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Water Resources and Surface Water Bodies in Hot Arid Zone

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INTRODUCTION

Water and soil are the most precious gift of the nature. The prosperity and history of nation depends to a great extent on these resources and their management. The natural resources of arid regions particularly soil and water is limited and is often in a delicate environmental balance. Desert encroachment due to lack of conservation planning, and the dangers of destroying or depleting beyond recovery these productive resources, are evident at present time and may be disastrous if development is based on short term expediency rather than long term stability.

The arid zone of India is spread over 38.7 million ha area, out of which 31.7 m ha in under hot arid region and 7 m ha under cold region. The hot arid region occupies major part of north-western India (28.57 m ha) and occurs in small pockets (3.13 m ha) in south India. The north-western arid region occurs between 22º30' and 32º05' N latitudes and from 68º05' to 75º45' E longitudes, covering western part of Rajasthan (19.6 m ha, 69%), north-western Gujarat (6.22 m ha, 21%) and south-western part of Haryana and Punjab (2.75 m ha, 10%). Rainfall distribution is highly uneven over space and time (CV>60%). The region receives low rainfall (<100 mm to 500 mm), has high evapo-transpiration and high temperature regime. Groundwater is deep and often brackish. The western-central area is devoid of drainage system and surface water resources are meager. Due to low and erratic rainfall, replenishment of water resources is also very poor. With vast variations in rainfall and ground water availability, some differences in access to water are apparent i.e. while the state average annual rainfall is 531 mm; it is 318 mm in the western parts. The whole Rajasthan state is being categorized as the driest state and water scarce (having per capita water availability below 1000 m^3 $year^{-1}$) since 1991 in the country (Narain *et al.,* 2006a). Increasing pollution by industrial units, big and small, unregulated mining and even over-extraction of water from deep wells also add to the water quality problem in number of districts. Rapid urbanization and industrialization make such existing differences even more glaring. During the twentieth century, the region 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 for the state is 47%. Every alternate year is drought year for the state. 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. The above scenario leads to question of risk in arid agriculture. The main cause of risk in arid agriculture is the variability of rainfall. There are many ways in which it is possible to adapt to it by research into new crop varieties, moisture conserving farming methods and irrigation.

The Indian arid zone is capable of supporting a very intensive biotic population provided the main input resource, water is available adequately. Therefore, availability and redistribution of available water resources assumed prime importance in the sustainable development of arid regions. Long term statistical analysis of rainfall data of the region indicate an asymmetric average storm intensity profile for storms of short duration, with the highest intensities falling in the first part of the storm. The statistical characteristics of high intensity and short duration are essentially independent of location within the region. Thus the main difficulty associated with water resource planning and management is due the inherent degree of variability associated with rainfall. Occurrence of surface water flow in the water-courses of this region is unpredictable, of short duration and highly variable. The instantaneous discharge-duration curve for this region shows a very high and irregular peaks indicating the problems of controlling runoff. Regulation of natural sporadic discharge distribution by means of surface reservoir presents many problems specially the high ratio of storage to mean annual runoff volume required to produce the degree of control necessary for economical agricultural development.

Rainfall characteristics of the Indian arid zone

The mean annual rainfall over the Indian arid region varies from more than 500 mm in the southeastern parts to less than 100 mm in the northwestern and western part of the arid region. More than 85% of the total annual rainfall is received during the southwest monsoon season July to September mainly under the influence of depressions passing across the Rajasthan. The eastern parts of Rajasthan get rains by the last week of June and gradually covers the entire arid region by middle of July. The withdrawal phase of monsoon again start in the extreme western part by middle of September and retreats by the end of September. The rainy season varies from 50 days in the western part to 80 days in the eastern part of arid Rajasthan. A small quantum of rainfall of about 7-10 percent of the annual is received during the winter season under the influence of western disturbances. Rainfall is low and erratic and the coefficient of variation of annual rainfall varies from 42 percent to more than 64 percent (Table 1).

Table 1. Normal annual rainfall and its coefficient of variation in the Indian arid region

Station	Rainfall (mm)	C.V. (%)	Station	Rainfall (mm)	C.V. (%)
Barmer	267	63	Nagaur	340	53
Bikaner	287	47	Sikar	457	42
Ganganagar	245	53	Hisar	446	45
Jaisalmer	188	64	Bhuj	342	65
Jodhpur	366	52	Anantpur	562	50

Rainfall distribution models of Jodhpur (Ramakrishna *et al.,* 1988) indicate that out of 97 years (1901-97), 52 years at Jodhpur recorded average to above average (350 to more than 400 mm) rainfall which indicate that one in two years, Jodhpur region receives substantial rainfall. About 19 years recorded, a rainfall of 250-350-mm. Appropriate crop production technology can stabilize yield levels in such years. The rest 26 years received less than 250 mm. This would mean specific technology to overcome deficit rainfall situations.

The surface water resources of the arid region is scarce and because of low and erratic rainfall, replenishment of these water resources is also very poor. Due to high atmospheric temperature and low humidity, a large part of the rainwater is lost as evapotranspiration. Surface water potential, except in canal command area, is very low in the central, western and southern parts. In central and western parts, the run-off generated in response to some high-magnitude rainstorms gets lost in sandy terrain. In recent studies carried out by CAZRI, the total surface water resources excluding IGNP of arid zone of Rajasthan is 1486 x 10^6 m^3 which is equivalent to 7.2 mm in depth or 7,200 m^3 km^{-1} in the region. Large numbers of tanks, reservoirs, minor irrigation dams and check dams have been constructed at different locations in Luni basin and other areas to store runoff water during monsoon period. In western Rajasthan, 550 storage tanks in the capacity ranging from less than 1.51 to 208 x 10^6 m^3 are functional with total utilizable capacity of nearly 1169.28 x 10^6 m^3 for providing irrigation in 0.102 x10^6 ha land. Out of these, six reservoirs viz. Jaswantsagar, Sardar Samand, Jawai, Hemawas, Ora and Bankali, are the major irrigation tanks with capacity of irrigation of more than 4000 ha each. Jawai is the main source of drinking water supply to many towns and villages (Source: Irrigation Department, Govt. of Rajasthan). Hydrologically the western Rajasthan can be divided into three broad zones.

Zone – I : Region with major input of surface water from more humid region, frequently with extensive irrigated agriculture. About 60 per cent area of Ganganagar district in the north and 50 per cent area of Bikaner district and 25 per cent area of Jaisalmer district in the northwest lie in this zone. This is the main canal irrigated zone in arid Rajasthan.

Zone –II: Plain lands with a primitive or no stream network. The region has a system of repetitive micro-hydrology. Churu, Jhunjhunun, Sikar, Nagaur, Jodhpur and parts of Bikaner, Jaisalmer and Barmer districts come under this category. This zone occupies 52% area of arid Rajasthan.

Zone-III: Sloping region with an integrated stream network. The Luni basin, occupying the districts of Pali, Jalore, part of Jodhpur and Barmer districts, lie in this zone.

Table 2 and 3 presents surface water bodies of western Rajasthan and the estimated water demand for the arid Rajasthan respectively.

Table 2. Surface water resources (mcm) in arid Rajasthan

District	Zone-I	Zone -II	Zone-III	Total
Ganganagar *	6.49	11.19	–	17.68
Bikaner	7.14	26.16	–	33.3
Churu	–	22.82	–	22.82
Jhunjhunun	–	8.04	96	104.04
Sikar	–	10.48	96	106.48
Jaisalmer	5.03	38.38	–	43.41
Jodhpur	–	20.66	–	20.66
Nagaur	–	53.18	–	53.18
Pali	-	–	869	869
Barmer	–	19.64	–	19.64
Jalore	–	–	71	71
Total	18.66	210.55	1132	1361.21

* including Hanumangarh

Table 3. Estimated present water demand (mcm) of arid Rajasthan (CAZRI, 1990)

Demand for	Year				
	1981	1991	1995	2001	2011
Human Consumption @ 40 lpd*	196.85	236.06	261.82	289.23	349.02
Livestock Consumption @ 30 lpd	249.00	290.00	308.00	332.50	376.00
Irrigation @ 0.30 m ha^{-1} $year^{-1}$	5178.00	5696.00	5900.00	6265.00	6892.00
Industry	16.00	17.00	17.50	18.00	21.00

*LPD: liter per day

Since the water is limited, such trend is forcing people to use even 'marginal' quality water in some areas.

Surface Water Resources Assessment using Remote Sensing & GIS

Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. In other hand, A geographic information system (GIS) captures, stores, analyses, manages, and presents data, which is linked to locations or having spatial distribution. Remote sensing has vast application since each band of data collected contains important and some unique information. Space-borne multispectral measurements made at regular intervals hold immense potential of providing such information in a timely and cost-effective manner, and facilitate studying dynamic phenomenon. The geographic information system (GIS) provides an ideal environment for integration of information on natural resources with the ancillary information for generating derivative information which is useful in decision making.

Database: Indian Remote Sensing Satellite (IRS-1B/-1C and -1D) Linear Imaging Self-scanning Sensor (LISS-II and -III) and Panchromatic sensor (PAN) data has been used for deriving information on various natural resources. In addition, Survey of India topographical maps at 1:50,000 scale, and published soils and other resources maps and reports were also used as collateral information.

Methodology: The methodology involves database preparation, generation of thematic maps on surface water resources. The thematic water body information extraction methods can be generally divided into two categories according to the number of bands used: the single-band method and the multi-band method. The single-band method usually involves choosing a characteristic band of water from a multispectral image, then determining a threshold at which to discriminate water from other surfaces. The multi-band methods, which are based on the spectral water index, are better at the detection of land surface water body information than the single-band method is because they take advantage of reflectivity differences of each involved band and extract water-body information based on the analysis of signature differences between water and other surface.

Database preparation: The first step in generating the multi-sensor data sets is the geo-referencing of the image to a common map grid. When merging higher resolution data with the lower resolution images, usually high resolution image (here PAN data with 5.8 m spatial resolution) is used as a reference for respective enhancement of the lower resolution (LISS-III data with 23.5 m spatial resolution) data. The digital LISS-III was later co-registered with digital, topographic database.

Image characteristics of water bodies: Surface Water Body is defined as a discrete and significant element of surface water such as a lake, a reservoir, a stream, river or canal, part of a stream, river or canal, which differ from each other in specific natural characteristics, the nature of the impact of human activity, or any other significant and distinguishable parameters. These water bodies are distinctly visible in light to dark blue tone with varying size, shape and fine texture on a LISS-III FCC image. These could be delineated with maximum accuracy on the IRS imagery based on their proximity to the settlements. The drainage basin of these water bodies appears in light brown to light red in tone depending on the density of trees and grass cover. These are of varying size, irregular shape and with coarse to mottled texture. Water bodies were identified by a spectral analysis of IRS imageries (Fig. 1 & 2).

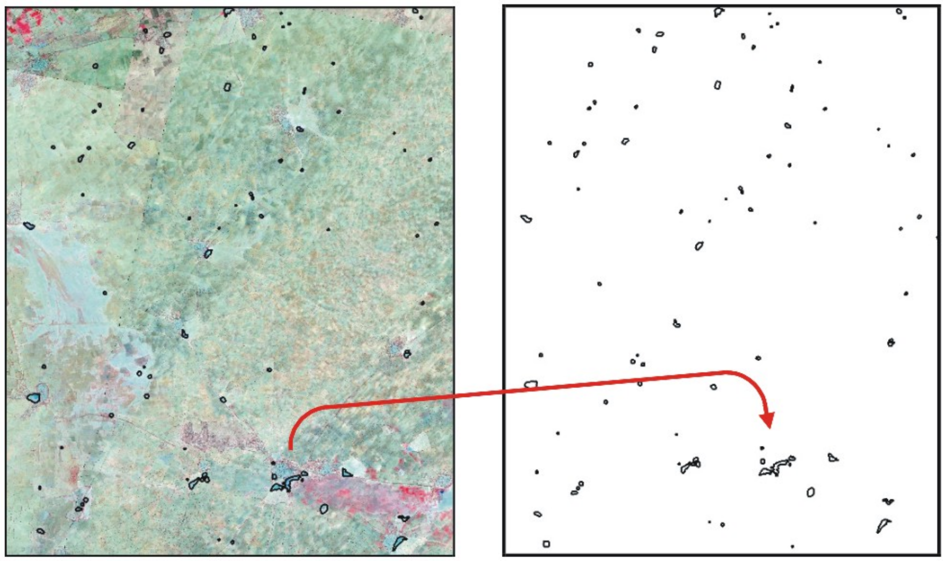

Fig 1. Surface water body delineation on satellite imagery

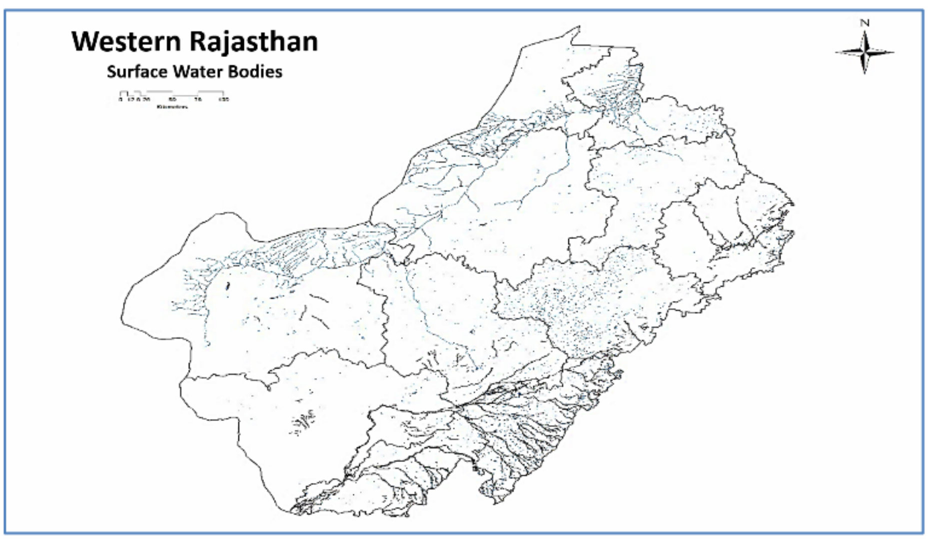

Fig 2. Surface water bodies of western Rajasthan

Strategies for Water Resource Management in Arid Rajasthan

Rainfall is the principal source of water, which augments soil moisture, groundwater and surface flows. Agriculture and several of the other economic activities in arid areas depend on rain. This region is devoid of any well-defined perennial river system. Under such circumstances every drop of water becomes very precious. Of the total water use about 85% of water is used for irrigation and remaining 15% is used for drinking, industrial and other purposes. About 65% of irrigation water and 30-40% of drinking water is subjected to serious losses. Hence, increasing water use efficiency coupled with increasing availability of water through rainwater harvesting and management can provide the answer to recurring drought on sustainable basis. Rainwater harvesting, its conservation and efficient utilization can solve problem of water scarcity to the greater extend. Rainwater harvesting in small ponds (*nadis*), underground tanks (*tankas*), *Khadins* (Low lying areas) etc. is an age-old traditional in arid zone of Rajasthan. These traditional rainwater harvesting structures vary in design, shape and size. These structures are partially or sometimes totally neglected because of increased dependence on tube well, tankers and canal water supply etc. The traditional methods require improvement for being more economical and efficient.

Rainwater Harvesting in Nadi and Ponds

The people of rural arid areas live in scattered settlements called *dhani's* distributed over sand dunes, interdunal plains and undulating landforms. Under such conditions it is inconceivable that organized water supply will be feasible to fully meet the demand of thirsty land, human and livestock. Under such circumstances the system of rainwater harvesting in *Nadi* and farm ponds are viable proposition for a group of farm families or community. *Nadi* is a dugout pond used for storing runoff water from adjoining natural catchment during rainy season. High evaporation and seepage losses through porous sides and bottom, heavy sedimentation due to biotic interference in the catchment and contamination are major bottlenecks. To overcome their problem CAZRI has developed designed *Nadis* with LDPE lining on sides and bottom keeping surface to volume ratio 0.28 and provision of silt trap at inlet. *Nadis* also help to recharge ground-water aquifers although their effect varies depending on the underlying soils and rocks. Where the substrate is rocky, it is estimated that they contribute a depth of 0.06 meters of water a year compared to 1.58 meters in sandy plains. A study of a 2.25-hectare *nadi* with a storage capacity of 15,000 cubic meters in the north Gujarat alluvial area calculated that the pond contributed as much as 10,000 cubic meters of water to the groundwater aquifer in one rainy season.

Farm Pond is an improved version of *nadi* with treated catchment and surplusing arrangement for removal of excess water. A farm pond of 20,000 m^3 capacity was constructed at Kukma watershed at Bhuj in Gujarat by CAZRI in year 2004. Construction of farm pond resulted in assured availability of 20,000 m^3 water even in as small as 150 mm rainfall region (Narain et al., 2006b). The collected water was used to provide irrigation to Datepalm, ber, aonla and other fruits plants in nearby area. Construction of large number of rainwater harvesting nadis and farm ponds can solve the problem of uncertainty of occurrence of rainfall and can store water during heavy rainfall for non-monsoon period for human, livestock and crops on sustainable basis. Construction/renovation and desilting of nadis/farm ponds during drought relief measures by state government and NGO's is necessary.

Rainwater Harvesting for Supplemental/lifesaving Irrigation

Studies conducted at CAZRI and elsewhere show that application of water at critical stages of trees/crops growth increases the yield substantially. Complete drought or long dry spells within a season are very common in this region. Harvested rainwater can be used to provide supplemental/life saving irrigation particularly to trees and crops. At Jhanwar watershed (Jodhpur) near Jodhpur, harvested rainwater from a farm pond (271 m^3 capacity) was used to grow *ber* plantation and subsequently to provide supplemental irrigation, which resulted in increased fruit yield of ber (8 q ha^{-1}) with 1.67: 1 benefit: cost ratio. Katiyar *et al.* (1999) reported a benefit to cost ratio of 2.5:1 with supplemental irrigation to wheat, mustard and gram with farm pond. The system of rainwater harvesting by way of farm ponds and subsequently its recycling for life saving irrigation can provide an effective check against dry spells and drought for economic yields (Goyal *et al.*, 1995, 1997; Goyal and Sharma, 2000).

Rainwater Harvesting in *Khadin* for Crop Production

Recurring droughts and long dry spells are regular feature of arid zone of Rajasthan, which results in crop failures or severely crop growth and yield reduction. A traditional practice of *khadin* farming in hyper arid region of Jaisalmer ensures better moisture conservation and cropping. The system is very effective even in hyper arid region of western Rajasthan where annual average rainfall is less than 200 mm.

Khadin is a unique practice of water harvesting, moisture conservation and utilization. It is suitable for deep soil surrounded by some natural rock outcrops constituting catchment area. CAZRI, Jodhpur has evolved a design package and guidelines for construction of *khadins*. Improved *khadin* has been constructed by CAZRI near village *Danta* in Barmer district (Khan, 1998a). The catchment area of the *khadin* is 137 ha with 6.88 ha submergence. Provision of 40 m bed bar in 450 m long earthen embankment was provided for spilling over excess water in *khadin* bed. The total water storage capacity of *khadin* is 54.2 x 10^4 m^3 and beneficiaries are four farm families. At another site *Khadin* of 20 ha areas was developed 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 1.1 metres, respectively. There were 500 such *khadins* covering an area of 12,140 ha in Jaisalmer and the crop production from such areas was adequate to feed the people of Jaisalmer district. Large-scale development of *khadin* farms at suitable locations in western Rajasthan can enhance land productivity.

Rainwater Harvesting for Ground Water Recharge

As per ground water estimates of Rajasthan for year 2001, total annual groundwater availability is 11,159 mcm as against total annual water demand (draft) of 11,626 mcm. The overall groundwater stage of development for the whole state is 104 %, which is categorized as 'over exploited'. Presently out of total 32 districts, 14 districts are in the category of overexploited, 4 in critical zone, 8 in semi critical zone and remaining 6 are considered in safe category. With increasing demand for water, more and more blocks are likely to be in the category of over exploited and needs immediate attention for recharge of ground water.

Percolation tanks, pondage in stock tanks with infiltration galleries, sand filled dam, anicuts across the stream, sub-surface barriers etc. are used for groundwater recharge (Ojasvi *et al.* 1996; Goyal, 1999). Adoption of conservation measures like anicuts, loose stone check dams, brush wood check dam etc. in watershed area has resulted in recharge/increase of ground water level @ 0.33m to 0.75m year^{-1} (Bhati *et al.,* 1997, Goyal *et al.,* 2007). In another watershed at Osian-Bigmi (1991-96), conservation measures like loose stone check dams; vegetative barriers and anicuts resulted rise in water table by 1.1 m indicating the effectiveness of conservation measures for the recharge of ground water (Gupta *et al.*, 2000). Sub-surface barrier constructed across ephemeral streams traps subsurface flow to recharge groundwater aquifer (Khan, 1998b). Construction of two sub-surface barrier of 10 m length each within 300 m from water supply well was found enough to store runoff water required for a village having a population of 500 (Anon., 1974). Singh *et al.*, (1989) reported that soil conservation practices have increased recharge to an extent of 14.02 to 19.52 % of rainfall in Udaipur region.

Rainwater Harvesting for Safer and Cleaner Drinking Water

Good quality potable water is a global issue, particularly in developing world because 80% of the diseases in the world are due to poor quality of drinking water. The problem of poor quality ground water used for drinking is more acute in the state of Rajasthan (Table 4). Concentration of fluoride ranges from 0.4 to 90 mg l^{-1} leading to various diseases like dental fluorosis, skeletal fluorosis and, non-skeletal manifestation etc.

Rainwater is the purest form of water. Appropriate harvesting of rainwater from roof top and open and its utilization can alleviate problem of fluoride to great extent. Studies conducted at CAZRI have revealed that roof made of different materials can generate 50 to 80% runoff can be stored in underground cistern (*tanka*) which could provide excellent drinking water round the year. Surface rainwater can also be harvested in tanka using artificially prepared catchment. Traditional *tankas,* constructed with lime plaster, typically have a life span of three to four years. They suffer from seepage and evaporation losses and, in the absence of proper silt traps and pollutant-free inlets, the quality of the conserved water deteriorates over time, making it unsafe for drinking. Also, in many situations, degradation of the catchment area means that it does not yield the quantity of water required to continuously replenish the structure.

Table 4. Comparison of ground water quality, Rajasthan and rest of India

Particulars	India	Rajasthan			
		Villages	Habitations	Total	% of country
Multiple quality problems	25092	9572	9067	18639	74
Only fluoride	31306	4477	4515	8992	29
Only salinity	23495	3235	2193	5428	23
Only nitrate	13958	4211	3671	7882	56.5
Only iron	118088	79	52	131	0.1
Only arsenic	5029	-	-	-	-
TOTAL	216968	21574	19498	41072	

Source: Report of expert committee on integrated development of water resources, June 2005

CAZRI has designed improved *tankas* with capacities of 5,000 to 600,000 litres. The improved *tankas* include silt traps at the inlets to prevent pollutants from entering the *tanka*. The improved designs have a lifespan of more than 20 years. Planting of suitable tree species around the periphery of the catchment area of a *tanka* is recommended to improve the local environment. CAZRI constructed 17 improved *tankas* in Kalyanpur (Distt. Barmer) and Borali-Bambore (District Jodhpur) under National Wasteland Development Board and National Agricultural Technology Projects (1998-2003). 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. The number of improved tanka in different capacity ranges constructed in the region are 11,469 with a total storage capacity of 4,75,200 cubic meters and are sufficient to meet the drinking and cooking water requirements for a population of 1,32,000 throughout the year (Khan & Venkateswarlu, 1993). *Tanka* is highly economical compared to hauling of water from long distances. The most economical size of tanka is 50,000 liters with Rs. 1.5 per liter cost of construction. Construction of tankas for raising orchard at few locations have significantly improved the economic condition of farmers.

Increasing Water Productivity by Reduction in Water Losses

Evaporation losses accounts for 20-25% water losses in arid areas. Reducing surface area by increasing storage depth can appreciably reduce water losses. The surface area can also be reduced by storing the water in a compartmented reservoir, and pumping the water from one compartment to another as the water is used, so that there are some full compartments and some empty, instead of a single shallow sheet when the reservoir is partly used. Covering the field with any kind of mulch also helps in reduction of evaporation losses from the surface.

Studies at CAZRI have shown that *in-situ* rainwater harvesting makes the efficient use of limited rainfall and nitrogen fertilizer in pearl millet. Similarly, instead of providing 100% irrigation level to smaller area with limited water, extensive irrigation is reported to maximize production in pearl millet and mustard in terms of productivity and water use efficiency. The micro-irrigation systems like drip and sprinkler economize both water and fertilizers. These systems could be popularized to increase the productivity of limited rainwater.

Table 5. Groundwater recharge potential of Arid Rajasthan (base year 2004)

District*	Potential Zone Area (km^2)	Average Ground water depletion (m) between 1984 to 2003	Unsaturated Volume (mcm)	Weighted specific yields (%)	Potential recharge volume (mcm)
Barmer	12734.65	-3.18	40496.2	5.3	2147.4
Churu	7895.62	-0.98	7737.7	6.0	466.8
Jaislamer	9868.30	-0.18	1776.3	5.0	90.4
Jalore	8228.10	-10.17	83679.8	6.0	5050.1
Jhujhunun	5273.69	-9.14	48201.5	5.4	2636.6
Jodhpur	18867.92	-9.08	171320.7	4.3	7513.7
Nagaur	16378.50	-8.68	142165.4	4.7	6805.8
Pali	7362.54	-10.11	74435.3	3.1	2315.5
Sikar	7263.46	-8.39	60940.4	5.3	3273.6
Total	107595.51		630753.3		30299.9

* Bikaner, Hanumangarh and Ganganagar districts have reported a rise of groundwater table due to canal irrigation, so these district have been not considered for groundwater recharge

Flash Flood Management

Although most parts of arid Rajasthan comes under drought prone area, however, flash floods are not uncommon in this region. Since rainfall in this region is of convective nature and usually occurs at a very high intensity for shorter duration creating situation of flash flood particularly in urban areas where buildings and roads generate very high runoff even for little rainfall. During 1979 large parts of state witnessed flash flood due to very heavy downpour of more than 500 mm in just 3-5 days which cut off the state from rest of the country for several days. In the last 103 years (1901-2003), western region witnessed nine moderate and 19 severe floods. Although, floods are considered a natural calamity, however, if the excess flood water or its part can be managed and utilized for rejuvenating the depleted aquifers as well as improving surface water resources the problem of water scarcity during droughts can be solved. Harvesting and conservation of flood water to rejuvenate the depleted potential aquifers by adopting artificial recharge techniques will remarkably improve the water availability for growing population. Out of 12 district of arid Rajasthan, Bikaner, Hanumangarh and Ganganagar districts have reported a rise of groundwater table due to canal irrigation and remaining 9 districts have recharge potential of $30.3 x 10^9$ cum based on groundwater depletion taken between 1984-2003 (Table 5). Narain *et al.* (2006a) have estimated a potential of 5.9×10^9 cum of flash flood for western Rajasthan. A part of flash flood can be used to recharge groundwater of these districts. Bilara limestone, Lathi and Jodhpur sandstone and alluvium aquifers covering large area in the region are most suitable for groundwater recharge.

Crop Planning and Management based on Rainfall

In arid areas crop production totally depends on magnitude and distribution of rainfall. However frequents droughts severely affects the growth and production of crops. Shastri *et al.* (1984) identified three common droughts viz. terminal, middle and early depending on cropping duration. The percentage of drought occurrence at terminal, mid and early crop stages was 62.2, 33.3 and 4.5 per cent respectively in 80 years. With the early onset of monsoon pearl millet and sesame get preference while with the late onset of monsoon cluster bean, mung bean and moth bean get preference (Shankaranarayan & Singh, 1985). Crops differ in their growing season, root system density, spacing, height, leaf orientation, reflection coefficients, photosynthetic efficiencies, etc. The C-3 plant types, particularly legumes, have a low photosynthetic rate, so they have low WUE. The C-4 (millet, sorghum) plants on the contrary, have a higher rate of photosynthesis and their WUE is twice as high (Singh, 1977a). So selection of particular crop can be decided on the basis of its WUE. Weeds compete for water, nutrients and light, especially during early stages of crop growth and cause considerable reduction in yield. Weeding at appropriate time significantly improves crop yields (Singh & Singh, 1988; Gupta & Gupta, 1982). Therefore, elimination of weed canopy early in the season is one of the important practices to reduce water use per unit of yield. Mulching reduces the evapotranspiration losses from soil surface and helps in promoting better plant establishment and results in higher yields. Polyethylene mulch was highly effective in controlling evaporation losses (Gupta, 1978, 1980). Application of grass mulch (6 t ha^{-1}) bought 200 percent increase in the yield of green gram, dew gram and cluster bean (Gupta & Gupta, 1983). Higher plant densities do not allow deep percolation of soil moisture resulting in more loss of soil moisture through evaporation. Similarly larger canopy growth is disadvantageous in arid areas as it exhaust available soil moisture from root zone during droughts. So optimum plant population and geometry is key to survive under drought conditions.

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.

CONCLUSIONS

Management of water resources for drought proofing in arid areas is real challenge and remotely sensed data with the application of geographic information system techniques can play an important role in the mapping, monitoring and efficient use of water resources. For management of scares water resources, multiple point strategies are needed. On one hand technological advancement is needed for the better and early forecast of drought and on other hand technologies of rainwater harvesting and conservation needs to be popularize and percolated at extreme down end. On cropping fronts appropriate technology is needed for development of drought tolerant early maturing crops to combat drought. Traditional rainwater harvesting structures like *nadi, baori, talab* etc needs renovation on continuous basis. Efforts should be made by the government for timely desilting of traditional rainwater harvesting structures. Since rainfall in this region is convective nature and occurs generally with high intensity for a shorter duration. The nature of this of rainfall not only causes flash flood situation but also leads loss of huge quantity of runoff water particularly in urban areas. So special efforts are needed to harvest flash floodwater for the lean period by construction of large storage structures at appropriate sites. Efforts are also needed to control the indiscriminate extraction of groundwater by the private tubewell owners by law and recharge of groundwater should be made mandatory.

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