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Abstract

Of the world's poor, 70% live in rural areas and are often at the mercy of rainfall-based resources of income. India ranks first among the rainfed agricultural countries in terms of both extent (86 M ha) and value of produce. Due to low opportunities and higher population of landless households and agricultural laborers as well as low land and labor productivity, poverty is concentrated in rainfed regions. The traditional subsistence farming systems have changed and presently farmers have limited options and have started growing high value crops which require intensive use of inputs, most importantly life saving irrigation, and find it difficult to manage and eke out a living. These rainfed regions have limited access to irrigation that is about 15 per cent compared to 48 per cent in the remaining irrigated sub-regions.

Frequent occurrence of mid-season and terminal droughts of 1 to 3-weeks consecutive duration during the main cropping season happens to be the dominant reason for crop (and investment) failures and low yields. Provision of critical irrigation during this period had the potential to improve the yields by 29 to 114 per cent for different crops. A detailed district and agro-ecoregion level study comprising of 540 districts was undertaken (i) to identify dominant rainfed districts for major rainfed crops (85% coverage), (ii) make an assessment of the surplus runoff water available for water harvesting and supplemental irrigation (iii) estimate the water use-efficiency and incremental production for different crops, and (iv) conduct a preliminary economic analysis of the water harvesting/ supplemental irrigation to realize the potential of rainfed agriculture. Climatic water balance analysis for 225 dominant districts provided information on the possible surplus/ deficit during the year and the cropping season. On a potential (excluding very arid and wet areas) rainfed cropped area of 25 M ha, a rainfall surplus of 9.97 M ha-m was available for harvesting. A part of this water was adequate to provide one critical irrigation to 18.75 M ha during drought year and 22.75 M ha during normal year. Water used in supplemental irrigation had the highest marginal productivity and increase in rainfed production above 50% was achievable. Water harvesting and supplemental irrigation was economically viable at national level and shall have limited impact downstream during normal years. This decentralized and more equitable intervention targeted towards the resource poor farmers has also the potential to serve as an alternative strategy to the proposed mega river linking and water transfer projects.

Introduction

The most recent estimates put global rainfed croplands at 1.75 billion hectares at the end of the last millennium, which are about 5.5 times the irrigated areas of the world (GIAM, 2006). The low and variable productivity of these lands is the major cause of poverty for 70% of world's poor inhabiting these lands. Conway (1997) reports a 'hidden food gap' of 400 million tons annually in terms of cereal requirements to meet the energy needs of the population above the sum of domestic food production and imports for Sub-Saharan Africa and South Asia. The largest challenges of poverty-related under nutrition are found in the arid, semi-arid and dry-humid regions of the developing countries (Falkenmark and Rockstrom, 1993). South Asia and Africa are also home to the world's largest proportion of drought prone areas- 43 % and 44% of the land areas, respectively with extremely low yield levels (≅ 1 t/ha) of staple food crops.

India ranks first among the rainfed agricultural countries of the world in terms of both extent (86 M ha) and value of produce. Due to low opportunities and higher population of landless households and agricultural laborers as well as low land and labor productivity, poverty is concentrated in rainfed regions (Table 1). The climate in these regions is characterized by complex climatic deficiencies, manifested as water scarcity for rainfed crop production. The climate is largely semi-arid and dry sub-humid with a short (occasionally intense) wet season followed by long dry season. Rainfall is highly unreliable, both in time and space, with strong risks of dryspells at critical growth stages even during good rainfall years. Inter-annual fluctuations are high due to monsoonal climate- characteristics of the atmospheric circulation and strong links to ENSO phenomenon in the Pacific Ocean.

Table 1. Comparison of important characteristics of predominantly rainfed and irrigated regions of India

Parameters	Rainfed regions	Irrigated regions	All regions
Poverty ratio, head count, %	37	33	35
Land productivity, INR/ha	5716	8017	6867
Labor productivity. INR/ha	6842	9830	8336
Per capita consumption of food grains, kg/year	260	471	365
Infrastructure development index	0.30	0.40	0.35
Social development index	0.43	0.44	0.43

Characteristics of Rainfed Agriculture

Rainfed areas in India are highly diverse, ranging from resource rich areas with good agricultural potential to resource-constrained areas with much more restricted potential. Some resource rich areas (normally under temperate climate) are highly productive and already have experienced widespread adoption of modern technology. On the other hand traditional farming systems in drier and less favored areas is more of a survival mechanism rather than a growth oriented activity. Earlier, the rainfed farming systems, because of its risky nature was dependent upon locally available inputs (seeds, manures, animal draft) and used to grow a number of crops, which were able to withstand drought-like situation. But over time, the cropping systems have changed (Table 2) and presently farmers in these rainfed areas have limited options and have stated cultivating high value crops which requires intensive use of costly inputs (chemical fertilizers/ pesticides, hybrid seeds, life saving irrigation, farm energy etc.) and find it difficult to manage the resources on their own.

Table 2. Change in net cultivated area (M ha) under different crops in India

Crop	1949-50	1992-93	2000-01
All crops			
Total net sown area	118.8	142.5	141.1
Net sown rainfed area	97.9	92.4	86.4
Food Crops			
Total net sown area	99.3	123.2	121.1
Net sown rainfed area under food crops	81.5	77.7	68.5
Net sown rainfed area under pulses	18.6	19.9	17.8
Net sown rainfed area under cereals	62.7	57.8	50.7
Other Crops			
Net sown rainfed area under oilseeds	9.1	19.2	17.5
Net sown rainfed area under cotton	4.5	5.0	5.6

Rainfed agriculture is practiced under a wide variety of soil type, agro-climatic and rainfall conditions ranging from 400 mm to 1600 mm per annum. It is estimated that 15 M ha of rainfed cropped area lies in arid regions and receives less than 500 mm rainfall, another 15 M ha is in 500-700 mm rainfall zone, and bulk of 42 M ha is in the 750-1100 mm rainfall zone. The remaining 20 M ha lies in 'above 1150 mm/ annum' zone. As rainfed production is spread over different climatic regions, it offers great scope for raising a number of diversified crops. At the same time, potential of improving agricultural productivity under rainfed conditions thus also varies considerably. The last four decades of Indian agriculture which registered overall impressive gains in food production, food security and rural poverty reduction in better endowed 'Green Revolution' regions , bypassed the less-favored rainfed areas which were not the partners in this process of agricultural transformation. Both national and international research at experiment stations, operational projects and demonstrations at farmers' fields (Kanwar, 1999) have conclusively shown that highest gains and acceptance of the interventions was seen when *in-situ/ ex-situ* rainwater harvesting and its subsequent utilization in the field was made an important component of technological interventions for improving productivity of drylands.

Influence of Dry Spells/ Droughts on Crop Production

Water stress during crop growth, even during short periods of a couple of weeks, is a major cause of yield reduction. The complexity in defining the magnitude of such water stress is due to (i) diversity of crops grown in a given location (ii) variability in soil type and conditions (iii) spatial variability of rainfall (iv) delay in timely of agriculture, and (v) diversity in crop management practices. These water stress periods are called 'breaks' in the monsoon and may occur in any of the monsoon months. The more prolonged 'breaks' are likely during the mid-season months of August. These breaks/ dryspells may range from a few days to two weeks or even more. Prolonged break often results in partial or complete failure of crops leading to scarcity conditions or even famine.

Temporal Distribution of Dry Spells/ Droughts

Based on its time of occurrence, such rainless periods/ agricultural drought may be termed as early season drought, mid season drought and terminal drought.

Early season drought generally occurs either due to delayed onset of monsoon or due to prolonged dryspell soon after the onset of the rainy season. This may at times result in seedling mortality needing re-sowing or may result in poor crop stand and seedling growth. Further, duration of the water availability for crop growth gets reduced due to delayed start and the crops suffer from acute shortage of water during reproductive stage due to early withdrawal of monsoon.

Mid season drought occurs due to inadequate soil moisture availability between two successive rainfall events during the crop growth period. Its effect varies with the crop growth stage and intensity and duration of dry spell. Stunted growth takes place if it occurs at vegetative phase and in case it occurs at flowering or early reproductive stage it will have an adverse effect on crop yield.

Late season or terminal drought occurs as a result of early cessation of monsoon rains and can be anticipated to occur with greater certainty during the years with late commencement or weak monsoon activity. Terminal droughts are more critical as the final grain yield is strongly related to water availability during the reproductive stage. Further, these conditions are often associated with an increase in ambient temperatures leading to forced maturity. Probability of getting affected by drought at terminal stage of crop is high in the regions of northern, western and part of central India and Tamilnadu. These regions receive high amount of rainfall and generate surplus runoff, which could be potentially harvested and used for supplemental irrigation.

Apart from these short period droughts (dry spells), in the low to medium rainfall regions, the rainfall amount and distribution may be sufficient to support only a low water requiring hardy crop but not a sensitive crop with high water requirements. Introduction of such a crop for economic reasons leads to early appearance of drought conditions and crop failure. The case in point is introduction of hybrid cotton in Vidarbha region of Maharashtra state where farmers attempted to diversify the cropping system without adequate support of water resources and thus lost all their borrowed investments and several of them committed suicides.

Impact of Irrigation Intensity on Crop Yield: District Level Analysis

Large public investments were made for development of irrigation infrastructure in different river basins spread across the country. Over a period of time, irrigation along with high input uses resulted in significant improvement in total production in specific regions. However, this also triggered changes in cropping pattern resulting in replacement of low water consuming crops (coarse cereals, pulses, oilseeds) with high water requiring crops (rice, sugarcane, winter maize). There is a high variability to response to irrigation due to input variability (seeds, fertilizers, mechanization etc.) at the farm level, source of irrigation (canal, groundwater, other sources), and socio-economic condition of the farmers. Due to limited and regulated supplies groundwater and harvested water from surface runoff allow higher water use efficiency as compared to canal irrigation. Most of the dryland crops depend for limited irrigation on sources other than canal irrigation.

The effect of irrigation (and no irrigation) was studied for various crops in 16 major states of the country covering arid, semi-arid and dry sub-humid climatic regions with a rainfall of less than 1500 mm per annum. The districts with same agro-climatic conditions having both irrigation (more than 30% irrigated area for the crop in the district) and rainfed (less than 30% irrigated area for a crop in the district) were identified for each crop. Quinquennial average production, total area and irrigated area (for the period ending 2000-01) and the agro-eco subregion (AESR, NBSSLUP, 1996) were utilized for constructing the data set. AESRs, which are having either exclusively irrigated or rainfed districts, were eliminated to avoid skew effects. A linear equation was derived for productivity as a function of irrigation intensity for each crop. Productivity estimates were made for 0% (rainfed) and 100% irrigation (Table 3). Gross returns (based on minimum support price (MSP) for each crop was also estimated for rainfed and irrigated conditions.

Salient observations based on the above analysis are given below:

- Productivity increase due to irrigation varies between 14 to 74% for different crops (except 0 % for soybeans and 550 % for rice (rabi).
- Achievable yields are much higher than productivity levels from irrigation.
- Among cereals, millets (pearl millet and finger millet) and maize recorded less than 30% increase in productivity due to irrigation.
- Productivity enhancement due to irrigation was also low for oilseed crops.

Difference between yields under rainfed and irrigated areas is more pronounced when the crop is grown under a wide variety of agro-ecoregions and it is low when crop is restricted to few agro-ecoregions (eg., soybean) or when crop is predominantly rainfed (eg., cotton). The difference is lowest for soybean as the crop is grown under high rainfall districts (> 1000 mm/ annum). However, improper distribution of rainfall with in the season also leads to waterlogging and drought conditions with in the same season requiring greater attention on water management in terms of drainage and water harvesting.

Table 3. Response of different crops to irrigation intensity and gross returns with and without irrigation in India

Crop	Estimated yield		Percent response	Gross returns, INR		Estimated increase in yield, kg per one percent increase in irrigation	Reported achieved/ potential yield, t/ha
	With no irrigation	With irrigation		With no irrigation	With irrigation		
Rice, K*	1236	1630	32	6922	9128	3.94	4.0
Rice, R**	445	2907	552	2537	16570	24.6	
Wheat	954	1554	63	6106	9946	6.0	6.5
Maize	1351	1690	25	7093	8873	3.39	10.0

Sorghum, K	405	706	74	2086	3636	3.01	4.3
Sorghum, R	919	1299	41	4825	6820	3.8	3.4
Pearl millet	925	1164	26	4764	5995	2.38	
Finger millet	1611	1868	16	8297	9620	2.57	4.0
Rapeseed/ mustard	653	796	22	11101	13532	1.43	1.7
Sunflower	704	1032	47	9434	13829		2.5
Soybeans	603	605	0	5427	5445	0.01	4.0
Groundnut	955	1085	14	14325	16275	1.3	2.2
Cotton	254	306	21	4470	5386	0.52	0.8

K*: *Kharif (Rainy season)* R** : *Rabi (Winter season)*

Though this district level analysis shows modest impact of irrigation for some crops, experimental results/ demonstrations suggest that the impact of irrigation alongwith other management practices is considerably higher (Table 4). Non-availability of irrigation at critical stages of plant growth and low efficiency of the canal irrigation systems may be the possible reasons for lower district level yields even under irrigated conditions.

Table 4. Effect of critical irrigation on yield rainfed crops at different locations in India

Location	Crop	Yield, t/ha		Per cent increase with critical irrigation (Ratio of irrigated versus rainfed yield)
		Without irrigation	With critical irrigation	
Ludhiana (4)*	Wheat	1.92	4.11	114.06 (2.14)
Agra(2)	Wheat	2.19	2.74	25.14 (1.25)
Dehradun(4)	Wheat	2.14	3.55	65.89 (1.66)
Rewa(4)	Wheat	0.57	1.88	229.82 (3.30)
Varanasi(2)	Barley	2.60	3.36	29.23 (1.29)
Bijapur (5)	Sorghum	1.65	2.36	43.03 (1.43)
Bellary (4)	Sorghum	0.43	1.37	218.60 (3.19)
Sholapur (5)	Sorghum	0.98	1.82	85.71 (1.86)
Rewa (4)	Upland rice	1.62	2.78	71.60 (1.72)

* Figures in parenthesis indicate average number of seasons

Source: Reports of All India Coordinated Research Project on Dryland Agriculture, Hyderabad

Supplemental Irrigation through Water Harvesting: An Assessment

The water related challenge in rainfed agriculture is to manage the high spatial and temporal availability of rainfall, which increases with lower average totals. There is generally enough rainfall in most of the moist semi-arid and dry sub-humid zones to meet the crop water needs. As indicated by Agarwal (2000), India should not have to suffer from droughts, if local water balances were managed better. Even during drought years watershed development efforts of improving rainfall management has benefited Indian farmers. National network on Model Watersheds had convincingly established that runoff to a limited extent can be harvested and recycled to stabilize crop production across different climatic zones and production systems.

This component of water harvesting has become the backbone in furthering the watershed programs in rainfed areas in most states of India (Sharma et. al., 2005; Wani et. al., 2005). The available runoff can be harvested and utilized broadly for two purposes- to provide supplemental irrigation to the standing *kharif* crop to offset mid-season dry spells/ terminal drought (flowering- grain filling stage) or facilitate sowing of the next *rabi* crop. On-station studies have shown strong benefits from supplemental irrigation (Table 5) but the extent may vary depending upon variation in soils, seasonal rainfall distribution, and rainfall occurrence after supplemental irrigation and several others input and management related factors. Thus it is difficult to establish a constant of water use efficiency at district or agro-eco sub region level.

Analysis under the present study was, therefore, conducted to:

- Identify dominant rainfed districts for major rainfed crops.
- Make an assessment of the surplus runoff water available for water harvesting and supplemental irrigation.
- Estimate the water-use efficiency and incremental production for important rainfed crops.
- Estimate increase in production for different rainfed rainfed crops across various districts.
- Conduct a preliminary economic analysis of the water harvesting/ supplemental irrigation to realize the potential of rainfed agriculture.

Identification of Dominant Rainfed Districts for Different Crops

Various national committees (National Commission on Agriculture, Commission for Identification of Drought Prone Areas Program (DPAP)/ Desert Development Program (DDP) districts etc.) identified rainfed districts for various purposes based on different criteria including fixed percent irrigated area uniformly across the country, variable percent-irrigated area based on climatic zone, dominant contribution of area for rainfed production etc. National Commission on Agriculture as well as Kerr (1996) identified a district, as rainfed district if irrigated area was less than 30 per cent. Hanumantha Rao Committee (1995) constituted for identification of DPAP and DDP areas considered variable per cent (50, 40 and 30 % for arid, dry semi-arid and wet semi-arid regions, respectively) for classifying a district as beneficiary under DPAP/ DDP. The main limitation of these classifications was that the distribution and extent of area under different rainfed crops was not considered. For the present analysis, the dominant rainfed districts, which constitute a significant contribution from national perspective, are identified for different crops so that the proposed water harvesting mechanism can be justified based on their possible utilization. Following process of identification of a dominant rainfed crop district is adopted:

i. States covering semi-arid regions in full and margins from dry-arid and sub-humid were identified. This limits the identification of 16 states out of 27 states in the country (Andhra Pradesh, Tamil Nadu, Karnataka, Orissa, Maharashtra, Madhya Pradesh, Jharkhand, Chattisgarh, Uttar Pradesh, Rajasthan, Haryana, Gujarat, Punjab, Bihar, West Bengal and Uttaranchal).

ii. A total of 77 M ha area is covered by dominant crops (cereals, coarse cereals, oilseeds, pulses and cotton) of rainfed nature in these 16 states and out of this 60 M ha is under rainfed cultivation.

iii. The area was further limited to AESR 3-13 covering semi-arid region in full and marginal areas from arid and sub-humid regions within the states. The coastal, sub-mountain, mountainous and cold arid regions were not included in the analysis due to limited potential. By this limitation 50 M ha area was covered under the study.

iv. To further limit the number of districts in the analysis, only top 85 % of the dominant rainfed areas in selected AESRs were selected. Thus out of 60 M ha of rainfed area in these states, 43.5 M ha (72.5%) was considered for this study. Further, season-wise rainfed area was identified by subtracting the irrigated area from total cropped area.

v. Crops covered are rice, sorghum, pearl millet, maize, sunflower, soybean, rapeseed mustard, groundnut, castor, pigeon pea and cotton in *kharif* and linseed and chickpea in *rabi* season. In the absence of the data on irrigation for few selected districts in various crops, an area of 4.5 M ha could not be included for the present study. Hence a total of 39 M ha was accounted for under the selected crops.

Focus under the present study is primarily on utilizing the inevitable runoff from southwest monsoon for supplemental irrigation.

The five-year average of irrigated area, production and total cropped area were prepared on district basis. Based on the area under each crop, the districts contributing to 85% of the area under the given rainfed crops were identified. This approach was followed mainly to identify the major region under which a particular crop is cultivated, and then develop a crop and water based strategy for realizing the potential. Except for a very few crops which have specific agro-climatic requirements (e.g., soybeans), small area of almost all crops may be found in all the districts under AESR 3-13.

Water Balance Analysis for Assessment of Surplus/ Runoff for Water Harvesting and Supplemental Irrigation

In India normal period of southwest monsoon, delivering about 70% of total annual rainfall, is from June to September/ October and this forms the main season (*kharif)* for cultivation of rainfed crops. Parts of south India covering Tamilnadu, Andhra Pradesh and Karnataka are transient zones of both southwest and northeast monsoon (October to December). As total rainfall is spread over few rainy days and fewer rain events (about 100 hours in whole season) with high intensity, it results in surface runoff and erosion or causes temporary water stagnation on agricultural fields resulting in higher evaporation from surface areas. In either of the cases, this 'green water' is not available for plant growth and has very low productivity. In order to raise better crops with higher productivity, it is necessary to convert a part of this lost green water (evaporation, excessive runoff) into a more productive use. Local harvesting of a small part of this water and utilizing the same for supplemental/ protective irrigation to mitigate the impacts of devastating dry spells offers a good opportunity in the fragile rainfed regions (Rockstrom et al., 2001 and 2003; Sharma et al., 2005; Wani et al., 2003). Objective of this analysis was to assess the water availability for harvesting and making the use of same for supplemental irrigation during the crop growth season.

Both crop season wise and annual water balance analysis were done for each of the selected crop cultivated in the identified districts. Whereas, annual water balance analysis assessed the surplus and/or deficit during the year to estimate the water availability and losses through evaporation; the seasonal crop water balance assessed changes in temporal availability of rainfall and plant water requirements. Utilizing the available database on actual rainfall, normal rainfall and normal potential evapo-transpiration (PET), the following methodology was adopted:

- FAO Water Balance Analysis for the cropping season for individual crops provided the information on surplus and deficit periods during the season. Mediating the critical water deficits through supplemental irrigation during crop growth shall minimize/ eliminate the effect of dry spells (sometimes leading to crop failures) and ensure sustainable yields.
- The available water holding capacity of soils for each district was identified depending upon the AESR. The crop coefficients and water requirements were utilized for the region with high humidity during the monsoon. Sowing would commensurate with normal onset of monsoon and crop shall have normal crop duration. To identify the the start and end of the growing period, the following criterion was used:

  (i) Start of the growing season (SGS) was considered when Actual Evapo-transpiration (AET)/ PET of that week was > 0.5 and consecutive 3 weeks had AET/PET > 0.5 to ensure continuity in water availability to crops after the start of the season.

  (ii) End of the growing season (EGS) was considered during the week AET/PET for the week was < 0.25 and the consecutive 3 weeks had AET/PET less than 0.25.

  (iii) Length of the growing season (LGS) which represents the water availability period was calculated as, LGS= EGS-SGS+1.

- Water requirement satisfaction index (WRSI) was used for assessing the sufficiency of rainfall vis-à-vis the crop water requirements. Surplus in the water balance was taken mostly as runoff (to a limited extent drainage) for deciding on the soil and water management requirements. Seasonal deficit index was calculated by using: 1-(AET/PET).
- Thornthwaite water balance was carried for the annual climatic water balance analysis. This provided estimates for surplus and deficit periods during the year and helps in designing suitable management plans to augment the resources within the year based on surpluses for meeting not only the crop water needs but also the demands of livestock, domestic and livelihoods. Few sample examples on crop water balance and annual water balance for representative crops and districts are given in Appendix-I.

Crop Water Balance Based Surplus/ Deficit Assessment for Different Rainfed Crops Across Dominant Rainfed Districts

Utilizing the procedure in the foregoing section, total surplus from a district is obtained by multiplication of seasonal surplus with the rainfed area under the given crop (Ferguson, 1996). Total surplus available from a cropped region is obtained by adding the surplus from individual dominant districts identified for each crop. Table 5 presents a summary of total rainfed cropped area (covering 85% of rainfed area in 16 states) for the important crops and estimated surplus and deficit across rainfed regions.

Table 5. Available surplus from the dominant rainfed districts/ regions for the important dryland crops of India (based on crop water balance analysis)

Crop/ Crop group	Rainfed crop area ('000 ha)	Surplus runoff (ha-m)	Deficit needs (ha-m)
Rice	6,442	4123673	0
Coarse cereals (Finger millet, maize, pearl millet, sorghum)	10,656	2096125	12929
Oilseeds (Castor, groundnut, linseed, sesame, soybeans, sunflower)	10,559	2448879	134800
Pulses (Chickpeas, green gram, pigeon peas)	7,238	2071007	19116
Cotton	4,143	759143	111069
Grand total	**39,038**	**11498827**	**277914**

An estimated amount of 115 M ha-m runoff is generated through 39 M ha of rainfed area under the selected crops. Out of the surplus of 11.4 M ha-m, 4.1 M ha-m (35.9%) is generated by about 6.5 M ha of rainfed rice, alone. Another 1.32 M ha-m and 1.30 M ha-m of runoff is generated from soybeans (2.8 M ha) and chickpeas (3.35 M ha). Total rainfed coarse cereals (10.7 M ha) generate about 2.1 M ha-m runoff. The analysis also reveals that rainfed cotton has a large deficit, which cannot be met from the local resources. This is one of the main reasons for low cotton yields, frequent crop failures and distress among the cotton farmers.

Based on the experiences from watershed management research and large scale development efforts, practical harvesting of runoff is possible only when the harvestable amount is greater than 50 mm or greater than 10% of the seasonal rainfall (minimum utilizable runoff, CRIDA,). Therefore, surplus runoff generating areas/ districts were identified after deleting the districts with seasonal surplus of less than or equal to 50 mm of surplus and those districts with less than 10% of rainfall. Table 6 gives the summary of surplus and deficit for various crops after deletion of districts, which generate less than the utilizable amount of rainfall. This constitutes about 10.5 M ha of rainfed area which generate seasonal runoff of less than 50 mm (10.25 M ha) or less than 10 % of the seasonal rainfall (0.25 M ha).

Thus the total harvestable surplus rainfall for various rainfed crops is about 11.4 M ha-m (114.02 billion cubic meters) from an area of about 28.5 M ha which could be considered for water harvesting. Among individual crops, rainfed rice contributes (4.12 M ha-m from an area of 6.33 M ha) followed by soybeans (1.30 M ha-m from 2.8 M ha). Only a fraction of this surplus runoff needs to be harvested and utilized for supplemental irrigation. Deficit of rainfall for meeting crop water requirements was noticed for crops like groundnut, cotton, chickpeas and pigeon peas and yield improvement and stabilization of these crops may not be possible through exploitation of local resources.

Table 6. Harvestable surplus runoff available for supplemental irrigation to the rainfed crops in India

Crop/ Crop group	Rainfed crop area (‘000 ha)	Surplus runoff (ha-m)	Deficit needs (ha-m)
Rice	6329	4121851	0
Coarse cereals (Finger millet, maize, pearl millet, sorghum)	7502	2057393	0
Oilseeds (Castor, groundnut, linseed, sesame, soybeans, sunflower)	6273	2421222	1646
Pulses (Chickpeas, green gram, pigeon peas)	5288	2044145	9404
Cotton	3177	757575	8848
Grand total	**28568**	**11402186**	**19898**

Harvestable Surplus during Drought and Normal Seasons

In order to ensure the assuredness of water availability, it is necessary to estimate the surplus runoff during drought seasons also, along with normal and above normal seasons. As per the current practice, the season/ year with 20% deficient than the normal rainfall is declared as a drought year (Samra, 2004).

Though there is good amount of surplus available as runoff in a season, the entire surplus is not available at one time during the season. Under the southwest monsoon, usually there are two peaks of rainfall during the season: first peak during the onset phase and second during the withdrawal phase. During these two phases, there is a better certainty in overflows. Even if it is a broader peak, the skew ness of peak is more towards withdrawal phase resulting in runoff at the end of the season. Thus, at least some runoff during withdrawal phase in September in September is a certainty even if early period is affected by aberrations in monsoon. This would be resulting in harvestable surplus, which could be used subsequently during terminal droughts/ dry spells.

Estimation of Potential Irrigable Area

In most canal/ groundwater irrigated areas an irrigation depth of 6to 7.5 cm is applied to most field crops. Considering that rainfed fields are generally inadequately leveled, an amount of 10 cm was considered for the supplemental irrigation. This also included allowances for conveyance, distribution and some storage losses and comparatively less experience of rainfed farmers. Based on the available surplus, irrigable area was estimated for single supplemental irrigation of 100 mm at reproductive stage of the crop. The estimates were made for both normal and drought years. Available runoff during drought year is assumed to be 50% of runoff/ surplus during normal rainfall year (based on literature and authors’ own estimates for selected districts and rainfed crops in Andhra Pradesh). However, during drought years more area can be brought under supplemental irrigation, as farmers tend to economize on water application and sometimes apply water on plant basis to save a withering crop. The estimated irrigable area under both the scenarios is given in Table 7.

Table 7. Estimates of potential irrigable area of important *kharif* crops through supplemental irrigation under normal and drought situations

Crop/ Crop group	Rainfed crop area ('000 ha)	Irrigable area during normal monsoon ('000 ha)	Irrigable area during drought season ('000 ha)
Rice	6329	6329	6215
Coarse cereals (Finger millet, maize, pearl millet, sorghum)	7502	6515	4601
Oilseeds (Castor, groundnut, linseed, sesame, soybeans, sunflower)	5684	4942	4171
Pulses (Chickpeas, green gram, pigeon peas)	4829	4634	3934
Cotton	3177	2656	1725
Grand total	**27520**	**25076**	**20647**

Water Use for Supplemental Irrigation and Remaining Surplus for River/ Environmental Flows

Provision of one supplemental irrigation to the identified rainfed crops in the selected crops requires only a small part of the total available surplus. Out of 114.2 billion cubic metre available as surplus about 28 billion cubic meters (19.4%) is needed for supplemental irrigation to irrigate an area of 25 M ha during normal monsoon year thus leaving 85 M ha-m (81.6%) to meet river/ environmental flow and other requirements (Table 8). During drought years also about 31 billion cubic meters is available as surplus after making provision for

Table 8. Runoff surplus available to meet river/ environmental flows after meeting the supplemental irrigation requirements of rainfed crops under normal and drought conditions

Crop/ Crop group	Rainfed crop area ('000 ha)	Remaining surplus in normal season, ha-m	Remaining surplus in drought season, ha-m
Rice	6329	3489577	1428353
Coarse cereals (Finger millet, maize, pearl millet, sorghum)	7502	1319751	377150
Oilseeds (Castor, groundnut, linseed, sesame, soybeans, sunflower)	6273	1813727	658783
Pulses (Chickpeas, green gram, pigeon peas)	5288	1524096	530423
Cotton	3177	446628	113242
Grand total	**27520**	**8593778**	**3107950**

supplemental irrigation for about 20 M ha. Thus it can be seen that water harvesting and supplemental irrigation do not jeopardize the available flows in rivers even during drought years or cause significant downstream effects in the study areas. Moreover areas with inadequate runoffs have already been excluded from the areas with potential for runoff harvesting.

Estimation of Seasonal Rainwater Use efficiency of Selected Rainfed Crops

In the preceding sections, the amount of available surplus runoff and the area that can be provided with supplemental irrigation during normal and drought years was estimated. However, in order to estimate the productivity returns from the supplemental irrigation, it is imperative to estimate the water use efficiency (kg/ha per mm of supplemental water). Values available from the experimental stations (from small and well managed plots) are generally very high and need to be suitably modified to take care of the regional scale effects (Molden et al., 2003). Water productivity studies can be contemplated at various levels starting from plant level to basin level covering individual crops, cropping systems or total system productivity. However, the data requirement for assessing the same would change based on the scale of study. There are difficulties in measuring regional WUE because the region may support multiple land uses and multiple crops during the same season. At a regional scale, estimation of rain water use efficiency (RWUE) could be obtained by aggregating the rainwater use efficiency available at field scale. However, for a limited period study it may not be practical solution as data requirements are large and mostly unavailable (in terms of productivity values from each land parcel, inflow/ outflow as surface/ sub-surface flow from cultivated fields. Thus a simple method to estimate RWUE at regional scale is to utilize the existing database of productivity statistics (available at district or lower level) and to derive the estimate of rainfall utilized for production purpose. RWUE, thus derived would be lower than the estimated values of RWUE available at farm level (as soil properties are aggregated) and would also result in conservative estimate of production potentials based on these values. Since the variability within soil properties, inflow/ outflow (surface and subsurface) are integrated and the area being addressed is very large, a single representative value of RWUE is estimated. The present aggregates water use efficiency at district level for major field crops. Thus district level RWUE was estimated as ratio of district level productivity (quinquennial average) to its respective effective rainfall. This analysis was carried out for various rainfed crops in the respective dominant districts. Water use efficiency for normal and drought years was not separately estimated, as data considered was for 5 years only. Long duration data on yields will have confounded by technology effects. To detrend the technology effects, crop statistics exclusively for rainfed agriculture are not available.

The average and range of WUE values estimated for different crops cutting across the dominant districts based on the proposed methodology are given below (Table 9). These calculations may overestimate the WUE for lowland rice crop, which receives the unaccounted run-on ponded water.

Table 9. Estimated water use efficiency values for important rainfed crops in India (based on district level analysis and traditional technology)

Crop	Water use efficiency (kg/ ha-mm		
	Average	Maximum	Minimum
Rice	3.30	7.09	1.19
Finger millet	2.76	7.76	1.27
Pearl millet	2.37	3.90	0.61
Maize	2.34	5.51	1.36
Sorghum	1.37	2.79	0.53
Groundnut	2.57	4.014	1.33
Castor	0.72	1.04	0.33
Sesame	0.96	1.68	0.33
Soybeans	1.74	2.53	1.29
Sunflower	1.71	2.21	1.20
Chickpeas	1.74	3.28	0.81
Pigeonpeas	1.67	3.41	0.20
Cotton	0.38	1.52	0.17

These values may be low in comparison to experimental data available through Indian national agricultural research system or elsewhere due to differentially adopted technologies by farmers based on socio-economic background and market conditions. Achievable yields from on-farm trials and long term average rainfall for each dominant district and for different crops was used for estimating the 'achievable water use efficiency' (Data from All India Coordinated Research Project on Dryland Agriculture with 30 network stations). The maximum and minimum values represent the (Table 10) spatial variability among dominant districts. The improved technologies involve adoption of improved varieties, recommended doses of fertilizers and better agronomic practices along with the supplemental irrigation.

Table 10. Estimated water use efficiency values for important rainfed crops in India (based on district level analysis and improved technology)

Crop	Water use efficiency (kg/ ha-mm		
	Average	Maximum	Minimum
Rice	9.40	11.29	7.34
Finger millet	6.80	8.01	6.30
Pearl millet	8.67	11.31	6.96
Maize	10.97	13.70	8.44
Sorghum	13.51	17.72	11.22
Groundnut	3.75	4.69	2.88
Castor	3.50	3.67	3.18
Sesame	3.11	3.68	2.48
Soybeans	7.11	8.15	5.38
Sunflower	3.05	3.13	2.97
Chickpeas	5.19	6.25	3.90

Pigeonpeas	2.44	2.96	1.86
Cotton	1.60	1.97	1.23

A comparison of data between Table 9 and Table 10 brings forth that in rice, coarse cerals, oilseeds (except groundnut and sunflower) and cotton, there is a potential for productivity improvement by 2-4 folds. These improvements can be attributed to superior management practices and adoption of improved varieties.

Potential of Rainfed Production Improvement through Supplemental Irrigation: An Assessment

Based on the assessment of rainfed areas in dominant districts, estimates of water use efficiency under traditional and improved practices, the projections of production from these rainfed areas were made for providing supplemental irrigation under normal and drought conditions (Table 11 and 12). Additional production figures in these tables were a product of irrigable area, water use efficiency and amount of irrigation (70% during normal and 75% during drought conditions).

Under traditional production systems and existing management practices (business as usual , no change in varieties and production inputs) an average of 12% increase in production cutting across drought and normal seasons is realizable with provision of supplemental irrigation alone. However, experience and data do show that farmers significantly change their management and agronomic practices and level of inputs (including varieties) once availability of water is assured. Detailed surveys in rainfed watershed areas by Bouma et al. (2005) showed that upon availability of water for supplemental irrigation farmers modify and diversify the traditional cropping systems to add value to the production system. Our estimates at the regional level indicate that rainfed production can be enhanced to an extent of 3 times the traditional production with improvement in agronomic practices and provision of supplemental irrigation. Significant production improvements can be realized in rice, sorghum, maize, cotton, sesame, soybeans and chickpea crops.

The overall productivity level in these identified rainfed districts covering an area of 27.5 M ha in the country can be enhanced to a level of 2.65 t/ ha (cereals- 3.64 t/ha; oilseeds-1.75 t/ha, pulses- 1.93 t/ha) from the existing aggregated level of 1.2 t/ha. As one can see these potential production levels are only marginally less than current fully irrigated national productivity levels of about 3.1 t/ha. Even with very conservative estimates and some skepticism about the proper adoption of improved practices in the target regions, the potential of improving production through supplemental irrigation in these identified districts and for the selected rainfed crops is substantive and needs to be given a fair trial at the national level.

Table 11. Production potential of rainfed crops with supplemental irrigation under normal and drought conditions (business as usual scenario, no change in inputs and management)

Crop	Rainfed cropped area (000 ha)	Irrigable area during ('000 ha)		Additional production during normal season ('000 tons)	Additional production during drought (000 tons)	Traditional production (000 tons)
		Normal season	Drought season			
Rice	6329	6329	6215	1405	1471	7612
Finger millet	303	266	224	51	44	271
Pearl millet	1818	1370	837	224	145	1902
Maize	2443	2251	1684	405	325	2996
Sorghum	2938	2628	1856	318	236	3131
Groundnut	1663	1096	710	183	131	1182
Castor	28	25	22	1	1	10
Sesame	1052	919	741	87	72	365
Soybeans	2843	2843	2667	330	329	2607
Sunflower	98	59	30	6	3	49
Chickpeas	3006	2925	2560	352	331	2367
Pigeonpeas	1823	1710	1374	190	171	1350
Cotton	3177	2656	1725	59	42	430
Grand Total	27520	25076	20647	3611	3301	24272

Table 12. Production potential of rainfed crops with supplemental irrigation under normal and drought conditions (with some improvement in management and inputs)

Crop	Rainfed cropped area ('000 ha)	Irrigable area during ('000 ha)		Additional production during normal season ('000 tons)	Additional production during drought ('000 tons)	Improved production ('000 tons)
		Normal season	Drought season			
Rice	6329	6329	6215	4141	4357	22150
Finger millet	303	266	224	124	112	757
Pearl millet	1818	1370	837	836	555	4546
Maize	2443	2251	1684	1744	1408	9772
Sorghum	2938	2628	1856	2439	1864	13139
Groundnut	1663	1096	710	284	203	2493
Castor	28	25	22	6	6	51
Sesame	1052	919	741	202	176	1051
Soybeans	2843	2843	2667	1429	1443	6254
Sunflower	98	59	30	12	7	107
Chickpeas	3006	2925	2560	1061	1000	7174
Pigeonpeas	1823	1710	1374	282	245	2186
Cotton	3177	2656	1725	294	206	3211
Grand Total	27520	25076	20647	12856	11581	72893

Epilogue: Promise of Supplemental Irrigation

With limits to further expansion of surface and groundwater irrigation fast approaching in several regions, potential rainfed areas need to be given greater thrust for meeting future food demand and ensuring food security. But agriculture in rainfed areas continue to be constrained by inadequate water availability as monsoon rains is undependable both in time and amount. Barring this constraint, a substantial part of the rainfed lands have the greatest unused potential for growth (Government of India, 2006). Rainfed agriculture is mainly and negatively influenced by intermittent dry spells during the cropping season. Delay in onset of monsoon season triggers shifts to other small duration crops tailored to the remaining length of the growing season rather than overall crop failure. Intensity of dry spells at other critical stages of crop growth, specially during the flowering/ grain filling stage of the crops (even for 1 to 2 weeks), have large bearing on the potential yields at the farmer fields and several times leads to even crop failures. In order to achieve stability in yields, it is imperative to provide protective/ critical/ supplementary irrigation during these short critical periods.

The district or regional average yields for rainfed crops over a period of time have not increased significantly. The difference in the district average yields for rainfed crops among different rainfall zones is also not very high indicating that total water availability may not be the major problem in different rainfall zones. In order to ensure the increase in yields from rainfed areas, the most potential strategy appears to harvest small part of the available runoff and reutilize it for supplemental irrigation at rainless critical crop growth stages. Available research in the country have conclusively proved that provision of limited water at the crucial stage shall be the convergence point for adoption of all other technologies and thus achieve a major jump in rainfed productivity and production.

For rainfall regions of less than 500-700 mm annual rainfall, water harvesting and recycling can be promoted on a limited scale due to very high variability and especially with a view to provide irrigation at critical growth stages and for ensuring stability in yields. Extensive area coverage rather than intensive irrigation need to be followed for achieving higher monetary gains with harvested water. Emphasis is to be given in rainfall regions with > 750 mm/ annum rainfall since there is a possibility to raise second crop with limited water application thus ensuring stability in yields and higher cropping intensity and water use efficiency. With the adoption of improved management and inputs 50-100% increase in yields can be obtained under farmers fields though the research stations obtained much higher increase (2 to 3 fold) in yields due to different schedules of supplemental irrigation.

Through the analysis presented in this study, out of 86 M ha under rainfed agriculture in the country, about 28 M ha was identified as prioritized area under various crops which hosted majority (85%) of the important rainfed crops and also received good total rainfall. About 114 billion cubic metres of runoff are generated from this 28 M ha of rainfed area. It was estimated that by utilizing only a part of this harvestable surplus, about 25 M ha during normal season and 20 M ha during drought season could be provided with supplemental irrigation (one irrigation of 100 mm). In both cases, the area shall still generate 85 BCM and 31 BCM during the two scenarios, respectively to meet the river flow/ environmental flow needs.

Through provision of this supplemental irrigation and with ‘ Business as usual scenario’, the crop production can be enhanced by a total of 28-36 M tons from an area of 20-25 M ha during drought and normal monsoon periods which accounts for about 12% increase over the present production from dryland areas. In the more likely scenario, when assured supplemental irrigation also induces adoption of improved varieties and agronomic practices, the dryland production in India can be 100-128 M tons with a provision for supplemental irrigation to an area of 20-25 M ha during normal and drought seasons, respectively. This increase amounts to 50% increase at the national level from the prevailing levels of production. These benefits could be still higher with large-scale adoption of initiatives ‘System of Rice Intensification, SRI’, crop and land use diversification, use of improved irrigation technologies like drip and sprinkler irrigation etc. Initial economic analysis suggests that the total investments for this local and more equitable water harvesting benefiting small and marginal farmers may be only around 20% of the estimated costs for the National River Linking Project. (detailed studies are underway).

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