information about weekly normal weather parameters (rainfall, temperature (maximum, minimum and mean), sunshine hours, relative humidity (morning, evening and mean) and evaporation) during the different phonological stages. In addition, climatic normals in terms of temperature, rainfall and consumptive water use required for optimum growth of wheat during different phonological stages also available in the crop-weather calendar. For instance, the optimum temperature is around 15-20^{o} C for CRI and jointing stage of the wheat crop in the central irrigated plain region of Punjab.

Crop weather calender for wheat in Central Irrigated plain of Punjab (Zone III) - Ludhiana center

MONTHS	OCT	NOVEMBER					DECEMBER			
Std.Week/No	43	44	45	46	47	48	49	50	51	52
Rain (mm)	0.5	3.8	0.7	0.9	2.5	1.6	0.5	2.8	6.1	5.9
Max T (°C)	31.0	28.1	28.1	27.1	25.3	23.8	22.9	21.6	20.7	19.1
Min T (°C)	14.2	11.3	11.3	10.3	8.8	7.4	6.4	6.3	5.6	5.9
Mean T (°C)	22.6	19.7	19.7	18.7	17.1	15.6	14.7	14.0	13.2	12.5
SShr (hrs)	9.5	9.1	9.1	9.0	8.8	8.5	8.2	7.6	7.0	6.9
Evap (mm)	25.8	22.4	22.4	20.4	18.1	15.7	14.4	12.8	11.7	11.9
RHmax (%)	78	83	83	86	86	87	87	90	90	91
RHmin (%)	36	36	36	38	39	42	36	46	50	53
RH mean(%)	57	60	60	62	63	65	62	68	70	72

MONTHS	JANUARY				FEBRUARY				MARCH					APRIL	
Std.Week/No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Rain (mm)	2.9	3.4	3.2	8.1	7.2	4.9	11.7	7.9	6.4	9.8	2.5	6.3	7.5	2.9	6.0
Max T (°C)	19.1	18.9	19.1	19.8	19.6	20.9	21.6	22.3	23.9	25.4	27.0	27.4	29.5	31.2	33.6
Min T (°C)	5.0	5.1	5.0	6.0	6.0	6.2	7.9	7.7	8.8	10.1	11.2	12.1	13.5	14.6	16.2
Mean T (°C)	12.1	12.0	12.1	12.9	12.8	13.6	14.8	15.0	16.4	17.8	19.1	19.8	21.5	22.9	24.9
SShr (hrs)	7.3	6.8	7.1	6.8	7.5	8.3	7.6	8.1	7.9	8.1	8.1	8.6	9.4	9.1	9.7
Evap (mm)	10.9	10.4	11.8	12.0	13.4	16.6	17.0	18.8	20.6	24.6	24.5	28.6	33.4	36.6	51.1
RHmax (%)	91	91	90	91	89	88	88	88	84	82	82	81	78	73	70
RHmin (%)	51	51	50	51	51	47	51	48	45	42	42	42	36	31	30
RH mean(%)	71	71	70	71	70	68	70	68	65	62	62	62	57	52	50

Phenological stages of wheat



Sowing & emergence | CRI | Jointing | Anthesis | Grain filling | Physiological Maturity

Climatic normals for Wheat

Min temp = 3- 4.5 °C,
Opt temp = 25 °C
Max temp = 30-32 °C

Optimum temperature = 15-20 °C
Consumptive water use = 50 -1000 g of water

Temperature < 30 °C

Optimum mean temperature =15 - 20 °C, Optimum Maximum temperature < 30-35 °C, Rainfall = 35-40 cm

Decision Support Tools for Generating Weather Based Farm Advisories

Technological tools are required to translate weather information into agro-management decisions. The management decisions that can be directly linked to weather forecast are irrigation management, fertilizer application, herbicide application, pest/disease control, and harvest. For this crop-soil simulation models are employed to predict crop-level responses to different weather situations. Such models are useful to develop decision-making information on weather based crop management. At a decision-making level, a series of short term decisions required to be made on the basis of knowledge or forecast of parameters which are derived from weather forecast e.g. soil moisture, phenological development etc. In such a case, it is important that the farmer is forewarned about the likely impacts and mitigation of negative impacts through objective understanding of interaction between various factors influencing the crop growth & development, water and nutrient supply, biotic stresses and the time of planting and harvesting of the crop.

Empirical/ Statistical Model

Crop growth is often described by an empirical model, consisting of a regression equation. These models can generate accurate yield predictions, especially when the regression parameters are estimated on the basis of extensive sets of experimental data (Diepen *et al.,* 1989). Various agro-meteorologically based models are generally crop weather relationship models which may be defined as a simplified representation of complex relationship between weather or climate and crop performance (such as growth, occurrence of phonological events, yield or yield components) using established mathematical and/ or statistical techniques (Bair, 1977). Generally, multiple and stepwise regression techniques are employed using more than one variable. Statistical models for simulating yield as a function of important climatic variables such as rainfall were started since Fisher's (1924) work. Statistical yield prediction models were developed for major crops based on past climatic data for different districts of Gujarat. Crop weather relationship of wheat crop was studied at Anand and a model was developed using 10 years data of weather and experimental yield. Results showed that among all the weather parameters only minimum temperature during different phenological phases as well as on monthly basis during December & January had significant influence on wheat yields. Looking to the significant association of various weather parameters with grain yield of wheat, regression studies have been performed for development of yield prediction models. The developed yield prediction models were validated for actual yield data for years 2004-05 to 2007-08 for 15th November sowing. The error in prediction of wheat yield was the lowest at 0.9% (2005-06) and the highest at 18.8% (2008-09). The average error was 11.1% between the actual and predicted yields. The regression model

$$Y = 12014.11 - 432.373*Tmin\ (Jan) - 206.133*Tmin\ (Dec)\ (R^2:0.90)$$

showed that an increase in the minimum temperature by 1^{0}C during January reduced yield by 432 kg/ha, and that during December reduced the yield by 206 kg/ha, when crop was sown on 15th November (Anonymous, 2009). Thus, higher minimum temperature during January is not desirable for the wheat crop.

Crop Simulation Model

A crop simulation model is a computer model used to simulate reality. These models are designed to predict the effect of a future land use scenario on a suite of plant indicators (growth, development and yield etc). Crop simulation models are state of the art technology that allows the user to estimate crop growth and yield as a function of weather conditions and management scenarios. Various crop simulation models are used now a days viz., DSSAT (Decision Support System for Agro-technology Transfer), WOFOST (World Food Study), WTGROWS (Wheat Growth Simulator), CROPSYS (Crop Systems), SUCROS (Simple and Universal CROP growth Simulator), SWAP (Soil Water Atmosphere Plant) etc. The tools required for running a crop simulation model are the software for the crop chosen and a PC with knowledge of computer (Rao, 2003).

DSSAT is documented by Jones *et al.,* (2003) provides an easy access to data base and crop models so that the user may 'test' on screen the performance of new cultivars, sites, or management practices. It is widely used for Global Climate studies, use with GIS, whole-farm system models, pest-crop interaction models, fertilizer strategies, and plant breeding. The model requires daily weather data of maximum and minimum air temperature, solar radiation and rainfall to simulate crop growth and yield. In agro-advisory services the DSSAT model can be used to give advice to farmers for optimum sowing date of crop a particular area based on the forecast given by IMD. Using forecast given by IMD for next 4 days, the model can help in taking decision regarding whether to apply irrigation or not, under the drought period conditions when dry spell prolongs, the model can help to decide when and how much quantity of irrigation should be applied during particular crop growth stage. The model can also used for yield prediction in response to forecast given by IMD.

Pest and Disease Forewarning Models

The losses in crop production caused year after year by insect pest and plant diseases afflictions are quite considerable. Effective and timely control measures of these biological setbacks in crop productions help to avoid these losses and to wipe out the deficit in food production to which country is subjected periodically. In fact production and protection technology must go hand in hand. The outbreak of any pest or disease in epidemic form is the interaction amongst the harmful organisms, the host and favorable environment. Environment consists of both biotic and abiotic factors. However, the weather parameters play a key role in the population dynamics. The development and growth of many pests and disease causing organisms are influenced largely by the micro and macro climate in which the organisms thrive. Thus, it is clear that Agrometeorologists can play a substantial role in crop production and crop protection by developing the advanced forewarning models for incidence/outbreak of pest and diseases using weather parameters. The study conducted at Centre of Advanced Studies in Agricultural Meteorology (CASAM) revealed that in grapes the downy mildew disease occurred during temperatures ranging from 10.2 to 28.1°C and RH from 56 to 96 per cent. The disease did not multiply below RH of 47%, air temperature above 31.5° C. The maximum temperature more than 28.0 °C for 4 h and RH more than 90% for 9 h, 3 days prior to incidence of disease can be considered as critical duration of critical temperature and humidity for the maximum rate of multiplication of the disease. The Disease Severity Index (DSI) for outbreak of downy mildew was established in the scale of 0 to 4 (Varshneya and Vaidya, 1999). While in case of powdery mildew on grapes, if cumulative disease severity values (CDSV) reach any value between 49 and 53, it can be inferred that the incidence of powdery mildew is likely to occur and preventive measures need to be applied.

Predicting Drought

Empirical studies conducted over the past century have shown that meteorological drought is never the result of a single cause. It is result of many causes, often synergistic in nature. A great deal of research has been conducted in recent years on the role of interacting systems, or teleconnections, in explaining regional and even global patterns of climate variability. These patterns tend to recur periodically with enough frequency and with similar characteristics over a sufficient length of time that they offer opportunities to improve our ability for long-range climate prediction, particularly in tropics. One such teleconnection is the El nino/Southern Oscillation (ENSO). Besides, appreciable statistical works have been accomplished on (i) probability distribution of rainfall amounts and timings, (ii) beginning and end of growing season and (iii) likely amount of water available for crops and animals.

After NWP model based medium range weather forecast was started by NCMRWF in 1991, Monsoon 2002 turned out to be worst drought year with the month of July to be driest in the recorded history since 1877. Subsequently Monsoon 2004 recorded seasonal rainfall 13% below its long period average. Such recurring situations of deficient monsoon conditions over the country prompted.

Drought Management

Drought management should not be treated as an isolated problem but as an integral and key factor in sustainable agriculture. Farmers should be encouraged to develop a range of flexible contingency plans that protect the soil, climate, and vegetation. In the field of agriculture in India, the contingency crop planning strategies at district scale have been developed through research efforts since mid-1970s to minimize crop losses due to aberrant weather conditions. Contingency crop planning under extreme events are implemented effectively through weather based Agro-Advsiories as it is supported by advance weather information (medium, extended and long range) during the monsoon season and this enables farmers to modify their usual cropping patterns before and during the crop season. Drought management operations include:

- Community nurseries at points where water is available,
- Transplantation,
- Sowing of alternate crops/varieties,
- Ratooning or thinning of crops,
- Soil mulching if the break in the monsoon is very brief,
- Weed control,
- *In-situ* water harvesting and/or run-off recycling,
- Broad beds and furrows,
- Graded border strips,
- Inter-row and inter-plot water harvesting systems,
- Intercropping systems for areas where the growing season is generally 20 to 30 weeks,
- Alternate land use systems,

- Development of agriculture on the basis of the watershed approach,
- Alley cropping,
- Agro-horticultural systems,
- Watershed approaches for resource improvement and use,
- Water resources development,
- Treatment of lands with soil conservation measures,
- Alternate land use systems, and
- Forage production.

Contingency Crop Plans

In preparation of contingency plans, not only long range and extended range forecast, but also medium range weather forecasts are taken into consideration. Contingency plans are needed if following conditions prevail:

- Failure of South- West Monsoon
- Delayed onset or early withdrawal of monsoon
- Deficit or erratic rainfall
- Damage to crops due to cyclones, floods etc.,
- Crop loss due to droughts
- Insufficient supply of irrigation water or late release of canal water
- Long dry spells
- Heat or cold waves
- Severe pest or disease outbreaks due to favourable weather conditions

The contingency strategies are to be based on location-specific needs and situation based (rainfed or irrigated). Within the region also they vary with soil types.

Advisory Dissemination Mechanism

AAS has considered different aspects pertinent to the flow and content of information and accordingly evolved a strategy for dissemination of agro-meteorological information. District-level agencies viz. District Agriculture Offices, Krishi Vigyan Kendras, Kisan Call Centres, NGOs etc) are mainly responsible for information dissemination to farmers. A mechanism has also been developed to obtain feedback from the farmers on quality of weather forecast, relevance and content of agromet advisory and effectiveness of information dissemination system. This involves the identification of weather & climate sensitive decisions and interactions between the weather forecasters from meteorological Centres of IMD and the agriculture scientists from Agriculture Universities and/ or Institutes of Indian Council of Agriculture Research to develop weather based advisories and technologies. Information is disseminated through multi-modes of delivery including mass and electronic media. It includes, All India Radio, Television, Print Media (local news paper in different vernacular languages), internet (Web Pages) as well as group and individual relationships through e-mail, telephone etc. The use of electronic media such as e-mail or the Internet is picking up as the access of these methods to the farming community is on significant rise. The agrometeorological bulletins always contain dynamic information hence, repetitive dissemination is being made. This reiterative process also helps to address large temporal and spatial variability having significant influence of weather & climate on agriculture.

The use of electronic media such as e-mail or the Internet depend on the availability and access of these methods to the users which is picking up in India particularly through initiative of Department of Information Technology, who is in the process of setting up a very strong net work of common service centres (CSC). Broadcasting of advisories in vernacular language provides an edge on other means of communication. Under Integrated Agromet Advisory Service (IAAS) scheme at IMD/MoES efforts are being made to strengthen the outreach of the agromet advisory as per the need of the farmers. Under the project advisories are primarily disseminated to the farmers by mass mode, outreach at village level and human face for advisory dissemination. Advisories are being disseminated to farmers through following the multi-channel system :

i. All India Radio (AIR) and Doordarshan
ii. Private TV and radio channels
iii. Newspaper
iv. Mobile phone / SMS
v. Internet
vi. Virtual Academy / Virtual Universities / NGOs
vii. Kisan Call Centres / ICAR and other related Institutes / Agricultural Universities / Extension network of State
viii. Krishi Vigyan Kendra (KVKs)

Role of All India Coordinated Research Project on Agrometeorology (AICRPAM) in Preparation and Dissemination of AAS

The spatial and temporal changes is important weather parameters such as rainfall, temperature, wind, cloud cover, humidity, etc would influence crop yields by affecting farmer's decision in selection of cultivar, use of inputs, crop management practices, etc. These decisions significantly influence the aggregate agricultural output, which, in succession has an impact on the economy of the country as a whole. Thus, the timely and accurate weather based agro-advisories is the need of the hour for sustainable agricultural production.

Further, the quality of utility of agro-advisories can be improved through value addition to the agromet information including forecast and demonstration of economic benefits accrued due to the following of the advisories. Thus making farmers to adapt weather-based advisories for (i) Increasing the quality and quality of produce, (ii) Efficient utilization of resources, (iii) Minimizing losses due to adverse weather, (iv) Effective utilization of favourable weather events, and (v) Reducing cost of cultivation to enhance profits.

The revolutions in Information Technology (IT) over the last few years have paved the way in providing effective communication linkages between the farmers and the agricultural scientists. The proposed village knowledge centres under the Mission 2007 by the Government of India shall enhance the capacity of the farmers to get the necessary information for improving the farm yields in an interactive model.

In this endeavor, Indian Council of Agricultural Research (ICAR) has already started a web-based dissemination of agromet advisories through its Coordinated Research Project on Agrometeorology (AICRPAM) located at Central Research Institute for Dryland Agriculture (CRIDA).

All India Coordinated Research Project on Agrometeorology (AICRPAM) is helping the agromet advisory services by providing necessary research backstop for improving the efficiency of agromet advisory system through its technical programme operating at 25 centres spread across the country. All the 25 centres of the Coordinated Research Project located in all the State Agricultural Universities assess the current crop situation based on the IMD forecast; the agro advisories are prepared and disseminated through mass media. They also make available the advisory through a website www.cropweatheroutlook.ernet.in operating at CRIDA **(Fig.2).**

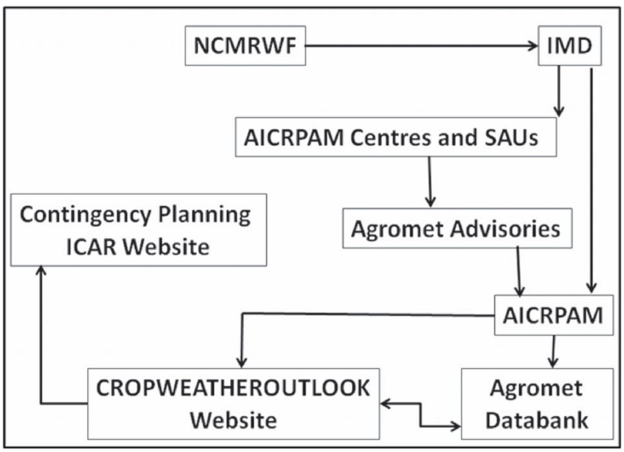


Fig.2. Agromet advisory system in ICAR

Further improving the advisory system at local level and extrapolate to national level, AICRPAM has envisaged a web-based National Agromet Advisory Services for effective and timely dissemination of advisories for the benefit of farming community.

Crop Weather Outlook

The Indian agriculture and it's economy are strongly influenced by the vagaries of the weather. The farming community is in great need to have access to weather information to plan and manage their crops and their livelihoods. One of the important communication systems, which is gaining increased acceptance in the recent times, is the Internet. Attempt is thus made to use this interface to provide valuable agromet information to the users through this Crop Weather Outlook of ICAR. The CWOL envisages providing the agrometeorological information highlights generated under the All India Coordinated Research Project on Agrometeorology (AICRPAM) and its Cooperating and Collaborating Centres along with 'Value Added Agromet-advisory Reports'.

The website is operating from the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad where the AICRPAM is located and is linked to the ICAR website for a wider use by the planners, researchers, farming community and other public users. The website not only provides information on the research activities of the Agromet Centres located at various State Agricultural Universities but also provides linkages to other associated websites where information of agrometeorological relevance is located so that the viewer has access to all related information of his needs. It is hoped that the website will help the user to utilize the information for improved management of agricultural system as well as achieving enhanced and sustained agricultural productivity.

Information from this website:

Agromet Advisories (Value Added Weather Information): This page contains links to various AICRPAM centres to view:

Weekly Report on Crop-Weather Conditions: Contains general rainfall and crop conditions in the region.

Current Weather Data: Displays the daily weather data such as minimum and maximum temperatures; rainfall; relative humidity; wind speed; evaporation; sunshine and soil temperature recorded at the centre during the week.

Agromet Advisory: Contains the weather-based agro advisory which is issued based on the models developed at the centre and the weather forecast issued by IMD, New Delhi.

Farmers Awareness on AAS

Efforts made by Ministry of Earth Sciences, India Meteorological Department (IMD), Indian Council of Agriculture Research (ICAR), State Agricultural Universities (SAUs), Union/State Departments of Agriculture and other collaborative agencies through Agrometeorological Advisory Service (AAS) have demonstrated the role of weather forecast in increasing overall preparedness of farmers, leading to substantially better outcomes overall in general and under few extreme climatic events – drought, heat and cold wave, cyclone in particular. Enhancing awareness of information user groups is done through organizing farmer's awareness programs, also termed as roving seminar that brings together research and development institutions, relevant disciplines, and farmers as equal partners to reap the benefits from weather and climate knowledge. Given the current concerns with climate change and it's impacts on crop productivity, there is an urgent need to sensitize the farmers about the increased weather variability in their regions, and different adaptation strategies that can be considered to cope with the extreme weather situations.

Such programs help increase the interaction between the local farming communities and the Meteorological Centres (MCs), Agro Meteorological Field Units (AMFUs) and Krishi Vigyan Kendra (KVK). Considering above, a large number of such seminars are organized in different agro-climates of the country to sensitize farmers about the weather and climate information and it's applications in operational farm management. These are jointly organized by India Meteorological Department (Ministry of Earth Sciences), Indian Council of Agriculture Research and State Agricultural Universities, Local NGOs and other stake- holders.

The programme for the seminars consists of (i) Weather and Climate of the Farming Region, Climate Change and Farming Risks, and (ii) Farmer Perception of Weather and Climate Information Provision and Feedback. The Roving Seminars are organized jointly by AMFUs and KVKs under aegis of IMD, ICAR, and SAUs. Primary emphasis here is placed on free and frank exchange of ideas and information. The Seminar has been designed in such a way as to engage all the participants in discussions and obtain full information from the farmers on their needs for weather and climate information and the ways and means to improve future communication of weather and climate information to them to facilitate effective operational decision-making. So far such seminars have been organized at 90 agro-climatic zones of the country.

Conclusion

In spite of advances made in weather forecasting and operational agromet advisory services to the users, the real value in terms of offering right advice at right time to the farmers is somewhat lacking. The integrated agromet advisory services launched with different collaborating organizations in the country from 2007-08 for providing real time crop and location-specific agromet services even up to village level will go a long way not only in reducing weather and climate related risks in Agriculture but also promote scientific agriculture.But there exists a wide information gap between information generator and user. The outreach of IAAS system to deliver the information at Block and Panchayat (village) level, in a timely manner, needs to be stepped up. The Common Service Centre (CSC) of Department of Information Technology (IT) is a good solution to bridge the information gap by exploiting advances in Information Technology, which has witnessed incremental use in dissemination of information in the recent past.

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Precision Water Application Systems for Enhancing Water Use Efficiency

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Water is the most important input not only for ensuring food security and sustainable socio-economic development but also for impacting the basic existence of life *per se*, and will continue to play crucial role in enhancing agricultural production in future as well. Food security can not be achieved without water security. South Asia (Afghanisthan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka) has been perceived as having plentiful water resources, including the Himalayan snows, a vast network of perennial rivers, high monsoon rainfall and rich ground water acquifers. However, with the rapid population growth during the last century, pressure on these water resources has reached alarming proportions. Water availability per capita has decreased by almost 70% since 1950 and it is projected that by 2025, most of the region will be facing either physical or economic scarcity of water (Ashok Jaitly, 2009). At the global level too, expansion of irrigation source during mid 1960's and 1980's contributing substantially to the present total irrigated land of roughly 280 M ha, is attributed to bring about 100% increase in food grain production (EI-Ashry and Duda, 1999). South Asian irrigation systems are one of the lowest efficient in their adoption wasting energy and affecting the crop production and soil environment.

On farm water application systems are normally classified in four basic categories or methods: 1) surface/gravity, 2) sub-surface, 3) sprinkler and 4) micro irrigation. The sprinkler and micro irrigation systems are together categorized as pressurized systems. Sprinkler method includes hand move, hose pull, side roll/wheel move, stationary big guns, solid state/permanent types, continuous move types such as center pivots, linear move and travelers. Water application through drip or trickle, micro sprinklers (spinners and rotators), micro jets(static and vibrating),micro sprayers, bubblers, drip tapes(both surface and sub-surface) referred to as micro irrigation. There is no definite distinction between conventional sprinklers and emitters used in micro irrigation, emitters having flow rates up to 200 l/h can be regarded as micro emitters (ISCID, 2006). Generally, drippers have flow rates from 2 to 8 l/h. Micro sprayers and static jets are not rotating type with flow rates from 20 to 150 l/h. Whereas, micro sprinklers are rotating type with flow rates ranging from 100 to 300 l/h. As per the recent trends and databases from FAO (Kulkarni et al, 2006), the global coverage of sprinkler and micro irrigated areas is 33Mha and 6 M ha respectively. The region-wise spread of sprinkler irrigated area is: America (13.3 M ha), Europe (10.1 M ha), Asia (6.8Mha), Africa (1.9 M ha) and Oceania (0.9 M ha)

Precision Water Application Systems

Efficient irrigation water management is the key to reap full benefit from the available water resources. This is essentially an integrated process involving conveyance, regulation, distribution, application and use of irrigation water for farm crops at the right time and in correct quantity in conformity with plant needs for optimum growth. This is necessary for the purpose of increasing crop production and water economy in conjunction with improved production practices. Voluminous research has been conducted on these aspects in different agro-ecological environments of the country under the AICRPs regarding water management and use of saline water, aiming at more economic, efficient and productive use of the resource.

Selection of irrigation method is guided by factors like texture, structure, depth and water transmission characteristics of soil climate, topography, quality of available water, crops to be grown and other associated features. The efficient irrigation method should provide for precise control of water during application. The drip irrigation method is most efficient in water application, in saving water and in improving nutrient use efficiency. The data relating to the increase in crop yields and in saving water with drip method in case of several crops and locations in India are reported by Kumar &Singh (2002). More than 5 lakhs ha of land has been covered under drip irrigation in India with maximum area in Maharashtra. Faulty water management has negative impact on production and environment. Approximately 71% of water released from the reservoir is reported to lost and not utilized by the plants, leading to low irrigation efficiency of hardly 30-40% with crop yields around 2-2.2 t/h as against more than 6 t/ha under efficient management. The main reasons attributed to this dismal situation are (i) faulty planning, design and construction of irrigation project, (ii) unrealistic assumptions regarding water supply, crop water requirement and over estimation of area that could be irrigated.(iii) land & farmers not ready to receive irrigation (iv) options of efficient drainage (v) lack of mass awareness about ill effects of poor management and (vi) deficient coordination between different agencies, line departments and beneficiaries.

Drip Irrigation

In India, the organized efforts in the key sector of plasti-culture in water management were initiated way back in 1981 with the constitution of National Committee on the use of Plastic in Agriculture (NCPA, presently NCPAH). Recognizing the urgent need for increasing water use efficiency, GoI has constituted a National Task Course on Micro

Irrigation under the Chairmanship of the then Chief Minister of Andhra Pradesh Shri N.Chandrababu Naidu which emphasizes the urgency of scheme on micro irrigation.

Drip irrigation has emerged an ideal technology through which the required amount of water is applied to the route zone of the crop. The efficiency of micro irrigation is as high as 80-90%. The system also permits the use of fertilizer, pesticides, and other water soluble chemicals along with irrigation water at optimum levels. Micro irrigation is ideally suitable for horticultural crops covering orchards, vegetables and plantations which do not require in ponding of water and facilitate proper alignment of the laterals and drippers. The estimated total cropped area suitable for micro irrigation in the country is to the tune of 27 M ha. Some of the countries have been quick to promote this technology for transforming their agriculture **(Table 1)**.

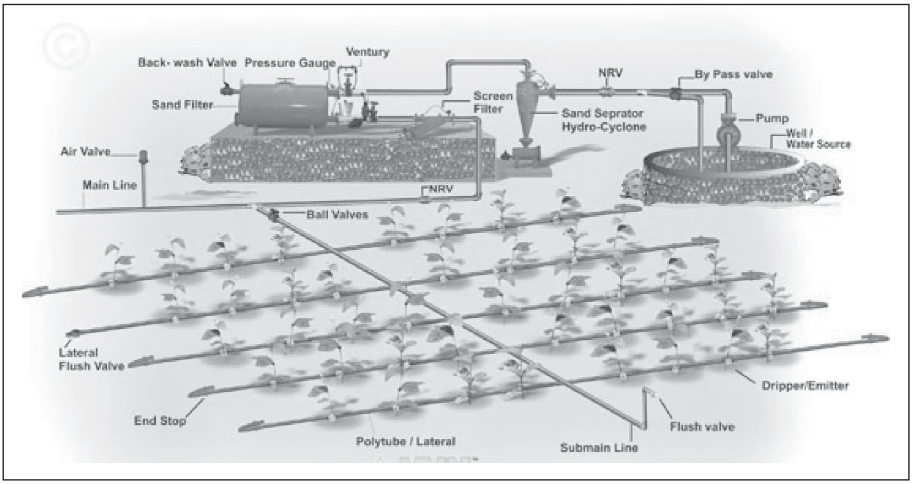


Table 1 : Comparison of area(ha) under different plasticulture applications in selected countries.

Application	India	China	Japan	USA	Italy	Spain	France
Micro irrigation	5,00,000	5,20,000	40,000	10,76000	89000	2,54,000	1,00,000
Green houses	1000	3,80,000	51,042	9,250	77,400	49,380	9,200
Low tunnels	100	8000	6000	5000	12000	10,000	10,000
Mulching	10,000	96,00,000	1,60,000	75,000	80,000	1,04,510	1,00,000

Source: Report of CIPA (2002)

Similarly sprinkler irrigation is a pressurized irrigation system wherein the water is sprinkled in small droplets simulating rain drops over the crop and soil with suitably sized pipes and nozzles at a rate equal to or less than the infiltration rate of soil .Sprinkler irrigation involves the spraying of water under pressure like rainfall . The spray is developed with the help of nozzles which are made of metal or plastics. This system is

useful for close space crops, particularly for necessaries of vegetables and fruit crops. The rain guns are also being used for covering large areas for application of water. The irrigation efficiency of sprinkler irrigation is 70-80%. The total potential for crops to be irrigated under sprinkler irrigation system is estimated to be about 42.5 M ha. Micro irrigation, could therefore, be seen as a holistic approach to address the issues of poverty alleviation, productivity enhancement, crop diversification, equity, environmental protection and reduced biotic stress.

The use of micro irrigation has revolutionized the state of horticulture in many of the states. Today, there are more than 13.1 lakh ha of horticulture crops on the drip irrigation. The Go I has a massive plan of bringing 17 M ha under micro irrigation in the X & XI Plan period. The other important plasti-culture application in the horticulture sector in the country relates to green houses, shade net houses / nursery structures, nursery bags, crates and boxes, flexible packaging (MAP & CAP) as well as a variety of other useful products such as plant protection nets, mulching etc. In India the area under micro irrigation was nearly 1600 ha in 1986, with the efforts of GOI, State Govt., Industries research institutes, the area under micro irrigation has been increased. The estimated state-wise area is given in **Table 2**.

Table 2 : Status of Micro/Sprinkler Irrigation in India (Area in ha)

State	Drip	Sprinkler	Total
Haryana	6243	684748	699996
Rajathan	15248	4,51,708	460599
Maharashtra	462240	207205	669445
Karnataka	169795	216978	386773
Tamil Nadu	124951	26739	151689
Andhra Pradesh	317935	182260	500195
Gujarat	158727	128942	287669
Madhya Pradesh	12518	104049	116567
Orissa	3361	23187	26548
Uttar Pradesh	10577	10,555	21132
Punjab	10427	10,276	20702
Kerala	14119	2516	16635
Chattishgarh	2627	44763	47391
West Bengal	123	150002	150143
Goa	762	332	1094
Sikkim	80	10,030	10110
Nagaland	0	3962	3962
Himachal Pradesh	116	581	696
Arunachal Pradesh	613	0	613
Jharkhand	133	365	498
Bihar	107	180	287
Grand Total	**1310956**	**2320586**	**3631542**

Source: NCPAH (2008)

Micro irrigation provides the advantages such as increase in water use efficiency (80-90%), increase in yield (32-70%), better quality of produce and saving in fertilizer (40-60%).

Table 3 : Saving of water in drip as compared to flood irrigation

Crop	Water used(m^3/ha)		
	Conventional	Drip	Water saving (%)
Beetroot	860	260	70
Banana	17,600	9,700	45
Cabbage	660	270	59
Chillies	1100	420	62
Grapes	5320	2780	48
Okra	540	320	41
Papaya	2280	740	68
Pomegranate	14400	7850	45
Sweet Potato	630	250	60
Tomato	3000	1840	39
Water melon	3300	2300	30

Drip irrigation system consists of laterals, sub mains and main lines. The lateral can be a small plastic tube combined with emitters or micro sprinklers. The laterals are designed for distributing water into the field with an acceptable degree of uniformity. The sub main acts as a control system which can adjust water pressure in order to deliver the required amount of flow into each lateral. It also controls irrigation time for individual fields. The main line serves as a conveyance system for delivering the total amount of water for the drip irrigation system. There are supporting parts such as filters, flushing units, pressure gauge, fittings, valves, fertilizer injection etc, which are used to serve different purposes in the irrigation system. The system applies water at low rate under pressure to keep the soil moisture within the desired range for plant growth.

A properly designed drip irrigation system can help growers of fruits, vegetable, flowers and other cash crops in many ways which are given below :

- Saves Water (from 30% in case of watermelon to 70% in beet root as compared to flood irrigation **(Table 3).**
- Increases yield
- Improves quality of produce
- Reduces labour cost
- Reduces salt concentration in the root zone
- Allows chemicals/ fertilizers (soluble) to be used through the system.
- Keeps inter row spaces firm and dry.
- Permits use in greenhouse.
- Controls and reduces diseases.

There are three general types of water emitting devices used in micro-irrigation:

- Water seeps out continuously along the lateral line (Porous pipe)
- Water sprays or drips from a micro sprinkler/ sprayer/ emitter/ splitter connected/ inserted in the lateral.
- Water sprays or drips from holes punched in the lateral (Perforated pipe).

Fertigation

The uniformity of fertilizer distribution and its availability to plant depends upon the selection and application of fertilizers, uniformity of water application and the flow characteristics of the water and the fertilizers within the soil. To increase the fertilizer use efficiency, fertilizer supplied must be distributed uniformly through out the field. Basically, there are four methods of fertilizer application i.e. broadcasting, drilling, foliar application and fertigation. The fertilizer is applied either broadcasting manually or through introducing it in the irrigation system.

Application of fertilizer through the drip irrigation system is called fertigation. It is the most advance and efficient practice of fertilization. Fertigation combines the two main factors in plant growth and development, i.e., water and nutrients. The right combination of water and nutrients is the key for high yield and quality of produce. Fertigation is the most efficient method of fertilizer application, as it ensures application of the fertilizers directly to the plant roots (Patel & Rajput, 2001a). In fertigation, fertilizer application is made in small and frequent doses that fit within scheduled irrigation intervals matching the plant water use to avoid leaching.

Fertigation is the essence of drip irrigation. Drip irrigation should actually be viewed as a method of growing crops and not simply as a method of irrigation. Many times people tend to compare drip irrigation to overhead irrigation (pivots, sprinklers, mini-jets) or flood irrigation. This is not an accurate comparison because the latter methods are viable mainly for irrigation while in drip irrigation, fertigation is a very integral part of the system. Fertigation is a must in order to realize the full potential and benefits of the system. Drip irrigation can be used solely for irrigation and would still be the most efficient method, but the foremost benefits are lost.

In many cases, depending on the year and location, the drip system is used predominantly as a fertigation system. In seasons or climates with abundant rainfall, there is many times no need to irrigate, but there is an obvious need to fertilize due to significant leaching conditions. Applying the seasonal amount of fertilizers in small doses at high frequency (spoon-feeding) will ensure a continuous and stable supply of nutrients. Moreover, this method meets the tree’s growth requirements without leaching the fertilizers below the root zone.

Fertigation has the following advantages:

- Less labor, equipment and energy needed for receiving, storing and fertilizer application.
- Reduced soil compaction.
- Prevents damage to crop during delivery.
- No restrictions or limitation on application timing.
- Accurate and uniform distribution for superior efficiency.
- Application restricted to most active root zone which reduces waste.
- Adaptability of nutrients supply to the growth curve resulting in better crop response.
- Split applications for better control of run-off and leaching into groundwater.
- Extremely efficient method of accurately delivering uniform, minute quantities of minor elements.
- Complete adaptability to automation.
- Can be used for other purposes, i.e. pestigation, soil amendments, maintenance.
- Can overcome negative effects of saline/waste water.

Significant savings in the use of fertilizers and increase in yield (**Table 4**) have been reported by different research workers (Anonymous, 2001). Although liquid fertilizers are most appropriate for use in fertigation, but in India the lack of availability and high cost of liquid fertilizers restrict their use for fertigation. Experiments with granular fertilizers also established their feasibility and revealed significant fertilizer savings and increase in the yields of onion (Patel & Rajput, 2001a), okra (Patel & Rajput, 2001b) and tomato (Patel & Rajput, 2002 b &c).

Table 4 : Savings in fertilizer and increase in crop yield under fertigation as compared to conventional method of fertilizer application

Sl.No.	Crop	Saving in fertilizer (%)	Increase in yield (%)
1.	Okra	40	18
2.	Onion	40	16
3.	Banana	20	11
4.	Castor	60	32
5.	Cotton	30	20
6.	Potato	40	30
7.	Tomato	40	33
8.	Sugarcane	50	40

Source : Rajput and Patel (2002)

Properties of Some Commercially Available Fertilizers

The data related to the aspects of fertigation like solubility and suitability of different fertilizers to be applied through drip system, acceptable concentration of different nutrients and their recommended dozes for different crops are presented in Tables 5 to 7.

Table 5 : Nutrient content of some commercially available granular fertilizers

Name of fertilizer	Chemical form	N:P:K (%)
Ammonium Nitrate	NH_4NO_3	34:0:0
Ammonium Sulfate	$(NH_4)_2SO_4$	21:0:0
Urea	$CO(NH_2)_2N$	46:0:0
Urane solution	$CO(NH_2)_2NH_4NO_3$	32:0:0
Mono Ammonium Phosphate	$NH_4H_2PO_4$	12:61:0
Diammonium Phosphate (DAP)	$(NH_4)_2HP_2$	18:46:0
Potassium Chloride	KCl	0:0:60
Potassium Nitrate	KNO_3	13:0:44
Calcium Nitrate	$Ca(NO_3)_2$	15:0:0
Potassium sulfate	K_2SO_4	0:0:50
Single Super Phosphate (SSP)	$Ca(H_2PO_4)H_2O+2CaSO_4+2H_2O$	18:0:0
Mono Potassium Phosphate	KH_2PO_4	0:52:34
Phosphoric acid	H_3PO_4	0:52:0

Source : Rajput and Patel, (2002)

Table 6 : Solubility of different fertilizers

Fertilizers	Solubility,(g l^{-1} of water)		
	10^o C	20^o C	30^o C
a) Nitrogen fertilizers			
Ammonium Nitrate	610	660	710
Urea	450	510	570
Calcium Nitrate	950	1200	1500
b) Phosphate fertilizers			
Mono-Ammonium Phosphate	290	370	460
Urea Phosphate	410	495	565
495Single Super Phosphate	100	150	170

c) Potassic fertilizers			
Potassium Nitrate	210	310	450
Multi-K Mg (2MgO)	230	320	460
NPK mixture	210	330	480
Potassium sulphate	80	100	110
Mono-potassium phosphate	180	230	290
Potassium Chloride	240	310	350

Source : Rajput and Patel, (2002)

Table 7 : Acceptable concentration of different nutrients

Nutrient	Acceptable limit of ppm concentration,	Average acceptable concentration, ppm
Nitrogen	150-1000	250
Phosphate	50-100	80
Potasium	100-400	300
Calcium	100-500	200
Magnesium	50-100	75
Sulfur	200-1000	400
Copper	0.1-0.5	0.5
Boron	0.5-5.0	1.0
Iron	2.0-10	5.0
Manganese	0.5-5.0	2.0
Molybdenum	0.01-0.05	0.02
Zinc	0.5-1.0	0.5
Sodium	20.0-100	50
Corbonates	20-100	60
Sulphate	200-300	250
Chloride	50-100	70

Source : Rajput and Patel, (2002)

Table 8 : Comparative studies of fertigation for pomegranate

Location	Yield (t/ha)		Increase in yield (%)
	Fertigation	Conventional	
A	76.0	56.0	40.0
B	76.3	56.4	26.0
C	73.0	43.8	40.0
D	68.6	41.5	39.5
E	57.0	40.3	29.3

Source : Aswanikumar (2001)

Table 9 : Comparative studies of fertigation for strawberry

Location	Yield (t/ha)		Increase in yield (%)
	Fertigation	Conventional	
A	23.8	14.0	41.0
B	22.0	13.0	10.9
C	19.3	10.5	40.5

Source : Aswanikumar (2001)

Table 10 : Comparative studies of fertigation for grape crops

Location	Yield (t/ha)		Increase in yield (%)
	Fertigation	Conventional	
A	38.0	29.5	22.4
B	36.5	29.0	20.5
C	40.0	36.8	8.1
D	41.0	37.0	9.8
E	25.5	13.0	29.4
F	24.3	16.8	30.9
G	37.0	28.0	24.3
H	38.0	29.8	21.7

Source : Aswanikumar (2001)

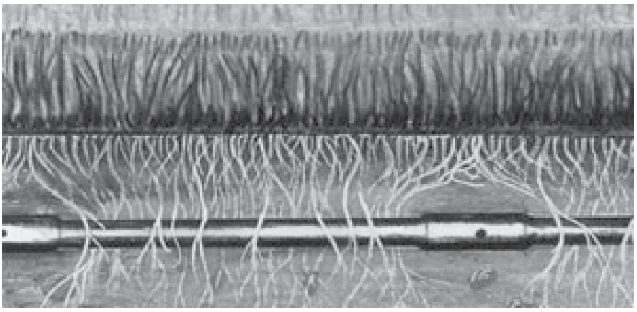
The fertilizer savings in pomegranate, strawberry and grapes are presented in **Table 8 to 10.**

Issues in fertigation

- Promotion of drip irrigation with use of other inputs like fertilizer and insecticides besides water to realize the overall potential of the system in the field
- Providing training to the drip users at local level by establishing the pilot projects of drip in orchards and vegetables
- Efforts for reduction in the cost of the fertigation equipment for more acceptability among farmers
- Subsidy to fertigation equipment may have to be given along with the drip system

Sub Surface Drip System (SDI)

The SDI system has been used for irrigating many crops including vegetables, horticultural and agronomic crops under different soil and climatic conditions. Around 40% of world vegetable crops are grown under SDI system (Toderich, *et al.,* 2004). Among vegetable crops grown under SDI system, tomato was the most popular one followed by lettuce, peas, sweet corn, melons, potato, cabbage, beans, squash, carrot, onion, broccoli, asparagus and others (Camp, 1998). The depths of placement of laterals varied from 2 to 70 cm (Camp, 1998). The recommended depths varied from 5 to 10 cm for shallow rooted tuber crops *e.g*. potato and onion; upto 25 cm for eggplant, okra and beans, and 30-45 cm for corn, cotton and Soya. However, more specific information will be required to determine lateral depths and spacing for specific soil and crop combinations (Toderich *et al*., 2004).



In most of research work reviewed, crops responded positively to SDI system. It has been compared to other methods of irrigation; and it was found that crop yields increased considerably due to SDI (Constable *et al*., 1990 and Oron *et al*., 1999). Under SDI systems, water was saved upto 25 to 55 % (Lamm *et al*., 1995 and Lamm and Trooien, 2003). It was found that irrigation frequency and application method did not affect the crop yield, but the deficit irrigation reduced the crop yield (Howell *et al*., 1996 and Lamm and Trooien, 2003). India is one of the leading countries in the world in terms of production and cultivated area under okra and yield of 7 to 12 t/ha is considered good. But, it has high potential yield of 30-40 t/ha (Duzyaman, 1997). good quality okra pods fetches good market price also. SDI system could be tried for okra cultivation to achieve its potential yields.

The performance of SDI system was evaluated to allow the management to determine and control the rate, amount and timings and distribution of irrigation water to crop in a planned and effective manner (Burt *et al.*, 1997. Ayars *et al.*, 1999 and Camp *et al.,*1997). The criteria for rating SDI system as fair to excellent was based on values of statistical uniformity between 70 to >90% and distribution uniformity between 62 to >87% (Pitts, 1997). For excellent rating of SDI system the coefficient of variation of discharge varied from 0.05 to 0.066 (ASAE, Std, 2002 and Bargel *et al*.,1996) and coefficient of uniformity more than 96% (Dasberg and Or, 1999). The acceptable emitter discharge variation was considered to be less than 20% (Wu and Gitlin, 1975). The studies revealed that most of SDI systems used were rated acceptable to excellent on the basis of performance parameters (Ayars *et al*., 1999 and Magwenzi, 2001). The studies by different investigators indicated uniformity parameters such as coefficient of variation of discharge, emitter discharge variation, distribution uniformity, statistical uniformity and coefficient of uniformity are being used as performance indicators.

Issues in SDI

- The SDI systems have to be evaluated critically at different agro-climatic regions for their acceptability by the farmers
- Though in India, biwall irrigation systems were tried as substitute to the drip systems laid on the ground surface, they failed among the farmers because of frequent clogging of the emitting points due to root encroachment into the laterals
- Need to develop the SDI laying equipment an attachment to tractors and its long term trials for its life and sustainability of the emitting points
- The systems have great potential for application of low quality water through drip system for irrigation to vegetables and other orchard crops. Research efforts have to be made in this direction

Precision Irrigation with Center Pivot Systems

With appropriate controls, sensors and decision-making tools, self-propelled center pivot (CP) and linear move irrigation systems can be managed to account for spatial variations in water and fertilizer requirements. Micro processor controlled systems linked to a central integrating computer provide a unique sensor platform and control capabilities for precision crop management. They are an effective, practical and economical means of site specific crop management for water and many agri-chemicals. Wide scale adoption of these technologies will depend on the development of inexpensive equipment which allows real time sensing of the soil and/or plant water status. It must also be integrated with a communications network and control and decision support system.

Despite the inherent high frequency and fairly uniform applications of self-propelled CP irrigation systems, considerable yield variations still exist which are often attributed to spatial variability in soil water holding capacities and related nutrient availability. Variations in water availability across a field result in a farmer:

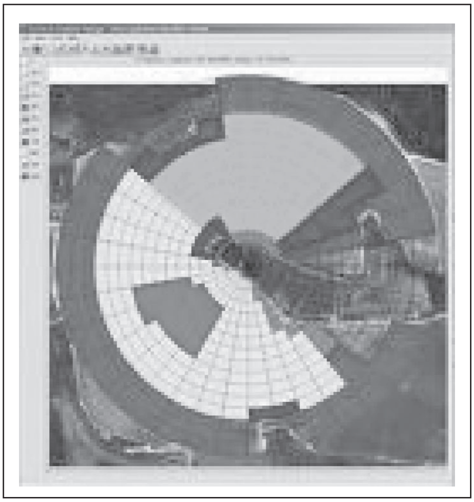
- managing to ensure that areas with the lowest water holding capacity maintain adequate water levels;
- managing the whole field based on average soil water depletions; or
- managing to avoid overirrigation in the wettest areas.

All of these cases will cause overirrigation or underirrigation of other areas due to the current inability to differentially irrigate based on soil and plant factors within a single CP irrigated field.

Self-propelled irrigation systems like center pivots and linear moves are particularly amenable to site-specific approaches because of their current level of automation and large area coverage with a single pipe lateral. In addition to irrigation, however, self-propelled irrigation systems also provide an outstanding platform on which to mount sensors for real time monitoring of plant and soil conditions which would interact with the control system for optimal environmental benefits.

Variable Rate Application Technologies

In the past, to improve operational efficiencies on a whole field basis depending on time of year, managers have resorted to practices such as manually changing sprinkler heads to match pre and post emergence conditions. Labor cost makes this technique unreasonably expensive. For within field variation in demand during the season, irrigators have had to vary end tower run speeds to adjust water applications during the season. This resulted in increased or reduced water applications that more closely met water requirements of the field for a given angle of rotation. With the use of a computerized center pivot control panel, the end tower speed (application depth) can be changed based on a preprogrammed position in the field. This has greatly enhanced the ability of the field manager to apply water to meet variable demand in wedge-shaped segments, but it still assumes an average application rate across each wedge shaped treatment area. Thus, areas of the field continue to be over or under irrigated, causing plant stress, reducing yield and quality and increasing potential for leaching water and chemicals.



The ability to vary water application along the main lateral of the center pivot based on position in the field allows the field manager to address specific soil and/or slope conditions. By aligning irrigation water application with variable water requirements in the field, total water use may be reduced, decreasing de-percolation and surface runoff. Precision application technologies can be used to treat small areas of a field with simple on/off sprinkler controls in single span-wide treatment areas or to treat the whole field by controlling all spans. Position in the field can be determined by differential GPS, electronic compasses or electronic resolvers.

It is possible to control every sprinkler individually, but the cost increases past the point that the system is economically feasible. On the other hand, it would be possible to increase the number of sprinklers per bank, which would decrease cost, but the control system would lose some ability to match pre-selected treatment areas.

Several innovative technologies have been developed to variably apply irrigation water to meet anticipated whole field management needs in precision irrigation, primarily with center pivot and lateral move irrigation systems. Most of these use standard, off-the-shelf equipment with much of the research effort directed towards developing the appropriate control systems. Other research has concentrated on applying different depths by pulsing flow and varying cycle times.

Small area control is a simpler subset of whole field control. These systems are used to manage irrigation in well-defined areas such as under the first span as well as fixed wet, dry or non-productive areas where the cost of a full precision irrigation control system is not justified.

Economics of Precision Irrigation with Center Pivots

Due to the random variability in water application distributions due to wind, start-stop operations of the CP machines, and sprinkler pattern variations combined with the low cost of water and nitrogen fertilizers, it is probably not economically feasible to site-specifically manage only for water and/or nitrogen. However, improvements in crop quality coupled with increased yields from lower yielding areas do provide economic incentives. It is expected that there will be some cost savings due to reduced aerial applications of pesticides, less water use, increased yields, less fertilizer use, increased accuracy of chemical applications, and better utilization of manpower which add to the economic returns. In addition, future environmental regulations may greatly change the economic feasibility of the site-specific irrigation control system. For example, application restrictions on aerial application of chemicals and recent changes in the endangered species listing of the various salmon and steelhead fish runs could have a large impact on the adoption of site-specific irrigation control programs in the Pacific Northwest.

A total PLC precision irrigation control system costs approximately $240 per hectare on a 370 meter long machine or about $24 per sprinkler. A pivot control system costs approximately $6000 per center pivot with a GPS compared to $4500 for the current version of commercially available digital control systems. End tower GPS positioning costs approximately $1,500 to $2,500. An electronic compass will cost between $500 and $750 for the electronic compass where as a digital resolver system costs approximately $500. Costs, including labor, for PLC controls, wiring, valves, air lines, etc installed directly on the center pivot machine come to about $6000. The controls at the cluster will cost an additional $18,000 which is divided between several machines. Costs for the custom built control system including the communications, installation of labor, computer, wiring and controls cost about $12,000 for one machine.

Researchable Issues

The ability to vary the application of water throughout a field suggests that water-soluble fertilizers can also be variably applied. A continuing part of the future development of the site-specific irrigation control system must be the application of fertilizers and fungicides using the precision irrigation control system. The next step will be the integration of irrigation, fertilizer and pest management strategies into “systems” that optimize total management practices for temporal and spatial variability. Research is needed to give farmers confidence that the use of these technologies is practical and potentially valuable in improving production.

Pivot/cluster controls should include constant concentration, variable rate injection of agri-chemicals. Experiments have indicated that a feed back control system based on the flow from flow meters from both the chemical injection system and the center pivot supply line will be required to integrate either constant rate or constant concentration fertilizer injection into the pivot control system. This will allow for either wedge-shaped applications of different amounts or the use of the irrigation treatment area definitions to variably apply agri-chemicals at either a constant rate or at a variable rate that allows changes by position in the field and by treatment areas.

The control programs also need to have automatic record keeping on the amount of water applied through the growing season (flow rate monitoring) taking into account the decreased water application when using the variable irrigation control program. Times when the systems are irrigating, traveling without irrigating, and maintenance down times as well as storage of treatment area databases also need to be recorded.

Many farmers realize the potential of remote sensing for early detection of problems before severe yield or quality damage occurs as well as to enhance IPM programs and reduce pesticide costs. Monitoring plant response to environmental stresses offers an opportunity for early detection and remediation.

Sensors development to economically conduct appropriate monitoring for different stresses and soil water levels on a near real time basis is urgently needed. To achieve maximum benefit from a site-specific irrigation control system, soil water levels in each treatment area need to be monitored.

Spray Sprinkler Systems

Spray irrigation is a modern and commonly-used system of irrigating, but it also requires machinery. This system is similar to the way you might water your lawn at home - stand there with a hose and spray the water out in all directions. Sprinkler selection,spacing, and orientation are based on trade offs between equipment costs and yield benefits associated with high application uniformity. Systems with closely spaced sprinklers generally apply water more uniformly, resulting in higher yields, but costs and application rates are higher. There are hand move sprinkler systems in the country widely used for irrigating cereals, oilseeds and tea and coffee gardens.

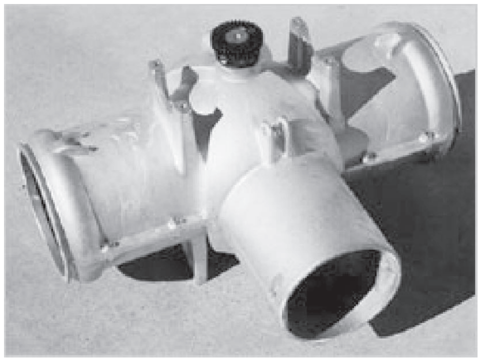
There are several studies on standardization of irrigation schudules, yield, uniformity under sprinkler systems. Large scale spray irrigation systems are in use on large farms today. The systems can simply be long hoses with sprinkers along the length or a center-pivot system that traverses a circle in the fields. The center-pivot systems have a number of metal frames (on rolling wheels) that hold the water tube out into the fields. Electric motors move each frame in a big circle around the field (the tube is fixed at the water source at the center of the circle), squirting water. The depth of water applied is determined by the rate of travel of the system. Single units are ordinarily about 1,250 to 1,300 feet long and irrigate about a 130-acre circular area. In high-pressure systems, there can be very big water guns along the tube. The system shown here is a low-pressure sprinkler system. Here, water is gently sprayed downward onto plants instead of being shot high in the air. Low-pressure systems are more efficient in that much less water evaporates.

Although still widely in use today, high-pressure spray irrigation system can be quite inefficient. A lot of water, up to 35 percent, is lost because of evaporation and the blowing winds.

Researchable Issues

- Development of tractor drawn boom type sprinkler systems for irrigating intercrop between trees and close spaced cereal and vegetable crops
- Development of moving type sprinkler system for irrigating small farms and green houses
- Development of linear moving type sprinkler system for canal commands
- Testing and performance evaluation of sprinkler irrigation systems,spray guns
- Assessmentof energy requiremnets of different spray irrigation systems

Precision Surface Irrigation Systems



Pulse or surge irrigation is a relatively new technique. In surge irrigation, water is delivered intermittently in a series of relatively short on and off tome periods of irrigation cycles. It is reported that the on & off cycling of flow for specific time period, produces "surges" during the on period and influences the soil intake rate during the off period when water soaks into the soil. The net result is a reduction in soil infiltration rates during subsequent surge on periods and increase in the rate of water front advance. Thus, the difference in intake opportunity time between upper and lower ends of irrigated field becomes less and results in a more uniform soil moisture storage and better distribution uniformity along the field after irrigation.

It was reported that there was a saving in water advance time to the extent of 40 to 60% under surge irrigation with distribution efficiencies varying from 85 to 95 % compared to continuous flow irrigation with 60-75 % distribution efficiency (Senthilvel, 1995). Senthilvel and Rajeswari observed that in case of surge flow at a cycle ratio of 0.5, the distribution efficiencies were in the range of 74 to 80% compared to cycle ratio of 0.33 with 66 to 75%.Vishalakshi and Rajput (1997) observed that the optimum number of surge required was 4 to 6 to complete one irrigation under surge flow irrigation to have maximum efficiencies.

An automatic surge irrigation system was fabricated and field tested to establish its efficacy in on-farm irrigation water management. The system was based on sequential operation. A time switch and an electromagnetic valve were the main components of the system. Automatic surge flow was found to make the soil reach its basic infiltration rate much quicker, 35 to 50% of the time elapsed in continuous flow. This facilitates quicker water front advance resulting in more uniform storage and distribution of soil moisture from head to tail end of the field with minimum losses. Irrigation distribution efficiencies achieved by automatic surge irrigation were high in the order of 92 to 96% as compared to 52-70% under continuous flow for a furrow of 120 m long(Mathew and Senthilvel,2005). This was tested in course textured soils with sand percentage of 56% in the soil . The above study is restricted to only for experimentation purpose and not for developing irrigation system and the cost details are not given.

Conclusion

A review into the irrigation systems operated in Asian Countries indicated that the field level irrigation efficiencies are very low ranging from 30-40%. Adoption of drip irrigationsystems in Asia is very low except in India, inspite of much scope in the field with particular reference to irrigating saline soils. The state of art technologies have been discussed in the paper giving their design, operation and efficiencies.

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Micro-Irrigation Adoption in India-
Role of Capacity Building Program

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Various options are available for reducing water demand in agriculture. Firstly, the supply side management practices include watershed development and water resource development through major, medium and minor irrigation projects. The second is through the demand management practices which include improved water management technologies / practices. The Micro-irrigation (MI) technologies such as drip and sprinkler are the key interventions in water saving and improving the crop productivity. Evidences show that the water can be saved up to 40 to 80 per cent and Water Use Efficiency (WUE) can be enhanced up to 100 per cent in a properly designed and managed MI system compared to 30-40 per cent under conventional practice (INCID, 1994; Sivanappan, 1994 cited in Suresh Kumar, 2008). The successful adoption of micro-irrigation requires, in addition to technical and economic efficiency, two additional pre-conditions, viz., technical knowledge about the technologies and accessibility of technologies through institutional support systems (Namara, 2005). Hence a study was undertaken to analyze the pattern of MI adoption across the states and farm groups during 2010 covering nine states, *viz*., Andhra Pradesh, Gujarat, Karnataka, Kerala, Maharashtra, Orissa, Punjab, Rajasthan and Tamil Nadu.

Methodology

Both secondary and primary data were collected. The secondary data were collected covering the state level MI sources, cropping pattern, existing area under MI and the Government subsidy details. The primary data included 150 farmer sample from each selected state using semi-structured questionnaire covering source of irrigation, farm size, irrigated area, area under MI crops grown, subsidy availed, income, expenditure under crops with and without MI. Farm level constraints for adoption of MI and suggestions for better adoption were also obtained from the field surveys. The sample was post-stratified into marginal, small and large farmers. The secondary data were used to work out the potential for MI in each state and the primary data were used to work out the economics of irrigation under different farm categories as well as to document the suggestions of the farmers for better adoption of MI in the state.

Major Findings

Potentiality and Current State of Micro-Irrigation

Potentiality of different MI systems in terms of drip and sprinkler was assessed (in terms of extent of area under the respective systems) using the state-wise secondary data (Raman, 2010). The potentiality assessment for MI in each state was made considering the source-wise crop-wise irrigated area and the suitability of different crops to cultivate with MI systems. It has been assessed that there is potentiality of bringing around 42 million ha under drip and sprinkler in the country (Raman, 2010). Out of this, about 30 million ha are suitable for sprinkler irrigation for crops like cereals, pulses oilseeds in addition to fodder crops. This is followed by drip with a potentiality of around 12 million ha under cotton, sugarcane, fruits and vegetables, spices and condiments; and some pulse crop like red gram etc.

The percentage of actual area against the potential estimated under drip irrigation in different states varied between nil in Nagaland to as high as 49.74 per cent in Andhra Pradesh and followed by Maharashtra (43.22%) and Tamil Nadu with 24.14 per cent. In case of sprinkler irrigation percentage of actual area against the potential was estimated as much low as 0.01 per cent in Bihar and highest of 51.93 per cent in Andhra Pradesh. Compared to the potential of 42.23million ha in the country, the present area under MI accounts to 3.87 million ha (1.42 million ha under drip and 2.44 million ha under sprinkler) which is about 9.16 percent only **(Table 1)**.

MI and Government Subsidy

Since the introduction of MI in India, government agencies are fully aware of the fact that the system cost is high particularly for the marginal and poor farmers to adopt. Realizing this, the Central and State Governments apart from announcing subsidy schemes, at their levels, mediate with the manufacturers from time to time and try to keep the unit cost as low as possible. Central Government also has launched a massive country-wide scheme to promote MI *viz.* Centrally Sponsored Scheme (CSS) on MI which came into effect from 2005-06 financial year. But even before the start of the CSS, Andhra Pradesh and Karnataka states have MI schemes at state level. However, the subsidy levels were comparatively low ranging from 50 to 65 per cent depending upon the MI systems and states. The implementation of MI has gradually accelerated in all the states due to CSS on MI and the increase in physical performance was in the order of nearly 800 per cent in Madhya Pradesh, 300 per cent in Punjab and 150 per cent in Orissa during 2006-08 (NCPAH, 2009). In a span of 5 years (April 2005 and December 2009) an area of around 3.56 lakh ha was brought under MI in the country.

Many times there is time lag between the decision taken on the quantum of subsidy and its actual implementation. For example, the subsidy for drip systems for banana crop in

Table 1 : Potential and Actual Area under MI in different States (area in '000 ha)

State	Drip			Sprinkler			Total		
	P	A	%	P	A	%	P	A	%
Andhra Pradesh	730	363.07	49.74	387	200.95	51.93	1117	564.02	50.49
Bihar	142	0.16	0.11	1708	0.21	0.01	1850	0.37	0.02
Chattisgarh	22	3.65	16.58	189	59.27	31.36	211	62.92	29.82
Goa	10	0.76	7.62	1	0.33	33.20	11	1.09	9.95
Gujarat	1599	169.69	10.61	1679	136.28	8.12	3278	305.97	9.33
Haryana	398	7.14	1.79	1992	518.37	26.02	2390	525.50	21.99
Himachal Pradesh	14	0.12	0.83	101	0.58	0.58	115	0.70	0.61
Jharkhand	43	0.13	0.31	114	0.37	0.32	157	0.50	0.32
Karnataka	745	177.33	23.80	697	228.62	32.80	1442	405.95	28.15
Kerala	179	14.12	7.89	35	2.52	7.19	214	16.64	7.77
Madhya Pradesh	1376	20.43	1.48	5015	117.69	2.35	6391	138.12	2.16
Maharashtra	1116	482.34	43.22	1598	214.67	13.43	2714	697.02	25.68
Nagaland	11	0.00	0.00	42	3.96	9.43	53	3.96	7.48
Orissa	157	3.63	2.31	62	23.47	37.85	219	27.10	12.37
Punjab	559	11.73	2.10	2819	10.51	0.37	3378	22.24	0.66
Rajasthan	727	17.00	2.34	4931	706.81	14.33	5658	723.82	12.79
Tamil Nadu	544	131.34	24.14	158	27.19	17.21	702	158.52	22.58
Uttar Pradesh	2207	10.68	0.48	8582	10.59	0.12	10789	21.26	0.20
West Bengal	952	0.15	0.02	280	150.03	53.58	1232	150.18	12.19
Others	128	15.00	11.72	188	30.00	15.96	316	45.00	14.24
Total	11659	1428.46	12.25	30578	2442.41	7.99	42237	3870.86	9.16

Note: P=Potential; A= actual area. Source: Raman, 2010 and Indiastat, 2010

2010 is Rs 65,000 per ha which is based on the calculation done in 2008. Any increase in the raw material prices during this time lag period will reflect on the actual cost of the system which will be Rs 80,000 per ha thus decreasing the subsidy per cent at the end users' level. Hence periodical review of the unit cost is important so that full benefit of the subsidy will be realized.

MI Adoption by Various Farm Categories

Farm Size and Area under MI

Table 2 reveals that majority of the farmers adopting MI in the case of Kerala state (52%) were marginal, whereas majority of farmers in Andhra Pradesh (70.67%), Karnataka (66%), Orissa (62.67%) and Punjab (55.34%) are small farmers. Only in the case of Maharashtra (63.33%) and Tamil Nadu (64.67%), majority of the farmers are large farmers. Namara (2005) reported that majority of the farmers who adopted drip and sprinkler

Table 2 : Farm size and area irrigated by micro irrigation systems

State	Farmer category	% of farmers	Average farm size (ha)	Average area under MI (ha)	% of area under MI
Andhra Pradesh	Marginal	6.00	0.82	0.76	92.68
	Small	70.67	1.7	0.90	52.94
	Large	23.33	14.08	2.96	21.02
Tamil Nadu	Marginal	13.33	0.62	0.48	77.42
	Small	22.00	1.72	1.31	76.16
	Large	64.67	4.67	2.41	51.61
Kerala	Marginal	52.00	0.54	0.15	94.44
	Small	28.00	1.44	1.25	86.80
	Large	20.00	2.38	2.22	93.27
Karnataka	Marginal	6.00	1.89	1.33	70.37
	Small	66.00	5.71	1.82	31.87
	Large	58.00	18.12	6.59	36.37
Maharashtra	Marginal	20.00	1.80	0.90	50.00
	Small	16.67	3.75	2.25	60.00
	Large	63.33	6.60	3.40	51.52
Orissa	Marginal	23.33	0.51	0.07	13.72
	Small	62.67	1.74	1.23	70.44
	Large	14.00	15.52	9.56	61.60
Punjab	Marginal	5.33	0.8	0.40	50.00
	Small	55.34	2.7	1.30	48.15
	Large	39.33	8.2	4.30	52.44
Rajasthan	Marginal	14.00	0.43	0.4	93.02
	Small	35.33	1.16	0.95	81.90
	Large	50.67	3.41	2.54	74.49
Gujarat	Marginal	02.00	0.8	0.58	72.50
	Small	20.67	1.75	1.13	64.57
	Large	77.33	3.65	3.0	82.19

The experiences of the GGRC in Gujarat indicated that in the recent years more number of small and marginal farmers are adopting the MI (personal communication from Raman, 2010).

Source: Survey data

irrigation systems in case of Gujarat and Maharashtra were very rich to rich farmers. Even after providing the much needed support for promotion of MI, the percentage of area under MI is not remarkable and it has been assessed by farmer category-wise in 9 states. Even though the return is high under the MI, farmers are reluctant to expand the area due to other constraints like high initial capital cost, lack of technical knowledge in the operation and maintenance of the systems and type of crops grown. The story is same like the SRI adoption where the SRI results in higher yields and income, but the adoption level is much less due to operating constraints like lack of skilled labour, high management intensity etc., (Palanisami and Karunakaran, 2010).

Cost and Returns in Micro Irrigation

MI system cost and farmers' share after subsidy varied across the farm sizes and it is comparatively lower in the larger farms compared to the other farms due to economies of scale **(Table 3).** In the case of Kerala, due to intercropping of the wide spaced perennial crops like rubber, coconut, areca nut, the unit cost of the system is comparatively less. In all the cases, the quantum of actual subsidy is more than 30 per cent which is considered

Table 3 : Micro-irrigation cost and returns across states and farm categories

State	Farmer category	Average total cost of the system (Rs/ha)		Net income (Rs/ha)		IRR (%)	
		Drip	Sprinkler	Drip	Sprinkler	Drip	Sprinkler
Andhra Pradesh	M (9)	71380	-	15340	-	16	-
	S (91)	69794	23282	17612	6104	25	27
	L (50)	65373	-	17112	-	27	-
Tamil Nadu	M (20)	81302	-	12842	-	3	-
	S (33)	74509	-	15339	-	14	-
	L (97)	66908	-	26039	-	60	-
Kerala	M (78)	15900	-	5310	-	35	-
	S (42)	18833	-	9217	-	88	-
	L (30)	18462	-	10525	-	128	-
Karnataka	M (9)	57906	-	15699	-	29	-
	S (99)	56950	-	15439	-	29	-
	L (42)	56553	-	15331	-	29	-
Maharashtra	M (25)	42053	-	10026	-	22	-
	S (20)	48085	-	13000	-	29	-
	L (105)	45400	-	24360	-	115	-
Orissa	M (15)	95600	25800	20770	15000	17	138
	S (114)	89750	22330	21515	13977	22	167
	L (21)	73800	22100	16365	14667	18	197
Punjab	M (8)	98456	-	22000	-	18	-
	S (83)	89745	57000	20000	9500	18	5
	L (59)	86563	42000	18000	9500	15	11
Rajasthan	M (25)	-	-	-	-	-	-
	S (50)		19736		6500	-	43
	L (75)		11765		5860	-	98
Gujarat	M (3)	61795		14106		19	-
	S (31)	72482	19300	19683	12617	29	188
	L (116)	73195	10512	19089	10864	27	410

S=Small farmer; M=marginal farmer; L=large farmer; IRR=Internal Rate of Return

Note: Figures in the parentheses indicate number of farmers under each farm category. Source : Survey data.

less compared to the subsidy percent announced in different states. Hence this may be one of the reasons for the slow spread of the MI in different states. Even though, MI could pay for the MI investment, farmers still expect the subsidy for MI because of two reasons: a) MI capital intensive as it varies from Rs 70,000 to 1.3 lakh per ha depending upon the crops and type of MI systems (drip or sprinkler) and farmers are reluctant to make this investment quickly, b) farmers knowledge in the operation and maintenance of the MI systems is much limited as often the systems are facing lot of problems in terms of clogging of the filters, drippers; also the required pressure from the pumps is not always maintained due to poor conditions of the pump sets, low pump discharge; c) except for wide spaced and commercial crops, the MI is not suiting well. Except in groundwater over-exploited regions, farmers in other regions don't see that MI is not an immediate need. Hence, providing incentives in terms of subsidy helps the farmers to introduce the MI in their farms and save the water.

The internal rate of return (IRR) is also varying across states and farm categories, where it was ranging from 3-35 per cent in case of marginal farmers, 14 to 88 per cent for small farmers and 15 to 128 per cent for large farmers. The IRR is higher in case of large farmers for Kerala and Maharashtra. In Kerala farmers have a diversified inter-cropping pattern in the orchard/ plantation crops, which has a higher rate of returns. In addition, the plantation crops are widely spaced and cost of investment is low.

Farmers' Suggestions for Better Adoption of Micro-Irrigation Systems

Even with the proved benefits and applicability of MI systems under different farm categories, still the overall adoption level is not high. This might be due to other constraints. This paper further examines the suggestions from farmers and also the policy recommendations at different levels.

The major suggestions include provision of technical support for MI operation after installation, relaxation of farm size limitation in providing MI subsidies, supply of liquid fertilizers, improved marketing facilities and access to more credit to expand the area under MI. Results indicate that small farmers from Andhra Pradesh and Punjab, large farmers from Tamil Nadu were in need of more technical support for the adoption and management of MI. Liquid fertilizers are highly requested from Karnataka state. Market facilities of MI systems are also important in the adoption as indicated by farmers in Tamil Nadu and Punjab. At the same time farmers from these two states suggested for the provision of more credit facilities to increase the area under MI **(Table 4).**

Capacity Building Program – A Case Study

The IWMI-TATA Policy Program (ITP) has introduced a drip capacity building and action research program (TNDRIP Initiative) covering 100 villages and 1000 farmers in Coimbatore and Erode districts in Tamil Nadu State, India during 2009-10. The main

Table 4 : Suggestions rendered by the farmers for better adoption and management of MI system

State	Farmer category	Percentage of farmers opined					
		More technical support	Supply liquid fertilizers	Providing marketing facilities	Credit to cover more area under MI	No farm ceiling	Scientific knowledge on crop production
Andhra Pradesh	M (9)	100.00	11.11	0.00	11.11	33.33	0.00
	S (91)	96.70	5.49	0.00	0.00	10.99	6.59
	L (50)	10.00	0.00	2.00	0.00	56.00	0.00
Tamil Nadu	M (20)	90.00	50.00	100.00	100.00	90.00	50.00
	S (33)	90.91	42.42	60.61	96.97	96.97	48.48
	L (97)	92.78	30.93	97.94	97.94	97.94	49.48
Kerala	M (78)	50.00	7.69	29.49	24.36	20.51	7.69
	S (42)	66.67	9.52	30.95	33.33	4.76	9.52
	L (30)	70.00	0.00	10.00	63.33	73.33	3.33
Karnataka	M (9)	11.11	88.89	11.11	66.67	0.00	0.00
	S (99)	5.05	19.19	22.22	44.44	5.05	4.04
	L (42)	4.76	21.43	23.81	50.00	59.52	0.00
Maharashtra	M (25)	20.00	24.00	16.00	32.00	8.00	88.00
	S (20)	25.00	30.00	90.00	100.00	40.00	70.00
	L (105)	5.71	21.90	54.29	53.33	55.24	50.48
Orissa	M (15)	80.00	40.00	40.00	40.00	6.67	0.00
	S (114)	47.37	12.28	32.46	14.91	25.44	7.89
	L (21)	100.00	85.71	66.67	90.48	80.95	9.52
Punjab	M (8)	0.00	0.00	0.00	100.00	0.00	0.00
	S (83)	93.98	0.00	97.59	95.18	30.12	91.57
	L (59)	89.83	38.98	96.61	94.92	54.24	89.83
Rajasthan	M (25)	40.00	0.00	56.00	20.00	0.00	48.00
	S (50)	46.00	60.00	86.00	64.00	24.00	58.00
	L (75)	1.33	20.00	74.67	80.00	64.00	24.00
Gujarat	M (3)	66.67	33.33	0.00	33.33	0.00	66.67
	S (31)	19.35	19.35	25.81	19.35	12.90	38.71
	L (116)	23.28	11.21	18.10	10.34	39.66	37.07

M=marginal; S=small; L=large farmers
Figures in the parentheses indicate number of farmers under each farm category.
Source: Survey data

objective is to sustain the drip farmers through capacity building programs with backup action research activities. The project partners include Tamil Nadu Agricultural University, Jain irrigation systems and Government departments. The results had indicated significant water saving and yield increase **(Table 5)**. Hence it is considered important to inbuilt capacity building programs along with the technology transfer programs.

Table 5 : Impact of drip capacity building program

Sl No.	Crop	Average area (ha)	Water saving	Conventional yield (t/ ha)	Yield with drip irrigation (t/ha)	Yield increase after TNDRIP (t/ ha)	Income increase after TNDRIP (Rs/ha)
1	Bitter gourd	2.4	21.5	15	20	3.0	6000
2	Snake gourd	1.8	24.0	15	18	2.1	4500
3	Ribbed gourd	2.5	19.0	16	18.5	3.2	6500
4	Tomato	1.6	15.0	20	28.7	4.5	18000
5	Pumpkin	1.5	18.0	7	12	2.0	4000
6	Maize	3.0	10.0	20	23	0.8	6400
7	Onion	1.5	26.0	15	18	1.0	9000
8	Beetroot	1.7	27.0	12	14	1.2	4600

Conclusion

Even after substantial promotional efforts from government and private organizations, the rate of adoption of MI technology is still very low compared to the potential estimated. Only few states like Andhra Pradesh, Maharashtra and Tamil Nadu have expanded the area under MI. The poor adoption can be attributed to number of factors such as high cost of the MI systems, complexity of the technology and other socio-economic issues such as lack of access to credit facilities, fragmented land holdings, traditional cropping pattern etc. Majority of them are large farmers in Tamil Nadu, Maharashtra, Rajasthan and Gujarat states compared to Kerala where marginal farmers got more access to MI. The large farmers have the advantage of economies of scale compared to small and marginal farmers whose unit cost is comparatively high thus constraining the spread of MI.

Hence reducing the capital cost and increasing the technical know-how will help the spread of the MI in a bigger way. There is a good scope of reducing the system cost by slight modifications in the agro-techniques to suit small and medium farms like paired row planting. Enough orientation needs to be given to the manufacturers/ dealers/ farmers such that most economic crop-specific design can be made. Soil texture should be one important parameter in fixing the emitter spacing. This also can reduce the system cost significantly as presently irrespective of the soil type the dripper spacing adopted is 60 cm and below. There is need to redesign low cost drip and micro irrigation systems to suit the needs of the small and marginal farmers.

Many times there is lot of time lag between the decision taken about the subsidy per cent and actual implementation. Any increase in the raw material prices during this time lag period will reflect on the actual cost of the system decreasing the subsidy per cent at the end users' level. Hence periodical review of the unit cost is important as is done in few states.

Currently different government departments or agencies are involved in the implementation of the subsidy oriented MI schemes. Due to the variation in the norms of different schemes which are implemented by different agencies, it is difficult to get the full details as and when required. Hence it is important to introduce a uniform subsidy across the states.

Capacity building of the implementing team is important which in turn can train the farmers in the use of MI systems. A capacity building program such as the TNDRIP implemented by IWMI-Tata Policy Program can be planned in all the states.(ITP, 2010)

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Participatory Soil Health Management for Productivity Enhancement and Climate Resilience

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Declining per capita availability of natural resources due to population growth, urbanization, industrialization, competing environmental demands and all inclusive growth are major concerns of resource management and conservation in most of the South Asian countries. India has only 2.5% of the world's geographical area, but has about 17% of its population. India's population increased from 361 million in 1951 to 1140 million at present, a three-fold increase in a span of little over 50 years. As of today, there is food sufficiency in the country, yet its availability to each citizen remains a problem due to disparity in purchasing power. By 2020, India needs about 300 million tonnes of food grains and the production in 2008-2009 was only 230 million tonnes, implying that about 70 million tonnes of food grains have to be produced from the same as lesser land, resulting in higher stress on soil system. Most of the intensive production systems in India showing a yield plateau and crop response ratio to inputs is being decreased. It means for extra kg yield, more and more nutrients are needed. This has negative economical as well as ecological implications in terms of low nutrient use efficiency, lesser biomass production per unit input, increase green house gasses like CO_2 and nitrogen oxides. Most important reason for declining yield trends of various production systems in the countries like India, Pakistan, Bangladesh, Srilanka and Maldives is degraded soil health. Most of the agro-ecological regions showing reduction in organic carbon with continuous cropping with improper crop management practices such as low biomass recycling, reckless tillage methods, harvest of every small component of biological produce and virtually no return of any plant residue back to the soil, burning of the existing residue in the field itself for preparation of clean seed bed, open grazing etc aggravate the process of soil degradation (Srinivasarao et.al., 2011). As a result of several above-mentioned reasons, soils encounter diversity of constraints broadly on account of physical, chemical and biological soil health and ultimately end up with poor functional capacity. The first predominant cause of soil degradation in rainfed regions undoubtedly is water erosion. The process of water erosion sweeps away the topsoil along with organic matter and exposes the subsurface horizons. The second major indirect cause of degradation is loss of organic matter by virtue of temperature mediated fast decomposition of organic matter and robbing away of its fertility.

If one looks at the Tenth Five Year Plan document of government of India, under Chapter 5.1(5.1.72-74) on agriculture, it has been stated that, a sizeable quantity of organic farm waste is generated which could be utilized for providing nutrition to the crops after converting it into compost or manure.

Maintaining or arresting the decline in soil organic matter (SOM) is the most potent weapon in fighting against soil degradation and ensure sustainability of agriculture in tropical regions. In India, 65 per cent of agriculture is rainfed and covering the categories of arid, semi-arid and sub-humid climatic zones. Consequences of depletion of organic matter are poor soil physical health, loss of favourable biology and occurrence of multiple nutrient deficiencies. It was stated that in rainfed arid, semi-arid and sub-humid tracts, next to poor rain water management, depletion of nutrients caused by organic matter deficiency is an important cause of soil degradation. Improving organic matter is, therefore, crucial in the sustenance of soil quality and future agricultural productivity. Humus is known to favour many useful physical, chemical and biological processes that occur within the soil. Accordingly, soil organic matter is a key element of soil management that prevents erosion and improves water availability. Other soil physical characteristics that are linked to soil organic matter are: infiltration, water retention, bulk density and soil strength. When spread on the surface as mulch, organic matter moderates the bomb-like effect of falling rain drops and prevents dispersion-mediated erosion, surface crusting, and hard setting (Srinivasarao et.al., 2009 a.b).

To maintain better soil health, sustainability and food security of South Asian countries, various integrated nutrient management (INM) options developed regions-wise, should be promoted more vigorously and most urgently. Keeping in view of importance of soil health and arresting its degradation, it is utmost important to have a national policy which may give some promotional guidelines for implementing INM practices. Bigger challenge in this direction is transforming INM recommendations into field scale adoption. To address the problem of translating soil health management issues, field level modes are required to demonstrate the technologies.

Soils of India and Characteristics

India has diverse soil types falling into eight orders. Taxonomically, Indian soils fall under Entisols (80.1 M ha), Inceptisols (95.8 M ha), Vertisols (26.3 M ha), Aridisols (14.6 M ha), Mollisols (8.0 M ha), Ultisols (0.8 M ha), Alfisols (79.7 M ha), Oxisols (0.3 M ha) and non-classified soil (23.1 M ha). Rainfall wise, 15 m ha area falls in a rainfall zone of <500 mm, 15 m ha under 500 to 750 mm, 42 m ha under 750 to 1150 mm and 25 m ha under >1150 mm rainfall. From practical classification, alluvial soils are the most dominant (93.1 M ha) followed by red soils (79.7 M ha), black soils (55.1 M ha), desert soils (26.2 M ha) and lateritic soils (17.9 M ha) **(Table 1)**. Both the ecological (supporting biomass, forests, buffering action) and the economic (food, fodder and fibre production) functions of the soils are important in India as the crop and livestock production systems are highly integrated in a farming systems mode.

Table 1: Broad soil groups and their moisture storage capacities of India

Broad soil group	Sub-group (based on soil depth)	Moisture storage capacity (mm)
Vertisols and related soils	Shallow to medium (upto 45 cm)	135-145/45 cm
	Medium to deep (45-90 cm)	145-270/90 cm
	Deep (>90 cm)	300/m
Alfisols and related soils	Shallow to medium (upto 45 cm)	40-70/45 cm (sandy loam)
	Deep (>90 cm)	70-100/45 cm (loam)
		180-200/90 cm
Aridisols	Medium to deep (upto 90 cm)	80-90/90 cm
Inceptisols	Deep	90-100/m (loamy sand)
		110-140/m (sandy loam)
		140-180/m (sandy loam)
Entisols	Deep	110-140/m (sandy loam)
		140-180/m (loam)

Low Organic Carbon

Most of the Indian soils are low in organic carbon (<0.5%) **(Fig 1)**. Among soil types, Vertisols and associated soils contained higher carbon stocks, followed by Inceptisols<Alfisols<Aridisols. In general, soil organic carbon (SOC) content was greater than inorganic carbon in Alfisols and Aridisols, while inorganic carbon was larger than organic carbon in Vertisols and Inceptisols. The SOC stocks ranged from 26.69 to 59.71 Mg ha^{-1} with a mean of 43.74 Mg ha^{-1} in Inceptisols, from 23.28 to 49.83 with a mean of 30.82 Mg ha^{-1} in Alfisols, from 28.60 to 95.90 Mg ha^{-1} with a mean of 46.38 Mg ha^{-1} in Vertisols and from 20.10 to 27.36 Mg ha^{-1} with a mean of 23.73 Mg ha^{-1} in Aridisols. Soil carbon content mostly depends on, climate, soil type and land use. Significantly lower levels of organic carbon in these soils are attributed to high rates of oxidation of soil organic matter due to high temperature in tropics (Srinivasarao et.al., 2009 b).

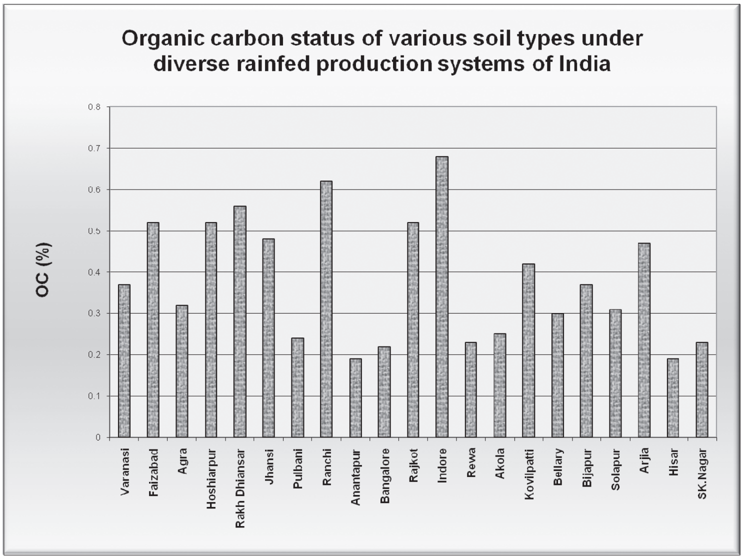


Fig. 1 : Organic carbon content in different soil types under rainfed production systems of India

Carbon stocks varied with production system and showed significant interaction with soil type. Soybean-based production system (62.31 Mg C ha^{-1}) showed higher organic carbon stocks, followed by maize-based (47.57 Mg ha^{-1}) and groundnut-based (41.71 Mg ha^{-1}) systems. Pearl millet and finger millet-based systems showed lower organic carbon stocks. On the other hand, cotton system (275.3 Mg ha^{-1}) and post-rainy (rabi) sorghum production system (243.7 Mg ha^{-1}) primarily on Vertisols and associated soils, showed higher SIC while the SIC was lowest in soils under lowland rice systems (18.15 Mg ha^{-1}). Highest total carbon stocks were found under cotton based production system, followed by *rabi* sorghum-based and was lowest in pearl millet-based system. However, percent contribution of organic carbon to total carbon stock was higher under rice-based system, while the highest inorganic carbon contribution to total carbon was observed under cotton-based.

In general, SOC stocks increased as the mean annual rainfall increased. Significant correlation ($p< 0.05$) was obtained between SOC stock and mean annual rainfall ($r=0.59^{*}$). On the other hand, SIC stocks decreased with the increase in mean annual rainfall from 156.40 Mg ha^{-1} (<550 mm) to 25.97 Mg ha^{-1} (>1100 mm). As the SIC stocks were more dominant than SOC, total carbon stocks decreased with increase in mean annual rainfall from 183.79 Mg ha^{-1} in the arid environment (<550 mm) to 70.24 Mg ha^{-1} in sub-humid regions (>1100 mm). However, CEC showed significant positive correlation ($r=0.81^{**}$) while clay content in soil showed non-significant positive correlation with organic carbon stocks. This indirectly indicates type of clay mineral with larger surface area is largely responsible for higher carbon sequestration (Srinivasarao *etal.*, 2009 a).

Poor Soil Fertility

Declining soil health in terms of soil fertility and nutrient imbalance is another major issue affecting agricultural productivity. Organic matter levels have declined sharply in intensively cropped Indo-Gangetic plains leading to stagnant yields of rice-wheat cropping system. In addition to universal deficiency of nitrogen, deficiencies of potassium, sulphur and micro nutrients are increasing. Zinc deficiency has become most acute followed by sulphur and boron (Srinivasarao and Vittal, 2007, Srinivasarao et.al., 2009 c.). It is estimated that 29.4 M ha of soils in India are experiencing decline in fertility with a net negative balance of 8-10 m t of nutrients per annum (Lal, 2004). Poor nutrient use efficiency is another cause of concern. Indian soils are low in organic matter thus soils are showing 63 per cent low, 26 per cent medium and 11 per cent high. About 80 per cent soils tested were low to medium in available P. Potassium status was low to medium in 50 per cent soil samples **(Table 2)**. Similarly among micronutrients, Zn is most deficient followed by Fe, Mn and Cu **(Table 3)**. So far soil fertility issues were mainly focused in irrigated agriculture, but recent studies indicated that drylands are not only thrusty but also hungry (Srinivasarao et al., 2006 and 2008). Most of the rainfed regions are low in organic carbon and available N and soils **(Fig. 2)** are multi-nutrient deficient **(Table 4)**.

Table 2 : Fertility status of N, P and K in some states of India

State	No. of samples analyzed	Nitrogen			Phosphorus			Potassium		
		L	M	H	L	M	H	L	M	H
Madhya Pradesh	1,38,553	40	41	19	39	38	23	10	32	58
Uttar Pradesh	8,07,424	80	15	5	71	26	3	12	55	33
Maharashtra	93,142	67	26	7	86	12	2	8	18	74
Andhra Pradesh	3,12,521	62	21	17	57	29	14	9	30	61
Karnataka	3,17,213	29	37	34	31	48	21	7	32	61
Orissa	2,51,196	60	23	17	59	28	13	33	41	26
Tamil Nadu	4,91,657	75	16	9	24	41	35	12	36	52
India	36,50,004	63	26	11	42	38	20	13	37	50

Table 3 : Micronutrient deficiencies in some states of India

State	No. of samples (range of samples analyzed for different states)	Percentage deficiency of available micronutrients			
		Zn	Fe	Cu	Mn
AP	5219-6563	51	2	1	2
Bihar	17802-19078	54	6	3	2
Gujarat	29532	24	8	4	4
MP	11204-12000	63	3	1	3
Tamil Nadu	19559-20580	53	15	3	8
UP	24425-25122	45	6	1	3
Karnataka	24411-25542	78	39	5	19

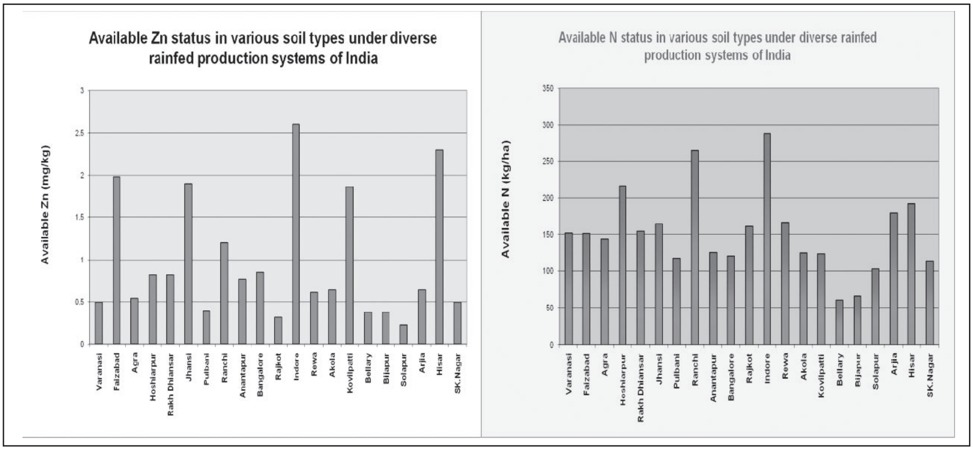


Fig. 2 : Available N and Zn status of 21 locations of AICRPDA centres

Table 4 : Emerging Nutrient Deficiencies in Dryland Soils (0-15 cm) under diverse rainfed production system of India

Location	Limiting Nutrient (Low/Deficient)
Varanasi	N, Zn, B
Faizabad	N
Phulbani	N, Ca, Mg, Zn, B
Ranchi	Mg, B
Rajkot	N, P, S, Zn, Fe, B
Anantapur	N, K, Mg, Zn, B
Indore	-
Rewa	N, Zn
Akola	N, P, S, Zn, B
Kovilpatti	N, P
Bellari	N, P, Zn, Fe

Bijapur	N, Zn, Fe
Jhansi	N
Solapur	N, P, Zn
Agra	N, K, Mg, Zn, B
Hisar	N, Mg, B
SK. Nagar	N, K, S, Ca, Mg, Zn, B
Bangalore	N, K, Ca, Mg, Zn, B
Arjia	N, Mg, Zn, B
Ballowal-Saunkri	N, K, S, Mg, Zn
Rakh-Dhiansar	N, K, Ca, Mg, Zn, B

Source: Srinivasarao and Vittal (2007)

Soil Health and Nutrient Use Efficiency

Better soil health is essential for higher use efficiency of applied nutrients. Efficiency of applied nutrients can be substantially improved by integrated nutrient management combining organic manures along with chemical fertilisers. Based on 32 years long term manorial trail at Bangalore under rainfed condition, it was concluded that partial factor productivity can be sustained with INM and organic manures while applying purely chemical fertilizers reduced PFP gradually in finger millet as depicted in **Fig. 3.** (Srinivasarao et al. 2011). Similarly agronomic efficiency drastically reduced in absence of organic manures. Therefore, improving soil health in form of soil organic carbon is needed for better NUE **(Fig. 4)**. Integrated nutrient management is essential for sustainability of agricultural production in India due to degraded soils with low organic matter and multi-nutrient deficiencies.

To develop a model of translating the soil health improvement technology a participatory action research was undertaken in about 50 villages initially and expanded to another 40 villages in eight backward and tribal dominant districts of Andhra Pradesh.
The strategy consists of :

1. Awareness on soil health in the target districts
2. Participatory soil sampling
3. Development of soil health cards
4. Site specific nutrient management (SSNM)
5. Integrated nutrient management (INM)
6. Community based interventions in soil health improvement
7. Promotion of soil health through balanced and INM by field days, wall writings, group meeting, gram sabha, news papers, mobile phone and Information and Communication Technology (ICT)
8. Impacts of participatory soil health programme on income and livelihoods.

Target districts: Eight backward and tribal districts were identified for soil health interventions as given in **Fig. 5** and **Table 5 & 6.**

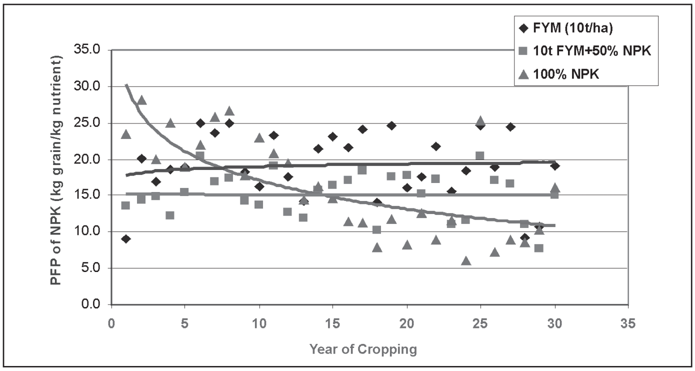


Fig. 3. Partial factor productivity of NPK in finger millet with various nutrient management options under rainfed conditions during 1978-2007

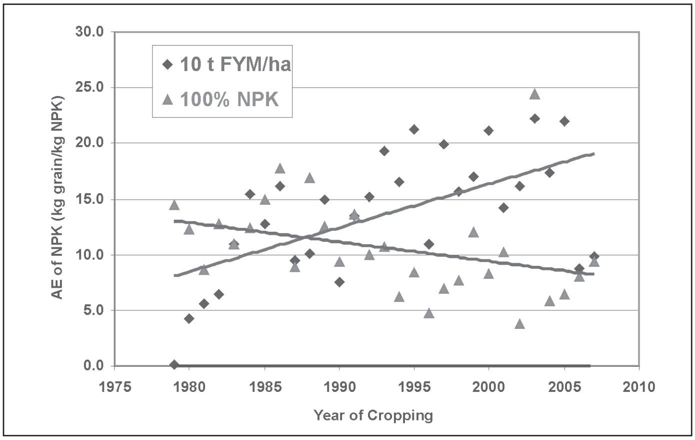


Fig. 4. Agronomic efficiency of NPK during 1975-2006 under finger millet based system at Bengaluru

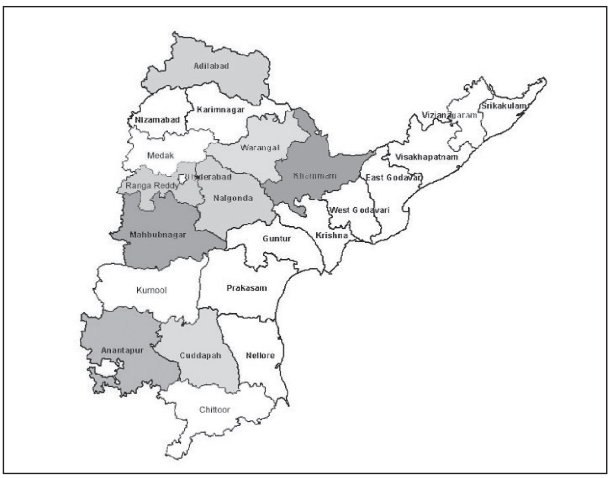


Fig. 5 Map of Andhra Pradesh indicating eight target districts where clusters are located

Table 5 : Details of Project Sites/Villages Selected for NAIP project

District	Panchayat/ Villages	No. of House-holds	Area (ha)	Unique feature
Adilabad	Seetagondi panchayat with 7 hamlets	575	1296	High tribal population (70%) and close to forests, very low productivity and technology adoption. VSS are active.
Nalgonda	Dupahad, Gajulamalka-puram, Chetla Mukundapuram	621	500	Highly drought prone area, off- season employment and high migration rates, small hamlets/ tandas with more than 50% tribes.
Khammam	Tummalachervu	650	1000	High tribal population assigned and forest lands, poor communication and market facilities, high indebtedness.
Mahabubnagar	Zamistapur Telugugudem Kodur Thanda	734	756	Highly drought prone area, more landless families, degraded lands, high livestock population, fodder scarcity, high migration and, limited livelihood opportunities.
Ananthapur	Pampanoor panchayat with thanda and Kothapalli village	576	1430	Most drought prone area, extensive monocropping of groundnut, repeated crop failures and water shortages, limited livelihood opportunities.
Kadapa	B.Yerragudi with 4 hamlets	216	1060	Drought prone area with predominance of small and marginal farmers with maximum erodable lands. Lacks proper credit and agricultural market facilities.

District	Panchayat/ Villages	No. of House-holds	Area (ha)	Unique feature
Warangal	Jaffergudem with 5 tandas/hamlets	689	2070	Village with high tribal population, degraded soils with good potential for water harvesting and drought proofing measures.
Ranga Reddy	Ibrahimpur panchayat with 3 hamlets	409	346	Village with high migration rates and lack of irrigation facility, more forest land, high use of chemical inputs and indebtedness.

Table 6 : Details of cluster, soil type and dominant crops of the clusters where participatory soil health management demonstrated

District	Cluster	No of villages	Soil Type	Crops
Adilabad	Seethagondi	8	Black	Cotton+pigeonpea
Nalgonda	Dupahad	9	Red and black	Castor+pigeonpea, vegetables
Khammam	T.Cheruvu	7	Red and black	Cotton, sorghum
Mahbubnagar	Zamistapur	3	Red and black	Castor, sorghum, groundnut
Anantapur	Pampanur	3	Red (gravelly)	Groundnut
Kadapa	B Yerragudi	8	Red and black	Groundnut, sunflower
Warangal	Jaffergudem	7	Red and black	Cotton, rice
Rangareddy	Ibrahimpur	4	Red sandy	Maize+pigeonpea

Participatory Soil Sampling: Soil samples from 1050 farmers' fields covering 50 villages in eight districts **(Fig. 5)** of Andhra Pradesh were collected by involving farmers as participants in soil sampling. Details of project sites and socio economic conditions of the villages are presented in **Table 5.** Number of households varied from 216 (B.Yerragudi) to 734 (Zamistapur). Details of cluster, villages, soil type and dominant crops are given in **Table 6**. Soil samples collected after conducting farmers meeting in each village and depending upon soil type, crop, slope and management, about 30 per cent farmers fields were selected for sampling. Once farmers identified, farmers were made into groups and demonstrated soil sampling procedure. The precautions like not to sample under shade, sloppy area, manured area, water logged area etc. Collected soil samples were labeled with cluster name, village name and farmer's name. In most of the clusters, village surpanch or village heads were involved in participatory soil sampling **(Plate 1)**.

Plate 1: Participatory soil sampling in the villages

Based on soil analysis **(Table 7),** nutrient recommendation developed for each individual farmer and accordingly plant nutrition was addressed for both major, secondary and micro nutrients **(Plate 2 & Table 8).** Farmers were using tank silt as amendment indiscriminately without its testing. Tank silts collected from various tanks in eight districts were analysed and identified the safe tank silt with lesser salts **(Fig. 6).**

Table 7 : Nutrient deficiencies in different clusters of 8 districts of Andhra Pradesh

Cluster	OC	N	P	K	S	Zn	B	Fe	Cu
Adilabad	L-M	L	L	H	D-S	D-S	D-S	S	S
Nalgonda	L-M	L	L-H	L-M	D-S	D	D	D-S	S
Khammam	L-M	L	L-H	L-H	D-S	D	D	S	S
Mahaboobnagar	L-M	L	L-M	M-H	D-S	D-S	D-S	S	S
Anantapur	L	L	M-H	L-H	D	D-S	S-D	S	S
Kadapa	L	L	L-M	L	D	D	D	D-S	D-S
Warangal	L-M	L	M-H	L-M	D-S	D	D	S	S
Rangareddy	L-M	L	L-M	L-H	D-S	D-S	D-S	S	S

L= Low; M= Medium, H= High, D= Deficient, S = Sufficient

Plate 2: Application of deficient nutrients by the farmers

Table 8 : Farmer field's specific fertilizer recommendation for cotton (variety) based on soil test value for Jaffergudem cluster, Warangal district, A.P.

Farm er No	Location	Fertilizer requirement (kg/ha)								
		Urea (total amt.)	2 splits 30 DAS	2 splits 60 DAS	DAP (entire amt as basal)	MOP (total amt)	2 splits 30 DAS	2 splits 60 DAS	$ZnSO^4$ (as basal)	Borax (as basal)
1	Jaffergudem	120	60	60	65	70	35	35	50	5
2	Ramannagudem	100	50	50	110	70	35	35	50	5
3	Kushmbai thanda	120	60	60	65	70	35	35	50	5
4	Jaffergudem	120	60	60	65	70	35	35	50	5
5	Jaffergudem	100	50	50	110	90	45	45	50	5
6	Jaffergudem	120	60	60	65	70	35	35	50	5
7	Yapalagadda thanda	120	60	60	65	90	45	45	50	5
8	Yapalagadda thanda	120	60	60	65	50	25	25	50	5
9	Satyanarayanapuram	100	50	50	110	70	35	35	50	5
10	Ramannagudem	100	50	50	110	50	25	25	50	5

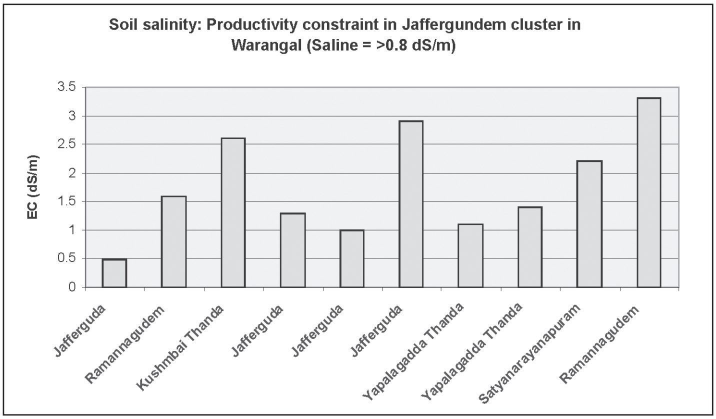


Fig. 6 Salinity status of various tank silts in Warangal district

Impacts of SSNM on Crop Productivity

Based on SSNM strategy, the productivity of various crops like cotton (Warangal, Adilabad and Khammam), groundnut (Anantapur, Kadapa and Nalgonda), sunflower (Kadapa), chickpea (Adilabad), pigeonpea (Rangareddy and Nalgonda), maize (Rangareddy), castor (Mahabubnagar), tomato, bendi, palak (Nalgonda), etc. improved substantially in the range of 10 to 30 per cent **(Plate 3 and Figs. 7 & 8).**

Plate 3: Impact of SSNM in cotton in Adilabad, Warangal and Khammam districts

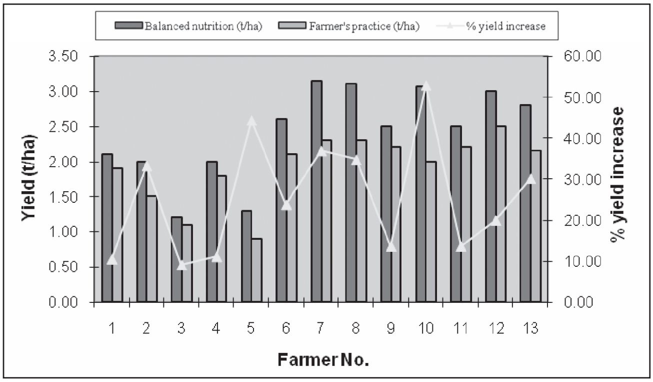


Fig. 7. Impact of balanced fertilization in Bt-cotton yield in some selected farmer's field of T. Cheruvu cluster of Khammam district, A.P.

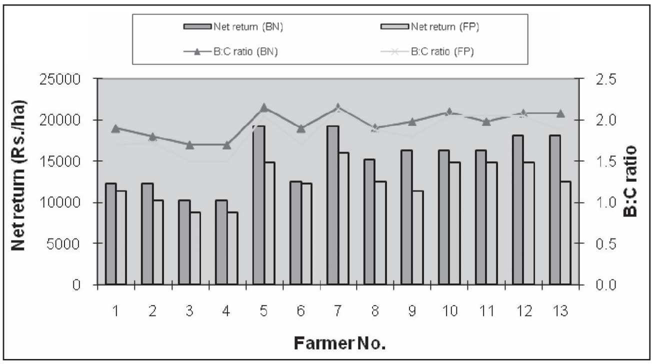
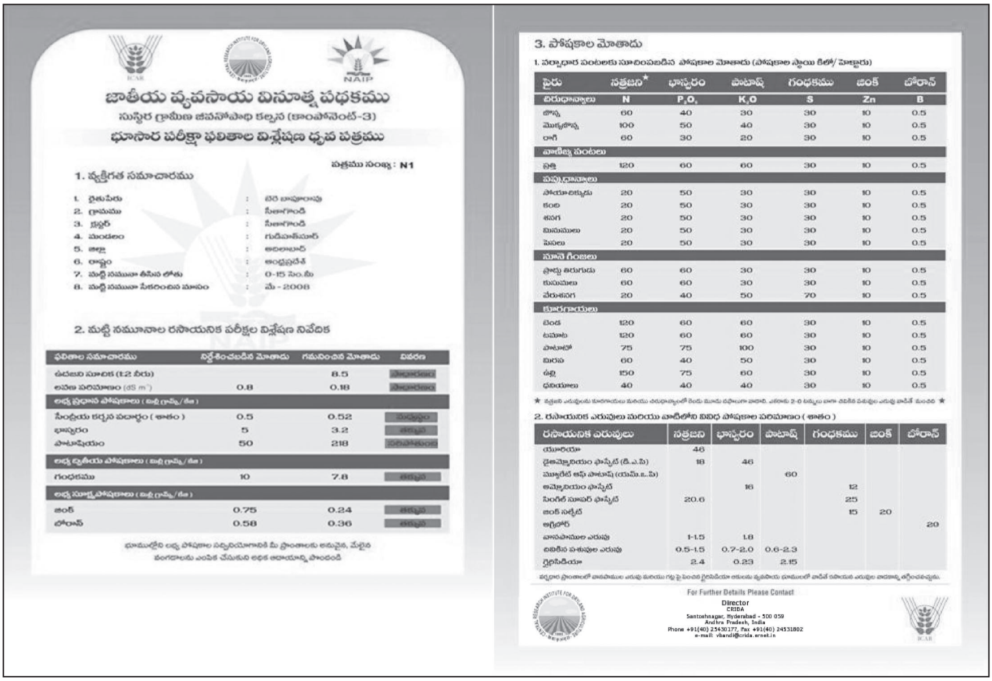


Fig. 8 Impact of balanced fertilization in net return and benefit:cost ratio of cotton cultivation in some selected farmer's field of Jaffergudem cluster of Warangal district, A.P.



జాతీయ వ్యవసాయ వినూత్న పథకము
సుస్థిర గ్రామీణ జీవనోపాధి కల్పన (కాంపోనెంట్-3)
భూసార పరీక్షా ఫలితాల విశ్లేషణ ధృవ పత్రము

పత్రము సంఖ్య : N1

1. వ్యక్తిగత సమాచారము

1. రైతుపేరు : [illegible]
2. గ్రామము : సీతాగొంది
3. క్లస్టర్ : సీతాగొంది
4. మండలం : గుడిహత్నూర్
5. జిల్లా : ఆదిలాబాద్
6. రాష్ట్రం : ఆంధ్రప్రదేశ్
7. మట్టి నమూనా తీసిన లోతు : 0-15 సెం.మీ
8. మట్టి నమూనా సేకరించిన మాసం : మే - 2008

2. మట్టి నమూనాల రసాయనిక పరీక్షల విశ్లేషణ నివేదిక

ఫలితాల సమాచారము	నిర్దేశించబడిన మోతాదు	గమనించిన మోతాదు	వివరణ
ఉదజని సూచిక (1:2 నీరు)		8.5	[illegible]
లవణ పరిమాణం (dS m⁻¹)	0.8	0.18	[illegible]
లభ్య ప్రధాన పోషకాలు (కిలో గ్రాము/ఎకరం)			
సేంద్రియ కర్బన పదార్థం (శాతం)	0.5	0.52	[illegible]
భాస్వరం	5	3.2	[illegible]
పొటాషియం	50	218	[illegible]
లభ్య ద్వితీయ పోషకాలు (కిలో గ్రాము/ఎకరం)			
గంధకము	10	7.8	[illegible]
లభ్య సూక్ష్మపోషకాలు (కిలో గ్రాము/ఎకరం)			
జింక్	0.75	0.24	[illegible]
బోరాన్	0.58	0.36	[illegible]

3. పోషకాల మోతాదు

1. వర్షాధార పంటలకు సూచింపబడిన పోషకాల మోతాదు (పోషకాల స్థాయి కిలో/హెక్టారు)

పైరు	నత్రజని*	భాస్వరం	పొటాష్	గంధకము	జింక్	బోరాన్
చిరుధాన్యాలు	N	P_2O_5	K_2O	S	Zn	B
జొన్న	60	40	30	30	10	0.5
మొక్కజొన్న	100	50	40	30	10	0.5
రాగి	60	30	20	30	10	0.5
వాణిజ్య పంటలు						
ప్రత్తి	120	60	60	30	10	0.5
పప్పుధాన్యాలు						
[illegible]	20	50	30	30	10	0.5
కంది	20	50	30	30	10	0.5
[illegible]	20	50	30	30	10	0.5
మినుములు	20	50	30	30	10	0.5
పెసలు	20	50	30	30	10	0.5
నూనె గింజలు						
[illegible]	60	60	30	30	10	0.5
కుసుమలు	60	30	30	30	10	0.5
వేరుశనగ	20	40	50	70	10	0.5
కూరగాయలు						
బెండ	120	60	60	30	10	0.5
టమాట	120	60	60	30	10	0.5
పొటాటో	75	75	100	30	10	0.5
మిరప	60	40	50	30	10	0.5
ఉల్లి	150	75	60	30	10	0.5
ధనియాలు	40	40	40	30	10	0.5

2. రసాయనిక ఎరువులు మరియు వాటిలోని వివిధ పోషకాల పరిమాణం (శాతం)

రసాయనిక ఎరువులు	నత్రజని	భాస్వరం	పొటాష్	గంధకము	జింక్	బోరాన్
యూరియా	46					
డైఅమ్మోనియం ఫాస్ఫేట్ (డి.ఎ.పి)	18	46				
మ్యూరేట్ ఆఫ్ పొటాష్ (యమ్.ఒ.పి)			60			
అమ్మోనియం ఫాస్ఫేట్		16		12		
సింగిల్ సూపర్ ఫాస్ఫేట్	20.6			25		
జింక్ సల్ఫేట్				15	20	
అగ్రిబోర్						20
[illegible]	1-1.5	1.8				
[illegible]	0.5-1.5	0.7-2.0	0.6-2.3			
గ్లైరిసీడియా	2.4	0.23	2.15			

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Fig . 9 Promotion of soil health cards among farmers

Integrated Nutrient Management (INM)

Considerable research on Integrated Plant Nutrient Supply (IPNS) has been done in India. Long-term fertilizer experiments both under irrigated as well as rainfed conditions have shown that addition of organic manures in addition to NPK results in higher yields over a long period of time as compared to a decline in yield over time when only inorganic fertilizers were applied besides improving soil organic carbon content. Though benefits of organic manure application at least to replace some of the nutrient requirements of

Plate 4: Promotion of biofertilizer and FYM by the farmers

crops were well established, its usage is being decreased over the years. Managing and adding chemical fertilizers to field is much easier and less labor intensive while organic manure preparation, storage, transport, additions etc are much cumbersome. A number of organic resources are available in India such as FYM, crop residue, livestock dung and green leaf manures, compost and vermi-compost, farm waste and municipal waste etc accounting up to 1400 million tones annually **(Plates 4 to 7)**. Various INM practices identified for different crops and regions are presented in **Table 9.**

Plate 5: Glyricidia plantation on field boundaries: Potential green leaf manure

Plate 6: Promotion of community based vermi composting

Plate 7 : Promotion of horsegram as a cover crop as a soource of organic matter with off-season rainfall

Table 9 : Effective Integrated Nutrient Management (INM) practices for rainfed crops across the country

Location		Fertilizer (kg ha^{-1})			
		N	P_2O_5	K_2O	
Jhansi	Cluster bean	15	60	0	Inoculation with *Rhizobium*
	Sorghum + Dolichos	60	20	0	
Rajkot	Sorghum	90	30	0	FYM@ 6 t ha^{-1}
	Pearlmillet	80	40	0	FYM @ 6 t ha^{-1}
	Groundnut	12	25	0	FYM @ 6 t ha^{-1}
	Cotton	40	0	0	FYM @ 6 t ha^{-1}
Solapur	Sorghum	50	0	0	9-10t/ha subabul loppings can substitute 25 kg N /ha^{-1}
Indore	General	(N plus P)			4-6 t ha^{-1} FYM in alternate years
	Soybean	20	13	0	FYM@ 6 t ha^{-1}
Bijapur		(NP or NPK)			Mulching with tree lopping @ 5 t ha^{-1}
Arjia	Corn -pigeonpea	50	30	0	50 % N through organics.
	Safflower and rapeseed-mustard	30	15	0	Reduction in N by half if these crops follow legumes such as greengram/chickpea
Agra	Barley	60	30	0	Use of FYM plus *Azotobacter*
Ranchi	Soybean	20	80	40	Inoculation with *Rhizobium*
	Groundnut	25	50	20	Inoculation with *Rhizobium*
	Pulses	20	40	0	Inoculation with *Rhizobium*
Dantiwada	Greengram	0	20	0	Inoculation with *Rhizobium*
Jodhpur	Pearlmillet	10	0	0	Addition of 10 t/ha FYM
Hoshiarpur	Corn	80	40	20	Addition of FYM
	Wheat	80	40	0	
	Chickpea	15	40	0	
Akola	Cotton + greengram	25	25	0	Along with FYM to meet 25 kg N ha^{-1}

Source: AICRPDA Annual Reports

Promotion of concept "Grain to Man and Residue to Soil"

In most of the parts of India, crop residue is used as cattle feed, firewood and field burning. Field burning of crop residue is majorly done for clean cultivation in dry farming and due to time shortage to manage crop residues in irrigated conditions. For example in a small village, Nandyala gudem in Atmakur Mandal of Nalgonda districts having 100 households, the amount of 800 tonnes of cotton stock and 300 t of pigeonpea stock is being burned every year **(Plate 8).** If the valuable crop residues are chopped, recycled as composed, it turns out to be productive manure adding nutrients and organic carbon reduce the green house grasses (GHGs). Nutrient content of various crop residues in comparison with different organic manures is given in **Table 10.**

Plate 8: Cotton stalk in Atmakur Mandal ready to burn

Table 10 : NPK content (kg/tonne) of some organic manures and crop residues

Manure / residue	N	P_2O_5	K_2O	Total
Manures				
Cattle / buffalo dung	5.0	2.0	5.0	12.0
Sheep / goat dung	6.5	5.0	3.0	11.8
Pig dung	6.0	5.0	4.0	15.0
Poultry manure	18.0	23.0	14.0	55.0
Farmyard manure	7.8	7.2	6.5	21.5
Biogas slurry	14.0	9.2	8.4	31.6
Vermi compost	18.0	20.0	8.0	46.0
Crop residues				
Rice	6.1	1.8	13.8	21.7
Wheat	4.8	1.6	11.8	18.2
Sorghum	5.2	2.3	13.4	20.9
Maize	5.2	1.8	13.5	20.5
Pearlmillet	4.5	1.6	11.4	17.5
Pulses	12.9	3.6	16.4	32.9
Oilseeds	8.0	2.1	9.3	19.4
Groundnut	16.0	2.3	13.7	32.0
Sugarcane	4.0	1.8	12.8	18.6

Impact of Soil Health on Water Retention and Drought Mitigation

Improvement in soil organic carbon results in improved soil moisture retention so that crops cope up water stress during intermillent droughts.

Conservation Agriculture (CA)

Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. CA is characterized by three principles that are linked to each other. The three principles along with the most important functions they serve are: 1) Minimum mechanical soil disturbance (Erosion control Soil C buildup), 2) Permanent organic soil cover (Erosion control biodiversity and environment) and 3) Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops (Pest and disease control, Soil infrastructure and Biodiversity). Due to crop residue cover under CA, horsegram crop was successfully grown after maize with enhanced soil moisture **(Plate 9.a).**

There was a considerable improvement in water retention at 1/3 bar and 15 bar and the available water content in soil profile due to incorporation of organic manures into the soil (FYM and groundnut shells) at Anantapur, Andhra Pradesh. In surface layer (0-20 cm), water retention at 1/3 bar increased from 9.49 per cent in control to 16.75 per cent in INM treatment. In all the treatments, water retention at 1/3 bar increased upto 60 cm and decreased thereafter. Differences in water retention between treatments were of larger magnitude in top two layers viz. 0-20 and 20-40 cm, below which all treatments showed similar values. Water retained at 15 bar varied from 5.03 per cent (control) to 9.43 per cent (50% NPK + 4t FYM ha^{-1}). In all the treatments, water retention increased upto 60 cm depth and then decreased. Available water (retained between 1/3 and 15 bar) ranged from 4.46 per cent in control to 7.32 per cent in 50% NPK+ 4t FYM ha^{-1}. Differences between control and INM treatments in available water content were maximum in surface layer and gradually decreased in lower depths. At Adilabad, addition of FYM to cotton in farmers' fields prolonged the wilting stage for 3-4 days against purely chemical fertilizer applied fields **(Plate 9 (b).**

Plate 9: Enhanced soil moisture due to organic matter (a) with surface cover (b) with FYM

Plate 10: Awareness on soil health by farmers meet and Information Communication Technology (ICT) in the villages

Conclusion

Improving and maintaining soil organic carbon is crucial for sustainability of agricultural productivity and food security of the country. This is atmost important in South Asian countries, where soils are degraded, low in organic carbon and multi-nutrient dificient. However, the challenge is to improve soil orgnaic carbon in these regions prevailing high temperature which rapidly decompose the added organic matter. Therefore special attention is needed in soil organic management in the region and farmer participation is essential. We need to have a national policy towards soil health management and with additional policy towards soil health management and additional of organic resources to the soil may need some incentivies to the farmers like fertilizer subsidy as soil health is crucial for food security and has environmental implications.

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Improvement of Soil Health for Better Moisture Stress Tolerance

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Maintenance of a healthy soil is the key to sustainable high productivity, good water and air quality and healthy human and animal population. The term soil quality and soil health are often used interchangeably in the scientific literature. Harris and Bezidicek (1991) defined soil health as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments. While Doran and Parkin (1994) defined soil quality as the capacity of soil to function within the ecosystem and land-use boundaries, to sustain biological productivity, maintain the environmental quality and promote plant, animal and human health. Gregorich et al. (1994) described soil quality as the degree of fitness of a soil for a specific use. Soil quality encompasses not only crop productivity and environmental protection but also food safety, and animal/human health.

Challenges of Soil Health

The Indian population, which increased from 683 million in 1981 to 1210 million in 2011, is estimated to reach 1412 million in 2025. To feed the projected population of 1.41 billion by 2025, India needs to produce at least 350 million tonnes of food grains. Fertilizers which contributed 50% towards improved food grain production were the fuel for the green revolution in the country. India produced about 218.2 million tonnes of foodgrains with the consumption of 26.5 million tonnes during the year 2009-10. Contrary to ever increasing demand for food, the yields of the crops grown in dryland areas remained very low (<1/ha) and the overall partial factor productivity of fertilizers to added fertilizers is declining year after year. The partial factor productivity of fertilizers decreased from 42 kg grain/kg NPK applied in 1975 to 18 in 1985, to 13 in 1995 and to 8 in 2010 (Fig. 1). The decline in rate of response of crops to added fertilizer under intensive cropping systems has possibly resulted from deterioration in physical, chemical and biological health of soils. Depletion of soil health in terms of soil organic carbon and available plant nutrients from dryland areas are some of the major threats to the soil productivity and land degradation. To meet the requirement of growing demand of food grains it is imperative to increase the production potential through improving soil health in rainfed and dryland regions besides the irrigated regions.

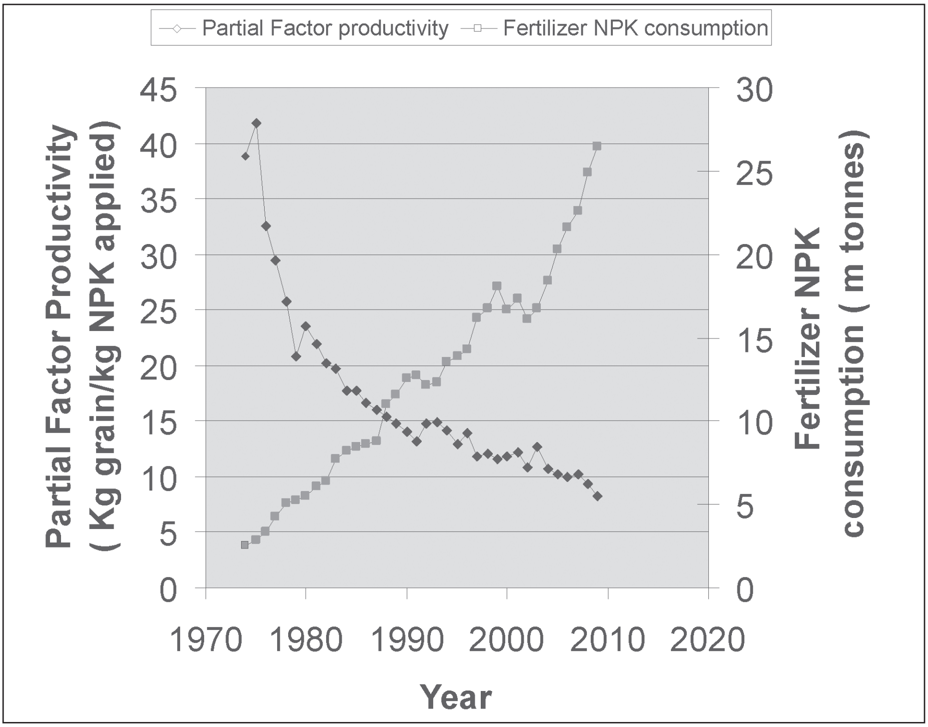

Fig. 1 : Partial factor productivity of fertilizers over years in India (Source: FAI Fertiliser Statistics 2009-10)

The major issues of soil health are :

1. Physical degradation such as compaction, crusting etc by excessive cultivation or puddling
2. Chemical degradation of soils: The major reasons of chemical degradation of soils are:
   - Wide nutrient gap between nutrient demand and supply
   - High nutrient turn over in soil-plant system coupled with low and imbalanced fertilizer use
   - Emerging deficiencies of secondary and micronutrients
   - Poor nutrient use efficiency
   - Insufficient input of organic sources because of other competitive uses
   - Acidification and aluminum toxicity in acid soils
   - Salinity and alkalinity in soils
   - Irrigation induced waterlogging and waterlogging in black soil areas during rainy season.
3. Biological degradation by organic matter depletion and loss of soil fauna and flora

4. Soil pollution from industrial wastes, excessive use of pesticides and heavy metal contamination.

Major Issues of Soil Health and Nutrient Management

Major Issues of Soil Health

The major issues of soil health are :

Wide nutrient gap between nutrient demand and supply: The growth in fertilizer consumption slowed down during 1990's and there was stagnation like situation for 4-5 years. Recently, however, there is again spurt in fertilizer consumption. After achieving a record consumption level of 18.1 mt of NPK in 1999-00, the total NPK consumption hovered around 16-17 mt during 2001-04 reaching 26.5 million tonnes in 2009-10. At present level of crops production, there exists a negative balance of 10 mt between the nutrient (NPK) removal by crops and addition through fertilizers annually.

High nutrient turnover in soil-plant system coupled with low and imbalanced fertilizer use: Yet fertilizer consumption in India is grossly imbalanced since beginning. It is tilted more towards N followed by P. Further the decontrol of the phosphatic and potassic fertilizers resulted in more than doubling the prices of phosphatic and potassic fertilizers. Thus, the fertilizer consumption ratio is highly imbalanced (N:P_2O_5:K_2O, 5:2:1) during 2008-09 as against favorable ratio of 4:2:1 implying thereby that farmers started adding more nitrogen and proportionately less phosphatic and potassic fertilizers.

Emerging deficiencies of secondary and micronutrients: Soil fertility maps of India showed that about 63% of soils are low, 26% of soils are medium and only 11% of soils are high in available nitrogen (Motsara, 2002). Similarly, about 42%, 38% and 20% soils are low, medium and high, respectively in available phosphorus. With respect to potassium, about 50% soils are high, 37% of soils are medium and only 13% of soils are low. Intensive cropping with only NPK fertilizers and limited use of organic manures, number of elements becoming deficient in soils and crops increased as food production increased with time.

About 49% soils are deficient in available zinc and its deficiencies spread all over the country. The extent of deficiency of available iron, manganese and copper in Indian soils is 12%, 5% and 3%, respectively. Continuous use of sulphur free fertilizers led to the wide spread of sulphur deficiency. The analysis of 1.35 lakh soil samples showed the deficiency of sulphur in 41% soils. Boron deficiency is wide spread to the extent of 69% in acid soils of Orissa, 38% in Bihar and 32% in light textured soils of Karnataka, 13-24% in different parts of U.P., M.P., Tamil Nadu, Assam and Punjab and 68% in tarai soils of West Bengal.

Rainfed areas are characterized by low and uncertain returns, land degradation, frequent mid-season dry spells and water scarcity but also hotspots of poverty, malnutrition and child mortality. Largely, soils of the region are not only thirsty but also hungry, particularly micronutrients such as Zn, Fe, B and secondary nutrient (S) along with macronutrients (NPK).

Declining organic matter status: Soil organic matter plays key role in soil fertility sustenance. In soybean-wheat system, without balanced input of nutrients, organic matter status of soil declined over a time in Alfisols of Ranchi **(Fig. 1)**. Whereas, balanced fertilization with NPK and NPK+FYM improved the organic matter status in Vertisols under soybean-wheat system at Jabalpur **(Fig. 2).** Thus, assessing soil organic carbon (SOC) accretions/sequestration under intensive cropping with different management practices plays an important role in long-term maintenance of soil quality.

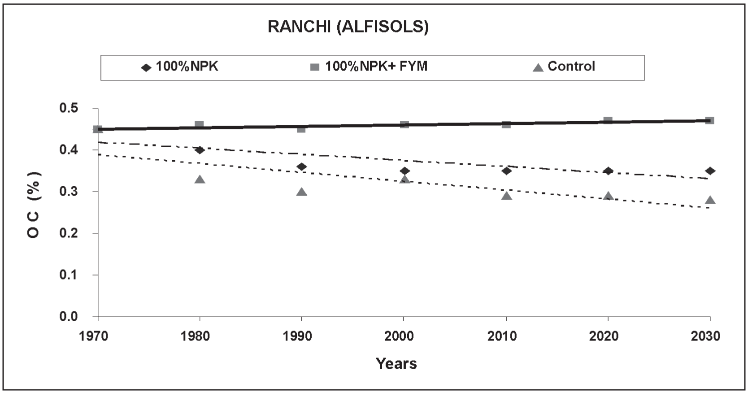

Fig. 1 : Long term trend of soil organic carbon status in Alfisol (Ranchi) under soybean-wheat system (Source: AICRP on LTFE, IISS, Bhopal).

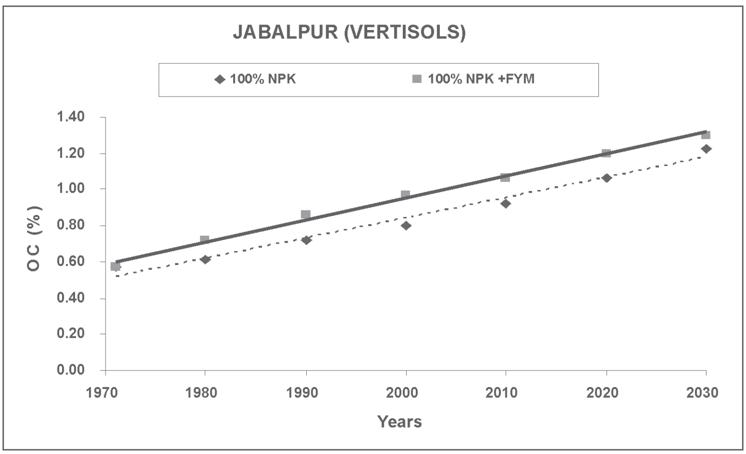

Fig. 2 : Long term trend of soil organic carbon status in Vertisol (Jabalpur) under soybean-wheat system (Source: AICRP on LTFE, IISS, Bhopal).

Poor nutrient use efficiency due to loss of nutrients through leaching, volatilization and gaseous emissions occurring due to non precise and faulty methods of application also leads to poor soil fertility and deteriorates soil quality: Due to poor health of soils, the current status of nutrient use efficiency is quite low in case of P (15-20%), N (30-50%), Zn (2-5%), Fe and Cu (1-2%). The use efficiency in case of micronutrients is extremely low (1 to 5).

Mono cropping and exclusion of legumes from the crop rotations lead to decline in fertility.

Insufficient input of organic sources because of other competitive uses

Waterlogging in black soil areas of central India due to poor drainage adversely affecting rainfed crops such as soybean in monsoon season. But in irrigated areas, waterlogging due to excessive irrigation and poor drainage is causing secondary salinization and alkalization.

Strategies of Efficient Nutrient Management for Sustaining Better Soil Health and Higher Productivity

The efficient soil management strategies such as selection of suitable crop rotations, balanced fertilization of crops, integrated plant nutrient supply, liming of acid soils, recycling of crop residues, modifying soil conditions of salt affected soils by amendments, improved tillage practices, not only help in sustaining higher crop productivity but also help in maintaining good soil health.

Choice of Suitable Crops and Cropping Systems

Different crops tap different soil layers for meeting their nutrient and water requirements depending on their root and shoot system. For example, cereals which have an adventitious root system mostly tap surface soil layer for water and plant nutrients. Under dry conditions cereals roots can penetrate a little deeper in search of soil water.

On the other hand legumes that have a tap root system absorb water and plant nutrients from surface as well as deeper soil layers. For sustainability of intensive cropping systems it is desirable not to grow a particular crop or a group of crops on the same soil for a long period. As corollary, productivity of soil can be prolonged if crops are changed over seasons or years. Some legumes have the ability to solubilize occluded P and highly insoluble calcium bound P by their root exudates in addition to improving the soil fertility. Legumes not only help in meeting part of the heavy nitrogen needs of modern intensive cereal-cereal cropping systems such as rice-rice, rice-wheat, maize-wheat etc. but also maintain SOC in the long run. It has been observed that the content of SOC in rice-wheat-green gram crop sequence was higher than rice-wheat-fodder followed by rice-mustard-green gram and rice-mustard-fodder sequences possibly due to inclusion of legume in cereal-cereal crop rotation (Sharma and Bali, 2000).

In semi-arid areas, continuous cropping reduces the decline in soil organic matter and microbial biomass compared with a wheat-fallow rotation (Campbell et al., 1991). Comparison of maize and sorghum cropping systems grown continuously and in rotation with soybean generally shows an increase in microbial biomass in the rotation (**Table 1**). Singh et al. (1996) showed that over a period of 5 years the net change in SOC was negative under cereal-cereal sequences, whereas in other sequences having legume component the changes were positive. Mixed or intercropping systems are also advantageous in many crops. For example, growing pea or pigeon pea with maize and green gram or black gram maintained higher organic carbon than growing maize with soybean (Sharma and Bali, 2000).

Table 1 : Effect of crop rotation on microbial biomass C and organic C

Previous crop	Soil type	Microbial biomass (mg C/ kg)			Organic C (g C/kg)		
		Mono-culture	Soybean	Difference (%)	Mono-culture	Soybean	Difference (%)
Sorghum	SiCL	600	650	+8.3	14.8	14.9	+0.1
Corn	SiCL	108	128	+18.5	16.7	15.6	+6.6

As an intercrop along with sorghum at 1:1 ratio, pigeon-pea grows extremely well. Apart from biological insurance against crop failure, roots of pigeon pea are able to break the hardpan in the sub-surface layer of black (clayey) soils. Intercropping also gives fairly good protection to mildly sloping land against erosion and helps in conservation of runoff by 11-15 per cent (Sharda and Ojasvi, 2005). It is also estimated that approximately 1200-1300 kg of leaf litters /ha from pigeon pea alone was added in to the soil every season. This in turn helps in enriching nutrient content and adds soil carbon during organic matter decomposition. Increased carbon accumulation (sequestration) though recycling of organic residues is not only increased the nutrient supply and turnover capacity of soils but also resulted in significant changes in the physical and biological properties of the soils. As a result, there was an increase in the water holding capacity of soils and ability to withstand longer dry spells during crop growing period. Alternate cropping sequence is very important for maintaining soil fertility in the rainfed region. Soil nourishing crops *viz*. greengram, blackgram, pigeon pea and soybean followed by nutrient depleting crops *viz*. sorghum, maize, safflower and wheat.

Improved Nutrient Management Practices

Technologies for natural resources management are usually site-specific and therefore, difficult to apply them universally. In order to minimize these limitations, resource regions that are homogeneous have been delineated into 20 eco-regions and 60 sub eco-regions to define the extrapolation domains of the technologies/management practices. It is through concerted efforts that a number of nutrient management practices for efficient utilization of fertilizers have been developed and tested over the last 3 decades. These practices can broadly be grouped as under:

- Nutrient supply to be matched to crop requirement and uptake (Top dressing, optimizing soil and plant nutrition factors such as soil moisture, liming, soil structure, soil test based recommendations).
- Improvement in nutrient application methods (broadcasting, band placement, split application etc.)
- Improvement in physical properties of fertilizers and use of inhibitors to reduce losses (Urea super granules, nitrification inhibitors, mineralisation of organic matter and efficient use of other plant nutrient sources, FYM, Phosphocompost etc.)
- Soil conditions and crop and water management (puddling, cropping system, residue management, break/catch crops, soil moisture regimes and irrigation schedules etc.)
- Bio-inoculants and green manures (Screening, evaluation of inoculants etc.)

Balanced and Integrated Nutrient Management (INM) Strategies for Different Cropping Systems

The basic concept underlying the principle of integrated nutrient management is to maintain or adjust plant nutrient supply to achieve a given level of crop production by optimizing the benefits from all possible sources of plant nutrients. The basic objectives of INM are to reduce the inorganic fertilizer requirement, to restore organic matter in soil, to enhance nutrient use efficiency and to maintain soil quality in terms of physical, chemical and biological properties. Bulky organic manures may not be able to supply adequate amount of nutrients, nevertheless their role becomes important in meeting the above objectives. Long-term studies being carried out under AICARP (Hegde and Dwivedi, 1992) have indicated that it is possible to substitute a part of fertilizer N needs of kharif crop by FYM without any adverse effect on the total productivity of the system in major cropping systems such as rice-rice, rice-wheat, maize-wheat sorghum-wheat, pearlmillet-wheat, maize-wheat and rice-maize.

Effect of Balanced and INM Practices on Soil Health

Soil Chemical Health

Integrated use of inorganic fertilizers and organic manure not only sustained the higher crop productivity but improved soil chemical, physical and biological health of different soils in various cropping systems. The organic carbon content of a Vertisol under different cropping systems over a 25 year period varied from 0.57 per cent in plots receiving no manure or chemical fertilizers to 0.97 per cent in plots receiving NPK through chemicals at recommended level in conjunction with 10 t ha^{-1} FYM applied to rainy season crop only. Despite the critical importance of organic carbon for soil quality and yield stability in semi arid areas, information on soil organic carbon (SOC) pools is sparse. In rice based cropping system followed on Inceptisol in high rainfall region (Barrackpore, India) organic carbon content decreased with soil depth **(Table 2)**. Further, soil carbon content was significantly influenced by nutrient management practices. The increase in organic carbon content of soil was the highest in plots receiving balanced fertilization. This was followed by plots which received N and P. The plots receiving N alone witnessed only marginal change in soil organic carbon. Application of manure with recommended NPK has increased organic carbon status in all soils to a varying extent (Manna and Ganguly, 2003).

Table 2 : Effect of long term fertilization on organic carbon build up in Indian soils

Location	**Cropping system**	**Soil**	**Initial SOC***	**SOC(%)****		
				Control (%)	**NPK**	**NPK+ FYM**
Bhubaneswar	Rice-Rice	Inceptisol	0.27	0.41	0.59	0.76
Pantnagar	Rice-Wheat	Mollisol	1.48	0.50	0.95	1.51
Faizabad	Rice-Wheat	Inceptisol	0.37	0.19	0.40	0.50
Barrackpore	Rice-Wheat-Jute	Inceptisol	0.71	0.51	0.72	0.76
Jabalpur	Soybean-Wheat-Maize fodder	Chromustert	0.57	0.53	0.62	0.97
Coimbatore	Fingermillet – Maize-Cowpea	Vertic Ustopept	0.3	0.44	0.5	0.64
Palampur	Maize-Wheat	Alfisol	0.79	0.62	0.83	1.20
Karnal, Alkali soil	Fallow-Rice-Wheat	Inceptisol	0.23	0.30	0.32	0.35
Nagpur	Cotton-Cotton	Vertisol	0.41			0.55
Trivandrum	Cassava	Ultisol	0.70	0.26	0.60	0.98

(Source: Manna and Ganguly, 2003)

Soil Biological Health

Soil microbial biomass C and N following the application of farmyard manure and inorganic fertilizers alone and in combination were quantified in a fingermillet-maize-cowpea cropping sequence grown under irrigated condition (Santhy et al., 1999). The data in **table 3** show that the highest microbial biomass C and N contents were observed under the integrated usage of FYM and fertilizer application (Santhy et al., 1999). There was no significant improvement of soil microbial biomass C (SMBC) and N (SMBN) in the treatment receiving inorganic fertilizer alone. The soil microbial biomass C and N was found to be positively correlated with clay content, pH, organic carbon and total N of the soil and was negatively correlated with sand, bulk density and C/N ratio of the soil. The significant positive correlation of SMBC with TOC and water soluble carbon, activity of enzymes and soil respiration might be due to the application of organic carbon addition which indirectly supports the development of living organisms and activity of enzymes.

Table 3 : Microbial biomass and its relationship with organic C and total N of the soil

Treatments	Microbial biomass C (mg kg-1)	Microbial biomassN (mg kg-1)	Microbial biomass C:N	Microbial biomass as % of soil	
				Organic C	Total N
100 % NPK	289	26	9.4	3.3	5.6
100% NPK + FYM	384	34	9.4	4.4	5.8
Control	283	26	13.4	3.3	5.9
CD (P = < 0.05)	10	1	0.4	-	-

Sharma et al. (2005) assessed the effect of different nutrient management options such as inorganic fertilizers alone, organic manures alone and integrated nutrient management practices on sustainable yield index (SYI) and soil quality of rice-blackgram-horsegram system under dryland conditions of Phulbani, Orissa. Integrated use of farmyard manure and inorganic fertilizer nitrogen not only produced higher SYI of rice-blackgram-horsegram system but also maintained the highest soil quality index. Similarly, Sharma et al. (2005) also found that at different rates of N application, the soil quality was better with conventional tillage with crop residue practices as compared to without crop residue under sorghum-caster system on an Alfisol soil.

Soil Physical Health

(a) Soil Bulk Density

Nutrient management practices have significant effect on bulk density of soil. Mishra and Sharma (1997) reported that balanced fertilization significantly reduced soil bulk density. Similarly, organic manuring and the application of blue green algae (BGA) either alone or in combination with FYM significantly reduced soil bulk density. The highest reduction in bulk density was observed in FYM + BGA treatment (**Table 4**).

Table 4 : Effect of balanced fertilization and organic manuring on soil bulk density ($Mg\ m^{-3}$) of soil.

Treatment	Soil depth (m.)		
	0-0.05	**0.05-0.10**	**0.10-0.15**
Control	1.48	1.47	1.50
100% NPK	1.42	1.40	1.44
C.D. (P=0.05)	0.03	0.02	0.02
No manure	1.52	1.52	1.53
FYM	1.41	1.40	1.42
BGA	1.45	1.43	1.48
FYM + BGA	1.41	1.38	1.40
CD (P=0.05)	0.05	0.04	0.04

Prakash et al. (2002) also reported that soil bulk density undergoes more reduction with the application of nutrients through FYM than through chemical fertilizers. The effect of FYM, however, is more pronounced after second year, due to accumulation of organic matter. Similarly, Biswas et al. (1970) reported higher soil bulk density under inorganic fertilization than under organic manuring. Incorporation of *sesbania* as green manure along with wheat or rice straw not only counteracts the adverse effect of the residues of rice but also improves organic matter content and physical properties of soil (Prakash et al. 2002). Long-term studies involving different soil types clearly revealed that incorporation of crop residues reduced bulk density of soils (Pandey et al., 1985). Tiwari et al. (2000) recorded the lowest bulk density (1.20 $Mg\ m^{-3}$) of Typic Haplustert under 100% NPK + FYM and 1.49 Mg. M^{-3} in plots receiving N alone or no fertilizer.

Long-term experiments (1982-83 to 2002-03) conducted at Bangalore showed that the bulk density (BD) of soil decreased significantly due to the enrichment of soil with organic matter content caused by continuous application of FYM in 100% NPK÷FYM and 100% NPK+FYM +lime. But the changes in BD under imbalanced treatments were not significant. The estimates of BD of soil in FYM amended plots viz., 100% NPK+FYM, and 100% NPK+FYM +lime recorded were 1.45 and 1.46 g/cm^{-3}, while the estimated of bulk density in 100% NP, 100% N and control recorded were 1.56, 1.57 and 1.55 g/cm^{-3}, respectively **(Table 5).**

Table 5. Effect of long-term fertilization and cropping on soil physical properties at Bangalore after 15 years

Treatment	Bulk density (g/cc)	Aggregate size (%)*	Mean weight diameter (mm)
50% NPK	1.54	69.1	1.42
100% NPK	1.52	73.4	1.49
150% NPK	1.54	76.3	1.65
100% NPK+HW	1.53	71.2	1.53
100% NPK +lime	1.53	79.8	1.75
100% NP	1.56	66.8	1.28
100% N	1.57	64.5	1.45
100% NPK+FYM	1.45	81.4	1.82
100% NPK(S- free)	1.54	75.0	1.52
100% NPK+FYM+lime	1.46	83.8	1.85
Control	1.55	61.2	1.29
C.D. at 5%	0.103	3.120	0.295

*<0.2mm diameter

At Pantnagar, the continuous cultivation of crops for 27 years (1976-77–2002-03) with fertilizer nutrients resulted in decline in bulk density (BD) and cone penetration resistance compared to control(no manure & no fertilizer). The decrease in BD of soil was maximum in NPK+FYM and the minimum in 100% N + Biofertilizer treatment. Similar trend was also noticed in cone penetration resistance. The estimates of bulk density and the cone penetration of control plot are 1.52 Mg m^{-3} and 3.49 kg cm^{-2} which reduced to 1.2 Mg m^{-3} and 2.42 kg cm^{-2} in NPK+FYM respectively. Perusal of data on hydraulic conductivity and mean weight diameter indicated improvement in both the soil properties on growing of crops with fertilizer and organic manure compared to control. The hydraulic conductivity of soil in control plot recorded was 0.68 mm hr^{-1} which increased to 0.74 mm hr^{-1} and 0.80 mm hr^{-1} on growing of rice and wheat at Pantnagar with NPK and NPK+FYM, respectively. A similar trend was also recorded for mean weight diameter **(Table 6)**.

Table 6 : Bulk density, penetration resistance, Hydraulic conductivity and mean weight diameter of soil during 2002-03 (Pantnagar)

Treatment	Bulk density ($Mg\ m^{-3}$)	Penetration resistance ($kg\ cm^{-2}$)	Hydraulic conductivity ($mm\ hr^{-1}$)	Mean weight diameter (mm)
50% NPK+Zn	1.36	3.34	0.73	0.70
100% NPK	1.35	3.32	0.74	0.72
150% NPK	1.32	3.28	0.75	0.72
100% NPK+HW.+Zn	1.34	3.30	0.75	0.71
100% NPK +Zn	1.31	3.26	0.76	0.72
100% NP+Zn	1.30	3.25	0.76	0.71
100% N+Zn	1.38	3.35	0.72	0.68
100% NPK+FYM	1.20	2.42	0.80	1.04
100% NPK(-S)+Zn	1.32	3.28	0.74	0.72
Biofertilizer	1.40	3.37	0.70	0.68
Control	1.52	3.49	0.68	0.63
S.Em±	0.01	0.01	0.03	0.01
C.D. at 5%	0.035	0.03	NS	0.03

Source: AICRP on LTFE, IISS, Bhopal

Similarly, the incorporation of farmyard manure at 10-15 tonnes ha^{-1} annually (along with NPK dose) for the last 7-13 years brought about a slight lowering in bulk density in almost all the soils, indicating improvement in soil physical properties. However, the effect was more pronounced on Hapludalfs (Palampur, Tropaquepts (Hyderabad), Haplaquepts (Bhubaneswar) and Chromusterts (Jabalpur) **(Table 7).**

Table 7 : Effect of long-term manuring and cropping on bulk density ($g\ cm^{-3}$) over the years (1971-85)

Location	Treatment				
	Un-manured	N	NP	NPK	NPK+FYM
Barrackpore	1.46	1.46	1.41	1.40	1.40
Delhi	1.47	1.48	1.44	1.41	1.42
Coimbatore	1.46	1.36	1.32	1.36	1.36
Jabalpur	1.22	1.26	1.22	1.21	1.18
Hyderabad	1.74	1.72	1.59	1.63	1.53
Bhubaneswar	1.18	1.12	1.13	1.17	1.05
Palampur	1.19	1.14	1.24	1.19	1.03

Source: Nambiar (1994)

(b) Aggregate Stability

The aggregate stability of the soils was evaluated in terms of the mean weight diameter of the aggregate particles (water-stable aggregates), ranging from 0.1-mm width to 5.0-mm width. The highest mean weight diameter was noted with NPK+FYM treatment, suggesting appreciable improvement in soil structure. However, the mean weight diameter showed a reduction on Hapludolls (Pantnagar) even under the NPK+ FYM treatment as compared and the fallow plot, indicating deterioration in soil structure **(Table 8)**. It was also corroborated with the loss of organic carbon resulting from intensive farming under NPK +FYM treatment but the least deterioration in soil structure. It was also corroborated with the loss of organic carbon resulting from intensive farming under NPK+FYM treatment but the least deterioration in soil structure was noticed under this. Thus, the incorporation of farmyard manure (along with NPK fertilizers) has been found to be promising in improving the physical properties of the soils.

Table 8 : Effect of long-term manuring and cropping on aggregate stability over the years (1971-85) (mean weight diameter in mm)

Location	**Treatment**				
	Un-manured	**N**	**NP**	**NPK**	**NPK+FYM**
Barrackpore	0.25	0.26	0.31	0.32	0.57
Delhi	0.31	0.31	0.33	0.33	0.38
Jabalpur	1.39	1.34	1.54	1.52	1.70
Hyderabad	1.47	1.50	1.59	1.64	1.80
Palampur	1.78	3.17	2.80	3.04	3.93
Pantnagar	1.09	-	-	0.73	1.20

Source: Nambiar (1994)

(c) Water Retention Characteristics

The positive changes in soil physical health such as bulk density, mean weight diameter, cone penetration ratio, etc due to balanced and integrated nutrient management under different production systems help in improving water retention characteristics and thereby overcoming the soil moisture stress under rainfed/dryland conditions.

The water-retention characteristics of the soils were evaluated after 7 to 8 annual cropping cycles both at 0.3 and 15 bars which showed a small improvement in water retention under NPK+FYM treatment in respect of all the soils **(Table 9).** The lowest water retention was observed in the case of unmanured plots except on Hapludalfs (Palampur), where the lowest water retention was noticed in respect of the N treatment. It was also borne out from the lower yields derived under this treatment as compared with that of the unmanured plots. Thus, reduced crop residues including root matter as a consequence of the poor crop growth resulted in lesser accumulation of organic matter in the soils, leading to comparatively poor soil physical condition.

Table 9 : Effect of long-term manuring and intensive cropping on water retention (%) characteristics over the years (1971-79)

Location	Suction (bars)	Treatment				
		Un-manured	N	NP	NPK	NPK+FYM
Barrackpore	0.3	29.9	30.1	30.2	30.2	30.1
	15.0	11.0	11.3	11.2	11.2	11.6
Delhi	0.3	19.9	20.1	20.5	20.6	21.8
	15.0	7.7	7.8	7.8	8.0	8.2
Jabalpur	0.3	34.9	35.3	35.7	36.0	37.3
	15.0	20.8	20.8	20.9	20.8	21.1
Bhubaneswar	0.3	9.1	9.9	10.2	10.2	12.0
	15.0	2.7	3.0	3.0	3.1	3.2
Palampur	0.3	25.3	24.6	-	26.9	27.8
	15.0	15.5	15.3	-	15.9	15.3
Pantnagar	0.3	30.1	-	-	26.9	27.8
	15.0	13.1	-	-	12.6	12.6

Source: Nambiar (1994)

A small improvement in hydraulic conductivity was observed on Eutrochrepts (Barrackpore), Ustochrepts (Delhi) and Chromusterts (Jabalpur) under NPK+FYM treatment **(Table 10).** However, there was a small decrease in hydraulic conductivity under NPK+FYM treatment in Haplaquepts (Bhubaneswar) which appeared to be due to reduction in non-capillary porosity as a result of aggregation of this coarse-textured (sandy) soil.

Table 10 : Effect of long-term manuring and intensive cropping on hydraulic conductivity of soils (cm hr^{-1}) over the years (1971-79)

Location	Treatment				
	Un-manured	N	NP	NPK	NPK+FYM
Barrackpore	0.088	0.095	0.095	0.095	0.106
Delhi	0.660	0.670	0.680	0.690	0.700
Jabalpur	0.126	0.116	0.125	0.124	0.133
Bhubaneswar	3.090	3.030	3.020	3.020	2.900

Source: Nambiar (1994)

Thus, addition of farmyard manure in combination with NPK fertilizers improved the water movement in fine-textured soils through the formation of larger water-stable aggregates while it reduced the water movement in coarse-textured soils through reduction in non-capillary porosity, thereby moderating both the adverse soil conditions.

(iv) Improved Agronomic Practices

Globalization and urbanization has changed the paradigm for agriculture. The age old paradigm based on massive soil inversion with a plough has changed to a new paradigm of conservation agriculture (CA) wherein some observed major shifts include the following:

- Conventionally tilled wheat to Zero tillage/reduced tilled wheat.
- Puddled transplanted rice to Direct dry seeded rice (zero-till rice)
- Residue burning/residue incorporation to Residue retention (mulching)
- Monocultures to Diversified agriculture
- Sole crops to Intercrops in bed-planting

The new multi-crop planters enable the farmers to plant the crops timely in residual soil moisture of preceding crops to save pre-sowing irrigation water, diesel, and labour. The drill places seed and fertilizers at an appropriate soil depth in a narrow slit which helps in enhancing the fertilizer use efficiency. By end of rabi 2006-07 more than 3.13 Mha were planted to zero-till, and reduced till systems in Indo-Gangetic Plains (Gupta, 2006). The CA production technology package is emerging as a clear winner. Probably it is adaptable, divisible, reliable, and spreading faster than projected.

Reduction in tillage intensity will conserve plant residues and may eventually increase soil organic matter. Microbial C has been used as an early indicator of the increase in soil organic matter. A decrease in tillage intensity results in a greater proportion of microbial biomass to organic C **(Table 11)** (Carter, 1991). This may indicate that the organic matter is increasing although soil organic C may not be significantly different between tillage systems.

Table 11. Effect of tillage on microbial biomass and soil organic C.

Crop	Tillage	Microbial biomass C (mg/kg)	Soil organic C (g/ kg)	Microbial C/soil organic C (%)
Maize	Plowed	120	19.6	0.61
	No tillage	237	21.5	1.10
Wheat/Barley	Plowed	150	22.3	0.67
	No tillage	299	25.5	1.18
Wheat	Plowed	760	44	1.73
	No tillage	940	48	1.96

Source: Carter, 1991

Mean value of soil samples revealed that the DTPA-available status of Fe and Zn had low to medium status (Somasundaram et al., 2009). By and large, the stagnation in crop productivity in rainfed areas was attributed to deficiencies of micronutrients as they play an important role in physiological process in crop plants, which is directly linked with yield parameters. The results suggested that Fe chlorosis /Zn deficiency symptoms may develop in the near future**,** which indicates that corrective measures like soil application or foliar spray of micronutrients would be required to overcome these deficiencies in the near future.

Fertiliser micro-dosing is one another technique developed by International Crop Research Institute for Semi-Arid Tropics (ICRISAT), where it enables farmers to measure the right amount of fertilizer in the caps of soft drink bottles and placing these along with the seed. *Micro-dosing* is the practice of providing the growing crop with appropriate quantity at the right time. This method helps thousands of farmers in western and southern Africa to get their crops to mature faster and overcome the worst effects of drought.

(v) Effect of Integration of Broad Bed Furrow (BBF) and Balanced Fertilization on Growth and Productivity of Soybean-Wheat System on Waterlogged Fields

About 20-25% of cultivable land in Black soil areas of Central India is left uncultivated by farmers during *kharif* season due to prolonged waterlogging condition. Even though farmers sow waterlogged fields with soybean, the yields are negligible due to poor establishment of soybean. Most of the fields in this region were also deficient in available N, P, S, and Zn but high in available K. Therefore, three demonstration field trials were conducted in Rangai village, Vidisha district to demonstrate the beneficial effect of integration of Broad Bed Furrow (BBF) with balanced fertilization or integrated nutrient management (INM) on soybean – wheat system. The beneficial effect of integration of BBF with balanced fertilization (100% NPKSZn) or INM on soybean seed yield was compared with that of flat-on grade (normal) with balanced fertilization or INM on waterlogged fields which could not be cultivated in most of the years (Sammi Reddy et al., 2010).

During *kharif* season, the results of demonstration trials showed that the integration of BBF with INM produced higher soybean yield by 83%, 78% and 96% at site 1, site 2 and site 3, respectively over the integration of flat land (normal) with INM **(Table 12)**. Whereas, the integration of BBF with balanced fertilization with inorganic fertilizers produced 73%, 82% and 75% higher soybean yield over the integration of flat land (normal) with balanced fertilization at site 1, site 2 and site 3, respectively. The pooled data of 3 sites showed an increase of about 92% in soybean seed yield with integration of BBF with INM on waterlogged fields over that of integration of flat land with INM. The crop stand on BBF was shown in Plate 1 and 2.

During *rabi* season, wheat was grown on flat land with INM, balanced fertilization and farmers' practice of nutrient management. On plots those had BBF in *kharif* season, INM and balanced fertilization produced 18% and 24% higher wheat yield, respectively over the farmers' practice.

Table 12 : Soybean grain yield (kg ha^{-1}) as affected by the integration of nutrient management and land treatments on waterlogged fields. (Mean of 3 Sites)

Land Treatment (LT)	Nutrient Management (NM) Options			Mean
	FP	BF	INM	
Flat (Normal)	1017	1159	1246	1141
BBF	1585	2047	2322	1985
Mean	1301	1504	1784	
LSD(5%)	LT	NM	LTx NM	
	481	309	487	
FP: Farmers' Practice; BF –Balanced Fertilization; INM-Integrated Nutrient Management				

Source: Sammi Reddy et al. (2010)

Economics of BBF and nutrient management in soybean – wheat system grown on waterlogged fields has been computed. The economic evaluation in soybean showed that a farmer can get a net income of about Rs.12000/- and a B:C ratio of 0.96:1 with the integration of BBF with INM on water-logged fields **(Table 13).** During *rabi* season, cultivation of wheat on plots those had BBF in k*harif* produced a per ha net income of about Rs.59000/- with balanced fertilization through inorganic fertilizers and a per ha net income of Rs.56000/- with integrated nutrient management **(Table 14)**. If soybean-wheat system grown on water-logged fields considered as a unit, a farmer can get a per ha net income of Rs.68121/- and B:C ratio of 3:1 with the adoption of BBF and INM in soybean and INM in wheat **(Table 15)**. These results have clearly indicated that the farmers can cultivate water-logged fields with soybean with BBF and INM in *kharif* and wheat with INM in *rabi* which facilitate higher cropping intensity and net income per unit of land to the farmers in Madhya Pradesh. If water pond is constructed on the farm, the drained water can be stored in the pond and used for supplemental irrigation.

Table 13. Economics of nutrient management in soybean grown on BBF plots (Mean of 3 sites)

Treatment	Mean soybean yield (kg/ha)	Gross income (Rs/ha)	Total cost (Rs/ha)	Net returns (Rs/ha)	B:C ratio
FP	1068 (±70)	17088	11353	5735	0.51
BF	1331 (±251)	21296	12369	8927	0.72
INM	1533 (±267)	24528	12520	12008	0.96

FP: Farmers' Practice; BF –Balanced Fertilization; INM-Integrated Nutrient Management, * Figures in parentheses are standard deviations.

Table 14 : Economics of nutrient management in wheat grown on plots those had BBF in *kharif* season (Mean of 3 sites)

Treatment	Mean wheat yield (kg ha^{-1})	Gross income (Rs. ha^{-1})	Total cost (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B:C ratio
FP	3977 (±184)	56424	10173	46251	4.55
BF	4931 (±272)	70178	11180	58998	5.28
INM	4690 (±284)	66620	10507	56113	5.34

* Figures in parentheses are standard deviations.

Table 15 : Economics of nutrient management (NM) in soybean-wheat system grown on waterlogged fields with BBF and NM in k*harif* and NM in *rabi* (Mean of 3 sites)

Treatment	Mean grain yield (kg ha^{-1})		Gross income	Total cost (Rs. ha^{-1}) (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B:C ratio
	Soybean	Wheat				
FP	1068	3977	73512	21526	51986	2.4
BF	1331	4931	91474	23549	67925	2.9
INM	1533	4690	91148	23027	68121	3.0

Conclusion

The decline in rate of response of crops to added fertilizers under intensive cropping systems has possibly resulted from deterioration in physical, chemical and biological health of soils. Depletion of soil health in terms of soil organic carbon and available plant nutrients from dryland areas are some of the major threats to the soil productivity and land degradation. To meet the requirement of growing demand of food grains it is imperative to increase the production potential through improving soil health in rainfed and dryland regions besides the irrigated regions.

Among the above nutrient management strategies, balanced and integrated nutrient management practices were found viable technologies to sustain higher crop productivity and maintain better soil health under rainfed as well as intensive agriculture systems. Integrated nutrient management improved the water movement in fine-textured soils through the formation of larger water-stable aggregates while it reduced the water movement in coarse-textured soils through reduction in non-capillary porosity, thereby moderating both the adverse soil moisture conditions.

Integration of Broad Bed Furrow (BBF) and integrated nutrient management helped in successful cultivation of soybean on waterlogged fields in *kharif* season and wheat in *rabi* season through conserved soil moisture.

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Agroforestry Measures for Effective Soil and Water Conservation

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Conservation of soil and water is a vital issue throughout the world as it is a threat to agricultural productivity. Soil conservation used to be equated with erosion control. The traditional "barrier approach" to soil and water conservation (mechanically constructing physical barriers and structures such as bunds and terraces to control runoff) involved excessive economic and labour costs (for both construction and maintenance) and cause irreparable loss of or damage to valuable topsoil, especially soil flora and fauna. Extension efforts concentrating on such an approach failed. Consequently, the emphasis shifted to using soil cover as a means of controlling erosion. This shift, brought agroforestry into focus because of its potential for providing continuous ground cover and soil fertility maintenance as well as the possible runoff barrier function of woody perennials. Arresting land degradation by conservation of soil and water helps in restoring the productive potential of soil. It calls for improvement in the physical, chemical and biological conditions. The advantage with agroforestry systems is in their ability to bring favourable changes in all the three conditions.

Agroforestry system is being popular in many countries to protect the land from various types of degradation. With the growing realization that agroforestry is a practical, low cost alternative for food production as well as for soil and water conservation, forest departments of many countries are integrating agroforestry programmes with conventional silvicultural practices (Swaminathan, 1987). Most agroforestry systems constitute sustainable land use and help to improve soil and water in a number of ways. Some of these beneficial effects are evidence in a number of experiments carried out in different parts of the world (Nair, 1987and Young, 1989). Through agroforestry, many countries could not only minimize the soil and water loss but also increased the production (GTI, 1995; Mishra and Sarim, 1987; Swaminathan, 1977).

Agroforestry is a collective name for a land use systems and practices where woody perennials (trees, shrubs, palms, bamboos etc) are deliberately used on the same land management unit with agricultural crops and or animals, either in some form of spatial arrangement or temporal sequence in which there are both ecological and economical interactions between different components (Kang, 1992). Agroforestry offers both productive (of basic needs), and protective (of the environment) benefits to man **(Fig 1).**

Among the productive functions, the three 'Fs' (fuel wood, fodder and fruit) are the most important. The service functions include shade, reduction in wind speed, conservation of soil and water, control of erosion and maintenance and improvement of soil fertility.

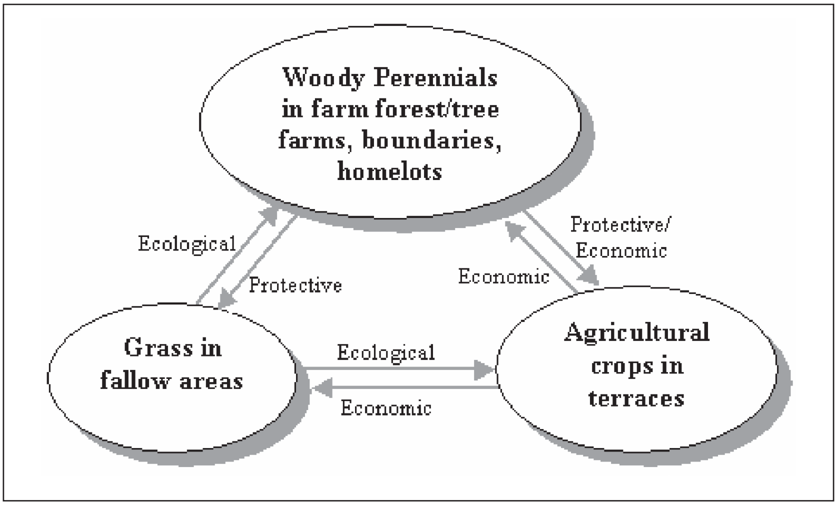

Fig. 1 : Agroforestry systems

Agroforestry as a land use system of farming offers a more viable option as it appears to be more environmentally friendly in maintaining and improving soil fertility status particularly in the third world countries, where poor resources farmers exist. It is a major shift from the traditional land use or farming system often referred to as shifting cultivation found in the topics. Agroforestry is vital for global food security and, helps in prevention or reversal of land degradation through soil and water conservation in the humid tropics (Cooper *et al.*, 1996). The key benefits in terms of natural-resources use are as follows:

- Soil conservation in terms of protection against erosion.
- Improvement or maintenance of soil fertility.
- Water conservation and more productive use of water.
- Providing environmental functions required for sustainability.

Soil and Water Conservation

Soil conservation basically means *a way of keeping everything in place*, literally as well as in a more abstract sense of maintaining the functions of the soil in sustaining plant growth. Soil conservation practices involve managing soil erosion and its counterpart process of sedimentation, reducing *its negative impacts* and exploiting the new opportunities it creates. Young (1989) defined soil conservation as a combination of *controlling erosion* and *maintaining soil fertility*. In the past the focus has often been on trying to keep the soil at its place by plot-level activities only. Currently, the attention has switched to landscape level approaches where *sedimentation* is studied along with *erosion*, and the role of '*channels*' (footpaths, roads and streams) is included as well as the '*filters*' that restrict the overland flow of water and/or suspended sediment.

Some Key Principles for Soil and Water Conservation (Modified From FAO and IIRR, 1995)

- The farm household shoulds be the focus of every soil conservation program, as they take the daily decisions that shape the landscape; communal action at local level can be an important entry point for outside 'soil conservation programs'.
- Farmers cannot ignore the short-term benefits of the land use decisions they make. Only those production strategies have a chance to be adopted that will provide a reasonable return on the labor and other resources a farmer has to invest. Conservation strategies or technologies that do not meet this criterion are doomed to fail.
- Lack of secure land tenure maybe a major cause of low interest of farmer in environmental conservation. Improving tenure security may be the main intervention needed for farmers to adopt reasonable soil conserving technologies. · Soil conservation programs have often led to 'pseudo-adoption' if strong social pressure, subsidies or other government incentives (including tenure security) were used to support adoption of practices that required substantial labor and other resource investment.
- Loss of soil productivity is often much more important than the loss of the soil itself, as the soil on the move tends to be rich in organic matter and nutrients, relative to the remaining soil.
- Loss of soil productivity is not easy to assess, however, because impoverished zones of net erosion may be accompanied by enriched zones of net sedimentation and the farmer may decide to grow different crops in these two environments
- In upland systems, plant yields are reduced more by a shortage or excess of soil moisture (especially for tuber crops) or nutrients rather than by soil losses *per se*. Therefore, there should be more emphasis on *rainwater management*, particularly water conservation, and *integrated nutrient management* and less on soil conservation *per se*. Agronomic processes such as tillage and mulching that maintain infiltration rates are more useful than mechanical measures blocking the path of water flowing at the soil surface in preventing erosion and runoff.
- Erosion is a consequence of how land and its vegetation are managed, and is not itself the cause of soil degradation. Therefore prevention of land degradation is more important than attempting to develop a cure afterwards.

- Erosion is a top-down process, because gravity determines the direction of water flow. Most past (and current) soil conservation programs focus(ed) more on land degradation than on the land user (the farm household), and used a top-down approach in 'dissemination' and 'extension' of 'best-bet' practices that were considered to be applicable for a wide range of farm situations. Top down programs tend to focus primarily on the symptoms of erosion through subsidized terracing, promotion of hedgerow intercropping systems or other measures which have had mixed success when introduced by outside agencies.
- Soil conservation programs that aim to reduce land degradation problems through treatment of causes, require a long term, bottom-up approach supporting farmers who generally have detailed knowledge of their farm, know a wide range of potential interventions (although they can still learn new ideas from experiences elsewhere) and choose between these interventions on the basis of the resources and pressures on the farm household.

Agroforestry and Soil Conservation

- Agroforestry is one of the principal biological methods of conservation and assists in maintenance of a soil cover.
- Agroforestry provides opportunities to link water conservation with soil conservation
- Agroforestry technologies exist which make the cultivation of sloping lands sustainable.
- By combining soil fertility improvement with conservation, agroforestry can maintain or improve crop yield at the same time as controlling erosion.
- By combining production with conservation, agroforestry systems increase the acceptability of soil and water conservation.

Functions of Agroforestry Systems in Soil and Water Conservation.

Supplementary use:

- To stabilize earth structure by root systems;
- To make productive use of the land occupied by conservation works.

Direct use:

- To increase soil cover, by litter or pruning, and hence reduce rain drop impact;
- To increase infiltration and hence reduce runoff;
- To provide partly permeable barriers to check runoff;

- To increase soil resistance to erosion through maintenance of organic matter;
- To maintain soil fertility by decay of litter or pruning;
- To add an element of production to conservation.

Importance of Soil Cover

There are two technical means of achieving soil and water conservation, the barrier approach and the cover approach. The barrier approach is to check runoff and down slope soil removal by means of contour aligned barriers. These may be terraces, ditch-and bank earth structure, grass strips or hedge rows. Barriers either divert runoff into safe channels, such as grassed waterways, or reduce it by promoting infiltration. Agroforestry can contribute to barrier approach directly, through the use of hedgerows as partly permeable barriers, and indirectly, through the role of trees in stabilizing earth structures and making productive use of the land they occupy.

The cover approach is to check raindrop impact and runoff through maintenance of a soil cover formed of living or dead plant material, including herbaceous plants, crop residues, tree litter and prunings throughout the period of erosive rains.. Techniques include cover crops, mulching and minimum tillage. Agroforestry can contribute to soil cover through the use of tree litter and prunings, in combination with the living plant cover. In agroforestry system maintenance of ground cover of 60% or more formed by any combination of living herbaceous plants has a high potential to reduce soil erosion and should be the primary objective in agroforestry system (Solanki and Ram Newaj, 2001). Effective land cover by vegetation is the key to arresting run-off and soil loss. It has been estimated that soil erosion is accelerated to >900 times when tree plantations were clean weeded or the litter was burnt. In semi arid alfisol degraded land, established pasture reduced run-off to 26% and soil loss to 8 % (Pathak, 2000).

Conservation Techniques

A risk of accelerated erosion exists on cultivated land from the moment trees, bushes, grass and surface litter are removed. Erosion will be exacerbated by attempting to farm slopes that are too steep, cultivating up-and-down hill, continuous use of the land without any rotation of different crops, inadequate input of organic materials, compaction due to footpaths or heavy machinery used for tillage and removal of harvest products etc. Erosion control depends on good management, which implies establishing sufficient crop cover and selecting appropriate practices to maintain infiltration with or without soil tillage. Thus soil conservation relies strongly on agronomic methods in combination with a realistic soil management while mechanical measures play only a supporting role.

There are two principal methods for the direct use of trees in soil and water conservation: dense, mixed agroforestry systems and spatial zoned systems. The main agroforestry technologies with a potential to conserve soil and water are :

1. Multistory/ strata tree systems(dense, mixed agroforestry systems);
2. Perennial - crop combinations (dense, mixed agroforestry systems);
3. Contour hedgerows (spatial zoned systems);
4. Soil conservation hedges;
5. Windbreaks and shelter belts.

Multistory/ Strata Tree Systems

Multistrata systems comprise both forest gardens and home gardens, the former being the main basis for soil and water conservation, because of their greater spatial extent. Multistrata tree gardens (also called analogue forests or agroforests), possess greater species heterogeneity and more closely resemble natural forests. These dense, multistrata systems control soil erosion not through the canopy but by means of the ground surface cover of herbaceous plants, mulch or litter. In Western Ghats of Kerala, India, erosion on recently cleared forest was 20t ha^{-1}, while on mature cardamom, pepper and mixed home gardens it was reduced to 1-4 t ha^{-1}(Moench, 1991).In Sri Lanka mixed species tree gardens were established to replace uneconomic tea smallholdings on eroded land, not only restoring and conserving the soil but giving considerable economic benefits (Sangakkara, 1991). Still more sustainable are home gardens, similar to Multistrata systems except that they are of smaller extent and receive more intensive management. The classic example is the Kandy home – garden system of Sri Lanka (Perera and Rajapakse, 1991).

Perennial- Crop Combinations

Plantations of perennial tree crops become agroforestry systems either when there is an over story of tress or when two or more woody perennial crops are grown in combination. Perennial - crop combinations of tea, coffee, cacao, oil-palm, rubber and pine apple with *Gliricidia sepium* is common in the tropics. The system is distinct where the crops are grown in orderly rows and replanted in blocks. Agroforestry in the form of perennial - crop combinations offers greater opportunities in conservation of soil and water in sloppy areas. The trees are often called as “shade trees” but have numerous other functions, those which are soil related (Beer, 1987).

- Reduction of evaporation from the shaded crop
- Increased water output
- Moderation of extreme soil – surface temperature
- Improvement in soil drainage and aeration by root systems
- Reduction in evaporation from the soil surface through mulch cover
- Control of erosion through the mulch cover.

Contour Hedgerow System /Alley Cropping

Contour hedgerow systems using nitrogen fixing trees/shrubs have been widely promoted to minimize soil erosion, restore soil fertility, and improve crop productivity (Young 1997; Sanchez, 1995 and Garrity, 1996).

Hedgerows of trees or shrubs (usually double hedgerows) are grown at intervals of 4- 8 m along the contours **(Fig. 2).** The hedge rows are usually either single, with a within-row spacing of 25 cm between plants, or double, two such rows 25 or 50 cm apart. The strips or alleys between the hedgerows are planted with food crops. The hedgerow trees are regularly pruned to minimize shading of food crops, the pruned biomass can be used as green manure or as mulch *in situ,* or as fodder. Through time, natural terraces can form at the base of the hedgerow trees, and thereby minimize soil erosion and surface run-off. Terrace formation can be rapid if the soil is ploughed, but slower in no-till or manual tillage systems. Contour hedge row takes less space than other conservation technologies. Agroforestry barriers are quite effective in controlling run-off and soil loss on 4 % slope. The total sediment deposited along hedge rows (3 – year period) and 3 rows (9-year period) ranged from 184 to 256 t/ha, equivalent to 5-20 mm of soil depth (Solanki and Ram Newaj, 2001).

This technique has been recommended as a common feature of extension programs for sustainable agriculture in Asia. The major problem in practice is the large amount of labor needed to prune and maintain woody hedgerows. ICRAF (1996) estimated that the amount of labor required to prune leguminous-tree hedgerows was about 31 days per hectare, or 124 days annual labor for four prunings in the Philippines. There is a need for simpler, less labor intensive but effective contour hedgerow systems. One can state that

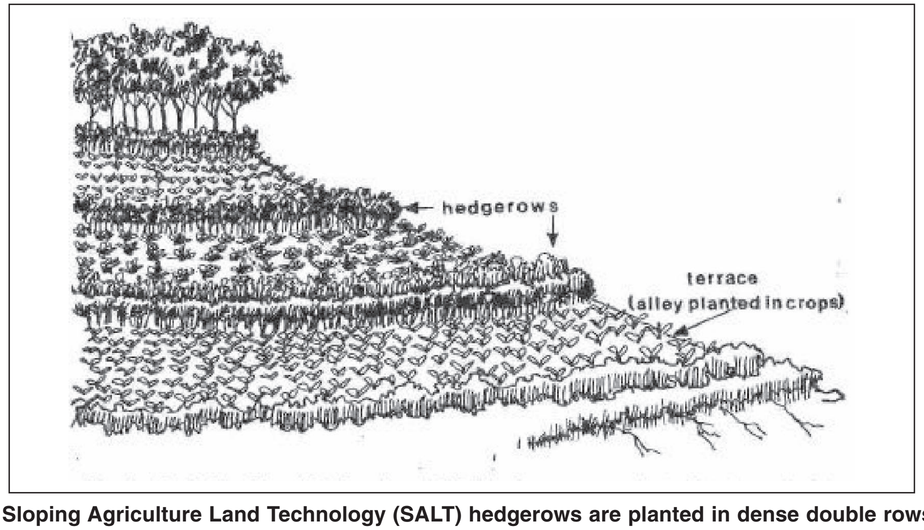

Fig.2 Sloping Agriculture Land Technology (SALT) hedgerows are planted in dense double rows and trimmed frequently to produce large amounts of green manure for crops

on flat land hedgerow intercropping is not interesting because of the high level of labor input needed. Some of the suitable species for hedge row system are *Leuceana leucocephala, Gliricidia sepium, Senna siamea, Senna spectabilis, Sesbania, etc*.

Soil Conservation Hedges

Trees can be planted on physical conservation works (grass strips, bunds, riser and terraces), wherein they play two roles: to stabilize the structure and to make productive use of the land they occupy. Stabilization is through the root system. In this system major groups of components are multipurpose fruit trees and common agricultural species. Fruit trees are usually planted along the edges of terraces. The following tree species are used for soil and water conservation: *Grevillea robusta, Acacia catechu, Acacia modesta, Prosopis juliflora, Alnus nepalensis, Leuceana leucocephala* etc.

Wind Breaks and Shelter Belts

Wind breaks and shelter belts are two distinctive features of agroforestry systems. Wind breaks are narrow strips of trees, shrubs and grasses planted to protect field, homes, canals and other areas from the wind and blowing sand. Shelter belts, a type of wind break, are long, multiple rows of trees and shrubs, usually along the sea coasts, to protect agricultural fields .There is a long tradition of using windbreaks in semi-arid regions of Asia for soil protection against erosion. The ideal design is a steep triangle in cross-section, tall trees in the center and shorter trees or shrubs along the sides, with the least damage prone species on the side of the prevailing winds. Spacing between the wind breaks is determined by the width of the zone over which wind speed is to be reduced. Depending on the degree of effect desired, the necessary distance between wind breaks varies from 10 H and 20 H (Stigter *et al.,* 1989 and Vandenbeldt, 1990).A wide variety of species are used. *Casuarinas equisetifolia* and *Casuarina glauca* are well suited and widely employed in the tropics and sub-tropical semi-arid zone. *Prosopis juliflora* is tolerant of saline soils and has moderately open canopy. *Azadirachta indica* is valued for the range of its products. Trees planted on farm boundary or shelter belts in arid climates and sea shores reduced the wind speed and sand drift. The strong network of roots, fall of litter and thick canopy of tree provide effective protection to the soil from erosion by direct impact of rain drops (Pathak, 2000). Wind breaks and shelter belts are quite effective in reducing the advective wind currents thus reducing the crop ET and protecting soil, its fauna from hot wind currents.

Other Tree Based Conservation Systems

Contour strips of natural vegetation are a simpler than hedge rows. Bands of 0.5-2.0 m wide are laid out along the contour and simply left unploughed, to be colonized by grasses or weedy shrubs. They have been subjectively observed to revue soil loss as effectively as planted hedgerows. In requiring less labor to establish, they are also more acceptable to farmers (Garrity, 1993).Under eucalyptus in Kerala, India, soil loss varied greatly with the crop management during the cropping period.

Conclusion

Choice of appropriate agroforestry technologies for conservation of soil and water in specific situations is an important factor in the design of such agroforestry systems. Several agroforestry practices have potential for erosion control, and many of them are being used in several countries around the world. For different situations, different types of agroforestry technologies will have to be designed. Best results can be obtained if agroforestry technologies are combined with other relevant land us technologies, even for a single farm, or land – management unit, in accordance with the bio-physical conditions of the farm, and the farmer's production objectives. Agroforestry for soil and water conservation cannot be considered in isolation from other land use approaches and needs.

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Opportunities for Converting Indigenous Technical Knowledge (ITK) on Soil and Rainwater Conservation to Modern Technical Knowledge (MTK)

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Soil and water are the basic resources and these must be conserved as carefully as possible. The pressure of increasing population neutralizes all efforts to raise the standard of living, while loss of fertility in the soil itself nullifies the value of any improvements made. This calls for more systematic resource conservation efforts. It is well known to every farmer that it is the top soil layer, which sustains agricultural production. Once this layer is lost or eroded, nothing can be done to replace it within a short period of time. Climate and hydrology, soil topography, soil surface conditions and their interactions are major factors affecting erosion-sedimentation processes. The semi–arid regions with few intense rainfall events and poor soil cover condition produce more sediment per unit area. But the man's intervention has disturbed the natural equilibrium and intensive and extensive agriculture has become a dominant factor in accelerating land degradation. The ever-increasing population pressure has brought intensive cultivation of land to the forefront through irrigated agriculture. No doubt these practices have resulted in a great increase in productivity, but they have resulted in large-scale water logging. Cultivable wastelands are increasing in the agricultural fields due to improper land management. The obvious remedy for this is to follow soil and moisture conservation practices along with integrated nutrient supply system for improvement of soil fertility as well as crop productivity on sustained basis. Soil conservation in any form is the only known way to protect the productive lands. In a predominantly agricultural country like India, where droughts and floods cause chronic food scarcity, adequate soil conservation programme, not only increases crop yield, it also prevents further deterioration of land. Methods to control surface runoff and soil associated erosion have been practiced in India from times immemorial.

Traditional knowledge is gathered over a period of time and transferred from generation to generation. It is synonymous to local knowledge and is defined as "A sum total of knowledge based on acquired knowledge and experience of people in dealing with problems and typical situation in different walks of life". For the term indigenous technical knowledge (ITK), "local knowledge'' and "Traditional knowledge" have been used in the literature inter–changeably. It is the knowledge, which has been accumulated by the people over generations by observation, by experimentation and by handling on old peoples' experiences and wisdom in any particular area of human behavior. Indigenous technical knowledge is the local knowledge that people have gained through inheritance from their ancestors. It is a people derived science and represents people's creativity, innovations and skills. Indigenous technological knowledge pertains to various cultural norms, social roles or physical conditions. Such knowledge is not a static body of wisdom, but instead consists of dynamic insights and techniques, which are changed over time through experimentation and adoption to environmental and socio-economic changes. This knowledge has backgrounds of hundreds and sometimes thousands of years of adoption, while bearing odds and evens of the time.

This knowledge is not possessed by only one sector of society, for example, in many cultures women and elders have passive insights into certain aspects of culture. Sometimes researchers have been unaware of such perceptiveness among rural people due to their biased focus on land-owning male farmers, neglecting other members of society. Traditional knowledge and practices have their own importance as they have stood the test of time and have proved to be efficacious to the local people. Some of these traditional practices are in the fields of agriculture – crop production, mixed farming, water harvesting, conservation of forage, combined production system, biodiversity conservation, forestry and domestic energy etc. SAARC countries are unique having a rich history of traditional systems of soil conservation and water harvesting in almost all the states. In fact, different type of ponds and tanks represent important community resources for drinking water in rural areas. Even today, the main attributes to their success are the sound scientific knowledge and methods on which they have been built.

Fortunately, we have many indigenous techniques for conserving natural resources (Agarwal and Narain, 1999). These have been in practice for number of years as presented in the write up. Therefore there is a need to enmesh these practices along with conventional soil and water conservation measures for promoting sustainable development of agriculture. It may not be out of place to mention that some of these ITKs may need minor modifications in different watershed situations as well as socio-economic fabrics across the country. Inclusion of these ITKs would ensure sustainability of different eco-systems, befitting the man-animal-plant-land-water complex in each watershed. The documentation of ITKs on soil and water conservation will form a basis for formulating coordinated research programme for validation and refinement of the ITKs on soil and water conservation. In recent years the idea of taking ITK into consideration in developing projects and locating research thrust areas has been gaining momentum. Moisture conservation begins right from seedbed preparation. Although farmers practice many indigenous technologies relating to soil and water conservation, there is a lack of documentation for identifying the constraints for possible refinements. There exists a need to evaluate the potential indigenous practices in the regions for their improvement and dissemination to new areas. There is also a need for scientist-farmer interaction for large-scale adoption.

The promotion of appropriate technology with indigenous knowledge base is gaining importance in the natural resource management programme for increasing their adaptability/acceptability and to bring down the dependence on cost intensive technologies. However the percolation of the technology is not as fast as it should be. The study by World Overview of Conservation Approaches and Technologies (WOCAT) shows that much of this valuable knowledge is poorly documented and thus mostly not accessible to analysis, evaluation and dissemination. Knowledge related to sustainable land management (SLM) and soil and water conservation (SWC) often remains only a local, individual and institutional resource, unavailable to others working in comparable areas and seeking to accomplish similar tasks (Ref: www.wocat.net). Some of the WOCAT network centres in SAARC countries are Chittagong Hill Tracts Development Board, Bangladesh, Pakistan Intercooperation-Pakistan, Hayatabad – Peshawar, Pakistan, International Centre for Integrated Mountain Development, Kathmandu, Nepal, Sustainable Soil Management Programme, Kathmandu, Nepal etc.

In India, a detail study of Indigenous Technical Knowledge (ITK) on soil and water conservation in rainfed areas was taken up through a National Agricultural Technology Project (NATP) entitled "Documentation & Analysis of Indigenous Methods of *In-situ* Moisture Conservation and Runoff Management" at Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad. These principles of documentation and analysis apply to the SAARC countries as well considering the similarity in socio-economic and cultural set-up of the region.

Methodology

In order to obtain the feedback of the farmers regarding soil and water conservation measures the survey using developed proforma was initiated in treated and untreated villages in different agro-ecological regions through the project centers. Farmers' awareness and adoption of soil and water conservation practices was attempted in the study. The study was carried out in 18 centers of All India Coordinated Research Project on Dryland Agriculture (AICRPDA) including Hyderabad, which was the nodal center of the project. These centers cut across various states and various rainfall zones but all represent rainfed zones of the country. The process followed during documentation was as follows:

1. The ITK proformae consisting of general information of village, views and observations on soil & water conservation measures, in-situ moisture conservation practices, technical information on run-off management practices and indigenous technical knowledge was developed.

2. The proformae for documenting ITKs on soil & water conservation and run-off management was finalized duly after getting the feed back from participants.

For the purpose of documentation and analysis of ITK, a simple ITK proforma was developed. This proforma contains Title, Purpose, Location, Ago-ecological setting, Description, Advantages, Constraints, Replicability / Feasibility and Researchable issues as given in the following table **(Table 1).**

The researchable issues open up new vistas for furthering the technologies towards development of farmer-friendly doable technologies. This is just an honest beginning of a validation process made by NATP, ICAR. Of the many available, a few ITKs could be documented in the limited time frame through the project centers located in various SAUs. There is a lot more to be done in this direction by the R&D and implementing agencies involved in the community development.

Table 1 : Sample ITK Proforma

1. Title (Local name, if any)	
2. Purpose / Objective / Rationale	
3. Location – Village, Block / Mandal, Dist, State	
4. Agro-Ecology	Agro-eco. Region: Soil: Rainfall (mm) : Crops
5. Percentage of problematic area covered (Farmers having similar problems)	
6. Description • Category of farmer (small/medium/big) • Individual / community basis • How the practice evolved • Since how long this ITK is in use • In case of crop planting & gap filling method and time with seed rate • Maintenance • Farm implements used (if any) • Cost/ha (or cost/structure) & labour involved • Methods of implementation / ITK specification	

7. Advantages	
8. Constraint (for adoption, implementation maintenance, replication, etc.	
9. Improvement (for wider adoption, of the system etc.) or simplification Whether any external support needed	
10. Replicability / Feasibility (other places in India where this can be adopted)	
11. Photographs / slides / Map / Videograph	
12. Additional information	

Documented ITKs

The ITKs were documented under following specific categories **(Table 2).**

- Agronomic Measures
- Tillage
- Bunding & Terracing (Mech. & Vegetative barrier)
- Land Configuration
- Soil Amendment / Mulching
- Erosion Control & Runoff Diversion Structures
- Water Harvesting, Seepage Control & Ground Water Recharge

Table 2 : A list of some documented ITKs on soil and water conservation measures under different categories

S. No	Categories	Name of ITK
1	**Agronomic Measures**	i. Intercropping ii. Cultivation and sowing across the slope iii. Wider row spacing and deep interculturing iv. Mixed cropping v. Cover cropping vi. Criss –cross ploughing vii. Hoeing with local hoes viii. Set furrow cultivation ix. Application of Farm Yard Manure (FYM) x. Strip cropping xi. Green capping xii. Green manuring

S. No	Categories	Name of ITK
		xiii. Pre-emergence soil stirring xiv. Ridge and furrow planting
2	**Tillage**	i. Conservation furrows with traditional plough ii. Deep pluoghing iii. Summer ploughing/ Off-season tillage iv. Repeated tillage during monsoon season
3	**Bunding & Terracing (Mech. & Vegetative barrier)**	i. Vegetative barrier ii. Stone bunding iii. Nala check with soil filled in cement bags iv. Compartmental bunding v. Peripheral bunding/ Field bunding vi. Ipomea as vegetative barrier vii. Conservation bench terrace viii. Loose stone surplus ix. Stabilization of field boundary bund with *Vitex negundo* x. Strengthening bunds by growing grasses xi. Bund farming of pulse crops in *kharif* under rainfed situation xii. Earthen bunds xiii. Stone-cum-earthen bunding xiv. Live bunding by raising Cactus xv. Grass Plantation on field boundaries (filter strip) xvi. Growing of Saccharum munja as vegetative barrier on field boundaries
4	**Land Configuration**	i. Use of indigenous plough for formation of broad bed & furrows ii. Furrow opening in standing crops local implement hoe (Dawara) for moisture conservation iii. Levelling the plots by local leveler iv. Opening up set furrow v. Conservation furrow : *Gurr*
5	**Soil Amendment/ Mulching**	i. Application of tank silt ii. Application of ground nut shells iii. Sand mulching iv. Gravel sand mulching v. Retention of pebbles on the soil surface

S. No	Categories	Name of ITK
		vi. Retention of sunflower stalks vii. Mulching of *Sal leaf* in turmeric viii. Crop residue application in the field
6	**Erosion Control & Runoff Diversion Structures**	i. Sand bags as gully check ii. Loose boulder checks iii. Stone waste weir iv. Waste weir (stone / sorghum stubbles) at the outlet of the field v. Brushwood structure across the bund vi. Grassed waterways vii. Spur structure viii. Nala plugging
7	**Water Harvesting, Seepage Control & Ground Water Recharge**	i. Seepage control by lining farm ponds with white soil ii. Harvesting of seepage water iii. Wells as runoff storage structures iv. Rain water management using indigenous rain gauge (*Role*) v. Farm pond vi. Percolation pond / tank vii. Ground water recharging through ditches and percolation pits viii. Well recharging through runoff collection pits ix. Dug wells x. Haveli / Bharel system xi. Bandh system of cultivation xii. Earthen check dams xiii. Field water harvesting xiv. Nadi farming system xv. Collection of sub-surface runoff water and recycling in Diara land xvi. Rain water harvesting from roof top and road surfaces xvii. Rain water harvesting in *Kund / Tanka*

Refinement of ITKs for Promotion of the Technologies

Some potential ITKs identified for further study, research and development of new projects is presented in **Table 3.** A scientific study may change this Indigenous Technical Knowledge to Modern Technical Knowledge (MTK). Prevailing ITKs should invariably be given priority. All the on going projects on resource conservation and management should focus on the viable and appropriate ITKs relating to soil & water for sustainable development and dissemination of the local technology.

As an initiative, the ITKs on S&WC for other agro-climatic regions may be documented and later validated and refined at local level. This will form a programme by itself to popularize indigenous knowledge with the developmental agencies. Exposure visit and farmer-to-farmer interaction on the subject may be encouraged for better adoption. The ongoing watershed programme should adopt the ITKs on S&WC in their project activities. During the first phase planning the local technologies should be documented.

The stakeholders in the conservation programme who can be partners for promoting the ITKs are:

- Farmers
- NGOs
- Government agencies
- Research Institutes / Scientists
- Administrators
- Policy makers / people's representatives

The research findings may be disseminated through the extension agencies. The research results will benefit both farming community as well as the promoting agencies i.e. the Govt. or non-government organizations. Some of the researchable issues pertaining to some ITKs have been identified and presented in **Table 3.**

Table 3 : Identification of researchable Issues of some selected ITKs

Name of ITK	**Purpose**	**Researchable Issues**
Furrow opening in standing crops	Rainwater conservation	• Modification of implement with different serrated blades and introducing additional tines • Effectiveness in conserving soil moisture
Nadi farming system	To collect runoff during *kharif* for life saving irrigation	• Documentation and analysis of socio-economic aspect of present *nadi* system for its sustainability

Name of ITK	**Purpose**	**Researchable Issues**
	during drought spell or pre- sowing irrigation (*Palewa*) for *rabi* crops	• Evaluation of present *nadi* farming system
Mixed pulses as vegetative barrier	Resource conservation	¨ Proportion of pulses as vegetative barrier ¨ Cost effectiveness of the system
Stabilization of gullies using sand bags	Gully control and runoff management	¨ Soil conservation efficiency ¨ Strengthening of sand bags structure with different vegetative barriers
Application of white soil as lining material in farm pond	To work as a sealant material for lining dugout farm pond	¨ Standardization of application technique and economic feasibility for wider application ¨ Study on the seepage losses at different hydraulic heads
Wider row spacing in pearl millet	Rainwater conservation and weed control	¨ Plant geometry and population research in different rainfall situations
Rainwater harvesting in *kund/tanka*	The harvested water in kund / tanka is used for drinking and establishment of tree	¨ Research should be done on the use of stored water for arid horticulture ¨ Design of *tankas* for different geo-hydrologic conditions
Crop stubbles and residue management	Improve the organic matter and water holding capacity of soil	¨ Quantification of soil and water conserved and yield advantage ¨ Better or improved implements for crop residue incorporation ¨ Alternate ways of composting and application
Brush wood waste weir	Safe disposal of excess runoff	¨ Design and stabilization of structure
Mulching in turmeric	To conserve rainwater	¨ Quantification of soil loss, improvement of soil quality and water availability ¨ Use of alternative organic material to *Sal* leaves as mulch

Name of ITK	Purpose	Researchable Issues
Indigenous stone / brush wood structure across the slope	To check soil loss	¨ Shape and size of brush wood structure depending on the runoff and site conditions
Agave sp. as vegetative barrier	To reduce runoff velocity and to increase infiltration opportunity time	¨ Different species of Agave can be evaluated ¨ Cost-benefits analysis.
Broad bed and furrow practice	To harvest rain water and dispose of runoff	¨ Width of broad bed needs to be evaluated for different crops and rainfall situations ¨ Identification of suitable low cost tractor/bullock drawn implement for layout of BBF
Water harvesting and recycling	Rain water harvesting and recycling to crop field as supplemental irrigation	¨ Recharging of water table ¨ Cost effectiveness ¨ Improvement in crop yield
Standardization of recharging technique	Augmentation of ground water	¨ Design of filter and improvement in filtering efficiency with better filtering material ¨ Effect of geology/soil formation on recharge
Set-row cultivation	For harvesting rain water and maintaining soil structure	¨ Quantification of rainwater conservation and water use efficiency (WUE) of the crops ¨ Improvement in soil health and crop yield over years
Summer / pre- monsoon tillage	Conservation tillage-to harvest early showers, facilitate timely seeding and weed control	¨ Identification of appropriate tillage implements for soil and water conservation ¨ Evaluation of root: shoot ratio and quantification of WUE of crops
Ridge & furrow planting for modulation of overland flow	Conservation of rain water, modulating excess water, control soil loss	¨ Fabrication and development of ridge former accommodating required row spacings and ridge cross- section

Name of ITK	Purpose	Researchable Issues
	and boosting productivity	
Formation of *Gurr*	Reduction of runoff and soil moisture conservation	¨ Effect of bullock and tractor made *Gurr* on runoff reduction, soil water conservation and crop productivity
Green manuring practice	To conserve soil water and improve soil health	¨ Growing of green manure crop and its management in improving soil health and crop productivity ¨ Economic evaluation of the system by addressing sustainability issues
Application of tank silt	To increase the fertility and water holding capacity of soil	¨ Method and quantity of tank silt application in different soils ¨ Improvement in soil water and fertility with tank silt application and its effect on crop productivity ¨ Cost effectiveness of silt application especially with Government programme of tank desiltation.

As an example the tank silt application was taken to a logical end by involving the district administration in creating awareness and including the technology as a policy intervention. But wider application of the technology is needed to get the desired visible effects in the national perspective (Osman et. al., 2011).

Indigenously followed soil health improving technologies can be popularized by improving the quality of intervention with proper research back up and capacity building. Some examples are presented in **Table 4.** Maruthi et al., (2008) experimented upon adding value to the groundnut shell, an indigenous resource conservation and soil fertility enhancing technology. Application of groundnut shell as such demands more water for decomposition and short-term application of organics can not show remarkable improvement in soil health. Hence they suggested the practice of cattle shed bedding of groundnut shell to prepare groundnut shell manure (GSM) to be adopted even to process other crop residues available locally for sustainable agriculture.

Table 4 : Soil health improving indigenous technologies

Technology	Intervention Needed
Composting of farm wastes/ FYM	Needs quality improvements and production of compostable biomass *in situ*, incentives to farmers
Use of concentrated manures (Neem, Castor, Pongamia, Groundnut cake etc.)	Strategies for local availability and reducing competition as livestock feed material, incentives to farmers
Soil amendments	Linkage with MGNREGS
Green manuiring and incorporation	Crop holiday, biomass production techniques on the field and on boundaries, intercropping with legumes, incentives to farmers

Conclusion

Many ITKs on in-situ soil and moisture conservation are not adopted everywhere throughout India because of constraints in adoption and unawareness of the effectiveness of such practices. The present documentation process has definite bearing on the future course of action in framing new projects. This short-term documentation project may lead to the following future activities:

1. Similar exercise can be undertaken to document the ITKs from all the Agro-ecological regions of the country.
2. The potential ITKs may be tested for their suitability and adoption in other Agro-ecological regions as a dissemination strategy.
3. The documented ITKs may be published/translated in all regional languages for the benefit of the farming communities.
4. Validation of the ITKs is a logical step to qualify and quantify the effectiveness of these practices. Suitable modifications of the traditional practices through on-farm research would help in developing appropriate and acceptable technologies for different local environments.
5. The effect of conservation measures on resource losses can be studied in detail through experimentation and use of stimulation model.
6. As a policy matter the local ITKs should be in built in the resource conservation programme.

To conclude, the documentation, refinement and promotion of ITKs should form the basis for implementing natural resource conservation technologies on watershed basis. There is a need to enmesh these ITKs along with conventional soil and water conservation measures for promoting sustainable development of agriculture. It may not be out of place to mention that some of these ITKs may need minor modifications in different watershed situations as well as socio-economic fabrics across the country. Inclusion of these ITKs would ensure sustainability of different eco-systems, befitting the man-animal-plant-land-water complex in each watershed. The focus should shift from pure data collection to evaluation and monitoring, as well as to training and research.

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Rehabilitation of Tanks and Field Soils through Desilting and Recycling of Silt for Drought Proofing

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Significant increase in productivity, improvement in resource quality, diversification of production system and generation of additional employment are needed in rainfed areas to achieve overall economic progress and renaissance in SAARC countries such as Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Srilanka. This requires a renewed focus on research, new and innovative approaches in development and support services matching with resource allocation and augmentation. Sharing of resources, pooling of expertise and leveraging of capacities come naturally with strategic thinking. There is, therefore, a need to revive agricultural policies of these South Asian countries for better implementation and efficient utilization of the available resources in a long-term perspective (Rai, 2005).

Under high risk, low productivity and fragile rainfed farming situation, 'water bodies' are found to be the way out. Swaminathan (2006) has endorsed that sustainable water security system can be put in place in rainfed areas to get agriculture back on rails to bring about Second Green Revolution in a country like India. Productivity and profitability from rainfed agriculture can be enhanced under conditions of conservation of natural resources like soil and water and also efficient use of nutrients. Among water bodies, tanks are viable and feasible option and their restoration and rejuvenation through renewed efforts, will enhance productivity. Droughts and floods are common to rainfed areas and tanks act as drought mitigators and flood moderators. Interestingly, functionality of tanks is well documented (CRIDA, 2006; DHAN, 2004 and Osman *et al.,* 2001). Tanks are eco-friendly and farmers'-friendly and deposit of gold mine in the form of tank silt. Recycling of tank silt will not only rejuvenate the tanks but also, the thirsty and hungry rainfed areas besides improving the soil properties in a cost-effective manner. That is, the strategy of rehabilitation of tanks and field soils through de-silting and recycling of silt to croplands for drought proofing. Desilting not only rejuvenate tanks but also improve recharge of groundwater. For a country like India, for instance, about 53% of net sown irrigated area is dependent on groundwater and its sustainability lies on efficient recharge. Small storages are much more appropriate and effective for groundwater recharge and also in arresting siltation of large reservoirs (Mc Cully, 2006). There is also a possibility of substituting inorganic fertilizers with silt as an organic amendment for improving soil quality and its resilience to moisture stress during dry spells in rainfed areas. Improvement of soil health and reduction in use of inorganic fertilizers are being advocated for eco-friendly agriculture. The quality of soil can be improved by adding tank silt rich in clay, organic matter and nutrients needed for better plant growth. In the past, application of tank silt was in vogue as an indigenous technical knowledge (ITK). This practice needs to be promoted with a scientific approach to bring policy issues in favour of recycling of tank silt (deposited nutrient rich top soil) to the farmers' fields for drought proofing. This will generate income; improve soil health and increases the crop yield and water productivity. Earlier research showed that application of silt / sediments is potentially capable of supporting agronomic crops due to higher fertility and water-holding capacity. The sediments deposited in the water bodies generally contain fine silt, clay, and organic matter and recycling helps in bringing them back to the original site (soil). However, the quality of silt varies with each tank, which is primarily, a function of soil type and land use of the catchment.

A Case Study of India

The Process and Methodology

The study was conducted at six centers namely Anantapur (AP), Nalgonda (AP), Warangal (AP), Kolar (Karnataka), Solapur (Maharashtra) and Bhilwara (Rajasthan) during 2008-09 (1st year) and 2009-10 (2nd year). The beneficiaries (sample farmers) identified for these centers are 20, 20, 22, 20, 10 and 10, respectively. The trials were conducted on two farmers' fields at each Farmer's Participatory Action Research Programme (FPARP) site, totaling to 51 sites (villages) and 102 farmers.

The process of action research starting from sensitization of the technology through modification, capacity building (by organizing *Water Days*) to action research phase enthused both participating farmers in FPARP villages and farmers from the adjoining villages. The process of programme implementation is depicted in **Fig.1.** There was an overwhelming response from the sample farmers (beneficiaries) that influenced other farmers (non-beneficiaries) too, in terms of visiting to the action research sites during both the years. The process involved a detailed analysis of agro-climatic situations and careful selection of locations and consortium partners (having long standing in the field work). This was followed by launch workshop, in which a common methodology and guidelines were finalized by involving all the consortium partners. Keeping in view the guidelines, the consortium partners identified 51 sites (villages) and conducted *gram sabhas* in all the villages. Farmers and paraworkers (*Jalamitra*) were identified exclusively for this purpose and soil samples were collected from fields and tanks. Physical and chemical analyses of samples both from field and tanks were carried out at CRIDA, Hyderabad. Recommendations on rate of silt application were made for each farmer based on the texture of field soil and tank sediment using simple software in excel sheet

(**Fig 2.**) and available in CRIDA website (www.crida.ernet.in). Farmers were motivated to meet the cost of transport and were exposed to latest research findings by conducting exposure visit. Seeds of improved varieties were provided. Regular field visits were made to record the farmers' perceptions. The data on growth and yield were collected for analysis. During the crop growing period, monitoring teams from Central Water Commission (CWC) visited randomly selected sites and interacted with the farmers. Data were compiled and discussed in the review workshop by involving all the consortium partners. Members from CWC also participated in the workshop. In the review workshop, strategies were worked out to upscale the programme by converging this with other on-going schemes of State and Central Governments. After the first cropping season, soil samples were collected once again from silt applied and un-applied plots (control) for studying the impact on physical and chemical properties for the first time in the country on such a large scale. Crops grown in the second year were also monitored and regular field days and water days were conducted to share the views of beneficiary farmers with the farming communities. An economic evaluation of the cost-effectiveness of the technology was also done.

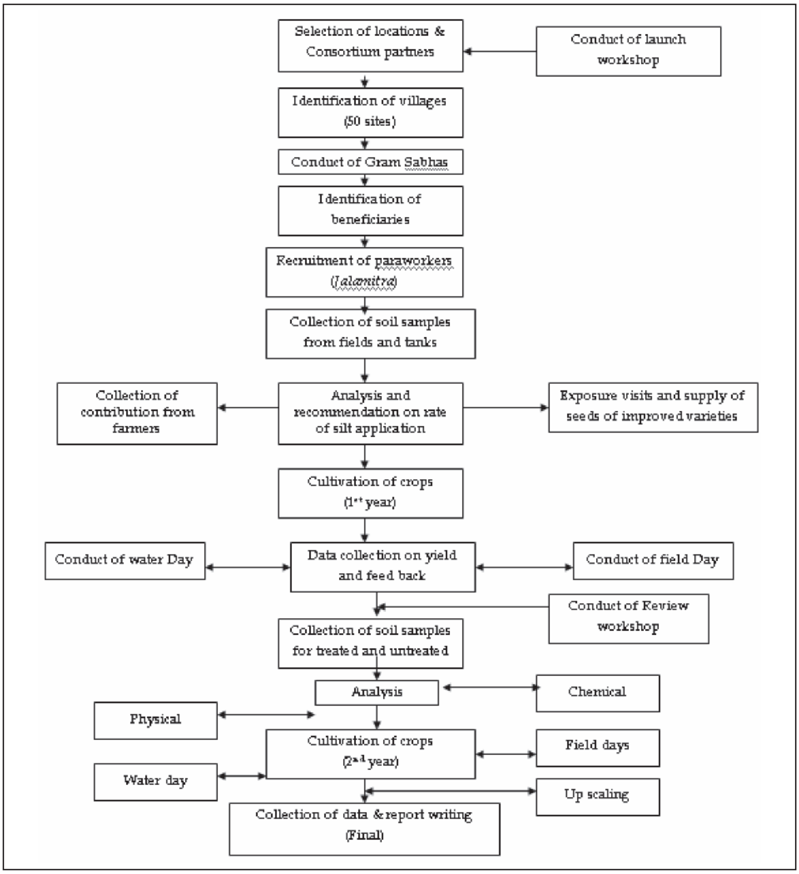
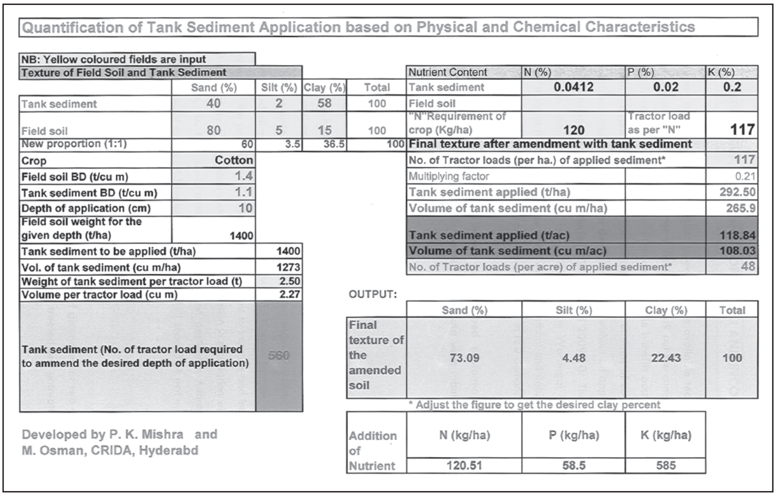


Fig. 1 : Schematic diagram showing the process followed



Quantification of Tank Sediment Application based on Physical and Chemical Characteristics

NB: Yellow coloured fields are input

Texture of Field Soil and Tank Sediment	Sand (%)	Silt (%)	Clay (%)	Total
Tank sediment	40	2	58	100
Field soil	80	5	15	100
New proportion (1:1)	60	3.5	36.5	100

Crop	Cotton
Field soil BD (t/cu m)	1.4
Tank sediment BD (t/cu m)	1.1
Depth of application (cm)	10
Field soil weight for the given depth (t/ha)	1400
Tank sediment to be applied (t/ha)	1400
Vol. of tank sediment (cu m/ha)	1273
Weight of tank sediment per tractor load (t)	2.50
Volume per tractor load (cu m)	2.27
Tank sediment (No. of tractor load required to ammend the desired depth of application)	560

Nutrient Content	N (%)	P (%)	K (%)
Tank sediment	0.0412	0.02	0.2
Field soil			
"N"Requirement of crop (Kg/ha)	120	Tractor load as per "N"	117

Final texture after amendment with tank sediment	
No. of Tractor loads (per ha.) of applied sediment*	117
Multiplying factor	0.21
Tank sediment applied (t/ha)	292.50
Volume of tank sediment (cu m/ha)	265.9
Tank sediment applied (t/ac)	118.84
Volume of tank sediment (cu m/ac)	108.03
No. of Tractor loads (per acre) of applied sediment*	48

OUTPUT:

	Sand (%)	Silt (%)	Clay (%)	Total
Final texture of the amended soil	73.09	4.48	22.43	100

* Adjust the figure to get the desired clay percent

	N (kg/ha)	P (kg/ha)	K (kg/ha)
Addition of Nutrient	120.51	58.5	585

Developed by P. K. Mishra and M. Osman, CRIDA, Hyderabd

Fig. 2 : Tank silt applicator- a simple user friendly DSS

Findings

Water Use Efficiency of the Technology (WUE)

WUE per crop season was studied for treated (with silt application) and untreated (without silt application) field experiments for two years, viz. 2008-09 and 2009-10 in terms of yield per millimeter of water (kg ha^{-1} mm^{-1}) and income per millimeter of water (Rs. $ha^{-1}mm^{-1}$) for six districts across four states. The results are presented in **Tables 1 and 2**.

Table 1: Water use efficiency of different crops w.r.t. yield

Sl. No.	District	Crop	WUE (kg ha^{-1} mm^{-1})			
			2008-09 (year I)		2009-10 (year II)	
			With silt	Without silt	With silt	Without silt
1.	Anantapur	Groundnut	1.86	0.74	3.34	2.07
2.	Nalgonda	Castor	0.48	0.14	*3.89	*1.74
3.	Warangal	Cotton	2.57	2.17	3.35	2.00
4.	Kolar	Mulberry	0.52	0.50	0.33	0.29
5.	Solapur	Rabi sorghum	6.30	4.24	8.08	6.01
6.	Bhilwara	Maize	6.89	5.57	5.28	3.93

Note: * indicates yield accrued from cotton crop, castor was substituted with cotton during the second year

Table 2 : Water productivity in terms of Rs. per hectare per millimeter of water use

Sl. No.	District	Crop	Water Productivity (Rs. ha^{-1} mm^{-1})			
			2008-09 (year I)		2009-10 (year II)	
			With silt	Without silt	With silt	Without silt
1.	Anantapur	Groundnut	46.0	14.8	84.5	47.0
2.	Nalgonda	Castor	10.9	3.3	*116.7	*52.2
3.	Warangal	Cotton	72.6	61.3	100.5	60.0
4.	Kolar	Mulberry	83.7	80.5	63.3	54.1
5.	Solapur	Rabi sorghum	59.9	40.3	97.0	72.1
6.	Bhilwara	Maize	54.4	44.0	55.4	41.3

Note: * indicates income accrued from cotton, castor was substituted with cotton during the second year

Interestingly, the yields accrued varied from crop to crop across districts in treated and untreated demonstrations and registered higher in case of the former (with silt application) than the latter (without silt application) in the two years **(Table 1).** However, higher water use efficiency in terms of yield(s) per millimeter of rain water use was noticed in the second year (2009-10) than the first year (2008-09) in almost all the crops excepting mulberry in Kolar and maize in Bhilwara. The response was high even in severe drought year (2009) indicating impact of silt application in obtaining higher yield. The impact of silt application on mulberry was not high as it is an established perennial plant while maize in Bhilwara performed poorly during 2009 as maize is very sensitive to moisture stress. Higher yields registered in Warangal were attributed mainly to the better soil mixing (aggregation) in the second year coupled with adequate rainfall. The yields without and with silt application during 2009-10 (2nd year) varied from 0.29 and 0.33 kg ha^{-1} mm^{-1} in case of mulberry in Kolar to 6.01 and 8.08 kg ha^{-1} mm^{-1} in case of *rabi* sorghum in Solapur, respectively. While the yields with silt application during 2008-09 (1st year) ranged between 0.48 kg ha^{-1} mm^{-1} in case of castor in Nalgonda and 6.89 kg ha^{-1} mm^{-1} in case of maize in Bhilwara, but the yields of crops without silt application varied from as low as 0.14 kg ha^{-1} mm^{-1} in case of castor in Nalgonda to 5.57 kg ha^{-1} mm^{-1} in maize in Bhilwara. The lower yield of castor in Nalgonda was due to the highly erratic and uneven distribution of rainfall i.e. rainfall started late in mid July and ended in early September in 2008. Thus, application of silt has resulted in resilience to moisture stress in terms of crops yield.

Income Per Unit of Water (Rs. ha^{-1} mm^{-1})

The higher water use efficiency in terms of income per millimeter of water was recorded during second year than in the first year (**Table 2**). The WUE is higher with silt application than without silt in almost all the crops excepting mulberry in Kolar. The income with silt application in the second year varied from 55.4 Rs. ha^{-1} mm^{-1} in maize in Bhilwara to 116.7 Rs. ha^{-1} mm^{-1} in case of cotton in Nalgonda, respectively. Similarly, the income without silt application in the second year ranged between 41.3 Rs. ha^{-1} mm^{-1} in maize in Bhilwara and 72.1 Rs. ha^{-1} mm^{-1} in *rabi* sorghum in Solapur. The reasons attributed for variations (lower and higher) is similar as cited in the case of yield per millimeter of water. While in the first year, the income with silt application ranged between 10.9 Rs. ha^{-1} mm^{-1} in castor in Nalgonda and 83.7 Rs. ha^{-1} mm^{-1} in mulberry in Kolar, however, the income without silt application varied from 3.3 Rs. ha^{-1} mm^{-1} in case of castor in Nalgonda to 80.5 Rs ha^{-1} mm^{-1} in mulberry in Kolar. Thus, it is evident from the above that water productivity in terms of yield and income per millimeter of water was found to be higher with silt application than without silt application indicating impact of silt application irrespective of erratic behavior of monsoon.

Impact on Soil Texture and Fertility

The proportion of sand, silt and clay in a soil decides the type of soil whether it is a sandy, silty or clayey. A right proportion of sand, silt and clay is essential for better plant growth. In light textured soils, sand per cent is high and results in higher infiltration rate, good drainage and aeration but retains little water and applied nutrients. Heavy textured soils have higher clay content but reduce infiltration rate and create anaerobic situation due to water logging. Therefore, balancing the different constituents of the soil in a desirable proportion to harness the benefit of retaining higher moisture as well as applied nutrients is the need of hour. Recycling of silt helped in improving and balancing the texture of surface soil essential for better plant growth. In all the six locations, the clay content improved while there was marginal increase in silt but sand content reduced. This favoured in retaining better soil moisture condition in the silt applied plots and also reflected in yield. Laboratory analysis of soil from treated and un-treated fields using pressure plate apparatus method indicated an improvement in available water content in all the fields. Many farmers reported reduction in number of irrigations and soil resilience to moisture stress during prolonged dry spells. Dry spells of two to three weeks are of common nature in dryland areas and the silt applied fields took one week extra to show the wilting symptoms due to moisture stress and many a times escaped from total crop failure. This way tank silt application acted as a water saver and also as an effective measure for drought mitigation. Besides change in soil texture and water holding capacity, an improvement in soil fertility was also noticed. Tank silt is considered as rich mine containing all the macro and micro-nutrients. Analysis of soil from treated and un-treated plots indicates an improvement in soil organic carbon content as well as available P and K (**Table 3**). Many farmers have endorsed improvement in soil fertility and reported saving on fertilizers from 30 to 50 per cent. Recycling of tank silt is indirectly helping the farmers in reduction in use and investment on fertilizers, which is not only farmer-friendly but also eco-friendly.

Table 3 : Impact of silt on soil organic carbon content and P & K

District	pH	EC (ds/m)	OC (%)	P (kg $ha^{-1)}$	K (kg $ha^{-1)}$	pH	EC (ds/m)	OC (%)	P (kg $ha^{-1)}$	K (kg $ha^{-1)}$
	Treated					**Untreated**				
Anantapur	8.19	0.17	0.38	38.7	283.4	8.19	0.21	0.30	36.6	232.6
Nalgonda	7.98	0.17	0.43	33.7	263.4	7.65	0.13	0.40	30.3	222.9
Warangal	7.80	0.08	0.55	33.0	401.5	7.69	0.28	0.47	39.0	314.1
Kolar	7.78	0.49	0.52	68.2	299.1	7.42	0.28	0.45	59.3	230.7
Solapur	8.19	0.17	0.38	38.7	283.4	8.19	0.21	0.30	36.6	232.6
Bhilwara	7.61	0.38	0.43	40.0	361.0	7.60	0.35	0.40	31.8	325.1
Mean	**7.93**	**0.24**	**0.45**	**42.0**	**315.3**	**7.79**	**0.24**	**0.39**	**38.9**	**259.6**

Reduction in Number of Irrigations and Saving of Ground Water

Farmers having some source of irrigation reported saving of ground water because of less number of irrigations applied for a given/tested crop (**Table 4**). Farmers in Warangal saved one irrigation as they generally apply irrigation to cotton three times after the rainy season at fifteen days interval. Farmers in Kolar district reported reduction of three to five irrigations for different crops

Table 4 : Saving of number of irrigations as influenced by application of silt

Sl. No.	Crop	No. of irrigations		No. of irrigations reduced
		Treated	Untreated	
1	Potato	15	18	3
2	Carrot	15	20	5
3	Tomato	15	18	3
4	Mulberry	10	13	3
5	Cabbage	20	25	5

Note: Cropped area is being 0.4 ha

All the farmers reported savings on inputs (manures and fertilizers). Farmers reduced the quantity of application of manures and fertilizers, which helped them in reducing the cost of cultivation and has positive influence on environment. The impact of silt application through FPARP during second year (2009-10) was more pronounced although 2009 was a mega drought year. Higher yield increase over un-treated (without silt application) registered in pigeonpea (412% or 4.6 q ha^{-1}), sorghum + pigeonpea (196% or 4.33 + 4.79 q ha^{-1}) in Nalgonda followed by groundnut (62% or 11.69 q ha^{-1}) in Anantapur, cotton (57% or 25.15 q ha^{-1}) in Warangal, *rabi* sorghum (48% or 17.9 q ha^{-1}) in Solapur, maize (35% or 9.75 q ha^{-1}) in Bhilwara, cabbage (28% or 320 q ha^{-1}), tomato (17% or 225 q ha^{-1}) and potato (17% or 140 q ha^{-1}) in Kolar. Increase in yield was registered irrespective of drought and crops across six districts and four States. Thus, silt application not only improved yield but motivated farmers to diversify to other crops for realizing higher economic benefits. The additional BCRs registered were substantially higher in cotton (5.09) in Nalgonda, followed by Warangal (4.74), rabi sorghum (2.68) in Solapur, groundnut (1.87) in Anantapur, tomato (1.55) and pumpkin (1.50) in Kolar and maize (1.12) in Bhilwara in the year 2009. This has been achieved irrespective of erratic behaviour of monsoon indicating viability and profitability of this technology

Technology Up-scaling

To begin with the foremost up-scaling strategy by CRIDA in this programme was converging with National Agricultural System i.e. with Operational Research Projects for Dryland Agriculture of Indian Council of Agricultural Research at Anantapur (AP), Bengaluru (Karnataka), Bhilwara (Rajasthan) and Solapur (Maharashtra) and State Agricultural Universities i.e. ANGR Agricultural University, Andhra Pradesh (at Agricultural Research Stations, Rekulakunta and Reddipally), Mahatma Phule Krishi

Sharing experiences by Jalamitra farmers, Mailaram village, Warangal district

Vidyapeeth, Maharashtra (at Zonal Agricultural Research Station, Solapur), University of Agricultural Sciences, Karnataka (at Dryland Project, Bengaluru) and Maharana Pratap University of Agriculture and Technology, Rajasthan (at Dry farming Research Station, Arjia) and private institutions i.e NGOs viz. MEOS in Ananatapur, PEACE in Nalgonda, MARI in Warangal and AME in Bengaluru.

The findings of FPARP for each district have been brought as a separate publication in the form of six bulletins for six districts Thousand copies of each bulletin have been published for creating awareness among stakeholders and for up-scaling the technologies. Efforts are being made to translate these bulletins in local language for the benefit of primary stakeholders (farmers) and up-scale the programme through the on-going Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS).

Farmers' Feedback on the Technology

There was an overwhelming response from both the sample farmers (beneficiaries) that influenced other farmers (non-beneficiaries) too, in terms of visiting to the action research programme conducted during both the years of programme i.e.2008-09 and 2009-10. During the first year, the total numbers of farmers (non-beneficiaries) visited to FPARP sites was recorded as 694 in Anantapur, 480 in Nalgonda, 301 in Warangal, 293 in Kolar, 344 in Solapur and 488 in Bhilwara while interestingly during the second year these numbers were higher up to 150 per cent. Out of which, the number of farmers that enthused and expressed their satisfaction and willingness to adopt the tank silt technology has registered substantially higher in Anantapur (99 percent) followed by Nalgonda (71 percent), Kolar (41 percent), Warangal (40 percent), Solapur (31 percent) and Bhilwara (30 percent). At the end of the project duration a focus group discussion was conducted with the farmers to objectively reflect on the achievements of the project in terms of actual benefit accrued to the land and land owners covered under the tank silt application as part of this project design. It is quite obvious that the scale or the extent of benefit is quite varying across the FPARP sites with spatial variability in climate, soil types, particularly the crops.

The overall responses of farmers were:

- Improvement in physical and chemical properties of soil.
- Longer soil moisture retention capacity.
- Good performance of the crops even in years experiencing prolonged dry spells (**Plate 1**).
- Reduction in number of irrigations in case of cotton and vegetable crops.
- Reduction in fertilizer application, subsequently reduction in the cost of cultivation. The quantity of chemical fertilizers applied reduced and thus there was less

dependency on external inputs, in the past two years that faced short supply of fertilizers.

- Healthy growth of crops.
- Increase in crop yields up to 100 per cent.
- Improved quality of the produce of the crops i.e grain, fodder, leaf (mulberry) and vegetables (carrot, pumpkin, tomato, potato etc.).
- Less pests and disease infestation because of healthy plant growth.
- Duration of the crop got extended e.g. tomato due to better availability of soil moisture and nutrients.
- Higher market price realization for the vegetables due to good quality in general, while carrot and tomato in particular.
- Increased additional net returns and increased benefit-cost ratio.

Maize with tank silt, July 21, 2009

Maize without tank silt, July 21, 2009

Plate 1 : Wilting of maize leaves indicating proneness of maize plants to dry spells without silt in Bhilwara, Rajasthan

Conclusion

A holistic perspective of de-silting and recycling of tank silt and sharing of common pool resources, in conjunction with the socio-cultural factors, is imperative in designing the tank management policies at the district level. It is essential that tank management and land use policies consider and incorporate socio-cultural and economic factors. Following points provide an insight for land managers and policy makers to evaluate the existing management strategies and take appropriate decisions.

- Awareness and creating a good understanding among farmers about the significance of tank silt application is an essential requisite for 'demand generation' on silt application.

- The match between local soil quality and the tank silt in terms of possible value addition must be assured through sample analysis and recommendations must be given to farmers based on the broad types of local soils in the vicinity of a tank.
- Preparing the farmers, leveraging resources from Banks and Development Agencies needs considerable work and hence the entire process should begin around October so that the actual silt application work can begin as soon as the tank goes dry.
- Excavation of silt should not weaken the bund, sluice, surplus weir, etc. Marking of the area to be de-silted in tank bed should be done in consultation with engineers or the knowledgeable farmers.
- Number of available tractors or bullock carts and labourers is most critical aspect for implementing this work particularly when it has to be done covering all the farmers. Due to sudden demand for tractors to transport silt the tractor owners might exorbitantly raise the hiring charges. All this must be negotiated well in advance.
- Silt application in fields must be done at least 2-3 weeks before onset of monsoon so that it is dried and can be properly mixed in the field. Otherwise they will remain as large clods taking away the crop area. Farmers may also not get the benefit in the immediate next season.
- It is good to desilt in proper shapes (square or rectangular boxes) so that the quantity of work done is very easily measurable. Accounting for the money spent, assessment of work output for the money spent would be easier.
- Cost sharing by the farmers within the limits of their affordability is a good principle to be practiced. It would help in mobilizing community ownership and peoples monitoring of the tank silt application programme. When farmers meet a part of the cost, the demand will be in match with the actual need rather than indiscriminate dumping of silt in huge quantities.
- Formulation of a scheme by NABARD for re-financing banks for the purpose of de-silting tanks similar to watershed. Provision of soft loan on the lines of crop loan for application of tank silt to the fields.
- Prioritization of tanks for de-silting based on quality and necessity, preference may be given to rainfed areas.
- Tank silt to be considered as a substitute to the fertilizer and a part of subsidy given to fertilizers need to be diverted to tank de-silting and recycling of nutrients to farm lands. Fertilizer provide one or two nutrients while tank silt provides all the nutrients in adequate quantities and also improves soil health and water holding capacity essential for drought proofing in rainfed areas.
- Tank silt of good quality should be used only for the agricultural purpose.

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Role of Conservation Agriculture in Protecting Land and Improving Soil Quality Amidst Changing Climate

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Intensive agriculture and recklessly excessive use of external inputs to enhance the food production to meet the requirement of increasing population world over has resulted in degradation of land, water and genetic resources. Consequently, the productivity of the farms have been declining. There are reports that land degradation has affected some 1900 million hectares of land word-wide UNEP, (1999). Further, there are estimates that about 10 million hectares of good quality land is lost annually for agricultural uses, due to degradative processes, which adversely effect farm production and profitability. In the most susceptible countries of Africa, an estimated 500 million hectares of land have been affected by soil degradation, including 65% of the region's agricultural land. The rate at which arable land is being lost is increasing and is currently 30-35 times the historical rate. The loss of potential productivity due to soil erosion world wide is estimated to be equivalent to some 20 million tons of grain per year UNEP, (1999). It has been reported that rivers in Nepal have damaged more than 400,000 hectares of productive agricultural land. The extent and severity of damage have increased year after year due to frequent changing nature of mountain- rivers. Farmlands near river bank are washed away by flooding, crops are damaged and width of rivers widen every year during monsoon. These rivers carry around 336 million tons of soil per year to the main river systems entering India. The productive capacity of riverside lands has been seriously affected by silting, flooding, and deposition of pebbles (Narayan Poudel, 2008).

In case of other countries too, the problem of land degradation is very severe. According to a pioneering study on the subject, the cost of land degradation in South Asian countries (India, Pakistan, Bangladesh, Iran, Afghanistan, Nepal, Sri Lanka, Bhutan) is at least US$ 10 billion annually. This is approximately 2% of the region's GDP which is equal to 7% of the value of its agricultural output. The breakdown of losses, according to types of land degradation, are: water erosion US$ 5.4 billion; wind erosion US$ 1.8 billion; fertility decline US$ 0.6-1.2 billion; water logging US$ 0.5 billion and salinisation US$ 1.5 billion. The study found that altogether 140 million hectares, which is equal to 43% of the region's total agricultural land, suffered from one or the other form of land degradation. Of this, 31 million hectares were strongly degraded and 63 million hectares moderately degraded. The worst country affected was Iran, with 94% of agricultural land degraded, followed by Bangladesh (75%), Pakistan (61%), Sri Lanka (44%), Afghanistan (33%), Nepal (26%), India (25%) and Bhutan (10%). In Pakistan, land degradation mainly encompasses deforestation and desertification, salinity and sodicity, soil erosion, water logging, depletion of soil fertility and negative nutrient balances (Shah and Arshad, 2006).

When it is said about land degradation, the term "Land'" includes not only the soil resource, but also the water, vegetation, landscape, and microclimatic components of an ecosystem. "Land degradation" is defined as a temporary or permanent decline in the productive capacity of the land and "Land improvement" is referred to an increase in its productive potential. Net productivity change reflects both natural- and human-induced processes of degradation and improvement. Some types of land degradation are, for all practical purposes, irreversible. Examples are severe gullying and advanced salinization. In these cases, the long-term biological and environmental potential of the land has been compromised. Displacement of soil material (erosion) is also irreversible, although its long-term effects on productive capacity depend on the depth and quality of soil remaining. Most types of soil degradation, however, can be prevented or reversed by, for example, adding nutrients to nutrient-depleted soil, rebuilding topsoil through soil amendments, re-establishing vegetation, or buffering soil acidity (Scherr & Yadav 1996).

Status of Land Resource and its Degradation in India

Of the total geographical area of 329 million ha, 142 million ha is devoted to agriculture (FAI, 1990). Out of an estimated net cultivated area of about 142.2 M ha, only about 55 M ha is under irrigation, while 87 M ha is unirrigated. The irrigated area produces about 56% of total food requirement of India. The remaining 44% of the total food production is supported by rainfed agriculture. Most of the essential commodities such as coarse cereals (90%), pulses (87%), and oil seeds (74%) are produced from the rainfed agriculture. Taxonomically, soils in India fall under Entisols (80.1 M ha), Inceptisols (95.8 M ha), Vertisols (26.3 M ha), Aridisols (14.6), Mollisols (8.0 M ha), Ultisols (0.8 M ha), Alfisols (79.7 M ha), Oxisols (0.3 M ha) and non-classified soil (23.1 M ha). The degradation of land occurs across different soil orders. In the country, the total degraded area accounts to 120.7 M ha, of which 73.3 M ha was affected by water erosion, 12.4 M ha by wind erosion, 6.64 M ha by salinity and alkalinity and 5.7 M ha by soil acidity (Anonymous 2008). These statistics reveal that land degradation is a major threat to our food and environmental security. Ravinder Kaur et al. (2003) have given a brief account of extent and magnitude of land degradation due to erosion and stated that extensive soil erosion has significantly degradaded the land and impoverished the people of India. Among the kind of erosions, sheet erosion exists throughout almost the whole country (Anon, 1996). It has been estimated that soil is being lost at an annual average rate of about 16.75 t/ha which is far above the permissible soil erosion rates of 7.5 to 12.5 t/ha/yr for various regions in the country. If this trend continued, it is estimated that one-third of the arable land is likely to be lost within next 20 years. According to Dhruva Narayan and Ram Babu, (1983), about 10% of the total 15334 million tonnes of soil lost annually from the Indian sub-continent is deposited in various reservoirs. Consequently, this is reducing their capacity to just one-quarter of what was assumed at the time these were designed. This, in fact, is a great national loss. Beside this, as the eroded soil carries huge amounts of essential nutrients, it is estimated that there is an additional annual loss of about 560 million dollars due to the loss of about 6.2 MT of plant nutrients (Suraj Bhan, 1997). In terms of annual food grain production, soil erosion accounts for a loss equivalent to about 40 million tonnes. Thus, such a situation demands concerted efforts in planning and implementation of soil and water conservation measures, together with integrated catchment management programmes in the catchment areas.

It is probable that human race will not be able to feed the growing population, if this kind of loss to soil and its fertility is continued at the existing rate. In many developing countries, hunger is compelling the community to cultivate land that is unsuitable for agriculture and which can only be converted to agricultural use through enormous efforts and costs, such as those involved in the construction of terraces and other surface treatments.
Indian sub-continent predominantly represents wide spectrum of climate ranging from arid to semi -arid, sub-humid and humid with wider variation in rainfall amount and pattern. Seasonal temperature fluctuations are also vast. The distribution of area rainfall-wise indicates that 15 M ha area falls in a rainfall zone of <500mm, 15 M ha under 500 to 750 mm, 42 M ha under 750 to 1150 mm and 25 M ha under > 1150 mm rainfall. Predominant soil orders which represent semi-arid tropical region are Alfisols, Entisols, Vertisols and associated soils. Other soil orders such as Oxisols, Inceptisols and Aridisols also form a considerable part of rainfed agriculture. As stated earlier, the majority of the area in the country is rain dependent and is characterized by low cropping intensity, low organic matter and very low fertility, and poor soil physical health. The first predominant cause of soil degradation in these regions undoubtedly is water erosion. The process of erosion sweeps away the topsoil along with organic matter and exposes the subsurface horizons. The second major indirect cause of degradation is loss of organic matter by virtue of temperature mediated fast decomposition of organic matter which robes away its fertility. Above all, the several other farming practices such as reckless tillage methods, harvest of every small component of biological produce and virtually no return of any plant residue back to the soil, burning of the existing residue in the field itself for preparation of clean seed bed, open grazing etc. aggravate the process of soil degradation.

Predominant Causes of Soil Degradation

The predominant reasons which degrade soil quality and deteriorate its productive capacity could be enumerated as: i) washing away of topsoil and organic matter associated with clay size fractions due to water erosion resulting in a 'big robbery in soil fertility', ii) intensive deep tillage and inversion tillage with moldboard and disc plough resulting in a) fast decomposition of remnants of crop residues which is catalyzed by high temperature, b) breaking of stable soil aggregates and aggravating the process of oxidation of entrapped organic C and c) disturbance to the habitat of soil micro flora and fauna and loss in microbial diversity, iii) dismally low levels of fertilizer application and widening of removal-use gap in plant nutrients, iv) mining and other commercial activities such as use of top soil for other than agricultural purpose, v) mono- cropping without following any suitable rotation, vi) nutrient imbalance caused due to disproportionate use of primary, secondary and micronutrients, vii) no or low use of organic manures such as FYM, compost, vermi-compost and poor recycling of farm based crop residues because of competing demand for animal fodder and domestic fuel, viii) no or low green manuring as it competes with the regular crop for date of sowing and other resources, ix) poor nutrient use efficiency attributing to nutrient losses due to leaching, volatilization and denitrification, x) indiscriminate use of other agricultural inputs such as herbicides, pesticides, fungicides, etc., resulting in poor soil and water quality, xi) water logging, salinity and alkalinity and acid soils. As a result of several above-mentioned reasons, soils encounter diversity of constraints broadly on account of physical, chemical and biological soil health and ultimately end up with poor functional capacity (Sharma et al., 2007). Scherr and Yadav (1996) studied the impact of land degradation on Global agriculture and reported the results in Paper No 14 of International Food Policy Research Institute (IFPRI). They stated that land degradation could have dramatic effects in specific countries and sub-regions in the form of nutrient depletion, salinization, agrochemical pollution, soil erosion, vegetative degradation of range lands and agricultural induced deforestation by 2020. The degradative effects will be more pronounced in rainfed areas due to the extreme events likely to occur as a result of climate change.

In order to restore the quality of degraded soils and to prevent them from further degradation, it is of paramount importance to focus on conservation agriculture practices on long-term basis. There is no doubt that, agricultural management practices such as crop rotations, inclusion of legumes in cropping systems, addition of animal based manures, adoption of soil and water conservation practices, various permutations and combinations of deep and shallow tillage, mulching of soils with *in-situ* grown and externally brought plant and leafy materials always remained the part and parcel of agriculture in India. Despite all these efforts, the concept of conservation farming could not be followed in an integrated manner to expect greater impact in terms of protecting the soil resource from degradative processes.

Likely Effects of Climate Change on Agriculture in General and Soil Health in Particular

According to (Rao et al, 2010), the major weather related risks in Agriculture could be as follows: Monsoons in India exhibits substantial inter-seasonal variations, associated with a variety of phenomena such as passage of monsoon disturbances associated with active phase and break monsoon periods whose periodicities vary from 3-5 and 10-15 days, respectively. It is well noticed that summer monsoon rainfall in India varied from 604 to 1020 mm. The inter-seasonal variations in rainfall cause floods and droughts, which are the major climate risk factors in Indian Agriculture. The main unprecedented floods in India are mainly due to movement of cyclonic disturbances from Bay of Bengal and Arabian Sea on to the land masses during monsoon and post-monsoon seasons – and during break monsoon conditions in some parts of Uttar Pradesh and Bihar. The thunderstorms due to local weather conditions also damages agricultural crops in the form of flash floods. Beside floods, drought is a normal, repetitive feature of climate associated with deficiency of rainfall over extended period of time to different dryness levels describing its severity. During the period 1871 to 2009, there were 24 major drought years, defined as years with less than one standard deviation below the mean. Another important adverse effect of climate change could be unprecedented heat waves. Heat waves generally occur during summer season where the cropped land is mostly fallow, and therefore, their impact on agricultural crops is limited. However, these heat waves adversely affect orchards, livestock, poultry and rice nursery beds. The heat wave conditions during 2003 May in Andhra Pradesh and 2006 in Orissa are recent examples that have affected the economy to a greater extent. Also occurrence of heat waves in the northern parts during summer is common every year resulting in quite a good number of human deaths. Further, the water requirements of summer crops grown under irrigated conditions increase to a greater extent. Another adverse effect of climate change is cold waves which mostly occur in northern states. The Northern states of Punjab, Haryana, U.P., Bihar and Rajasthan experience cold wave and ground frost like conditions during winter months of December and January almost every year. The occurrence of these waves has significantly increased in the recent past due to reported climatic changes at local, regional and global scales. Site-specific short-term fluctuations in lower temperatures and the associated phenomena of chilling, frost, fogginess and impaired sunshine may sometimes play havoc in an otherwise fairly stable cropping/farming system of a region.

a) Influence of Climate Change on Soil Quality

Climate change is likely to have a variety of impacts on soil quality. Soils vary depending on the climate and show a strong geographical correlation with climate. The key components of climate in soil formation are moisture and temperature. Temperature and moisture amounts cause different patterns of weathering and leaching. Wind redistributes sand and other particles especially in arid regions. The amount, intensity, timing, and kind of precipitation influence soil formation. Seasonal and daily changes in temperature affect moisture effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation. Soils and climate are intimately linked. Climate change scenarios indicate increased rainfall intensity in winter and hotter, drier summers. Changing climate with prolonged periods of dry weather followed by intense rainfall could be a severe threat to soil resource. Climate has a direct influence on soil formation and cool, wet conditions and acidic parent material have resulted in the accumulation of organic matter. A changing climate could also impact the workability of mineral soils and susceptibility to poaching, erosion, compaction and water holding capacity. In areas where winter rainfall becomes heavier, some soils may become more susceptible to erosion. Other changes include the washing away of organic matter and leaching of nutrients and in some areas, particularly those facing an increase in drought conditions, saltier soils, etc.

Not only does climate influence soil properties, but also regulates climate via the uptake and release of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Soil can act as a source and sink for carbon, depending on land use and climatic conditions. Land use change can trigger organic matter decomposition, primarily via land drainage and cultivation. Restoration and recreation of pealands can result in increased methane emissions initially as soils become anaerobic, whereas in the longer term they become a sink for carbon as organic mater accumulates. Climatic factors have an important role in peat formation and it is thus highly likely that a changing climate will have significant impacts on this resource.

b) Carbon Build-up and Rising Temperatures

In India, over two-thirds of the increase in atmospheric CO_2 during the past 20 years is due to fossil fuel burning. The rest is due to land-use change, especially deforestation, and to a lesser extent, cement production. Global average surface temperature increased 0.6 (0.2) °C in the 20th century and will increase by 1.4 to 5.8 °C by 2100. Estimates indicate that India’s climate could become warmer under conditions of increased atmospheric carbon dioxide. The average temperature change is predicted to be in the range of 2.33°C to 4.78°C with a doubling in CO_2 concentrations. Over the past 100 years, mean surface temperatures have increased by 0.3-0.8°C across the region. The 1990s have been the hottest decade for a thousand years. The time taken for CO_2 to pass through the atmosphere varies widely, with a significant impact. It can take from 5 to 200 years to pass through the atmosphere, with an average of 100 years. This means that CO_2 emission produced 50 years ago still lingers in atmosphere today. It also means that current emissions won’t lose their deleterious effect until year 2104. Eventhough drastic measures to reduce climate emissions have been taken in recent years, climate change is impossible to prevent. As a result of increasing pressure from climate change on current key areas of food production, there might be a rising need for increased food production.

The production of food more locally is also being promoted in an attempt to reduce food miles. To meet food production and security objectives, there might be the need to afford prime agricultural land more protection. The rise in temperatures will influence crop yields by shifting optimal crop growing seasons, changing patterns of precipitation and potential evapotranspiration, reducing winter storage of moisture in snow and glacier areas, shifting the habitat's of crops pests and diseases, affecting crop yields through the effects of carbon dioxide and temperature and reducing cropland through sea-level rise and vulnerability to flooding.

c) Climatic change effect on soil fertility and erosion

No comprehensive study has yet been made of the impact of possible climatic changes on soils. Higher temperatures could increase the rate of microbial decomposition of organic matter, adversely affecting soil fertility in the long run. But increases in root biomass resulting from higher rates of photosynthesis could offset these effects. Higher temperatures could accelerate the cycling of nutrients in the soil, and more rapid root formation could promote more nitrogen fixation. But these benefits could be minor compared to the deleterious effects of changes in rainfall. For example, increased rainfall in regions that are already moist could lead to increased leaching of minerals, especially nitrates. In the Leningrad region of the USSR a one-third increase in rainfall (which is consistent with the GISS 2 x CO_2 scenario) is estimated to lead to fall in soil productivity of more than 20 per cent. Large increases in fertilizer applications would be necessary to restore productivity levels. Decreases in rainfall, particularly during summer, could have a more dramatic effect, through the increased frequency of dry spells leading to increased proneness to wind erosion. Susceptibility to wind erosion depends in part on cohesiveness of the soil (which is affected by precipitation effectiveness) and wind velocity.

Nitrogen availability is important to soil fertility and N cycling is altered by human activity. Increasing atmospheric CO_2 concentrations, global warming and changes in precipitation patterns are likely to affect N processes and N pools in forest ecosystems. Temperature, precipitation, and inherent soil properties such as parent material may have caused differences in n pool size through interaction with biota. Keller et al., (2004) reported that climate change will directly affect carbon and nitrogen mineralization through changes in temperature and soil moisture, but it may also indirectly affect mineralization rates through changes in soil quality.

d) Impact on Biodiversity

Climate change is having a major impact on biodiversity and in turn biodiversity loss (in the form of carbon sequestration in trees and plants) is a major driver of climate change. Land degradation such as soil erosion, deteriorating soil quality and desertification are driven by climate variability such as changes in rainfall, drought and floods. Degraded land releases more carbon and greenhouse gases back into the atmosphere and slowly kills off forests and other biodiversity that can sequester carbon, creating a feed back loop that intensifies climate change.

Conservation Agriculture and its Components

Conservation agriculture is a practice that reduces soil erosion, sustains soil fertility, improves water management and reduces production costs, making inputs and services affordable to small-scale farmers. Conservation agriculture is defined as a set of practices aimed at achieving the following three principles simultaneously: i) maintaining adequate soil cover, ii) disturbing the soil minimally, and iii) ensuring crop rotation and intercropping. Conservation agriculture as defined by Food and Agricultural Organization (FAO) of the United Nations is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agro-chemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt the biological processes (Philip et al.,2007). Conservation agriculture, in broader sense includes all those practices of agriculture, which help in conserving the land and environment while achieving desirably sustainable yield levels. Tillage is one of the important pillars of conservation agriculture which disrupts inter- dependent natural cycles of water, carbon and nitrogen. Conservation tillage is a generic term encompassing many different soil management practices. It is generally defined as 'any tillage system that reduces loss of soil or water relative to conventional tillage; mostly a form of non-inversion tillage allows protective amount of residue mulch on the surface (Mannering and Fenster, 1983).

Lal (1989) reported that the tillage system can be labeled as conservation tillage if it i) allows crop residues as surface mulch, ii) is effective in conserving soil and water, iii) maintains good soil structure and organic matter contents, iv) maintains desirably high and economic level of productivity, v) cut short the need for chemical amendments and pesticides, vi) preserves ecological stability and vii) minimizes the pollution of natural waters and environments. In order to ensure the above criteria in agriculture, there is a need to follow a range of cultural practices such as i) using crop residue as mulch, ii) adoption of non-inversions or no-tillage systems, iii) promotion of crop rotations by including cover crops, buffer strips, agroforestry, etc., iv) enhancement of infiltration capacity of soil through rotation with deep rooted perennials and modification of the root zone; v) enhancement in surface roughness of soil without jumping into fine tilth, vi) improvement in biological activity of soil fauna through soil surface management and vii) reducing cropping intensity to conserve soil and water resources and building up of soil fertility. The effects of conservation tillage on various soil properties, organic matter status, soil nutrient status and environmental quality have comprehensively reviewed by Blevins and Frye (1993), Lal (1989), Unger and McCalla (1980) and Unger (1990). From the various reviews, it is understood that no single tillage system is suitable for all soils and climatic conditions. The predominant advantages of the conservation tillage have been found in terms of soil erosion control, water conservation, less use of fossil fuels specifically for preparation of seed bed, reduced labour requirements, more timeliness of operations or greater flexibility in planting and harvesting operations that may facilitate double cropping, more intensive use of slopping lands and minimized risk of environmental pollution. Some of the discouraging and undesirable effects of conservation tillage have been reported as: (1) increase in use of herbicides and consequently increased cost, (2) problems and difficulties in controlling of some of the infested weeds, (3) difficulty in managing poorly drained soils, (3) slower warming of temperate soils due to surface residue layer during winter and springs which delays germination and early growth. However, in tropics this negative aspect can become an asset in helping in maintaining relatively lower temperature and thereby enhancing germination. It also helps in preserving soil and water resources.

Importance and Scope of Conservation Agricultural Practices in Relation to Land Protection and Soil Health in Rainfed Areas

As discussed in the foregoing section, soil quality degradation is more prominent in rainfed agro-ecoregions because of natural processes and human induced crop husbandry practices, which call for the adherence to the conservation agriculture management as top priority. Conservation agriculture has the main aim of protecting the soil from erosion and maintaining, restoring and improving soil organic carbon status in the various production systems, hence more suited and required in rainfed agriculture. Predominantly, this goal can be achieved through minimizing the soil tillage, inclusion of crop rotation or cover crops (mostly legumes) and maintaining continuous residue cover on soil surface. The former is governed by the amount of draft power a farmer is using and the latter by the produce amount, harvesting index and fodder requirements including open grazing. The crop rotations are induced by crop diversification, which has wider scope in the rainfed agriculture than in irrigated agriculture. Diversification will help not only in minimizing the risk occurred due to failure of crops, improving total farm income but also in carbon sequestration.

Tillage, which is one of the predominant pillars of conservation agriculture, disrupts the inter-dependent natural cycles of water carbon and nitrogen. Tillage unlocks the potential microbial activity by creating more reactive surface area for gas exchange on soil aggregates that are exposed to higher ambient oxygen concentration (21%). Tillage also breaks the aggregate to expose fresh surfaces for enhanced gas exchange and perhaps, may lead to more carbon loss from the interior that may have higher carbon-dioxide concentration. Thus, an intensive tillage creates negative conditions for carbon sequestration and microbial activity. However, the main question is whether the intensity of tillage or length of cultivation of land which is an environment enemy in production agriculture in terms of loss of carbon-dioxide, soil moisture through evaporation and biota dwindling is a major production constraint to agriculture or not. The developed countries suffer from heavy-duty mechanization, while India is suffering from long use of plough without caring much about the maintenance of land cover. The major toll of organic C in sloppy lands has been taken by water erosion due to faulty methods of up and down cultivation. Ramakrishna et al. (2005) and Venkateshwarlu et al. (2010) have comprehensively reviewed the scope of conservation agriculture in rainfed areas.

Conservation Agriculture *vis-à-vis* Soil Quality

Various research reports have emphasized that conservation agricultural practices play an important role in preventing the soils from further degradation and in restoring back the dynamic attributes of soil quality. According to Doran and Parkin (1994) and Karlen et al. (1997), soil quality is defined as the functional capacity of the soil. Seybold et al. (1998) defined the soil quality as 'the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation.' Quality with respect to soil can be viewed in two ways: (1) as inherent properties of a soil; and (2) as the dynamic nature of soils as influenced by climate, and human use and management. This view of soil quality requires a reference condition for each kind of soil with which changes in soil condition are compared and is currently the focal point for the term 'soil quality'. The soil quality as influenced by management practices (tillage, use of organics, fertilizers and chemicals, cropping system, irrigation, etc.) can be measured quantitatively using physical, chemical and biological properties of soils as these properties interact in a complex way to give a soil its quality or capacity to function. Thus, soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as 'indicators'. Indicators of soil quality should give some measure of the capacity of the soil to function with respect to plant and biological productivity, environmental quality and human and animal health. Indicators are measurable properties of soil or plants that provide clues about how well the soil can function. They provide signal about desirable or undesirable changes in land and vegetation management that have occurred or may occur in the future. Some of the important indicators which are given below can be influenced by appropriate soil management practices which in turn can help in moderating the ill effects of climate change (**Table1**).

Table 1 : Major soil quality indicators and related processes and functions which can moderate the ill effects of climate change

Soil quality indicators	Soil processes and functions
i) Physical indicators	
A. Mechanical	
Texture	Crusting, gaseous diffusion, infiltration
Bulk density	Compaction, root growth, infiltration
Aggregation	Erosion, crusting, infiltration, gaseous diffusion
Pore size distribution and continuity	Water retention and transmission, root growth, and gaseous exchange
B. Hydrological	
Available water capacity	Drought stress, biomass production, soil organic matter content
Non-limiting water range	Drought, water imbalance, soil structure
Infiltration rate	Runoff, erosion, leaching
C. Rooting zone	
Effective rooting depth	Root growth, nutrient and water use efficiencies
Soil temperature	Heat flux, soil warming activity and species diversity of soil fauna
ii) Chemical indictors	
pH	Acidification and soil reaction, nutrient availability
Base saturation	Absorption and desorption, solubilization
Cation exchange capacity	Ion exchange, leaching
Total and plant available nutrients	Soil fertility, nutrient reserves
iii) Biological indicators	
Soil organic matter	Structural formation, mineralization, biomass carbon, nutrient retention
Earthworm population and other soil macro fauna and activity	Nutrient cycling, organic matter decomposition, formation of soil structure
Soil biomass carbon	Microbial transformations and respiration, formation of soil structure and organo-mineral complexes
Soil quality indicators	**Soil processes and functions**
Total soil organic carbon	Soil nutrient source and sink, biomass carbon, soil respiration and gaseous fluxes

Source: Lal (1994)

Role of Conservation Agriculture (reduced tillage and residue management) on Soil Health Amidst Adverse Effect of Climate Change

Conservation tillage and residue management helps in the following ways in influencing some of the soil properties and mitigating the adverse effects of climate change :

- **Soil temperature**: Surface residues significantly affect soil temperature by balancing radiant energy and insulation action. Radiant energy is balanced by reflection, heating of soil and air and evaporation of soil water. Reflection is more from bright residue.

- **Soil aggregation:** It refers to binding together of soil particles into secondary units. Water stable aggregates help in maintaining good infiltration rate, good structure, protection from wind and water erosion. Aggregates binding substances are mineral substances and organic substances. Organic substances are derived from fungi, bacteria, actinomycetes, earthworms and other forms through their feeding and other actions. Plants themselves may directly affect aggregation through exudates from roots, leaves and stems, leachates from weathering and decaying plant materials, canopies and surface residues that protect aggregates against breakdown with raindrop impact, abrasion by wind borne soil and dispersion by flowing water and root action. Aggregates with. 0.84 mm in diameter are non-erodable by wind and water action. Well-aggregated soil has greater water entry at the surface, better aeration, and more water-holding capacity than poorly aggregated soil.

- Aggregation is closely associated with biological activity and the level of organic matter in the soil. The gluey substances that bind components into aggregates are created largely by the various living organisms present in healthy soil. Therefore, aggregation is increased by practices that favour soil biota. Because the binding substances are themselves susceptible to microbial degradation, organic matter needs to be replenished to maintain aggregation. To conserve aggregates once they are formed, minimize the factors that degrade and destroy them.

- Well-aggregated soil also resists surface crusting. The impact of raindrops causes crusting on poorly aggregated soil by disbursing clay particles on the soil surface, clogging the pores immediately beneath, sealing them as the soil dries. Subsequent rainfall is much more likely to run off than to flow into the soil. In contrast, a well-aggregated soil resists crusting because the water-stable aggregates are less likely to break apart when a raindrop hits them. Any management practice that protects the soil from raindrop impact will decrease crusting and increase water flow into the soil. Mulches and cover crops serve this purpose well, as do no-till practices which allow the accumulation of surface residue.

- **Soil density and porosity:** Soil bulk density and porosity are inversely related. Tillage layer density is lower in ploughed than unploughed (area in grass, low tillage area etc). When residues are involved, tilled soils will reflect lower density. Mechanization with heavy machinery results in soil compaction, which is undesirable and is associated with increased bulk density and decreased porosity. Natural compaction occurs in soils, which is low in organic matter and requires loosening. But, practicing conservation tillage to offset the compaction will be effective only when there is adequate residue, while intensive tillage may adversely influence the soil fauna, and indirectly influence the soil bulk density and porosity.

- **Effects on other physical properties:** Tillage also influences crusting, hydraulic conductivity and water storage capacity. It has been understood that the textural influences and changes in proportion of sand, silt and clay occur due to inversion and mixing caused by different tillage instruments, tillage depth, mode of operation and effect of soil erosion. Soil crusting which severely affects germination and emergence of seedling is caused due to aggregate dispersion and soil particles resorting and rearrangement during rainstorm followed by drying. Conservation tillage and surface residue helps in protecting the dispersion of soil aggregates and helps in increasing saturated hydraulic conductivity. Increased HC in conjunction with increased infiltration resulting from conservation tillage allows soil profile to be more readily filled with water. Further, less evaporation is also supported by conservation tillage, and profile can retain more water.

- **Effect on soil organic matter and soil fertility:** Conservation agricultural practices help in improving soil organic matter by way of i) regular addition of organic wastes and residues, use of green manures, legumes in the rotation, reduced tillage, use of fertilizers, and supplemental irrigation ii) drilling the seed without disturbance to soil and adding fertilizer through drill following chemical weed control and iii) maintaining surface residue, practicing reduced tillage, recycling of residues, inclusion of legumes in crop rotation. These practices provide great opportunity in maintaining and restoring soil quality in terms of SOM and N in SAT regions. It is absolutely necessary to spare some residue for soil application, which will help in improving soil tilth, fertility and productivity.

Research based Experiences - Effect of Conservation Agriculture Management Practices on Soil Quality Improvement

There are several reports on the influence of conservation agricultural management practices comprising of tillage, residue recycling, application of organic manures, green manuring and integrated use of organic and inorganic sources of nutrients, soil water conservation treatments, integrated pest management, organic farming, etc., on soil quality. Improved soil quality parameters create additional muscle power to soil to combat the ill effects of climate change. Some of the results pertaining to the effect of conservation agricultural practices on soil quality are given below:

The studies conducted over a 9 year period in Alfisols at Bangalore with finger millet, revealed that the yields were similar with optimum N, P, K application and with 50% NPK applied through combined use of fertilizers + FYM applied @ 10 t ha^{-1}. Application of vermicompost in combination with inorganic fertilizer in 1:1 ratio in terms of N equivalence was found very effective in case of sunflower grown in Alfisol at Hyderabad (Neelaveni, 1998). Combined use of crop residues and inorganic fertilizer showed better performance than sole application of residue. Use of crop residue in soil poor in nitrogen (Bangalore) showed significant improvement in the fertility status and soil physical properties. Continuous addition of crop residues for five years enhanced maize grain yield by 25%. Organic matter status improved from 0.5% in the control plots to 0.9% in plots treated with maize residue at 4 t ha^{-1} $year^{-1}$. In Alfisols at Hyderabad, use of crop residues in pearl millet and cowpea not only enhanced the yields but also made appreciable improvements in stability of soil structure, soil aggregates and hydraulic conductivity.
Capitalisation of legume effect is one of the important strategies of tapping additional nitrogen through biological N fixation. There are many reports on this aspect (Singh and Das, 1984; Sharma and Das, 1992). The beneficial effect of preceding crops on the succeeding non-legume crops has been studied at many locations. When maize was grown after groundnut, a residual effect of equivalent to 15 kg N ha^{-1} was observed at ICRISAT (Reddy et al., 1982). Sole cowpea has been reported to exhibit a residual effect of the magnitude of 25-50 kg N ha^{-1} (Reddy et al., 1982). Based on a five year rotation of castor with sorghum + pigeonpea and greengram + pigeonpea in an Alfisol of Hyderabad, it was observed that greengram + pigeonpea intercrop (4:1) can leave a net positive balance of 97 kg ha^{-1} total N in soil (Das et al.1990).

Results of a long-term study conducted on soil quality improvement revealed that the application of gliricidia loppings proved superior to sorghum stover and no residue treatments in maintaining higher soil quality index (SQI) values. Further, increasing N levels also helped in maintaining higher SQI. Among the 24 treatments, the highest SQI was obtained in conventional tillage (CT) + gliricidia loppings (GL) + 90 kg N ha^{-1} ($CTGLN_{90}$) (1.27) followed by $CTGLN_{60}$ (1.19) and minimum tillage (MT) + sorghum stover (SS) + 90 kg N ha^{-1} ($MTSSN_{90}$) (1.18), while the lowest was under minimum tillage + no residue (NR) + 30 kg N ha^{-1} ($MTNRN_{30}$) (0.90) followed by $MTNRN_0$ (0.94), indicating relatively less aggradative effects. The application of 90 kg N ha^{-1} under minimum tillage even without applying any residue ($MTNRN_{90}$) proved quite effective in maintaining soil quality index as high as 1.10. The key indicators, which contributed considerably towards SQI were, available N, K, S, microbial biomass carbon (MBC) and hydraulic conductivity (HC). Among the various treatments, $CTGLN_{90}$ not only had the highest SQI, but was most promising from the viewpoint of sustainability, maintaining higher average yield levels under sorghum-castor rotation. From the view point of SQI, CT approach remained superior to MT. To maintain yield as well as soil quality in Alfisols, primary tillage along with organic residue and nitrogen application are needed (Sharma et al., 2005).

Another long-term experiment was conducted with two tillage (conventional (CT) and reduced tillage (RT)) and five INM treatments (control, 40 kg N through urea, 4 t compost + 20 kg N, 2 t Gliricidia loppings + 20 kg N and 4 t compost + 2 t Gliricidia loppings) using sorghum and greengram as test crops. Tillage did not influence the soil quality index (SQI), while the conjunctive nutrient use treatments had a significant effect. The conjunctive nutrient use treatments aggraded the soil quality by 24.2 to 27.2 %, while the sole inorganic treatment could aggrade only to the extent of 18.2 % over the control. Statistically, the overall superiority of the treatments in aggrading the soil quality was: 4 Mg compost + 2 Mg gliricidia loppings (T5) > 2 Mg Gliricidia loppings + 20 kg N through urea (T4) = 4 Mg compost + 20 kg N through urea (T3) > 40 kg N through urea (T2). The extent of percent contribution of the key indicators towards soil quality index (SQI) was: microbial biomass carbon (MBC) (28.5%), available nitrogen (28.6%), DTPA-Zn (25.3%), DTPA- Cu (8.6%), hydraulic conductivity (HC) (6.1%) and mean weight diameter (MWD) (2.9%) (Sharma et al., 2008).

Based on the network tillage experiment being carried out since 1999 at various centers of All India Coordinated Research Project on Dryland Agriculture (AICRPDA), it was observed that in arid (< 500 mm rainfall) region, low tillage was almost comparable to conventional tillage and the weed management was not so difficult, whereas, in semi-arid (500–1000 mm) region, conventional tillage was found superior. It is a well-established fact that infiltration of rainfall depends on soil loosening and its receptiveness and thus requires more surface disturbance. Success of crops depends on rainfall infiltration and soil moisture holding in the profile.

For improving the carbon content in soil, apart from crop residues, the agro-forestry also becomes important. However, nothing comes free. The agro-forestry system comprising of perennial components depends on the sub-soil components. It has been observed that grasslands and tree system play an important role in improving soil properties such as bulk density, mean weight diameter, water stable aggregates and organic carbon. Apart from the above, other soil properties such as infiltration rate and hydraulic conductivity were also influenced due to agro- forestry systems compared to agricultural systems.

Status of Conservation Agriculture in South Asian Countries

In South Asian countries, the credit of protecting the lands through Resource Saving Technologies goes to South Asian Countries Agricultural Network (SACAN). This organization was established during 2007 with the aim to combat against resource degradation caused by agricultural practices being following to harvest food, fiber and shelter requirements, particularly in South Asian countries. The SACAN through its subsidiaries, SACAN Services, SACAN Consultants and SACAN Supplies provide their valued input for the promotion, research, evaluation and development of resource conservation technologies besides supply of technical knowledge, human resources, machinery and equipment to the public and private enterprises. SACAN also works in close liaison with local, regional and international networks of its kind. Presently SACAN is participating in the following various mega developments being undertaking in the agricultural and water sectors :

- Mining of soil nutrients
- Declining of organic matter
- Increasing salinity
- Depletion of groundwater, and
- Build up and control of weeds and pests

It was realized that effective linkage are required with famers and other stakeholders to accelerate the transmission of these innovations to the user community. A more participatory approach among an expanded set of stakeholders will be needed to accelerate adoption of more efficient technologies quickly. Otherwise it will be extremely difficult to confront the hunger knocking at the door (http://www.sacanasia.org).

International Efforts and "The New Delhi Declaration on Conservation Agriculture"

There have been consistent efforts internationally to promote conservation agriculture to protect the land resource. So for, there have been four world congress on this subject which have exposed the world scientific community to the prospectus and limitation of conservation agriculture. These international efforts have ignited the spark in the minds of different stake holders. The recent 4th World Conference on Conservation Agriculture was held from 4 to 7 February 2009, at New Delhi. In this conference, an important declaration was made which is known as the Delhi declaration. (Joshi et al., 2010 and http://www.conservationag.wordpress.com)

The contents of the New Delhi Declaration were as follows:

"The 1,000 delegates, gathered in the 4th World Congress on Conservation Agriculture, held from 4 to 7 February 2009 in New Delhi, India, among them farmers, private sector enterprises, scientists, development organizations, donor organizations and policymakers from all world continents, recognizing the urgent need

- to double agricultural production over the next few decades,
- to reverse the trend of degradation of natural resources, in particular soil, water and biodiversity,
- to improve the efficiency of the use of ever scarcer production resources,
- to address the fact that agriculture and agriculturally induced deforestation cause 30% of the actual green house gas emissions,
- to answer the increasing threats of a changing climate to agricultural production, it is agreed that Conservation Agriculture based on the three principles of
- minimum mechanical disturbance of the soil
- permanent organic cover of the soil surface, and
- a diversified sequence or association of crops

is the foundation of a sustainable intensification of crop production, being as such the necessary condition to achieve, along with other complementary technologies, a sustained increase of world agricultural production and at the same time a recovery of the natural resource base and environmental services.

The delegates therefore urge all stakeholders involved at international, regional and national level in agricultural production, research and policy making to mainstream Conservation Agriculture as the base concept for agricultural production.

Governments of the world are requested to

- harmonize their policies in support for the adoption of Conservation Agriculture
- introduce mechanisms which provide incentives for farmers to change their production system to Conservation Agriculture
- pursue the case of Conservation Agriculture as the central mechanism for agricultural sector climate change mitigation in the international negotiations for a post Kyoto climate change agreement
- include Conservation Agriculture as base concept for the adaptation of agriculture to the challenges of climate change in the National Action Plans
- support the UN Food and Agriculture Organization in the endeavour to establish a special programme on Conservation Agriculture to facilitate this process in its member countries".

Steps Required to Promote Conservation Agriculture

The following steps are needed to promote conservation farming in the future:

1) There is a need to create awareness among the communities about the importance of soil resources, organic matter build up in soil. Traditional practices such as burning

of residues, clean cultivation, intensive tillage and pulverization of soil upto finest tilth need to be discouraged.

2) Systems approach is essential for fitting conservation tillage in modern agriculture. In order to follow the principle of "grain is to man and a residue is to soil", farming systems approach introducing alternative fodder crops is essential. Agroforestry systems with special emphasis on silvipastures systems need to be introduced. Unproductive livestock herds need to be discouraged

3) For the adoption of conservation tillage, it is essential that complete package of practices may be identified based on intensive research for each agro-ecological region.

4) The increased use of herbicides has become inevitable for adopting conservation tillage/conservation farming practices. The countries that use relatively higher amount of herbicides are already facing problem of non-point source pollution and environmental hazard. In order to reduce the herbicidal demand, there are scopes to study the allelopathic effects of cover crops and intercultural and biological method of weed control. In other words, due concentration is needed to do research on regenerative cropping systems to reduce dependence on inorganic fertilizers.

5) Low tillage, crop rotation, cover crops, maintenance of residues on the surface, control of weeds through herbicides, are the key components of conservation farming. Therefore, it is essential that these themes must be studied in depth under diverse soil and climatic conditions across the country on long-term basis.

6) The other objective of conservation farming is to minimize the inputs originating from non-renewable energy sources. Eg. Fertilizers and pesticides. Hence, research focus is required on enhancing fertilizer use efficiency and reduction in use of pesticides. This aspect can be strengthened by following integrated nutrient management and integrated pest management approaches.

7) The past research experiences of conservation tillage reveal that the major toll of yield is taken by poor germination and poor crop stand because of poor microclimatic environment and hard setting tendencies of soil, excessive weed growth and less infiltration of water to the crop root zone. Therefore, the important aspects which need concentrated research focus include appropriate time of sowing, suitable seed rate, depth of seed placement and soil contact, row orientation, etc. Suitable cultivars having responsiveness to inputs also become important component of conservation farming.

8) The issues related to development of eco-friendly practices for tillage and residue recycling – appropriately for specific combination of soil-agro climatic cropping

system – to alleviate physical constraints with higher water and nutrient use efficiency need to be addressed

9) Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero tillage, residue incorporation and inter-cultural operations.

Research focus is needed on modeling of tillage dynamics and root growth, incorporation of soil-physical properties in crop-growth simulation models and relating it to crop yields under major cropping sequences.

Research and Management Strategies for Improving Soil Health

The following research, developmental and policy strategies are suggested to restore and maintain soil quality on long-term basis.

- **Checking soil resource through effective soil and water conservation (SWC) measures:** It is well accepted connotation that 'Prevention is better than cure'. In order to protect the top soil, organic matter content contained in it and associated essential nutrients, it is of prime importance that there should be no migration of soil and water out of a given field. If this is controlled, the biggest robbery of clay-organic matter -nutrients is checked. This can be easily achieved, if the existing technology on soil and water conservation is appropriately applied on an extensive scale. The cost for *in-situ* and *ex-situ* practices of SWC has been the biggest concern in the past. There is a need to launch 'soil resource awareness program' among the farming community. Suitable incentives / support need to be given to the farming community by way of employment / food for work program, etc.

- **Rejuvenation and reorientation of soil testing program in the country:** About more than 600 soil testing labs situated in the country need to be reoriented, restructured and need to be given fresh mandate of assessing the soil quality in its totality including chemical, physical, biological indicators and water quality. The testing needs to be on intensive scale and recommendations are required to be made on individual farm history basis. Special focus is required on site-specific nutrient management (SSNM). Soil Health Card system needs to be introduced. Soil fertility maps of intensive scale need to be prepared. District soil testing labs need to be renamed as 'District Soil Care Labs' and required to be well equipped with good equipments and qualified manpower for assessing important soil quality indicators including micronutrients. Fertilizer application needs to be based on soil tests and nutrient removal pattern of the cropping system in a site-specific manner. This will help in correcting the deficiency of limiting nutrients. Keeping in mind the sluggish and inefficient activities of regional soil testing labs of the states, private sector can also be encouraged to take up Soil Care Programs with a reasonable cost using a principle of 'Soil Clinics, Diagnosis and Recommendation'.

- **Promotion of management practices which enhance soil organic matter**: Management practices such as application of organic manures (composts, FYM, vermi-composts), legume-crop based green manuring, tree-leaf green manuring, residue recycling, sheep-goat penning, organic farming, conservation tillage, inclusion of legumes in crop rotation need to be encouraged (Sharma et al. 2004). Similar to inorganic fertilizer, subsidy provisions for organic manures can also be made so that growers should be motivated to take up these practices as components of integrated nutrient management (INM). As is being done in a country like USA, conservation tillage and land cover need to be promoted in India too for better carbon sequestration.

- **Development and promotion of other bio-resources for enhancing microbial diversity and ensuring their availability**: In addition to organic manures, there is a huge potential to develop and promote bio-fertilizers and bio-pesticides in large scale. These can play an important role in enhancement of soil fertility and soil biological health. Use of toxic plant protection chemical can also be reduced. In addition to this, there is a need to focus on advance research for enhancing microbial diversity by identifying suitable gene pools.

- **Ensuring availability of balanced multi-nutrient fertilizers:** Fertilizer companies need to produce multi-nutrient fertilizers containing nutrients in a balanced proportion so that illiterate farmers can use these fertilizers without much hassle.

- **Enhancing the input use efficiency through precision farming:** The present level of use efficiency of fertilizer nutrients, chemicals, water and other inputs is not very satisfactory. Hence, costly inputs go waste to a greater extent and result in monetary loss and environmental (soil and water) pollution. More focus is required to improve input use efficiency. The components required to be focused could be suitable machinery and other precision tools for placement of fertilizers, seeds and other chemical in appropriate soil moisture zone so that losses could be minimized and efficiency could be increased. This aspect has a great scope in rainfed agriculture. This will also help in increasing water use efficiency (WUE).

- **Amelioration of problematic soils using suitable amendments and improving their quality to a desired level:** History has a record that poor soil quality or degraded soils have taken toll of even great civilizations. No country can afford to let its soils be remaining degraded by virtue of water logging, salinisation, alkalinity, erosion etc. Lots of efforts have already gone into the research process. There is a need to ameliorate the soils at extensive scale on regular basis. No matter, how much it costs.

- **Land cover management:** Promotion of land cover management is must to protect the soil and to enhance organic matter in soil.

- **Mass awareness about the importance of soil resource and its maintenance:** There is need to introduce the importance of soil resource and its care in the text books at school and college levels. The subject is dealt at present apparently along with geography. Farming communities too need to be made aware about soil, its erosion, degradation, benefits and losses occurred due to poor soil quality. This can be done through various action learning tools which explain the processes of soil degradation in a simple and understandable manner.

- **Need to constitute a high power body such as National Authority on Land and Soil Resource Health or National Commission on Soil Resource Health:** State Soil and Water Conservation departments restrict their activities only up to construction of small check dams, plugging of gullies etc in common lands. State soil testing labs are almost sluggish in action, poorly equipped and are with under-qualified manpower. Mostly, no tests are done except for Organic C, P and K. State agricultural universities (SAU) only adopt few villages, and consequently, no extensive testing of soil health is done. ICAR institutions also take up few watersheds. Then, there will be no one to work for Soil Health Care program at extensive scale. Hence, a Central High Power Authority / Commission on soil Resource Health is needed to coordinate the program with States. It is beyond the capacity of research organizations to take up such giant and extensive task in addition to their regular research mandates.

Conclusion

Conservation agriculture comprising of conservation tillage, crop residue retention on surface, effective crop rotation and weed management can help in i) protecting the land from direct hitting by the high intensity rains, ii) conserving soil, iii) enhancing organic carbon, iv) protecting land from high temperature, frost and other ill effects. If these practices are followed over years, they can improve physical, chemical and biological soil quality attributes. Hence, the only remedy to protect the lands and to restore and improve the soil quality is effective conservation agriculture. The promotion of conservation agriculture requires effective strategies, awareness and importance of the subject among the communities, and inputs and infrastructure development.

"Soil is Gods gift to Nation. Mans' success in responding to the latest challenge that of global climate change will depend on how we manage this vital resource"

"Conservation Agriculture leads to Healthy Soils - Better Environment - Better Nutrition Healthy Society – Healthy Nation"

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Artificial Recharge of Water by Diverting field Run-off into Dried up Dug Wells

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The dryland farming based on the monsoon rains is of only subsistence nature. But the well or bore well irrigation has added huge economic dimension as the farmers have adapted to the irrigated dry crop cultivation which are basically commercial crops. The dependency on the surface and ground water resources is becoming uncertain and farmers are facing enormous problems. The climate change will further aggravate the ground water situation specially monsoon dependent region in South Asia.

The ground water table is falling down due to mining of the water resources i.e., pumping is not consistent with the annual recharge rate of aquifer which results in a negative water balance and lowering of the water table, sometimes to the extent of complete drying up of wells. Moreover declining water table increases the pumping energy needed to produce the same irrigation service. With roughly 30.5% of India's electricity production currently devoted to pumping ground water and massive energy shortage affecting all sectors, the energy related economic cost of falling water table could be huge. For a district like Mahabubnagar Andhra Pradesh state of India, which is reeling under frequent drought situation due to scanty and erratic rainfall (Average 600 mm) - there is need to conserve each and every drop of water by all means - Diversion Drains for diverting field run-off in to dried up dug wells is one such idea.

In-situ precipitation will be available at every location, but may or may not be adequate to cause artificial recharge. As such the run-off going unutilized can be diverted for recharge in the dried up dug wells at appropriate locations.

Origin of Concept

The idea flashed when the Project Director was discussing with the DCBC members and members of WASSAN who came for doing livelihood analysis in Kakarlapad village of Mahabubnagar district. While discussing with them it was noticed on the village map that out of 77 open wells in the village only one well is functional in spite of 4 Irrigation Tanks, Watershed programme implementation and Joint Forest Management programme. Moreover equal number of bore wells are existing in the village. When the Project Director visited the village for field analysis, then idea of diverting farm run-off in to the dried up well came in to origin and same day in presence of Project Director field demonstration was given to the villagers.

Consolidation of Concept

The working procedure is finalized after discussing with Assistant Director of Agriculture, Dy. Executive Engineers, farmers and finally the concept was presented to District Collector for approval.

Objectives

- Recharging existing nearby bore wells for sustained water yield so that some extra area could be brought under irrigation.
- To fill up the existing space, which is in the form dried up wells by tapping, the field runoff and use it for production activities like vegetable growing etc.
- To control falling water table because of which the existing bore wells are becoming defunct, pumping is not consistent with annual recharge rate of aquifer.
- Conserving soil and water within own land.
- To reduce the pumping cost of water on account of electricity by raising water table.

Design

1. The run-off from one hectare area is sufficient on 6 cm rainfall day to fill the dried up well of a volume 300 m^3.
2. The diversion drain to silt trap should be of 30 cm width only.
3. The diversion drain is connected to the silt trap of 1.2 m diameter.
4. Stone pitching is required at inlet drain area in silt trap.
5. The silt trap should be atleast 5 m from well.
6. The inlet drain pipe in to well is of 4” dia. and 20’ length.
7. The inlet drain pipe in to well should be at least 2 feet beyond the rim of the well.
8. The inlet pipe in to well should be placed lower than the diversion drain in to silt trap.

Cost Involved

Silt trap earth work 4 cm	: Rs.	107=00
Diversion Drain earth work 4.5 cm	: Rs.	120=00
Inlet drain in to well to keep pipe 1 cm	: Rs.	28=00
Cost of 4” dia & 20’ length pipe including transport	: Rs.	410=00
Stone pitching approximately	: Rs.	35=00
Total	: Rs.	700=00

Watershed Development Fund deposition from each farmer@Rs.70/-

Potential Areas

Though ground water development in the district is only 52%. The imbalanced development has led to water stress and scarcity in certain areas. Midjil mandal is a dark mandal, Kothur, Veldanda, Kalwakurthy, Koilkonda are classified as grey mandals. There is a need to treat these areas with special effort.

Space Available

There are thousands of dug wells which have either gone dry or water levels have declined considerably. These dug wells can be used as structures to recharge ground water regime.

Trend of wells in Mahabubnagar District

Sl. No.	Type of Wells	Total wells upto 1986-87 (No.)	Total wells upto 1993-94 (No.)	Total functioning wells as on June 2000 (No.)
1	Dug Wells	72601	101618	5319
2	Bore Wells	2385	21540	146665
3	Total	74986	123158	151984
4	% of Dug Wells to total Wells	96.82	82.51	3.50
5	% of Bore Wells to total Wells	3.18	17.49	96.50

Source: Groundwater Department, Mahabubnagar, A.P.

Indication is that there are more than 70,000 dried up wells in the district and others are only seasonal.

Works Completed

Area	No.of Diversion Drains	No.of villages
Mahabubnagar	1220	24
Narayanpet	212	18
Nagarkurnool	687	21
Gadwal	309	17
Shadnagar	530	31
Kalwakurthy	639	26
Kosgi	504	27
Achampet	351	15
Wanaparthy	640	23
Total	5192	202

Because of the dry spell of 45 days in the month of June and July, the farmers were not really enthusiastic to take up work though they showed interest. It picked up in August 1st week and by September end almost all the wells are full of water. Each well has potential of holding water equivalent to 1/3 Check Dam storage volume with just 1% cost of Check Dam. Moreover if all the 70,000 dried up wells are filled up with run-off it shall create an additional irrigation potential of atleast 20000 acres in the district.

Immediate Benefits

- Recharging existing bore wells and improvement in yield levels.
- Water is being used for growing vegetable crops.
- Water is available in proximity for pesticides spraying thus avoiding long distances to procure water, by engaging bullock carts, drums etc.
- The recharging has increased the potential for new bore well, in the vicinity
- Minimum expenditure and maximum water is harvested.
- Farm run-off and silt is trapped with in farm.
- Scope for decrease in power consumption because of improvement in ground water table rise in nearby bore wells.
- The most important is immediate involvement of all the dried up well owners in watershed development programme and developing stakeholders and concern for soil and water run-off from their land.

Technical Improvements and Suitability

- Circular silt traps are more compact in strength than the rectangular/square pits.
- Slopes should be maintained for the silt traps basing on the soil type.
- Revetment to the inflow slope.
- Store base in the silt trap so that silt removal is easy.
- Plants agave/plants on the dug out soil.
- Only totally dried up dug wells should be treated.
- Sufficient run-off catchment area should be considered.
- When the well is totally filled up case should be taken to close diversion drain.
- The surface run-off stored in short span of time to recharge the aquifer, the formation of the well must have sufficient permeability and weathered formation.
- The fractures/joints existing in the formation will increase the rate of percolation in the well.

Impact studies

The impact analysis studies are conducted involving Ground Water Department in four villages in Mahabubnagar District, all together a total of 117 dried up dug wells are provided diversion channels with the total cost Rs.81,900/- in these four villages. Due to execution of above scheme 62,737 m^3 of space for recharge has been filled and total volume of 77,413 m^3 water has been percolated to the dried up aquifer. The average cost incurred for cubic meter of water to dissipate in to the aquifer is Rs.1.05. The dug wells converted as recharged structures can be categorized in two types i.e., 1) wells with aquifer having weathered granite followed by fractured /jointed granite and (2) wells with limited thickness of weathered granite followed by shallow basement. The first category will have the high percolation capacity and first filling will be dissipated within one or two days and second filling will take 8 to 10 days to dissipate, as the aquifer will be already saturated. The second category wells will take 2 to 3 days for first-filling and taken 10 to 15 days for second filling and shallow basement wells will be over-flowing as the aquifer will not be in a position to percolate any more. As the result of the above activity there is buildup in ground water levels and yields of the nearby bore wells have increased from 500 to 1200 gph. The dried up bore wells are rejuvenated and functioning presently.

Impact study on Diversion drains for Diverting field Run-off into Dried up Dug Wells

The diversion of rain water run-off in to dried up dug wells, for recharge purpose is implemented by the Project Director, DPAP, Mahabubnagar. The Ground Water Department has taken four DPAP, watershed villages for sample study to know the impact of these diversion channels in to dried up wells on Ground Water regime. The surveys were conducted on 17-18th, October 2001.

1. Chennavelly (vg.) Balanagar mandal

The Chennavelly village is situated at 5 km. due west of Rajapoor village. The area is covered with Pediplain, Burried alluviaum and denuded hillocks. The topography of the area is with gentle slopes due southeast and undulating plain underlain by Archean granites. The first order streams of the village are joining the Rajapoor vagu. The area is covered with top sandy soil, followed by weathered Granite and fractured Granites. The ground water occurs under semi-confined conditions in weathered and fractured granites. The area falls under Balanagar Rainguage station and the normal rainfall of the mandal is 596 mm. The area received erratic rainfall since onset of the monsoon. The rainfall received from 1st to 19th, September is 24.2 mm in 7 days. The intensity of the rainfall is 2 to 7.2 mm during the above period and lag period between the rainfall events is 1 to 10 days.

During the above period there was no flow in to the wells. The rainfall of 90.6 mm occurred continuously from 26 to 29th, September and 128.6 mm from 30th September to 3rd, October 2001.

The filling of dried up wells is functional to the intensity and lag period between the rainfall events. Under the study area two fillings have occurred from 26th September to 3rd October, 2001. The first filling occurred from 26 to 30th, September with rainfall of 90.6 mm. The second filing occurred from 1st to 3rd October after the rainfall of 128.6 mm. The DPAP has taken up 17 proposals for Diversion Channels in to Dried up Wells. During the surveys 7 proposals were inventoried. The total volume of space created by 17 wells in Chennally village is 13,425 m^3. The total volume of water dissipated by two filling is arrived at 13,779 m^3 for 17 wells. The total cost incurred for 17 wells is Rs.11, 900/-.

During the first filling the dissipation time was one to two days, as the aquifer was in dried up condition, as such all the wells were emptied due to dissipation. The second filling has taken more time as the aquifer was already saturated and is dissipating slowly. The time for dissipation in sandy soils is 80 m^3/hr, where as in highly weathered granite rate of dissipation is 12 to 20 m^3/h, and in the shallow basement areas the rate of dissipation is 5 to 8 m^3/hr. The rainfall of 19 mm occurred from 6th to 10th, October was not adequate to occur flow into wells. In few wells the water was not dissipating quickly as the wells encountered shallow basement without fractures and fissures and it will take more time to recharge the limited space available.

2. Peddadarpally (vg.) Hanwada mandal

The village Peddadarpally is situated at 4 km due west to Hanwada Mandal Headquarters. The area is covered with pediplain and denuded hillocks. The topography of the area is with gentle slope and undulating plains geographically the area is underlain by Archean granites. The area falls under Hanwada rainguage station and the annual normal rainfall of the mandal is 669 mm. The area received erratic rainfall since onset of monsoon. The total rainfall received up to 30th September is 334 mm with 32 rainy days. The rainfall received from 1st to 17th, October is 150 mm.

During the survey, it is observed that two filling have occurred in to dried up wells. The fist filling was from 26th September to 1st October with rainfall of 90 mm. The second filling occurred from 6th to 10th October with rainfall of 68.4 mm. The DPAP has taken up 28 proposals for diversion channels in to the dried up wells. During the survey 10 proposals were inventorred and details are given in Table 2.

The total volume created by 25 wells in Peddadarpally village is 16,345 m^3. The total volume of water dissipated by two fillings is arrived as 6,467 m^3 for 25 wells. The total cost incurred for 25 wells is Rs.17, 500/-.

During the first filling the dissipation time was one to two days as the aquifer was in un-saturated condition and all the wells were emptied due to dissipation. The second filling has taken more time as the aquifer was already saturated and was dissipating slowly. As there were rainy days continuously from 6th to 17th October the runoff water was flowing in to the wells as such 60% of the wells were overflowing on 17th October. This condition is due to occurrence of shallow basement in the wells under recharge. These wells will take more time to dissipate as only limited recharge space is available.

3. Ramanunthala (vg.) Amangal mandal

The village Ramanunthala is situated at 8 km due North of Amangal mandal. Geographically area is classified as pediplains and denuded hillocks. The topography of the area is with gentle slope and undulating plains underlain by Archean granites.

The area falls under Amangal rainguage station and the annual normal rainfall of the mandal is 607.0 mm. The area received erratic rainfall since onset of the monsoon. The rainfall received from second week of June to 30th September, 2001 is 419.5 mm in 28 rainy days. The rainfall received from 1st to 17th October 2001 is 128.8 mm.

During the inventory, it is observed that two fillings have occurred from 24th September to 1st October 2001 with the rainfall of 185.4 mm. The 2nd filling occurred from 5th to 10th October 2001 with a rainfall of 79.4 mm. The DPAP has taken up 30 proposals for diversion channels in to dried up wells. During the inventory 11 proposals were inventoried. The total volume created by 30 wells in Ramunantala village is 15,210 m^3. The total volume of water dissipated by two filling is arrived as 4,390 m^3 for 30 wells. The total cost incurred for 30 wells is Rs.21,000/-.

During the first filling the dissipation was within one to two days as the aquifer was in unsaturated condition as such all the wells were emptied due to dissipation. The second filling has taken more time as the aquifer was already saturated and was dissipating slowly. As the area received rainfall continuously from 5th to 18th, October the runoff water is flowing into the wells and the wells were overflowing.

4. Macharam (VG.) Amrabad mandal

The Macharam village is situated at 4 km due South of Amrabad mandal. The area is covered with pediplain, colluvum and red sandy soils. Topographically, the area is plain to gentle slope, underlain by Archean granites and dolerite dykes. The drainage pattern is course dendritic and is a forming 2nd order stream joining to the local tanks. The thickness of the soil ranges from 0.5 to 1.5 m, followed by weathered granites, fractured granites and hard granites. The granites are traversed by the dolerite dykes and are acting as barriers to the ground water movement.

The area falls under Amrabad rainguage station and normal rainfall of the mandal is 756 mm. The rainfall received from 1st to 25th, September, 2001 is 102 mm with 4 rainy days. The rainfall events separated with 4 to 10 days lag period. The maximum rainfall received in the area is 197 mm on 29th and 30th, September, 2001, again the 28 mm of rainfall received from 1st to 6th, October, 2001.

Under the study area two fillings have occurred from 29th September to 6th October 2001. The 1st filling occurred from 29th to 30th, September with rainfall of 197 mm. The second filling occurred from 1st to 6th, October 2001 with the rainfall of 28 mm. The DPAP has taken up 45 proposals for diversion channels in to dried up wells. During the survey 10 proposals were inventoried. The total volume of space created by 45 wells in Macharam village is 17.757 m^3. The total volume of water dissipated by two fillings is arrived at 25,294 m^3 for 45 wells. The total cost incurred for 45 wells is Rs.31,500/-.

During the first filling the structures in low lying, flat areas, have dissipated in two days, and for the highly weathered granite areas the time taken for dissipation is one day. The wells located in low laying area have taken more time to dissipate due to deposition of red loamy soils and low gravitational flow into the underlying aquifer. The dug wells in gently sloping areas have fast dissipation due to coarse grained, weathered granites, high gravitational flow through transmitting media. There are 8 wells occurring in the shallow basement, having low rate of dissipation i.e. 8 to 10 m^3/h. The water available in the wells at the time survey will dissipate in 8 to 10 days.

Conclusion

The impact analysis studies are conducted involving Ground Water Department in four villages in Mahabubnagar district, all together a total of 117 dried up dug wells are provided diversion channels with the cost Rs.81,900/-. Due to execution of above scheme 62,737 m^3 of space for recharge has been created and total volume of 77,413 m^3 water has been percolated to the dried up aquifer. The average cost incurred for cubic meter of water to dissipate in to the aquifer is Rs.1.05. The dug wells converted as recharged structures can be categorized in two types i.e., 1) wells with aquifer having weathered granite followed by fractured /jointed granite and (2) wells with limited thickness of weathered granite followed by shallow basement. The first category will have the high percolation capacity and first filling will be dissipated within one or two days, and second filling will take 8 to 10 days to dissipate, as the aquifer will be already saturated. The second category wells will take 2 to 3 days for first filling and taken 10 to 15 days for second filling and shallow basement wells will be overflowing as the aquifer will not be in a position to percolate any more. The individual village wise details are enclosed.

As the result of the above activity there is buildup in ground water levels and yields of the nearby bore wells have increased from 500 to 1200 gph. The dried up bore wells are rejuvenated and functioning presently.

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Management of Groundwater for livelihood

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Agriculture is predominant sector in SAARC region. A vast majority of population lives in rural areas and depends on agriculture. The region is home to 1.6 billion people (23.7% of global population). The share of the region in terms of global and water recourses is however much lower than the population share. Based on country-wise data, it is estimated that 451 million people(28.83%) in the region live below poverty line with 23.7% share in global population, the region has only 2.6% share in global income (Asian development Bank).

Majority of population in South Asia depends on Agriculture as their principal source of income and employment. Agriculture farming in South Asia is dominated by small holdings i.e., average size of holding is below 0.5 hectare in Bangladesh, below 1.0 hectare in Srilanka and Nepal. In India average farm size is 1.4 hectares. Pakistan is better endowed with land resources (average farm size is 3.0 hectares). Except Pakistan, land holdings below one hectare account for more than 60% of total farm holdings in South Asia.

Natural resources viz. land, water and ecosystems are showing symptoms of degradation and fatigue and causing adverse effect on sustainability and prosperity of future growth in SAARC region. Water is emerging as main constraining factor. Particular attention needs to be given for its better management. A paradigm shift is needed in SAARC countries in promoting agricultural productivity not only per unit of area, but also per unit of water and time.

Institutional changes to improve overall water governance need to be reinforced by creating strong incentives for individual users to make prudent and economical use of water. Resource based institutional arrangements i.e., devotion of control to local organizations for community natural resource management is important. Future growth in SAARC countries has to be achieved from shrinking natural resources base i.e., growth would come largely from increase in productivity.

Groundwater plays an important role in many parts of SAARC countries including India as well as Andhra Pradesh because of reliability in its availability as well as supplies in space and time as compared to surface water sources. Availability of groundwater in a given region depends on physiographic features, especially drainage pattern, climate, geology and soils. Andhra Pradesh with an area of 275 thousand sq.kms is endowed with three major rivers, viz. Godavari, Krishna and Pennar. The state falls under semi-arid region of peninsular India and 85% area of Andra Pradesh is underlain by hard rocks. Red sandy soils cover about 67% of the state. The other prominent types of soils are the Black and Alluvial soils. The state receives an annual rainfall of 940 mm on an average. It ranges from about 1200 mm in Srikakulam district to 550 mm in Anantapur district. Most of the rainfall is received during south-west monsoon from June- September.

Groundwater, until recently, has been viewed as a sustainable resource for irrigation and accounts for over 50 percent of irrigated area in Andhra Pradesh. At present groundwater meets about 80% of domestic needs in rural areas and 30 and 50% of urban water and industrial uses, respectively. However due to increase in demand and lack of well defined property rights, institutional financing for development of agro-wells and subsidized electricity for pumping groundwater for irrigation has led to over-development in semi-arid parts of the State (Mukherji and Shah, 2002). As a result, its availability is threatened in terms of depletion in groundwater levels and deterioration in quality especially fluoride and other contaminations in semi-arid areas and saline water intrusion in coastal region. Water quality in peri-urban is a major problem due to contamination from wastewater and industrial effluents. Consequently economic growth in rural areas and health of rural and urban communities are at stake (Rema Devi, 1991).

Both groundwater and surface water resources in Andhra Pradesh are estimated to be 108.15 billion cubic meters (bcm), out of which about 62.29 bcm is currently being utilized for drinking, agriculture, industry and power generation purposes. The per capita annual water resources work out to be slightly more than 1400 cum, and utilization is about 800 cum (AP Water Vision, 2004). According to UN indicators, areas with annual per capita availability of 1000-2000 cum water are categorized as water stressed. With the availability below 1700 cum, a region is deemed ‘water scarce’ and with less than 1000 cum, it is “severe”. As the per capita availability in India is 1750 cum, reaching towards “water scarce” situation. The current average percentage of withdrawal of available water in Andhra Pradesh is 41%. As per UN indicator, if the percentage withdrawal is more than 40%, the country is considered as water scarce. In accordance with the above, the Andhra Pradesh falls under “Water Scarce” category warranting appropriate water governance techniques.

The average per capita water availability in Andhra Pradesh as against India during the period 1951 to 2001 and requirements for the year 2050 is given below in Table-1. The Andhra Pradesh dropped from excess to scarce within forty years and likely to be severe in future. Hence efforts need to be made to prevent this drastic fall through efficient management supported by appropriate policy framework.

Table-1. Per capita availability of water in India and Andhra Pradesh

Year	India(cum)	Andhra Pradesh(cum)
1951	5000	3600
1991	2100	1600
2001	1750	1400
2050	1140	912

Contribution of Ground Water Resources in State Gross State Domestic Product (GSDP) of Agriculture Sector from 2004-05 to 2009-10 in Andhra Pradesh

The role of Agricultural sector in Andhra Pradesh economy is very significant and is predominantly rainfed in nature depending on the vagaries of the monsoons. The GSDP contribution for agriculture sector was Rs. 317,220 millions in 2004-05 and it has increased to Rs.743,760 millions in 2009-10. The contribution of GSDP of Andhra Pradesh in Agriculture sector has been steadily increasing from 14.12% in 2004-05 to the present 15.47% in 2009-10.

The contribution of ground water resources in GSDP of Agriculture sector rose from Rs. 97,390 millions in 2004-05 to Rs. 284,050 millions approximately (2009-10) and the increase is three fold. The ground water contribution is sustainable and reliable, in the total agriculture its contribution has been increased approximately from 31 to 38 % from 2004-2010 **(Table 2).**

Table-2. Contribution of ground water in Agriculture GSDP

Rupees in millions

S.No.	Sector	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
1	Agriculture	317220	358120	392660	551730	649560	743760
2	Contribution by Agriculture sector (%)	14.12	13.99	13.04	15.12	15.55	15.47
3	Contribution of Ground Water in Agriculture GSDP (%)	31	31	32	34	35	38

In view of the important role played by the groundwater in the economic development of the State, the initiatives by the Government for sustaining the precious groundwater resources and its management strategies are discussed below.

Groundwater Resource Status, Quality and its Utilization

The annual groundwater availability in Andhra Pradesh during the past two decades has increased from around 25,000 Million Cubic Meters (MCM) to 32,000 MCM on account of different interventions for conserving rainwater at the macro level. The Ground Water Resources were estimated for the entire country by adopting GEC 1997 methodology, during the year 2004-05. The status of Ground Water Resources of India and Andhra Pradesh is given in the following table **(Table-3).**

Table-3. Status of Groundwater in Andhra Pradesh with reference to India

S. No	G.W Resource	India	Andhra Pradesh	%of Andhra Pradesh Share
1	Annual groundwater availability(MCM)	398700	32578	8%
2	Utilization(MCM)	230440	14835	6%
3	Balance available(MCM)	168260	17903	11%
4	Extent of GW development	58%	45%	

The total groundwater resource as estimated in the year 2007 by the State Groundwater Department following the procedures given by Ministry of Water Resources, Government of India, 1997, is 34700 MCM (17886 in non-command area + 16814 in command area) and utilization is 14112 MCM (10526 in non-command area + 3586 in command area), while balance available resource is 20588 MCM (7360 in non-command area + 13228 in command area). The extent of overall groundwater development for the entire state is 41% while it is 59% in non-command area, where the demand is very high and 21% in command area.

At the micro level the draft has increased due to intensification of agriculture under well irrigation resulting in fall of groundwater levels at places as evident by the presence of overexploited and critical villages. The overall draft increased from around 7,000 MCM to 14,000 MCM approximately from 1985 to 2007. The ground water availability and utilization on time scale is presented in **Table-4.**

Table 4. Groundwater estimates in different years

GROUNDWATER ESTIMATIONS AND Extent OF GROUNDWATER DEVELOPMENT IN ANDHRA PRADESH FROM 1985 TO 2007

S.No	Groundwater Assessment Year	Annual Groundwater availability MCM	Groundwater Utilization MCM	Groundwater Balance MCM	Extent of Develop - ment %	Assessement units	Methodology adopted	Category	No.of Over-Exploited villages proposed for notification
1	1985	25303	7074	18229	**28**	Taluk-wise	Water table fluctuation method	Red (24 Taluks), Dark(8 Taluks) and Grey(15 Taluks)	
2	1993	35292	10132	25160	**29**	Mandal-wise	Water table fluctuation and Rainfall infilteration method	Red, Dark and Grey	
3	2002	30562	12972	17590	**43**	1157 Groundwater Basins	GEC 1997 Methodology	Over-Exploited(118) , Critical (79), Semi-Critical (188) and Safe(772)	
4	2004	32758	14855	17903	**45**	1229 Watersheds	GEC 1997 Methodology	Over-Exploited (215), Critical (85), Semi-Critical(208) and Safe (721)	4190
5	2007	34700	14112	20588	**41**	1229 Watersheds	GEC 1997 Methodology	Over-Exploited (132), Critical (89), Semi-Critical (175) and Safe(833)	3449

About 85% of domestic water supply in rural areas depends on groundwater resources, while 85% groundwater is being used for irrigation purposes. It is also the main source for urban water supply in India, as is evident from the increase in number of mechanized water extraction mechanisms from less than one million in 1960 to almost 26 to 28 million in 2002 (Mukherji and Shah, 2002). The large amount of groundwater utilization for irrigation is impacting drinking water sources to a great extent and is of great concern. The state has been categorized into four categories-safe (<70%), semi-critical (70% to 90%), critical (90 to 100%) and over-exploited (>100%) based on the percentage of groundwater exploitation with reference to recharge. About 5096 villages spread over 111 mandals are falling in over-exploited category. The number of mandals and villages falling into various categories are given in **Table-5.**

Table-5. Mandals and villages under different categories in Andhra Pradesh

Sl.No	Category	Number of Watersheds	Number of Mandals	Number of Villages
1	**Over- Exploited**	**132**	**111**	**5096**
2	**Critical**	**89**	**60**	**1064**
3	**Semi – Critical**	**175**	**160**	**2632**
4	**Safe**	**833**	**777**	**17219**

Groundwater Quality

The chemical quality of groundwater exhibits variations from place to place. The geological environment, climate, drainage, land use and engineering structures have profound influence on groundwater quality. Groundwater in Archaean crystalline rocks is neutral and chloride content ranges from 30 to 525 ppm. The quality of groundwater in Cuddapah and Kurnool formations is generally poor and Total Dissolved Solids (TDS) in some of these places exceeds 1000 ppm while in Gondwanas the quality is good except in some local patches. In Deccan traps, the TDS of groundwater ranges from 200 to 300 ppm in upland areas and 400 to 700 ppm in valley portions. Groundwater is often brackish to saline in black cotton soils. Fluorides, Salinity and Nitrates are the major quality problems of drinking water. The presence of fluoride in excess of permissible limits is a major health problem and new excess fluoride habitations are emerging mostly due to over-exploitation of groundwater. The fluoride concentration in groundwater is highly variable in space and time and ranges from 1.5 ppm to 11.0 ppm and related to extraction of groundwater as well as occurrence of associated minerals. Fluoride concentrations are often found in waters having TDS concentration in excess of 1500mg/l. The TDS concentrations are associated with chlorides in the plains. The pH of groundwater ranges from 7.0 to 9.0 and bicarbonates range from 160 to 500mg/l and electrical conductivity varies from 260 to 5700 micro Siemens / cm.

Drinking water samples analysis across Andhra Pradesh indicated that 38 mandals are fully saline (Ground Water Department, Government of Andhra Pradesh) and about 400 villages are fluoride affected (Rural Water Supply and Sanitation Department, Government of Andhra Pradesh). One of the main threats to Groundwater resources is of over-abstraction leading to lowering of the water table and quality deterioration. Over-abstraction in coastal areas has additional risk of salt-water intrusion (Hodgson, 2004). The indicative spatial variations of electrical conductivity based on the available limited samples in Andhra Pradesh are presented as an example in **Fig 1 and Fig 2.**

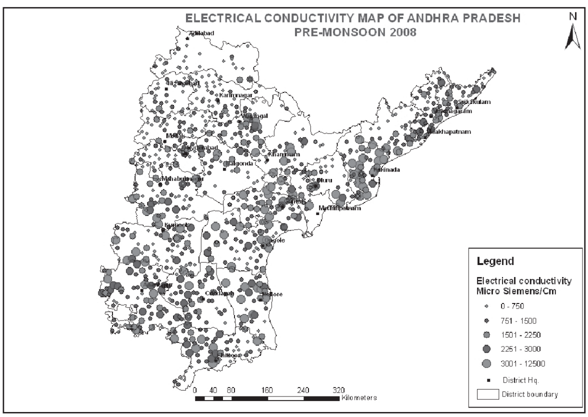

Fig. 1 : Pre-monsoon Electrical Conductivity Map of Andhra Pradesh

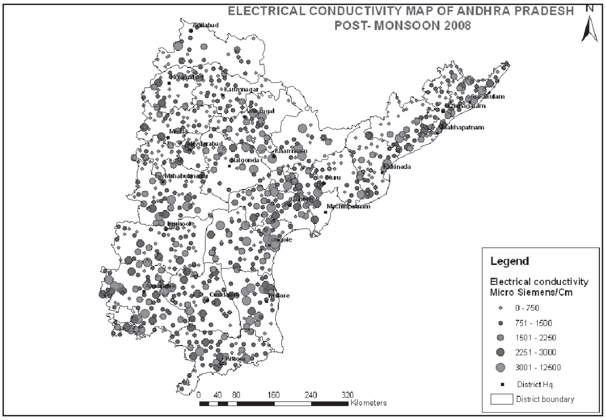

Fig. 2 : Post-monsoon Electrical Conductivity Map of Andhra Pradesh

Groundwater Sustainability

The area irrigated with groundwater is nearly equal to the area irrigated under surface water sources, especially during the years of low rainfall as observed from the data of 2002 to 2010 **(Fig 3).** This situation now causes concern in terms of groundwater availability and enormous electric power consumption for lifting groundwater to surface. The well population has increased from 1.0 million (mostly dug wells) in 1980 to about 2.5 millions (mostly bore wells) in 2010 **(Fig 4).** The area irrigated through groundwater has also increased from about 1.0 million hectares to about 3.3 million hectares during the same period(Fig 3). On an average the density of wells increased from 5 wells per sq.km. to over 10 wells per sq.km. But, in hard rock areas it is over 20 wells per sq.km. and in some pockets it is as high as 100 wells per sq.km. Consequently, the well yields have decreased drastically and water levels have gone down alarmingly. It can be seen that the area irrigated per well is almost constant, but water is being drawn from deeper depths.

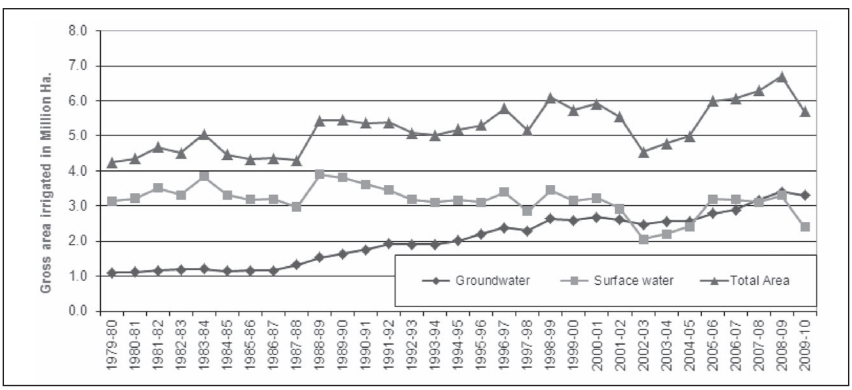

Fig. 3 : Gross area irrigated under groundwater and surface water during 1979-80 to 2009-10

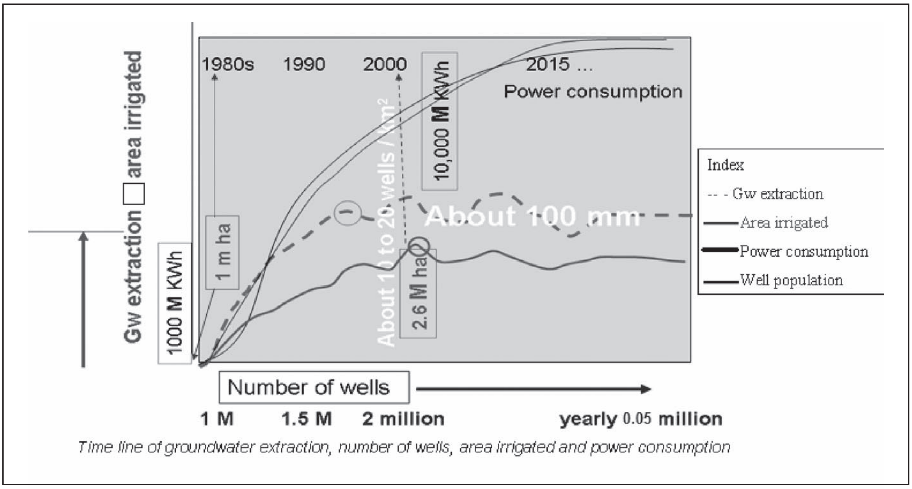

Fig. 4 : Groundwater extraction and number of well Vs. Power consumption in A.P. (Schematic diagram)

The increase in well population has put tremendous stress on power consumption and it is estimated to reach 10,000 MKWh by 2015. The power consumption for groundwater lifting was 6,285 million units in 1995 and has gone up to 13,267 million units approximately at present **(Fig-5).**

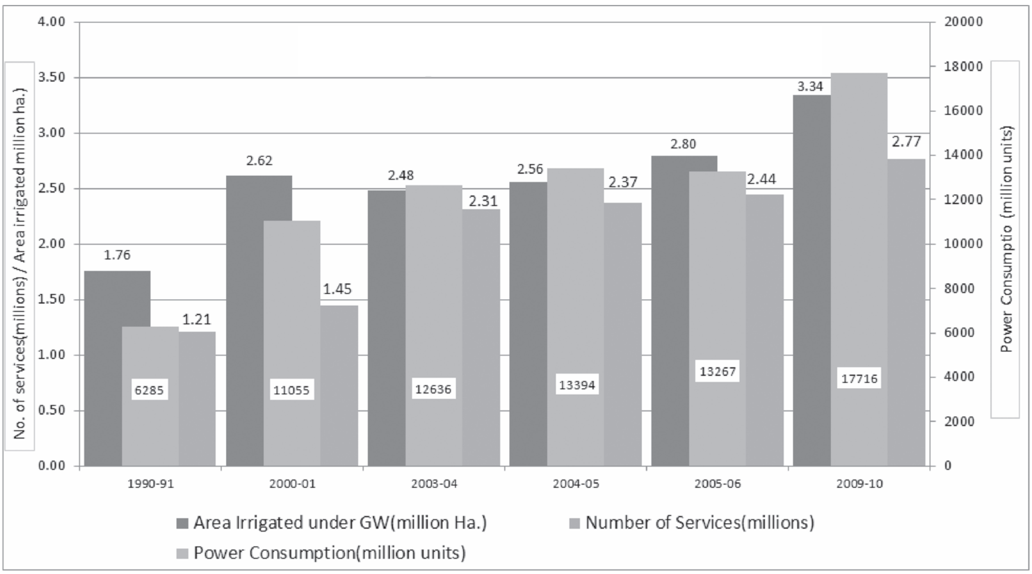

Fig. 5 : Number of Services/Wells, Power Consumption and Area Irrigated under GW in Andhra Pradesh

The overall stage of groundwater development increased from 28% to 41% since 1985 across the state and may not sustain on long-term basis. The non-command areas constitute 77% of the area of the state wherein the groundwater availability is only 52% while utilization is at 59%. Thus, the over-exploitation is causing a wide gap in demand and supply. On the other hand about 48% of net groundwater availability in command areas constitutes about 23% of the State's geographical area and where groundwater utilization is only 25%. The under-utilization of groundwater is resulting in water logging and quality problems.

Groundwater Recharge

The existing surface water bodies and canal seepages are able to contribute about 4 to 5% of annual rainfall towards groundwater recharge while 9 to 10% by way of natural infiltration. In non-command and low rainfall areas appropriate strategies have to be formulated, where the recharge to groundwater is naturally low and evaporation is high.

On-going Ground Water Recharge Initiatives in Andhra Pradesh

In order to improve Groundwater situation in Andhra Pradesh State, the Government of Andhra Pradesh is planning and implementing various groundwater recharge projects under different schemes. Some of those projects are given below.

Centrally Sponsored Scheme (CSS)

Under this scheme, the Ministry of Water Resources, Govt. of India is assisting the State Governments and other organizations to take up the Artificial Recharge Structures to boost the groundwater recharge. In Andhra Pradesh, such projects on Artificial Recharge to Ground Water and Rain Water Harvesting are being implemented in chronically drought affected areas of Kadapa, Chittoor, Rangareddy and Medak districts.

Impact Studies

In Kadapa district 22 water harvesting strctures were constructed in 14 villages. One hundred key observation wells and 12 purpose built piezometers have been established to study the behaviour of the aquifer systems. The hydrograph analysis of piezometric head data shows rise in water level from 10 to 20 meters, indicating an overall improvement in the groundwater scenario. Various observations have been made and quantitative and qualitative impact is also studied during the project period.

Mainly the impact has been studied on water levels, cropped area and cropping intensity, pumping hours and power saving, drinking water resources and socio-economic status. The overall groundwater recharge at 22 water harvesting structures has shown commendable impact on various environmental and socio-economic aspects and paved way for improved livelihood in the villages and shown improvement in economic conditions of the local people. The investment of Rs 11.75 millions has resulted in positive cost-benefit ratio and stood as an example for future demonstrative artificial recharge structures in rain shadow areas of the State as well as country. Some hydrographs showing the impact on groundwater levels **(Fig. 6)** and photos of water harvesting structures **(Figs. 7 & 8)** are shown below.

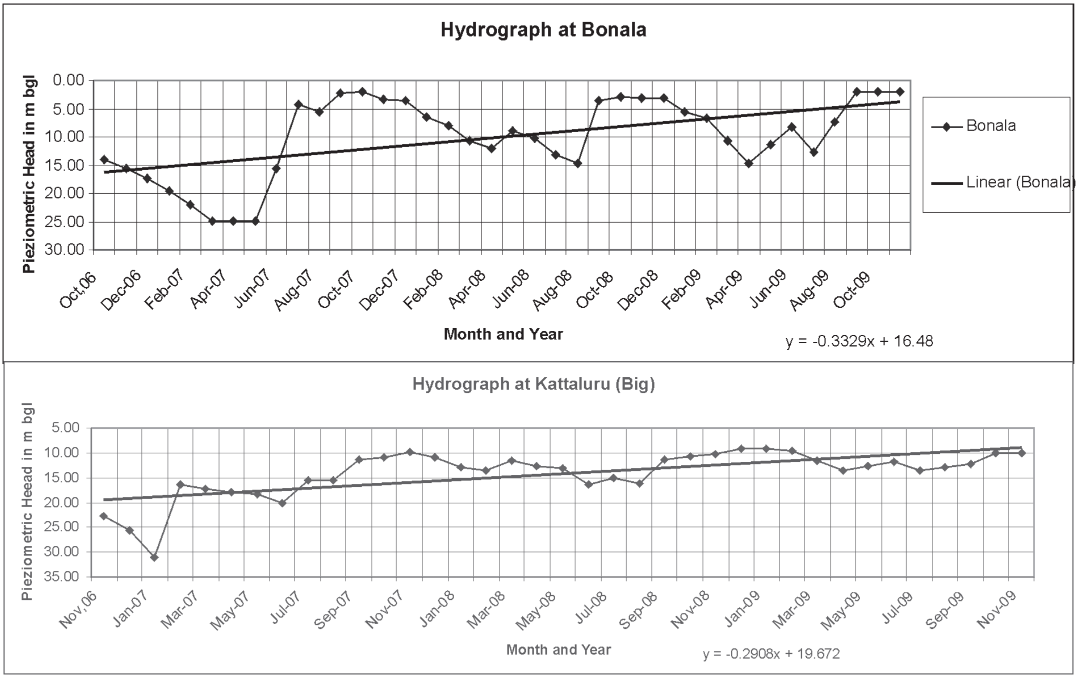

Fig. 6 : Hydrographs showing the impact of artificial recharge structures constructed in Kadapa district under CSS Programme

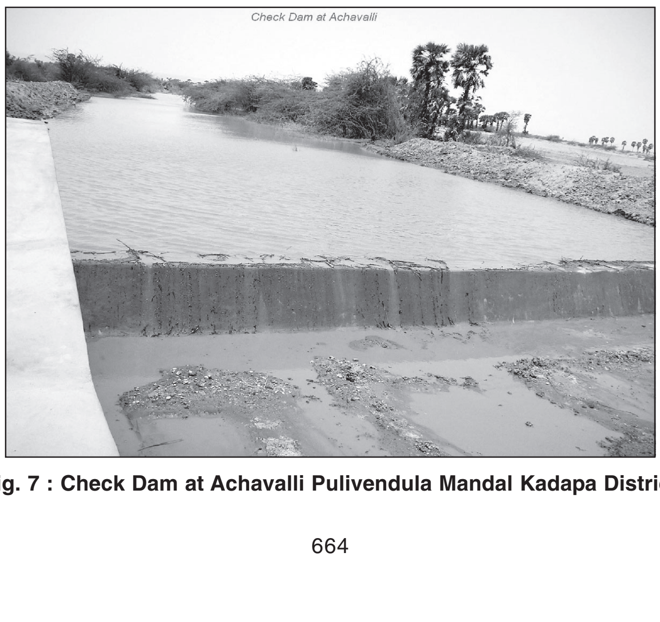

Fig. 7 : Check Dam at Achavalli Pulivendula Mandal Kadapa District

Fig. 8 : Percolation Tank at Kattaluru (Mittapalli)

Mahatma Gandhi Groundwater Recharge Project (MGRP):

Under this project, Rural Development Department, Government of Andhra Pradesh has evolved a plan for survey and identification of sites for construction of Artificial Recharge Structures in Over- Exploited, Critical and Semi Critical groundwater basins in Andhra Pradesh.

Objectives:

a) To develop a holistic strategy for recharge of Groundwater in Over-Exploited, Critical and Semi- Critical basins.

b) To conduct comprehensive survey of all the villages in the basin for identification of Artificial Recharge Structures (ARS) by experienced Geologists using satellite and other scientific data.

c) To create a data base of all the interventions taken up in the past, concurrently and in future with respect to Water Harvesting Structures(WHS) in the basin.

d) To execute the suggested works under the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), Comprehensive Land Development Programme (CLDP) and Integrated Water Management Programme (IWMP) projects.

e) To increase Ground Water Recharge at least by 5% from the present level.

f) To monitor and evaluate the impact of interventions against the set goals.

Provision for Lower Riparian Rights and Projects and Assessment of Non-committed Runoff

i. Village-wise and basin- wise total annual rainwater is calculated.

ii. A total of 80% of the rainwater in the village / basin is allowed towards various components such as natural recharge (10%), soil moisture (10%), evaporation losses (40%) and lower level Projects/ Dams outside the village/ basin (20%).

iii. From the remaining 20%, the storage capacity of existing tanks and WHS in the village / basin is deducted and net non-committed runoff is assessed.

iv. New Water Harvesting Structures are proposed against the available non-committed run- off.

Types of Structures

Various types of structures suitable for runoff harvest and decreasing the velocity of runoff are being taken up, for example rock fill dams, water absorption trenches, dugout ponds, farm ponds, sunken pits, check walls, gabion structures, mini percolation tanks, percolation tanks, subsurface dykes, recharge of open wells, check dams and desiltation of existing percolation tanks.

Groundwater Management

The present trend in groundwater management is related to demand management without any consideration to augment its supply. There is a need to reestablish balance between supply and demand by developing region specific strategies. The past approaches have conclusively proved that the command and control will not help to reverse the situation but the Community Based Ground Water Management (CBGWM) through appropriate education would help to restore the water table by improving water use efficiency.

There are two models of CBGWM. One is the charismatic leadership model and the other collective groundwater users/farmers model. Despite a number of attempts and ongoing efforts, the former model has few success stories. The CBGWM is done through the community by making groundwater users to come together and treat it as common property resource and manage it for the benefit of all. This has been well demonstrated under A.P. Well project across seven drought prone districts in Andhra Pradesh covering 370 villages. Under the project, 3,462 bore wells were commissioned and about 34,791 acres of ayacut created benefitting 14,524 families. The bore wells were managed through 3,455 Water User Groups (WUG) formed among the farmers involved in the project through the participatory approach. The total cost of the project was about Rs. 830 millions, including about Rs. 530 millions for bore well schemes (financial assistance) and Rs. 300 millions under technical assistance for capacity building including evaluation. The district-wise details are given in **Table.6.**

The above clearly demonstrates the need to revert to the past i.e. community irrigation. This technique is being adopted in the zone of influence of Minor Irrigation tanks under the Andhra Pradesh Community Based Tank Management Project (APCBTMP) being assisted by Government of India and World Bank.

Table 6. Overview of APWELL Project coverage

District	No. of Villages Groups	Water User families (WUG) WUG	No of Families	Av. No. of (acres) per/ (acre)	Total ayacut per (acre)	Av. Ayacut per WUG	Av. Ayacut (GPH) family millions)	Av. Yield borewell	Av cost per contri- (Rs. in	Av. WUG bution (Rs. in millions)
Anantapur	41	415	1,270	3.1	4,026	9.7	3.2	4,009	0.131724	0.016159
Chittoor	45	419	2,090	5.0	3,747	8.9	1.8	3,109	0.141242	0.017171
Kadapa	57	415	2,198	5.3	4,066	9.8	1.8	2,995	0.150625	0.018167
Kurnool	68	516	2,021	3.9	5,348	10.4	2.6	4,557	0.143036	0.016765
Mahbubnagar	44	816	2,946	3.6	8,822	10.8	3.0	2,604	0.129987	0.015610
Nalgonda	47	299	1,396	4.7	2,940	9.8	2.1	3,569	0.153300	0.018796
Prakasam	68	575	2,603	4.5	5,842	10.2	2.2	3,523	0.142660	0.016635
TOTAL	**370**	**3,455**	**14,524**	**4.2**	**34,791**	**10.1**	**2.4**	**3,523**	**0.140102**	**0.019790**
Drinking water schemes*		**7**								
GRAND TOTAL		**3,462**								

**Seven low yielding wells were commissioned for drinking water use only (two in Kurnool and 5 in Mahbubnagar). Thus the total number of wells commissioned comes to 3,462.*

(Source: Compiled from *APWELL Project: Final Report*. ARCADIS EUROCONSULT. 2003.)

Future Challenges

The water challenges are manifold- improving and safeguarding the existing water sources, improving water use efficiency through effective water management and prevention of pollution without causing the environmental degradation.

In order to sustain the groundwater and its economy, several measures are required to be initiated. The important measures will be (i) improving the recharge to groundwater (ii) improving water use efficiency in intensively irrigated areas by promoting consumptive use (iii) promoting less water intensive crops and crops that give higher net returns per unit of water.

In line with the above, the Government of Andhra Pradesh has initiated several programmes by establishing Water Conservation Mission (WCM) in the year 2000 to undertake water conservation measures appropriate to the region and to re-establish the ecological balance. In addition to this, Government of Andhra Pradesh has fully utilized centrally sponsored watershed development programmes to conserve rainwater over an area of about 10.0 M.ha. These programmes have resulted in increasing the groundwater levels by 9% and an additional recharge by 1% which is evidenced by the reduction in well failures from 12,633 to 4,111 (Swallow, *et al*., 2001) and drinking water transportation habitations from 1979 to 756 (Rural Water Supply and Sanitation Department, Government of Andhra Pradesh).

The Rural Development department has taken up the watershed development programme across Andhra Pradesh. Out of 11,137 watersheds sanctioned in Andhra Pradesh, 4741 watersheds have been completed and about 2.37 million hectares of area has been treated. In addition to this, the Municipal Administration department has taken up rainwater / rooftop harvesting structures in 87 Urban Local Bodies, 6 Corporations and 6 Urban Development Authorities. A total of 4,92,628 water-harvesting structures at a cost of Rs.122,798 millions have been completed and additional storage space of 25,88,698 cum has been created.

Regulatory Approach to Manage Groundwater

Keeping in view the drastic reduction in well yields and failure of wells due to increase in well population and well density, the Government of Andhra Pradesh has introduced Andhra Pradesh Water, Land and Tree Act (APWALTA) in 2002 to promote water conservation and tree cover for sustainability.

Under the Act, all groundwater users must register their wells and seek permission to construct new groundwater extraction structures. No well shall be sunk in notified over-exploited areas except for drinking purpose. Guidelines are issued to prevent over-exploitation and safeguarding drinking water sources.

Sofar 22,34,723 wells have been registered in Andhra Pradesh and 1,450 rigs have been registered for drilling the bore wells. APWALTA has brought good public awareness, which has led to booking of 167 illegal sand mining cases and collection of penalty of Rs.2.4 millions from offenders.

In areas where there is large-scale exploitation of groundwater for commercial use resulting in drying up of wells in the neighborhood, people have approached the courts for redressal of their grievances. They are also approaching the Ground Water Department for technical help in this regard.

Considerable awareness has been created regarding sand mining activities, as it has an adverse impact on the groundwater regime in the area. This is proved by the fact that 27 public interest litigation cases have been filed in the High Court of Andhra Pradesh. These cases are mostly related to sand mining in many districts of Andhra Pradesh.

Ground Water Management Strategies

Now-a-days groundwater regime in India is under severe pressure as the exploitation of groundwater resources has become manifold be it for agriculture, domestic or industrial purposes in a short period of about 40 years of its exploration. Many reports and research papers have indicated that many parts of the country are categorized as "Over-Exploited". Now for the last two decades efforts are being made about the management of groundwater resources.

The basic utility of groundwater is to support the livelihood of human beings since the wisdom to explore and exploit groundwater, is a gift to human beings alone apart from the plant kingdom of the biosphere. The plant kingdom consumes the amount of water that reaches to its roots only. Whereas the human beings have developed the technology over the ages, to explore and exploit groundwater and to some extent manage them. In this process lot of research is being done worldwide for better management of groundwater resources. The comprehensive plan required for groundwater resource management encompasses:

1. Estimation of groundwater resources for a manageable size of watershed
2. Economically viable and reliable methods of exploration
3. Effective, easy and low cost methods of well construction
4. Efficient energy systems for groundwater extraction
5. Monitoring system for both quantity and quality
6. Design of consumption of water per crop/industrial product / per capita
7. Remedial measures to combat quantity and quality issues including regulation
8. Both public and private involvement in managing the resource

Over the years the researchers are developing new techniques, methods, instruments etc., which, ultimately fit into the above discussed points. Therefore, implementing the above steps in a systematic manner with a holistic approach will help in solving the problem. One must realize that groundwater is only a limited resource and it can be partially augmented to a certain extent but it cannot be augmented to the extent we wish. Hence, planning for development of groundwater resources has to be done within the gamut of its availability.

To ensure sustainable water use, there is a need for a Policy change for facilitating a paradigm shift from designing strategies for increasing supplies to altering the socio-economic systems for effective water use to ensure demand management. Such a policy change should include the following:

- Create awareness regarding occurrence, distribution and limitations for exploitation of groundwater to ensure whole hearted participation of people
- Application of improved methods and creating sufficient infrastructure for estimating groundwater resources as precisely as possible
- Priority on management of water resources efficiently by integrating development of water across various sectors and geographies.
- The planning, management and regulating the use of groundwater should be in consultation with groundwater scientists.
- APWALTA is not applicable to extraction of groundwater from existing sources, which are responsible for over-exploitation in the area. As such a mechanism has to be devised in order to control draft from existing sources.
- New strategies of electricity distribution for the purpose of regulation of groundwater extraction need to be contemplated. This is the most critical area where government can control over-exploitation of groundwater resources.
- Artificial recharge should be site and objective-specific and taken up especially to solve the drinking water problems.
- Recharge through defunct dug wells is a good concept of artificial recharge and may prove to be effective and needs proper planning.
- Certain pockets in every village have to be identified for creation of drinking water sanctuaries i.e. in these areas there should not be any groundwater exploitation except for drinking purpose during emergencies.
- Creation of mass awareness among the people about the quality of the water and health hazards especially in areas having industries, mining and aquaculture activities etc.,
- The sources of pollution affecting the water quality should be identified and remedial measures should be taken to safeguard the water quality. Appropriate remedial measures should also be taken in the areas having high Fluoride and Nitrate concentrations.
- The regulations for sand mining for protection of drinking water sources and preventing release of industrial effluents into the rivers more so near the drinking water sources should be enforced effectively.

- Prioritise the demands and necessities on a watershed basis and an effective action plan should be carved out to achieve sustainable development and management of groundwater resources for better livelihood.

Change in Livelihoods

The appropriate groundwater management systems like adopting micro irrigation, community based groundwater management and by implementing suitable regulatory measures etc., the livelihoods of people can be changed remarkably. By adopting micro irrigation the water use efficiency, productivity of crops under irrigated area can be enhanced and the present ultimate irrigation potential of 3.2 million ha. through groundwater may reach to 4.8 million ha. in Andhra Pradesh which would result in economical as well as environmental sustainability. With the management of available limited groundwater resources, directly or indirectly, the bbenefits will be manifold like increase in cropped area, reliable high incomes, reduction in migration of people from villages to towns for their livelihood, development of agro-based industries and thereby generation of employment, availability of better quality of drinking water and elimination of poverty etc.,

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Aquaculture in Rainfed Areas of India: Emerging Possibilities for Food and Nutrition Security

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Aquaculture is a most recent sub-sector added to the agriculture sector in the country since last 40 years. Within a short span of time, the sector has grown at the rate of more than 6 % per year contributing significantly to the overall growth of the agricultural sector. During last few decades, Aquaculture sector has been able to compensate the loss in the fish production due to decline in the capture fisheries as well as increasing overall fish availability in the country. The aquaculture has been recognized globally for its multifarious role in sustainable development and improvement of the livelihoods of the large section of the people. Its potential to increase rural employment and improve the nutrition and income of rural population, particularly in developing countries has attracted the many development initiatives. The labour-intensive nature of certain types of farming and the opportunities for waste recycling and integration with crop and animal farming have made development agencies consider aquatic farming as particularly appropriate to developing areas. (Pillay & Kutty, 2005)

There is a vast untapped potential for the aquaculture development in the country. Scope for horizontal, vertical and qualitative improvement in the aquaculture in rural areas is immense. Presently only about half of the 2.2 million ha of the ponds and tanks are in use. In addition to the traditionally recognized aquaculture resources there were many newly developed water bodies through various schemes like Watershed development, MGNREGA, Repair-Renovation-and-Restoration (RRR) of water bodies, minor irrigation schemes and farm pond schemes to name few. These new aquaculture resources can be used for the fish production in the rural areas.

Traditionally, the aquaculture development has taken place in the water abundant and irrigated regions of the country. Most of the developed aquaculture zones are located in the coastal, water surplus or irrigated areas like West Bengal, Orissa, Andhra Pradesh, and Punjab. Extension and communication efforts for aquaculture development have been focused in these regions. However, of late non-traditional areas like rainfed regions have demonstrated tremendous potential to fish culture which has increased the overall fish production potential of the country to a great extent. The technological package developed for perennial water bodies will have to be suitably modified to suit the culture environment prevailing in the seasonal tanks, which are essentially rainfed. Appropriate technological package also needs to be developed for remote and inaccessible terrains. Therefore, the new strategy required to be developed to develop aquaculture in the rainfed areas. Some of the agro-ecological constraints plaguing rainfed areas are highly erratic and seasonal rainfall, degraded environment, primitive agricultural practices, minimal irrigation facilities and predominance of uplands. To adapt to these adversities various water bodies are being created by different agencies and programmes which can be used for the aquaculture purposes without much investment in the creation of new resources.

Evolution of Aquaculture in India

The aquaculture has a longer history in China and earliest record of aquaculture was in 500 BC in China and Kautilya's Arthasastra - one of the oldest Indian epics indicates that fish culture activity in India dates back to 300 BC. Before introduction of the scientific culture the fish culture was reported in the eastern part especially in the Bengal areas. The traditional system followed "trapping and holding" of fish seed and raising them to table size and thus this marked the beginning of aquaculture in India (FAO, 1999). Such system continued till recently in these parts of the country. The organized research on the aquaculture was initiated with the establishment of the Central Inland Fisheries Research Institute in Barrackpore during 1945. Indian Council of Agricultural Research (ICAR) gave great emphasis on aquaculture research and training and established Fresh Water Aquaculture Research and Training Center (FARTC) in 1977 under CIFRI at Kauslyaganga, Bhubaneswar, which also housed the Pond Culture Division. The Trainers Training Center (TTC) and Krishi Vigyan Kendra (KVK) were also established there at the same time. These institutions later made into independent institute as Central Institute of Freshwater Aquaculture on 1987.

The major breakthrough in the aquaculture was achieved when the Indian Major Carp was induced bred so as to achieve the seed production in captivity. This was followed by development of the principles and practices of culturing multiple species so as to optimize potential of the fish growth in the aquatic ecosystem. The two fundamental technologies i.e induced breeding (seed production) and composite fish culture (Fish culture) have created the technological foundation of the aquaculture growth in the country. Since then more sophistication in the aquaculture technology has been achieved through development technology for improvement of the pond productivity, feeding, health management and other aspects of the aquaculture managements. Now a wide diversity of the fish species are being brought within the ambit of the aquaculture so as to give the options of the fish farming in the country.

The Development pathways of aquaculture in India followed the footsteps of the research. Many national-wide projects were launched to take the research to the farmers' ponds. Initiation and remarkable success of the All India Coordinated Research Project on

Composite Fish Culture and Fish Seed Production in 1971 had been the turning point in the annals of freshwater fish culture in India (Jhingran 1975). The successful results of which not only instilled the confidence in the State and Central governments but in the farmers also (Sinha 1975). A number of development programs followed; the most notable are the creation of the Fish Farmers Development Agencies, and the World Bank Fish Seed Hatchery Project. A major national program of Fish Farmers Development Agencies at the district level was initiated in 1973 to provide administrative and infrastructural support, training to beneficiaries, mobilization of inputs and extension support to fish farmers and also for arranging institutional finance through bank credits. The FFDA was entrusted to bring all the fallow culture fishery resources under optimum fish production progressively. The agency played leading role in extension of fish culture technology and also created well organized skilled and enterprising fish farmers communities. The agency selects suitable water area, arranges lease on long-term basis, provides incentive for renovation of ponds and input in the first year of fish culture. Thus, while the FFDAs concentrated on utilizing more of the fallow and unutilized pond resources needing developmental support, the traditional fish farmers culturing carps in ponds upgraded the technology of both seed and fish production and improved aquaculture productivity (FAO 1999). Among the spectacular achievements of the scheme is the improvement in average yield level, which has touched 2600 kg/ha/yr in 2008-09. In last plan period National Fisheries Development Board (NFDB) was established to develop the fisheries sector of the country. At present, there are heightened awareness and public investment in promotion of aquaculture in India.

Small Scale Aquaculture for Ecosystem Health and Social Welfare

The aquaculture is increasingly replacing the capture fisheries in the fish production and it has the advantage in terms of responding to the demand of the fish with respect to the size, species and time. There are also scientific principles that weigh very much in favour of aquatic farming . It is a relatively efficient means of producing animal protein which can compare very favourably with poultry, pork and beef in the economies of production, when appropriate species and techniques are adopted. Poikilothermic (cold-blooded) animals, especially fish, have relatively low energy requirements, as they do not spend any energy for the maintenance of a constant body temperature and the energy spent for routine locomotory activity is normally low. Since the specific gravity of their bodies is nearly the same as that of the water they inhabit, loss of energy in supporting themselves is minimal. These advantages result in higher growth rates and greater production per unit area, taking full benefit of the three-dimensional nature of water bodies (Pillay & Kutty, 2005). Fish are highest on the comparative list in terms of gross body weight gain and high in terms of protein gain per unit of feed intake (Hastings and Dickie, 1972). When fed balanced diets under favourable environmental conditions, the feed conversion ratio (wet weight gain per unit of dry feed intake) has been found to be in the range 1 : 1 to 1 : 1.25. The protein efficiency ratio (weight gain per unit of protein intake) is either equal to or higher than that for poultry and higher than for swine, sheep and steers (Hastings and Dickie, 1972). Fish are able to utilize high levels of protein in the diet, whereas in poultry almost one-half of the amino acids are deaminated and lost for protein synthesis. A weanling pig may lose as much as two-thirds of the amino acids through deamination.

The absolute economics of a culture system depend very much on the species, production technology and market conditions. Basically, low trophic feeders can generally be raised at lower costs than those which are high in the food chain and which thus require a higher proportion of proteins, particularly animal proteins. However, the latter species usually fetch higher prices in the market place and compensate for the higher production costs. The aquaculture offers the option to produce low- or high-cost products, and it is up to the farmer to decide which. However, it has to be remembered that many types of proteins that are not consumed by man can be upgraded through aquaculture to produce highly acceptable and well-relished products. Very often, waste products of capture fisheries and animal and crop farming form the main basis of aquaculture feeds. Also, much of present-day aquaculture is based on the natural fertility of soil and water, supplemented by organic or inorganic fertilizers and the plentiful energy of the sun. (Pillay & Kutty, 2005)

Amidst these possibilities, there are huge sense of loss as these water bodies are not adequately put into the aquaculture uses. Loss of productivity and of water from fallow ponds is of great concern. With the influx of adequate sunlight, aquatic ecosystem has the potential for a sustained rate of assimilation as high as 4 to 8g biomass/m^2/day or about 30 tonnes of dry weight/ha/yr. If this productivity is not optimally utilized through aquaculture, it disrupts the aquatic environment and with continued nutrient run off from the catchment, results into eutrophication of the ecosystem, giving rise to algal bloom and water hyacinth and other obnoxious weed infestation. It is important to note that animal waste in the form of urine and excreta of 186 million cattle, 77 million buffaloes, 45 million goats, 10.8 million pigs and 258 million poultry, continually find their way to aquatic ecosystem. Because of poor productivity management and eutrophication, aquatic ecosystems to a large extent are stressed and disrupted in the country. Wherever fish culture is taken scientifically, it improves and maintains the oxygen balance which is the lifeline of the ecosystem like that of any plants and animals. Thus fish is to be viewed as a major ecological player and fish culture as a major tool to improve and restore the aquatic ecosystem (FAO 1999).

At the initial stage of the aquaculture development, the farmers or community or entrepreneurs operates at the very low level of the technology. The interventions are only limited to stocking and harvesting. In this stage, the inherent fertility of the ponds and primary productivity of the aquatic resources get utilised and the fish food organisms are being get converted into useful fish biomass (Edwards et al., 1988). At this stage profitability is quite high and it is not unusual to get a return of 15- 20 times to that of the cost of seed and monitoring and harvesting. Even though the productivity is as low as 200 to 500 kg per ha, the net social gain from the vast expanse of the water resources are very high. Potential of the employment generation from the aquaculture is difficult to estimate as the actual level of employment dependent on size and distribution of pond, level of technology adoption and disposal pattern and actual practices of the aquaculture. But it is assumed that one hectare of pond with the productivity of about 2 tonnes can produce about 100 man days in management, 110 man days in labour inputs, 70 man days in marketing, 20 man days in inputs supply. Therefore, the aquaculture with the medium level of technology has the potential to create the employment of about 300 man days per ha (FAO, 1999). Shang (1981) estimated that the production of 4 metric tons of fish provides one full-time job and an income adequate for a family. In Bangladesh, the net income derived from the production of 1,000 kilograms of fish a year can support a family of up to eight people. Stated in another way, the net income derived from aquaculture in 0.2 hectares of water surface area, is adequate to support a family in some developing countries. Moreover, the rainfed areas are considered as the protein scarce region and access to the protein is very low (NSS, 2007). All the fish produced in these regions are sold fresh and mostly within the localities. Many times, the local productions are only source of the fish protein. Therefore, the aquaculture directly increases the fish protein consumption in the poorer regions of the country. Therefore, the net gains from the aquaculture activities are very high in the rainfed regions.

Small-scale aquaculture can substantially increase the household income of a family in Bangladesh from 6 percent of the total family income to 38 percent in one year of fish culture. The percentage of income from the relatively small pond area of 0.1 hectare can double if the fish operation is integrated with chicken-rearing (Islam, 1988). In most areas of South Asia, a farming family can be supported by the returns from aquaculture from 0.2 hectare of water. In general, small-scale aquaculture operations provide more employment per unit of capital invested than larger farms (Pillay 1990). Aquaculture unlike agriculture does not yield in comparable quantitative terms but qualitatively it has no parallel. It is well known that fish is a wholesome food and highly nutritive. It is a rich source of protein (crude protein in the range of 14.2-22.8 %.) with all essential amino acids. Besides being a good source of calcium and vitamin A, fish is also having vitamin B 12. It contains fat as high as 6% and also has high energy content. It is also a rich source of essential fatty acids and polyunsaturated fatty acids. It is said that those eating adequate amount of fish, have shining eyes and hair, a sign of better health. This is well reflected in the population of the fishing villages (FAO 1999).

Role of Aquaculture in the Rainfed Regions

The term rainfed emerges out of the attempt made to classify and characterize certain broad agricultural systems in the country. According to NCAP an agro-eco region or agro-ecosystem (AES) is a homogenous geographical area where the production environment of the region in terms of agro-climate, resource endowments and socio-economic conditions is homogenous and majority of farmers have similar production constraints and research needs. Accordingly, the entire country has been divided into 5 broad agro-ecosystems namely Arid, Coastal, Hill & Mountain, Irrigated and Rainfed ecosystems. Rainfed system covers about 54% of the land and cropped area and supports about 44% of the population. Rainfed areas primarily or exclusively dependent on the rains, within range of 450 to 1600 mm per year (Kerr 1996) and areas with less than 25% of the cropped area under irrigation. The net rainfed areas in India are 85.7 M ha within the net cropped areas of 139.7 M ha. Hence, the rainfed system is the most important agro-ecosystem in India.

Rainfed areas remained as challenge for researchers and development workers to increase productivity of natural resources and sustain environment and livelihood options of the people. At present several technologies are available to increase the productivity of the land and water, but among them aquaculture remains as the weak link. Less attentions and efforts were taken for fisheries as compared to other components of the watershed. But, there is large opportunity available in the fisheries sector for enhancing the productivity of water, generation of wealth, alleviation of poverty, and food & nutritional security in the rainfed areas. In recent times, various fisheries technologies are being used, particularly in the water resource rich regions in the country to achieve commercialization of the fish production for domestic and export markets. On the other hand, in the resource poor regions (like rainfed areas) the technologies are either not used or used in the limited scale for domestic consumption and local markets. The opportunities in enhancing productivity and livelihood through fisheries and aquaculture are large in the rainfed areas, which can be realized by adequate technology intervention, policy implementation and institutional support. The rainfed areas are generally inhabited by the poorest of the poor people of the society, including the tribal people. Fish can contribute significantly to the nutritional security of these groups. Even fish for a limited period in a year can also provide the essential proteins and other micronutrients to the people.

Low-input fish culture not only provides an opportunity for income generation but also locally available animal protein and a range of vitamins and essential trace elements, which are found only in few other food items. Fish contains large quantities of high biological value protein, particularly sulphur-containing amino acids representing a significant supplementary value to vegetable proteins. In particular it contains appreciable quantities of lysine, an essential amino acid found in only small amounts in the local cereals, rice, wheat and maize, which form the basis of the diet of many low-income groups. Fish is one of the preferred sources of the protein and consumption is primarily dependent on the availability. Therefore, the means to increase the fish consumption is to increase the availability. Local availability of fish is crucial to increase the nutritional status of the people in the rainfed areas. In these areas the fishes from the outside places like Andhra Pradesh area not available as these fishes are marketed in the large markets with higher demand and consumption. Therefore increasing fish production in the rainfed areas is the only option available to increase the fish consumption in these localities.

Demand-Supply Scenario for Fish in India

There is an ever increasing demand for fish in the country and the growth in the demand is estimated to be 4% per annum (NCAP 2008). It has also been predicted that there will be reduction in the capture fisheries production of the country and therefore the whole of the additional demand needs to be met through the aquaculture development of the country. To match to the growing demand of the fish, the fish production has to be doubled within a span of 7 to 8 years. The projected annual growth of the freshwater fish production for the period of 2005-2020 is 3.99 percent which is among the highest in the Asian counties (Dey et al., 2004). The projected per capita increase in the consumption is 0.97 for the same period indicating that there will be a secular increase of about 1% in the real consumption of the fish among the Indian population. The higher demand stimulates faster technical progress as it creates opportunity through market and price. In India this is a realistic scenario for aquaculture. Globally, aquaculture is recognized as the primary source of growth in the fisheries sector (Delgado et al., 2003). The study found that the income elasticities of fish demand were positive and high and it is higher for the low income group. Therefore, a high fish demand is expected with higher economic growth and shifts in the dietary pattern. But, the lower income group demands more fish and demand will be higher for the low value fish like carps (Kumar 2005). Therefore, an increase in demand is anticipated for the fish and most of these demands are to be met through the freshwater aquaculture. Aquaculture needs to explore the strategies of horizontal, vertical as well as qualitative expansion in coming times.

Aquatic Resources in the Rainfed Areas

The aquaculture resources in the country are vast and differentiated. It varies along the physical, technical and socio-economic characteristics. The physical characteristics of the aquatic resources are governed by shape, size, water retention, catchment, soil and water nutrients, aquatic biomass etc. Whereas the socio-economic characteristics are governed by property rights, legal and institutional framework, management institutions, institutional support from public agencies, market and conflicts. The level of the aquaculture development is a function of access to resources, security of tenure, incentives and capacity to invest, access to technology and market and conflict resolution. Due to these variations there are diverse levels of the technology available and adoption in the country. Some of the typical characteristics of the aquaculture resources are presented in **Table 1**.

Table 1 : Types of ponds and ownership

	Pond category	Typical sizes	Ownership	Aquaculture status
1.	Very small Homestead pond	.001-.009	Rural poor households	Neglible
2.	Small homestead ponds	.01-.09	Poor households	Extensive system
3.	Medium sized pond	0.1-1	Medium sized farmers	Seed production or extensive system
4.	Large sized pond	1-5	Large farmers	Semi-intensive system
5.	Community ponds	1-5	Panchayat	No aquaculture/ extensive
6.	Farm ponds	0.02-0.2	Farmers	No aquaculture
7.	Minor irrigation tanks	10-40	Irrigation department	Capture fisheries
8.	Water harvesting structures	0.5-5	Village community	No aquaculture

The rainfed areas are scarce in water but not without it. Water resources of these areas are largely dependent on rain. Due to the lack of irrigation and other secured source of the water, the water bodies are highly dependent on the monsoon runoff. Traditionally, the water resources are being conserved in various forms and over a period public agencies are creating a large sheets of water bodies primarily for conservation and utilization of water. There are various categories of the water resource with differential characteristics. Available water resources of the rainfed areas can be divided into the following categories.

Water Harvesting Structures in Watershed Development Project Areas: Watershed development projects are being pursued by various government as well as non-governmental organizations in the rainfed areas. One of the most important aspects of the watershed development is the creation of the rainwater harvesting structures which are of the various shapes, sizes and characteristics. Until recently, the water harvesting structures were not been used effectively for aquaculture due to constraints like seasonal and fluctuating nature of the water storage, over abstraction for irrigation and lack of technical knowledge. But, gradually the importance of the aquaculture in these water bodies is being realized. Many technological options are available to utilize these water resources for fish farming.

Community Ponds: In most watersheds a village has at least one perennial tank (often several) built to conserve water and filled during the monsoon. In a number of cases where fishing rights are leased by the Gram Panchayat, others may have rights to abstraction for irrigation and the community as a whole may have rights of use for domestic (washing and drinking) and livestock (bathing) needs. The pattern of ownership, types of users, uses and management is almost the same in seasonal and perennial ponds, except that the perennial ponds involve comparatively larger groups for management and control. Most water resources in the project area are highly seasonal. These water bodies are vulnerable to siltation due to soil erosion and surface runoff.

Reservoirs and Irrigation Dams: The rainfed areas are mostly plateau and upland areas suitable for the construction of the reservoirs and small and medium irrigation dams. There are large numbers of such structures in the rainfed areas which are primarily designed to provide water for irrigation in the down streams. These water bodies are generally government controlled and managed by the irrigation departments. There is little integration of the fisheries department in the water management. Therefore, these water bodies lack any organized fisheries management activities. In many cases, the water bodies are leased out to the contractors for capturing fish with limited incentives and mechanisms for enhancement of it. There are many water impoundments emerged out of the collection of the wastewaters or seepage waters. These waters are in the degraded conditions which can be suitably modified and improved to be used for the fisheries purposes.

Farms Ponds and Small Tanks: There are many small ponds and tanks in the farms primarily owned by private people. These are small water bodies used for the farm requirements. These water bodies are seasonal and stores limited amount of water. The average size of farm ponds is about 0.1 ha. There are about 2.2 lakh such ponds in India and out of which half of them are seasonal and others are perennial. The perennial water bodies can be used for the aquaculture for the whole year where as seasonal water bodies can be used for culture of the small fishes and seed production.

Rice Fields: The low land rice fields standing water over much of the rice growing periods provides an opportunity to the aquaculture in these areas. The water retention in these water bodies can be improved by digging and other suitable modifications. The neighboring rice fields with connection to the seasonal streams can also be used for the aquaculture purposes. The central portion of the flooding zone in the watershed is an ideal place for the aquaculture as the perianal water bodies can be created in such locations.

Seasonal or Perennial Streams, Flow Waters etc.: There are many seasonal streams, rivers and canals which are seasonal in nature and related to the rain or discharge from reservoirs. These flows are mostly connected with the rice fields or any reservoirs. This flow water can be used for fisheries purposes. Along these streams many low laying areas are suitable for the development of the ponds for the aquaculture purposes.

Minor Surface Irrigation Structures: The minor irrigation structure encompasses a wide gamut of the water bodies with culturable command area of less than 2000 ha is considered as minor irrigation. The actual size of the water bodies is generally less than 500 ha and most of the storage tanks have the command area of about 20 ha with assumed size of about 4 to 5 ha are predominantly found across the country. These small water bodies can easily be used for the aquaculture purposes.

Making Water Resources Useful for Aquaculture

The locations and design of the aquaculture ponds is key to the success of the fish farming in the rainfed regions. In realities most of the ponds in the rainfed areas are not being created for the aquaculture purposes. Hence, the aquaculture technologies need to be fitted into the existing pond systems. In general, the watershed ponds are being created by building a cross dam across the stream or channel to store water. Many times, the watershed ponds are cheaper to create as there is no cost involved in digging the ponds. If there is poor soil over a portion of the pond, large amounts of clay may have to be trucked in to make it impervious, and that could make construction cost too high. The size of a watershed pond should be based on the availability of water from the watershed. The water should be deep enough to compensate for evaporation and seepage. Even during summer drought the water should be at least 3 to 4 feet deep. Ideally, the average water depth in a commercial watershed pond should be 4 to 5 feet. The pond area should contain a relatively impervious layer of clay or silty clay soils. Coarse soils containing large amounts of sand and/or gravel are unsuitable. If the soil can be formed into a tight ball that maintains its shape or is moldable, it is suitable for pond construction. A rule of thumb is that soil must contain at least 20 percent clay. The pond must be sited properly and designed for efficiency. An inaccessible location, leaks in the pond, poor seining conditions, or lack of good quality water will doom an aquaculture enterprise to failure. On rolling terrain the annual rainfall may be enough to completely fill and periodically recharge production ponds. Such watershed systems are not so dependent on groundwater. They also act as flood control reservoirs and can greatly reduce erosion and conserve the water effectively (White, 2001). In addition, there are diverse size and shape of the water bodies. The tiny water bodies are useful for the nursery raising, smaller water bodies for seed rearing and larger for the table fish production. As thumb rule any water bodies keeping minimum of 3-4 feet upto six month can be used for the aquaculture purposes.

Technological Options for Aquaculture Development

The technological options available for the aquaculture development are very wide. The aquaculture has a unique advantage for horizontal, vertical as well as quality intensification. The more of fish can be produced per unit area, unit water, unit inputs, unit time and unit investment. The fish farmers can chose from the wider choice of the technologies from species, types of inputs, level of inputs and investment. The aquaculture provides various level of the return with the farmers' decisions. The details of the fish culture technology available to the farmers are presented in the **Table 2**.

Table 2 : Technology options and expected level of production

	Systems	Species	Seed	Feed	Fertiliser	Aeration	Production (t/ha)
1	Polyculture	IMC	Fry	-	-	-	0.1-0.3
2	Polyculture	IMC	Fry	-	Partially	-	0.3-0.6
3	Polyculture	IMC	Fingerlings	-		-	0.6-1.0
4	Polyculture	IMC	Fingerligs	-	Partially	-	1.0-2.0
5	Polyculture	IMC	Fingerlings	Fully	Partially	-	2.0-3.0
6	Polyculture	IMC	Fingerlings	Fully	Fully	-	3.0-5.0
7	Composite fish culture	IMC, Exotic carps	Fingerlings	Fully	Fully	-	3.0-10.0
8	Composite fish culture		Fingerlings	Fully	Fully	Fully	10.0-15.0
9	Airbreathing fishes	Murrels, magur	Fry	RB+OC+ Fish meal	Fully		1.0-2.0
10	Prawn monoculture	Rosenbergi, malcomsoni	Post larva	Formulated fee		partially	1.0-2.0
11	Carps and prawn poly culture	Carps, prawn	Fingerlings, post larva	RB+OC	fully		3.0-5.0 fish 0.3-0.5 prawn
12	Rice-fish	Carps/catfish	Fingerlings	-	-	-	0.1-0.3
13	Fish-livestock/ birds	Carps	Fingerlings	-	-	-	3.0-5.0

(Source: FAO (1999), CIFA (2009))

The rate of production is directly dependent on the extent of input supply and the degree of management (Sinha & Shrivastava, 1991). In order to enhance the natural productivity, pond water is fertilized with organic and inorganic fertilizer or wastewater is fed to the pond. Sometime biogas slurry is put in the water. The fish is normally fed with rice bran and oil cake. Formulated feed is given for higher production and pond water is also aerated or changed to support a very high biomass. But normally feeding with formulated feed or aerating the water is beyond the means of common farmers. Polyculture of Indian major carp alone or together with exotic carp as Composite Fish Culture are most popular which are undertaken as with or without fertilization and feed based systems. Package of practices has been standardized for wastewater-based system, biogas slurry based system, and aquatic weed-based system (FAO 1999).

Productivity enhancement is the key instrument of aquaculture development in the rainfed areas. Presently, the aquaculture productivity in these areas is very low in tune of 0.5 to 1.5 tons per ha per year. In most of these water bodies, the natural stock from the flow of the connected water bodies like rivers or streams or other perennial water bodies constitutes the main fish stock. In few cases, the stocking is being done but the other management measures like manuring, fertilisation and feeding are often missing. Therefore, the productivity of these ponds is determined largely by the natural food available in these ponds. Hence, the productivity enhancement requires application of manures and fertiliser and feeding of the stocked fish. Under the scientific management the ponds of perennial water bodies, the productivity can be increased by 2.5 to 3.5 tonnes, whereas seasonal water bodies by 1.5 to 2.5 tonnes per ha per year. Moreover, modern farm technologies could realize increased output without meeting fundamental resource constraints, such as limited farm area.

Water resource structures like farm ponds, percolation tanks, check dams etc. retain large quantities of water for 6 to 8 months or even more. Fish culture in Trapa and makhana ponds in traditional agriculture has been a recent introduction (Tripathi, 1997). Common carp in trapa ponds and air breathing catfish such as singhi and magur in makhana ponds give yields of about 1.0-1.5 tonnes per hectare per annum. Aquaculture absorbs all the wastes and by- products of agriculture and livestock at the farm and recycles the same through production of protein food. Livestock wastes are used as fertilizers in fish ponds, those from poultry, goat and rabbit being far richer in nitrogen than from cattle (Tripathi, 1997). This is an added benefit of water harvesting structures that could be harnessed.

There are two technological options for the aquaculture development i.e. aquaculture introduction or intensifications in the ponds and other water bodies and integration of the aquaculture in the existing farming systems. The seasonal or perennial ponds are either not in use for aquaculture or in the limited use with the practice of only stocking. In such water bodies there is a scope for the intensification of the aquaculture. The community-multipurpose water bodies are in the social and cultural use like bathing, religious ceremonies etc. In such water bodies, the intensification can be done by selection of the right species with stocking in adequate numbers with limited fertilization options. Even with these limited interventions, the fish production in such water bodies can be increased significantly by about 1 to 1.5 tons/ha. The perennial small ponds or other small water bodies holding water for a most of the period of the year (8-12 months) are the best possible resources for the aquaculture development. In such water bodies, the intensification of the production can be attained up to 5 tonnes/ha or more fish production. The technology options are stocking, feeding, fertilization, health management and harvesting. As most of the rainfed areas exist in the tropics with abundant sunshine, the scope for the faster growth of the fishes is high. Even in case of the water bodies holding water for the limited period of time (6-8 months) can also be used for the aquaculture purposes. Generally the natural productivity in these water bodies are low, hence the fertilization an important interventions in these waters. The short growing periods needs to be used judiciously by stocking the faster growing species. Even high value catfishes like magur, murrels, pangus etc. can be stocked as there is limited scope of the escape of the fishes to other waters and all the fish stocks can be harvested. But, stocking has to be done at the earliest possible time to allow the fish to attain the economic size.

In the pond based aquaculture, the farmers with pond ownership or access can be benefited. But, by integration of the aquaculture in the crops field, even, small and marginal farmers can be benefited directly. The technology for the integrated farming has been developed by CIFRI, CIFA, CRRI, IRRI etc. These technologies can be made use of for developing structures and facilities for growing fish in the agricultural farms. The necessary farm modifications like creation of the ditches, water storage structures, bunds, etc. are to be made. Selection of the suitable species, fertilization and feeding are some of the technological options (**Table 3**). The low land areas and rice field with stagnating water can easily be converted into the rice-fish farming system.

Table 3 : Technological options for the rainfed areas

Resources	**Resource developments**	**Technology options**	**Aquaculture potential**
Seasonal water bodies	Facilitation of the maximum storage of water	Seed production Culture of minor carps Early stocking	1.5-2.5 tons/ha
Perennial water bodies	Weed clearance, water exchange, bund development	Hatchery development Carp culture Mixed farming	2.5 to 3.5 t/ha

Resources	Resource developments	Technology options	Aquaculture potential
Water harvesting structure	Ensuring minimum water level for 6 months	Culture of carps or small catfish like magur, murrels	1-1.5 t/ha
Community pond	Development of institutions for community management	Carp culture	2-3 t/ha
Farm pond	Deeping of pond, water storage	Seed production Freshwater prawn Composite culture	1.5- 2 t/ha
Paddy fields	Field modification	Paddy-cum-fish culture Integrated farming	1-2 t/ha
Small irrigation tanks	Maintenance of minimum water level	Culture based fisheries	0.5 to 1 t/ha

Case of Western Orissa Rural Livelihood Project

In the rainfed regions, the water resources remains grossly under utilised in the perspectives of aquaculture owing to many constraints. Amidst these constraints there are islands of aquaculture successes in the rainfed areas. Gradually more and more of the water bodies are brought under aquaculture uses. The successful cases of the aquaculture developments in the Western Orissa under Western Orissa Rural Livelihoods Project (WORLP) are good example. It is estimated that over a period of 6-7 years about 1000 acres of the water bodies were brought under aquaculture in one district of Nuapada. With the increased awareness the community water resources are being leased out regularly to the community organisation for a period of three years of fish culture. Two sets of the FRP hatcheries are being set up at Bilenjor (Nuapada district) and Diptipur (Bargarh district) to supply seed to the rainfed region. In addition, four government hatcheries and two private hatcheries are in operation which works exclusively in rainfed regions. But, the technology of the aquaculture is at the very low level limited to the stocking and in few cases feeding only in the initial stages. The net gain in the productivity is only 250 to 1000 kg/ha which is quite low as compared to the potential. Nevertheless the increase in the aquaculture activities has brought a large amount of money (about 70,000 to 1,00,00 rupees per ha). All of these additional production are being consumed locally, therefore, enhancing nutritional security of the poor households. The capacity of the project staffs and NGOs and village leaders are positive aspects of the aquaculture development in the region.

Constraints

As has been discussed earlier, development of the fisheries and aquaculture in the rainfed areas are harder compared to others owing to the market, institutional, technological and policy constraints. Till today, a great deal of attention has been paid for the development of the fisheries and aquaculture in the selected water-rich areas of the country. Therefore, the technological supports available to the rainfed areas are less. The presence of the extension agencies or the technical staff of the state departments are not readily available for providing the technical support. Unlike the other developed areas, the skills and tradition of the managing fisheries and aquaculture is also lacking in these areas. Therefore, technical and managerial capabilities are the major constraints for the fisheries development in these areas.

Input supply system is poorly developed in the rainfed areas. The critical inputs required for the fisheries are seed, feed, manures, fertilizers and lime. The inputs specific to the fisheries are seed and feed. Therefore, providing at least these two inputs either through government or markets is critical for the development of the fisheries. Among the critical inputs, seed is the most critical as it should be availanble to the farmers within the accessible distance of 50-60 kilometers.

In the absence of sound marketing network, marketing of the fish is limited within the neighborhood of the fish production centres. The self-consumption by the small and marginal farmers producing smaller quantities of the fish is an encouraging phenomenon. But, the selling of the fish in the localities in case of the large production will reduce chance of the success of the fisheries enterprises owing to the dampening of the price. The means and mechanisms for the development of the market information, infrastructure and facilities are required for the sustainable development of the fisheries and aquaculture in the rainfed areas.

The institutional constraints are conspicuous in case of the public or community owned water bodies like reservoirs, streams, WHS of watershed and community ponds. The issues of the access, management and use rights are governed by the institutional framework. Larger water bodes like reservoirs are controlled by the irrigation departments having limited interaction with the fisheries people. The access to the water bodies is either open or restricted to the lease holders or contractors. In both cases, the fisheries and fishers are affected. Therefore, community based institutions are required for the management of these water bodies. The interest of the fisheries needs to be incorporated in the management of the water. Though fish does not consume much water, necessary water management is required to create favourable environment for the development of the fisheries. In the community water bodies, minimum necessary interventions like stocking, fertilization and harvesting should be allowed for the effective use of the water for fish culture purpose.

Of late, lease and leasing policy are emerging as constraints in the fisheries development in the country. Experience from various parts of the countries shows that upon fisheries development, there is a demand for the access rights and therefore induces the controlling authority to increase the lease rate in a linear fashion. Such increase raises the revenues of the government in the initial period, but in the later stage, it discourages the fisheries development and encourages overexploitation of the fish stock. Therefore, need based rational leasing policy should be made for the sustainable development of fisheries and aquaculture in these water bodies.

Suggestions

In order to develop aquaculture in the rainfed areas following suggestions are made. These are indicative themes along which more comprehensive strategies can be developed for the sustainable aquaculture development in rainfed areas.

(i) Creation of reliable data base for rainfed aquaculture resources

The data base of the resources available for the aquaculture resources in the country is quite inadequate and unreliable. It is based on the many secondary information which don't comprehensively reflect information useful for the aquaculture purposes. Worse still in the information in the rainfed areas. The information on physical, technical and socio-economic characteristics will enable planners and development agencies to invest more attention and resources in this potential areas of aquaculture. Therefore a systematic effort towards assessment of available resources and the present status is very important as it helps in planning and developing strategies for sustainable utilization of the resources.

(ii) Refinement of culture technologies

Proper refinement of fish culture technology in terms of stocking density, species combination, species suitability etc. considering the geographical variations is of paramount importance. Composite fish culture has already been standardized for the perennial water bodies involving candidate species such as Indian major carps and Chinese carps. However, it may be mentioned that these technologies may not be replicated in all types of water bodies including rainfed systems. Therefore considerable research to refine and develop fish culture technologies for small seasonal waters, rainfed aquaculture system is entailed. The viability in terms of production and economic output also need to be worked out thoroughly.

(iii) Development of seed production system

Success of fish farming highly depends on the availability of good quality seeds of desired size, which however, is inadequate especially for seasonal water bodies. In addition, fish seed accessibility to the fish farmers in such far flung areas remains a problem. Hence an effort towards production of good quality seed at adequate quantity is of paramount importance. In order to promote quality seed production, governmental organizations have to make concerted efforts involving private entrepreneurs. Further, provision of incentives to private hatchery owners will immensely help in ensuring sustained production of quality seeds. Use of the Portable FRP hatchery developed by the CIFA has been successful in promotion of the small scale aquaculture in the rainfed areas.

(iv) Stocking of fingerlings

The major problem in seasonal water bodies is the availability of water. In such ponds average water retention period varies around six months. Fish culture in this kind of water bodies, although has enormous potential for livelihood development of the rural people of the country, can be carried out only for short period. Therefore, stocking of stunted juveniles or larger size juveniles will be more suitable rather than stocking smaller fingerlings. Stunted juveniles are reported to grow at a faster rate than normal fingerlings, thus enabling good production within short culture duration. Further, it is also reported that stunted juveniles perform better under adverse environmental condition, which is the case in most of the seasonal water bodies. Additionally, stocking of faster growing strain will also serve as suitable means of utilizing these untapped water resources.

(v) Diversified fish culture

One of the most important factors determining the production in pond is selection of the right species for stocking. Adverse environmental condition often exists in small water bodies as a result of limited availability of water. In this regard careful consideration needs to be given while selecting the species for culture. Species such as murrels, magur, pangus, *Anabas* etc. are reported to perform better as they are hardy species and are able to tolerate varying water condition. However, it should be noted that complete technology including seed production and grow out culture of these species should be made available. Further, species selection also depends on local availability as well as the consumer preference.

(vi) Capacity building of farming community

Lack of technical knowledge of the farmers is one major constraint in development of aquaculture. Most marginal and small farmers in the country still follow traditional practice for fish culture, and do not follow the right species combination, stocking density, and other management measures. Hence, specific programme on fish farming and on-farm demonstrations to the farmers is an urgent need. Establishment of an effective mechanism by which the advances made in the technology of fish culture could be disseminated for the purpose of increasing fish production in small water areas such as ponds and tanks.

(vii) Rational leasing policies

A large number of the water bodies like WHS, community tanks, irrigation structure etc. are in the public domain controlled and regulated by the public bodies like government departments or Panchayat. Most of this structure is being leased out on a periodic basis. The system of leasing suffers from many anomalies like short period of lease, excessive lease rent, conflicts, recapture by elites etc. In such cases, the water bodies could not be improved. Therefore some of the measures like minimum tenure of 5-7 years of lease, lease to genuine cooperatives or SHG, fixation of minimum and maximum lease rent and productivity linked incentives should be part of the leasing policies to encourage aquaculture development in rainfed water bodies.

Conclusion

Present aquaculture production in the country not only growing fast and steadily, there are a large unutilised potential in the vast country. With the present level of the fish consumption of around 7 kg for rural and 9 kg for urban per capita per year, there is a considerable demand for the fish in the country. Within the rainfed regions, there is a huge potential as well as demand for the fish culture in the many small water bodies in the region. The aquaculture technologies provide various options for the improving productivity of the ponds. The social and ecological advantages of the aquaculture are quite large and create a win-win situation. But it requires focused research, policy and development action to realise the potential. Many successful cases of the development of aquaculture in the rainfed areas are available which can be used as a motivation for furthering aquaculture development in rainfed areas. In such endeavour the small and marginal farmers as well as poor households will benefit immensely.

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SAARC DISASTER MANAGEMANT CENTRE (SDMC)

SAARC Disaster Management Centre (SDMC) was set up in October 2006 at the premises of National Institute of Disaster Management in New Delhi. The Centre has the mandate to serve eight member countries of South Asia Association of Regional Cooperation (SAARC) - Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka by providing policy advice and facilitating capacity building services including strategic learning, research, training, system development and exchange of information for effective disaster risk reduction and management. The Centre conducts studies and research, organizes workshops and training programs, publishes its reports and documents and provides various policy advisory services to the member countries.

Central Research Institute for Dryland Agriculture (CRIDA)

Central Research Institute for Dryland Agriculture (CRIDA) was established at Hyderabad in 1985 to carry out basic and strategic research in Dryland Agriculture. CRIDA was assigned the responsibility of planning and coordinating research on a production system mode under the rainfed agro-eco system. The Institute works closely with State Agricultural Universities (SAUs), through various projects in dry-land agriculture (AICRPDA) and Agro-meteorology (AICRPAM) with centres located at different research stations of SAUs. CRIDA also acts as main lead centre for a network project on climate change with partners from ICAR*F* research institutes and universities. Currently, CRIDA is involved in studying the adaptation potential of soil and rain water management practices to climate change. CRIDA collaborates with several national and international organizations. It is leading training and capacity building center in south Asia on Dryland Agriculture.