Groundwater Management in Rajasthan: Identifying Local Management Actions

Final report

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1. Introduction

Rajasthan is one of the naturally water scarce regions in India. This is due to very low to medium rainfalls, high inter-annual variability in rainfall magnitudes, very few rainy days, and high aridity. The mean annual rainfall, however, varies significantly from 100 mm in Jaisalmer to around 900 mm in Udaipur. The Thar Desert in Rajasthan receives the lowest annual rainfall of the entire country. Along with spatial variation in rainfall, the number of rainy days also changes with lowest figures for the areas receiving lowest rainfall in western parts to relatively larger number of rainy days for areas receiving higher rainfall in southern parts. In fact this is one of the characteristics of Indian rainfall (source: Pisharoty, 1990).

Still, in terms of per capita renewable water resources, Rajasthan is not one of the most water-scarce regions in the country. The fact that the region has one of the lowest population densities pushes Rajasthan's position upwards in terms of per capita renewable water resource availability, a strong indicator of physical scarcity of water, developed by M. Falkenmark. But, physical water scarcity conditions exist throughout many parts of Rajasthan. The reason is the agrarian nature of the economy of the region, and the large amount of arable land, which need irrigation water owing to the large gap between effective rainfall and the reference evapo-transpiration. In fact, the per capita arable land in Rajasthan is one of the highest in the country, next only to Punjab and Haryana. This is compounded by the high variability in rainfall which under arid climatic conditions means much higher variability in runoff, and stream-flows causing hydrological droughts.

Rajasthan's vulnerability to droughts is one of the highest in the country, more so in the western parts, with the probability of occurrence as high as 25 per cent (source: based on Sinha and Wale, 2006). This makes irrigation development imperative, to proof against droughts. While the renewable freshwater resources available from the state's river basins are extremely limited, there is high level of development of available water resources for irrigation, municipal and industrial uses. In lieu of the limited surface water resources, the dependence has been extremely high on groundwater. Heavily subsidized electricity for agricultural sector, and massive rural electrification has lead to over-exploitation of groundwater in most parts of the state.

2. Background

In response to the growing problems of groundwater depletion in north Gujarat, the IWMI-Tata water policy program has been implementing a project in partnership with three civil society organizations (CSOs) with support from SRTT, to establish local groundwater management regime in the alluvial areas of the region. The project was titled north Gujarat Groundwater Initiative[1]. The project is based mainly on the concept of water demand management in agriculture. Improving productivity of water use in agriculture is a major strategy to manage the demand for water in agriculture. The project evolves sustainable farming system models that are based on technologies and practices which would enhance water productivity in agriculture, through action research, and facilitate their large-scale implementation through a well-designed extension program.

The impacts of the project are quite sharp and visible. There are positive developmental outcomes of this project with the changes in farming system brought out through the introduction of new crop and irrigation technologies. It is found that with the use of efficient micro irrigation (MI) systems, the adopter farmers could cut down water use not only for every unit of land irrigated but also at the aggregate level. Their income from farming has increased substantially with the yield increase in existing crops and with adoption of high valued crops. NGI Project: the need to identify viable strategies for other semi arid regions.

There is a need to understand how the interventions tried in alluvial north Gujarat would help address groundwater problem in other geo-hydrological environments. The underlying concern is that adoption of water saving technology would not necessarily lead to reduction in water use at the farm level, the reason being that there is a strong incentive among farmers to expand the area under irrigation using the saved water. Also, with the opportunity to increase the returns from every unit of water through the adoption of water-efficient crops and WSTs, the farmers might tend to abstract more water from the aquifers to generate more income. These can pose new challenges of resource use sustainability. Hence, there is a need to try and the experiment the strategies tried and tested in north Gujarat in other geo-hydrological and socio-economic environments to examine their effectiveness

Rajasthan, which is the adjoining state of Gujarat, is most ideal for piloting the ideas. One of the reasons is that the state has the highest degree of groundwater over-exploitation, and over-development problems have affected large geographical areas (GOI, 2005). Groundwater is a very significant resource for the rural economy of this state, which is still agrarian. The resource characteristics are much more complex in Rajasthan. The other reason is unlike Gujarat, the state is not well-endowed with large NGOs and civil society organizations, which have professional competence in dealing with complex issues of groundwater management issues.

3. Objectives of the Research Study

The objectives of the research study to be undertaken on local groundwater management in Rajasthan are the following:

- Identify the regions in Rajasthan which experience the most severe problem of groundwater over-exploitation, and analyze the causes;

- Select a district where the pre feasibility for undertaking resource management interventions from technical and socio-economic points of view exist;

[1] The project later on got hived off from ITP and got registered as a separate entity called Society for Integrated Land and Water Management (SOFILWM).

- Identify the key physical interventions for resource management for piloting from either supply augmentation side or demand management side or from both;

- Suggest the operational strategies for piloting them

The present study attempts to address the first two objectives.

4. Approach and Methodology

The following methodology was adopted for. Spatial analysis of hydrological, geo-hydrological, agro-meteorological and socio-economic data was carried out on GIS platform was carried out to identify the districts which face the most severe problem of groundwater degradation and where interventions would be technically feasible.

Several considerations were applied for identifying the most suitable district for groundwater management intervention. They are: importance of agriculture for the district's rural economy; groundwater resource endowment in the district; significance of groundwater for the district's agriculture and the degree of dependence on groundwater for irrigation; seriousness of groundwater over-development problems; the physical and socio-economic feasibility for introducing MI systems. All these considerations are captured in some quantitative variables.

These variables are: 1] total availability of renewable groundwater; 2] groundwater richness; 3] groundwater use intensity; 4] groundwater irrigated area per capita; 5] degree of over-exploitation of groundwater; 6] the land holding pattern, particularly the percentage of operational holding area belonging to large and medium farmers and the aggregate number of large & medium farmers; 7] gross cultivated land per capita of rural population; 8] irrigated area under cash crops per capita of rural population and percentage of total area under irrigated cash crops of the state falling in the district; and 9] total area under surface irrigation in the district.

The institutional mapping data and insights gained from field visits in conjunction with the spatial analysis of physical and socio-economic data were used to assess the overall feasibility for undertaking interventions.

It included the following activities:

a] **Macro-level Spatial Analysis**: secondary data on hydrology, agro meteorology and socio-economic characteristics affecting water resource availability and water demands from various official agencies such as CGWB, state groundwater department, Central Arid Zone Research Institute, Central Water Commission and State Agricultural Directorate were collected, thematic overlays would be generated on GIS platform, and analyzed.

b] **Field Visits**: in different locations to understand the soil & crop types, the well ownership and groundwater use patterns, irrigation water use practices, adoption of agricultural water management technologies and practices

c] **Institutional mapping**: visits to various organizations (NGOs, research institutes and agricultural universities) in order to map the various institutions working on water management in the region and assess their potential to play a future role in groundwater management activities in the region.

The secondary data collected include: official estimates of groundwater development status (for the year 2005); geo-hydrological map; district level data on cropping and irrigation pattern, net sown area and gross cropped area, net and gross irrigated area, irrigated area by source, area under different crops, and land ownership pattern (for the year 2006-07); the soil map of the state, district-wise monthly and annual rainfall data; isohyets of rainfall, reference evapo-transpiration and potential evaporation for the state; characteristics of groundwater abstraction structures (2006-07); map showing irrigation schemes; and drainage map. The geo-hydrological map, physiographic map, soil map and rainfall isohyets were obtained from the water resource atlas of Rajasthan.

5. Water Resource Availability and Use in Rajasthan

The water resource availability in the state is governed by the rainfall, climate, topography, soils and aquifer characteristics. All of these show high degree of spatial heterogeneity. The characteristics of rainfall, soils, climate, physiography, and geo-hydrology are described in the respective sections.

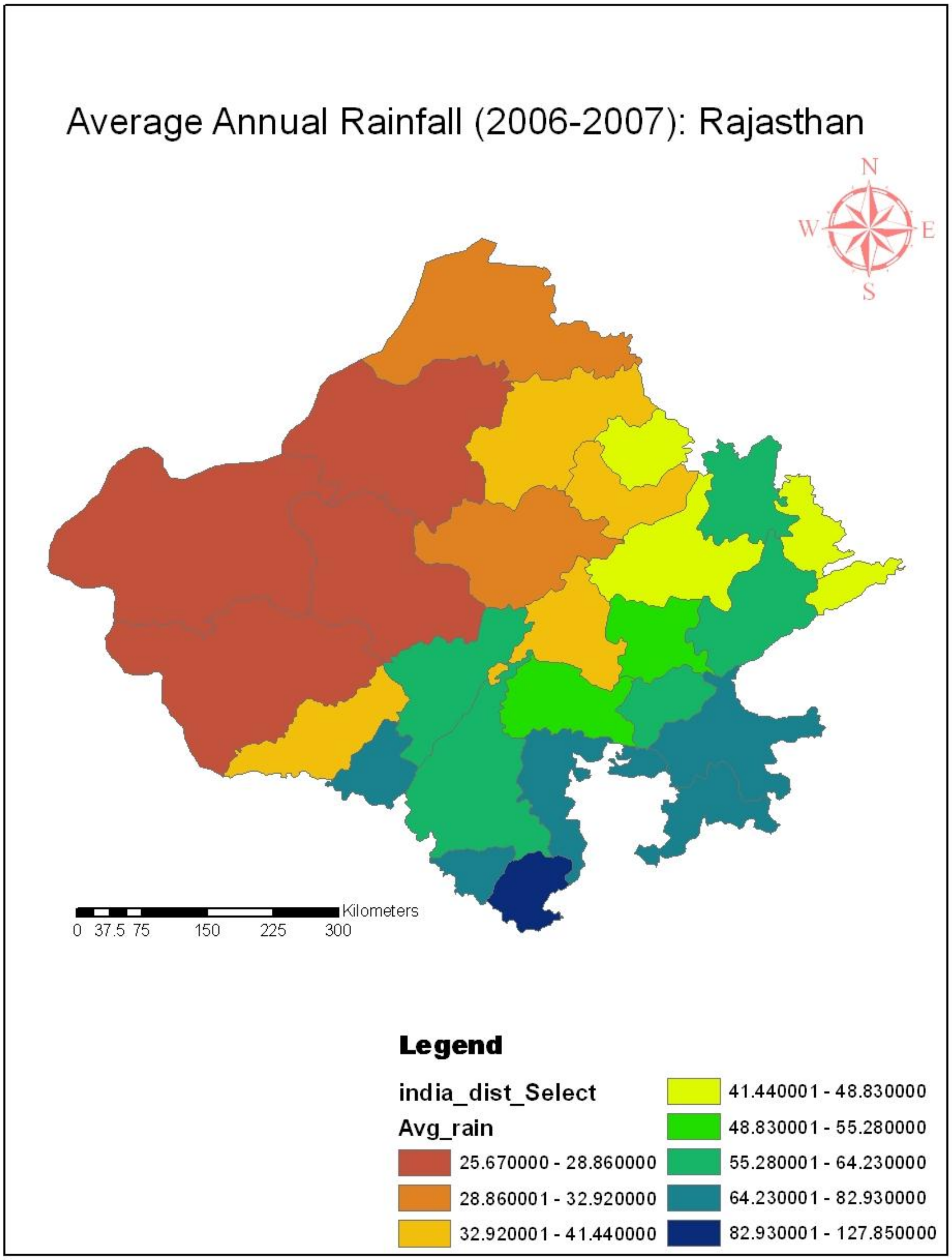
5.1 Rainfall, Climate, Soils and Physiography

Map 1 shows the rainfall in Rajasthan based on the average of mean values for different districts. Going by district-wise figures, the highest average mean annual rainfall is in Banswara, and lowest in Jaisalmer. The mean annual rainfall in the state varies from 250 mm in the northwestern parts in Jaisalmer to 1100 mm in the south-east. The coefficient of variation is the rainfall is also very high, particularly in the lower rainfall regions, with the values as high as 60 per cent. Number of rainy days decreases gradually from 31-40 days in the south-east to less than 20 days in the north-west (Pisharoty, 1990).

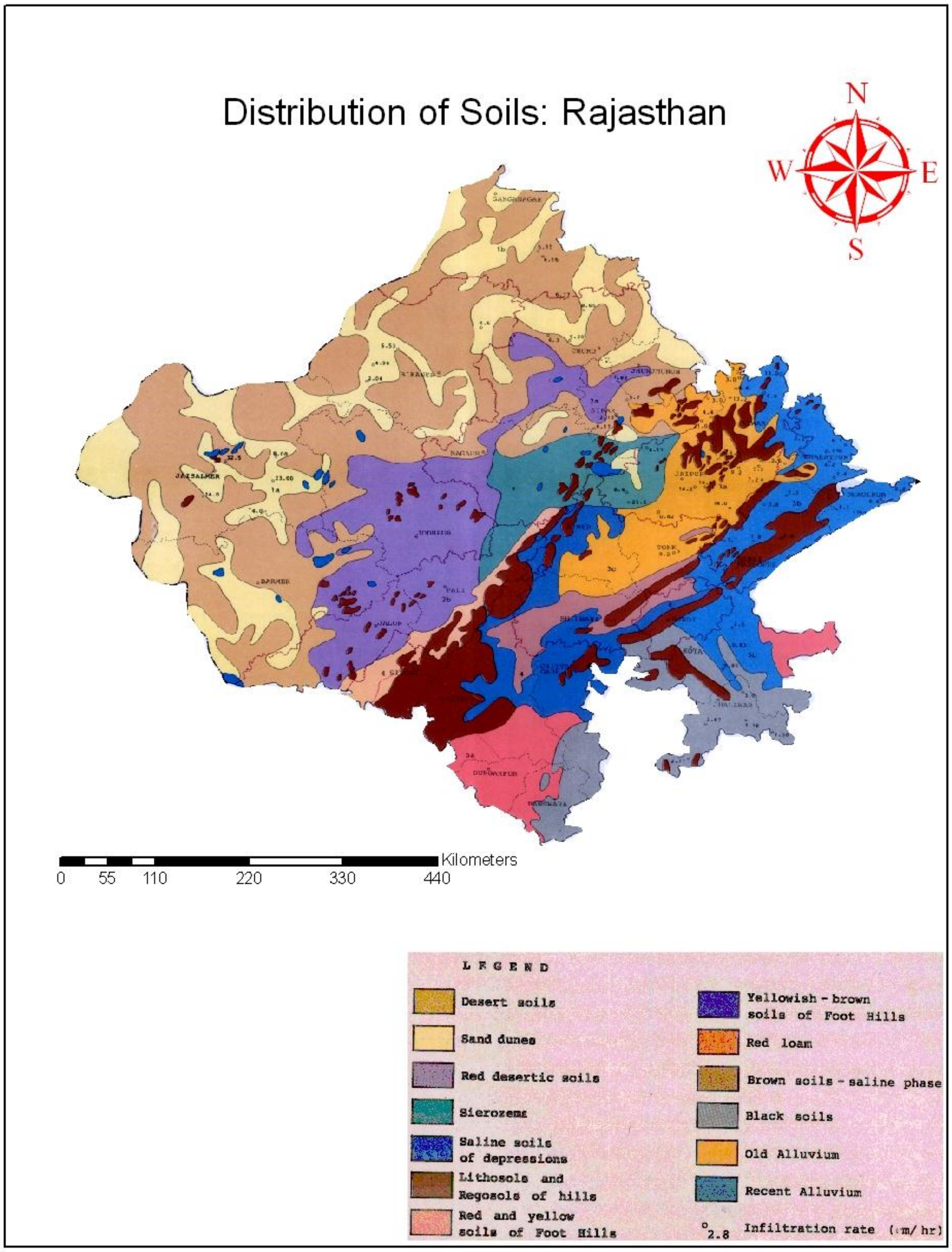
The Aravalli ranges lying in the NE-SW direction make a marked influence on the rainfall in Rajasthan. There is a sharp reduction in the amount of rainfall on the western side of Aravalli ranges, making western Rajasthan the most arid part of India. The average annual rainfall of different districts is given in Figure below. It is as high as 1278.5mm in Bhilwara.

The climatic variable which poses the greatest water management challenge to the state is the high evaporation. The annual reference evapo-transpiration values range from 1500 mm in the southern part of the state to 2000mm in western part in Jaisalmer (GOI, 1990). The annual potential evaporation is also very high as evident from the map. The spatial trend in reference evapo-transpiration in the state is almost opposite to the spatial trend in rainfall. But, in some parts of Udaipur, the reference evapo-transpiration is as low as 1400mm.

Map 1: Rainfall Isohyets of Rajasthan



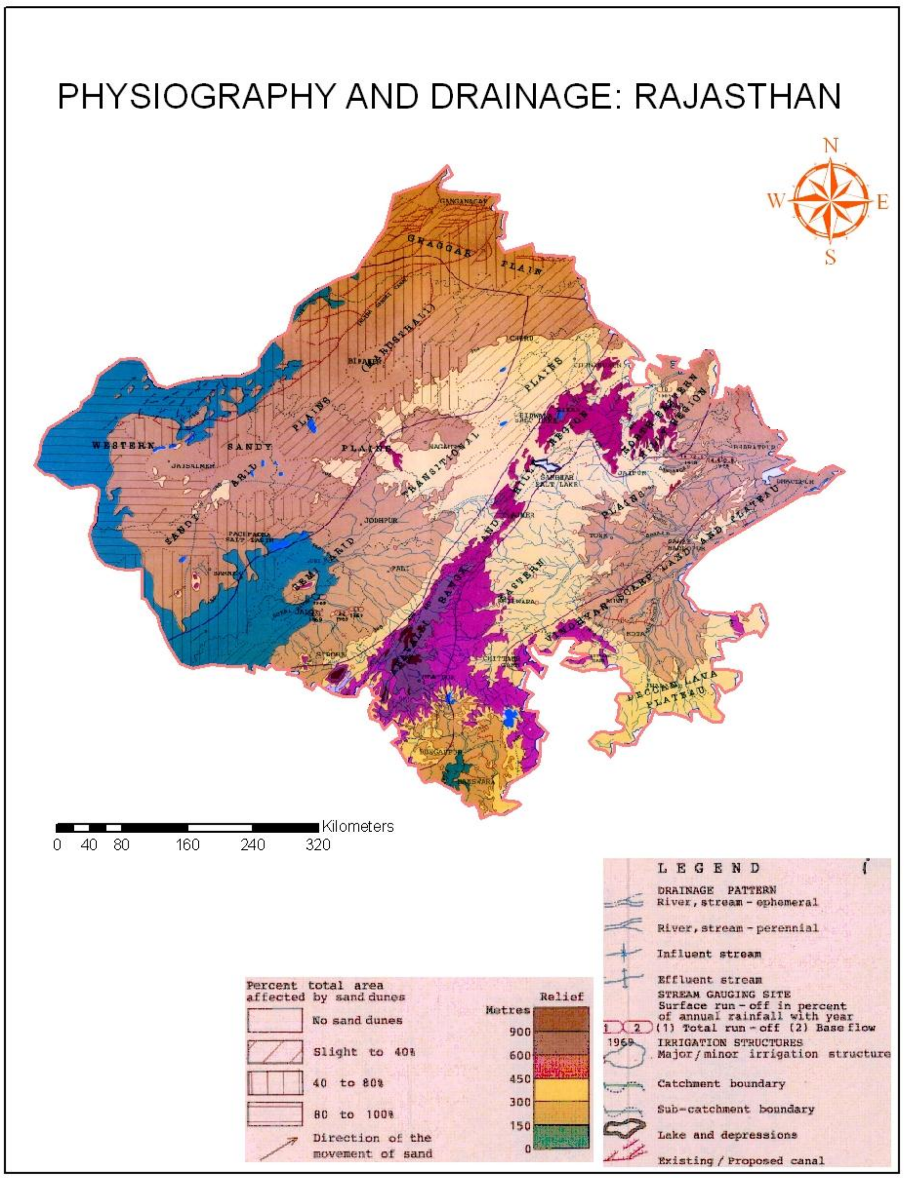
Map 2: Distribution of Soils



The different types of soils found in Rajasthan are desert soils with sand dunes extending over the entire western and northern Rajasthan; red desertic soils found in the south central parts covering most parts of Jodhpur, Pali and Jhalore districts; red loam found in parts of Udaipur, the entire Dungarpur and parts of Banswara and Kota district; old alluvium found in most parts of Jaipur, Ajmer, Alwar and Tonk districts; recent alluvium found in the entire eastern side of Rajasthan covering most parts of Dholpur, Sawai Madhupur, Bundi, Kota; Yellowish brown soils in parts of Bhilwara, Chittorgarh and Udaipur; Sierozeme found in parts of Nagaur and Jaipur districts. In addition, red and yellow soils are found in the foot hills of the Aravalli ranges on the western side.

Very high soil infiltration rates pose another big challenge to water management. Soil infiltration rates show wide variation across Rajasthan from 0.63 cm/hour to 32/5 cm/hour. The infiltration rates are extremely high in the desert soils found in Churu, Bikaner, Jaisalmer and Ganganagar (2.04 to 32.5 cm/hour), and old alluvium found in Tonk, Alwar and Jaipur (0.82 to 21.0 cm/hour). It is relatively lower in the recent alluvium found in parts of Chittorgarh, Sawai Madhupur, Bundi, Udaipur, Dholpur and Bharatpur (0.63 to 12.0 cm/hour), and black soils found in parts of Jhalawar, Kota and Banswara (0.86 to 2.77 cm/hour). It is high in the red desertic soils found in most parts of Jodhpur, Jhalore, Pali and small parts of Jhunjhunu and Sikar (11.82 cm/hour measured only at one location). Sierozeme found in parts of Jaipur, Nagaur and Pali have infiltration values ranging from 8.11 to 25.2 cm/hour.

Map 3: Physiography and Drainage of Rajasthan



Map 3 provides the physiographic features of Rajasthan. Physiographically, Rajasthan can be divided into seven distinct parts, viz., western sandy plains (0-150 m) having 80-100 per cent sand dunes; Ghaggar plain with 40-80 per cent sand dunes (150 -300m); sandy arid plains with slight to 40% sand dunes; semi arid transitional plains with slight to 40% sand dunes but at an elevation of 300-450 m; Aravalli range and hilly regions from 600 to 900m and above; north eastern hilly region; eastern plains; Vindhyan scarp land and plateau; and Deccan lava plateau. Both the western sandy plains and sandy arid plains have almost no drainage. The semi arid transitional plain is drained by Sukri river and Luni river. The Aravalli ranges in the southern part are drained by rivers flowing towards the south, viz., Banas and Sabarmati. The eastern plains, the Vindhyan scarp land and plateau and Deccan lava plateau are drainage by Banas river and Chambal river flowing towards the eastern and north eastern direction, respectively.

5.2 Groundwater resources and the heterogeneity

The geo-hydrological map of Rajasthan shows that the state is characterized by heterogeneity in groundwater conditions. The state has all formations, viz., unconsolidated, semi consolidated fully consolidated, with varying groundwater potential.

The unconsolidated formations include: 1] recent alluvium, brown sand, clay, silt and gravel, pebble, calcareous concretion, which are fairly thick and regionally extensive, confined to semi-confined aquifers ; and 2] older alluvium, laterite, silt, sand , ferruginous concretion and cobbles, confined to semi confined aquifers to a depth of 39-300 metre below the ground. They are porous formations. The aquifer potential varies widely between (40-100 litres per second) for the very good ones, to 10-40 litres per second for moderately good ones to less than 10 lps for low potential ones.

The semi-consolidated formations include: clay-stone, sandstone, grit, silt stone, conglomerate, and limestone. They also form porous aquifers, and have groundwater potential varying from less than 10 lps to 100 lps.

The consolidated formations are classified into four categories: 1] "effusives" comprising basalt with inter-trappean clay; 2] "sedimentaries" comprising sandstone, limestone, dolomite and shale; 3] "meta-sedimentaries & meta volcanics" comprising slate, quartzite, schist, gneiss and marble; and 4] "basal crystallines" comprising phyllite and granite. All these are fissured rocks. The yield of the aquifers varies widely between 5-10 litres per second (good for fissured rocks) to below one litre per second. The hilly aquifers are found in very small pockets in south Rajasthan.

Geographically, unconsolidated porous regionally extensive formations, with low groundwater potential cover the northern and north eastern and southern parts the state, comprising the entire Ganganagar, most parts of Churu, Pali, Balmer, Jaipur and Alwar districts. But, there are some pockets within these unconsolidated formations which have high yields. These patches are in Jhunjhunu, Sikar and Sirohi districts (see map 2). But, the groundwater underlying the entire Ganganagar and Churu districts is saline, and therefore unfit for irrigation and drinking.

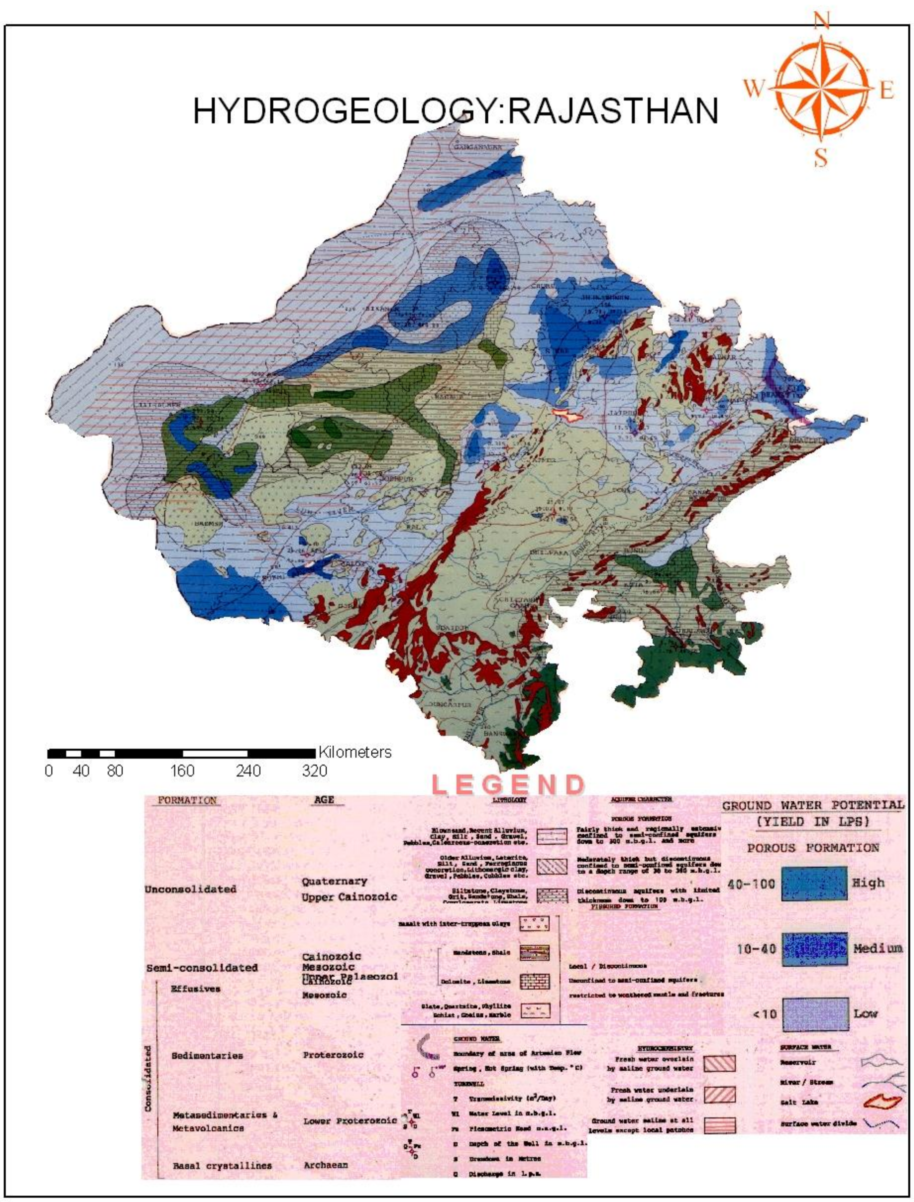
Unconsolidated discontinuous aquifers with poor yield potential cover the western parts covering the Thar Desert in Jaisalmer. Most of it is saline, except some patches in the extreme west,

Semi consolidated aquifers of low yield potential are found in parts of Jaisalmer, Bikaner and Churu districts. There are patches of semi consolidated aquifers with moderate yield potential in Balmer and Sirohi districts, and high yield potential in the lower north western parts, covering parts of Bikaner and Churu districts. These aquifers are inherently saline. But, over the years, the quality of groundwater in this region has improved, reasons for which would be discussed in the next section.

Consolidated fissured formations of sandstone and shale with low yield are found in Nagaur and Jodhpur districts, and that with moderate yield potential are found in other parts of Nagaur, Jodhpur and Jaisalmer districts. Consolidated limestone and dolomite formations in small patches are found in Nagaur, Jodhpur and Jaisalmer districts.

Consolidated fissured formations of meta-sedimentary and meta- volcanic origin with low yield potential (1-5 lps) are found in the southern parts extending up to the central part of Rajasthan. They cover the entire Udaipur and Dungarpur, and parts of Bhilwara, Jhalore, Chittorgarh and Tonk districts, and also in some pockets in Jaipur and Alwar district. Consolidated fissured sedimentaries with low yield potential are found in parts of Jhalore, Bhilwara, Chittorgarh and the entire Sawai Madhupur, Dholpur and Kota districts. Basalts with inter-trappean clay is found in southern part of Jhalawar, and eastern part of Dungarpur and Banswara districts.

Map 4: Geo-hydrological Map of Rajasthan



5.3 Surface water resources and irrigation development in Rajasthan

Rajasthan does not have a great history of surface irrigation, unlike south India. Though the state has several traditional water harnessing systems such as the *johads*, *kadin*, *nadi*, *kund* and tanks, the contribution of these systems to expanding irrigation hasn't been remarkable.

The state has very few major rivers, namely, Sabarmati, Banas, West Banas, Banganga, Chambal and Mahi. Banas is part of Chambal river system. The total Chambal catchment is 72,032 sq. km. Only the upper catchments of these major rivers (Mahi, Banas, West Banas, Sabarmati and Chambal) are located within the state. As the result, the state's rights to water from these basins are extremely limited. All the rivers originating from the state, including the major rivers, are seasonal in nature. Some of the west flowing rivers of the state are highly ephemeral in nature, and carry stream flows for very few days during the rainy season. In western Rajasthan, most of the area (except that of Luni river) drainage is internal, and streams are lost in the desert.

Rajasthan has several large freshwater lakes. Some of them were major sources of water to some cities. The RaJasamand lake, Fateh Sagar lake and Pichola lake in Udaipur, Ana Sagar lake in Ajmer, Pushkar lake, and Gadsisar lake in Jaisalmer are the most important freshwater lakes in the state.

Table 1: Description of River Basins of Rajasthan

Sr. No	Name of the Basin	Description	Drainage Area (sq. km)
1	Ahar River	Ahar River is a tributary of the Berach River. It originates in the hills of Udaipur District, and flows through the city of Udaipur before it joins the Berach	3516.50*
2	Chambal River	The Chambal river remains one of North India's most unpolluted rivers, home to a rich diversity of flora and fauna. National Chambal Wildlife Sanctuary is famous for the rare Ganges river dolphin.	18,446.45
3	Banas River	The Banas is a river of Rajasthan state in western India. It is a tributary of the Chambal River, which in turn flows into the Yamuna, a tributary of the Ganges. The Banas is approximately 512 km in length.	33,760.05
4	Banganga River	River Banganga originates in the Aravali hills, near Arnasar and Bairath in Jaipur District. It flows towards the south up to the village of Ghat, then east through partly hilly and partly plain terrain.	6742.57
5	Sabarmati River	Sabarmati River Basin is situated in the mid-southern part of Rajasthan, between latitudes 23o25' and 24o55' and longitudes 73o00' and 73o48'.	3288.68
6	Luni River	Luni River Basin is located in south-western Rajasthan, between latitudes 23o41' and	34,866.4

		27o05' and longitudes 71o04' and 74o42'.	
7	Mahi River	The Mahi is a river in western India. It rises in Madhya Pradesh and, after flowing through the Vagad region of Rajasthan, enters Gujarat and falls into the sea by a wide estuary near Cambay. Its total length is 500 km and its drainage area is 40,000 sq. km.	16,551.18
8	Gomati River	Gomati River is a small river. It originates in the hills of central Udaipur District, flowing south to join the Som River in the southern part of the district. The river was dammed in the 17th century to create Dhebar Lake, also known as Jaisamand Lake, which has an area of 50 km².	Tributary of Mahi river
9	West Banas River	It originates the southern Aravalli ranges in Sirohi District of the state of Rajasthan. It flows south, draining the valley between Mount Abu on the west and the easterly ridge of the Aravallis on the east. It continues south through the plains of Gujarat state, flowing through Banaskantha and Patan districts and finally empty into the seasonal wetland of Little Rann of Kachchh	2837.81

*Note: the drainage area is of Barah basin.

The important surface irrigation schemes in terms of irrigable command area in the state are: IGNP, Chambal, Ganganagar and Bhankhara. IGNP covers large parts of Bikaner, Ganganagar, Hanumangarh and Jaisalmer and a small area in Churu. Chambal scheme covers areas in the districts of Baran, Bundi and Kota. Ganganagar scheme covers parts of Ganganagar district. Bhankhara scheme covers areas in Ganganagar and Hanumangarh.

The total surface water irrigated area in the state is only 2.507 million hectares. But, a large share of the surface irrigation (80 per cent) is concentrated in northern and north-western Rajasthan in the six districts of Ganganagar, Hanumangarh, Bikaner, Bundi, Kota and Jaisalmer. Three of these districts (Ganganagar, Jaisalmer, Bikaner and Hanumangarh) have saline groundwater and this is not suitable for irrigation.

5.4 Groundwater development for irrigation in Rajasthan

Rajasthan stands first in terms of degree and extent of over-exploitation of groundwater resources in the country. One reason for this phenomenon is the absence of sufficient number of large-scale surface irrigation facilities, well-spread geographically. The low to medium rainfall in most parts, high evapo-transpirative demands for water, high frequency of occurrence of droughts resulting from the departure of rainfall from mean values, and the high per capita arable land (0.18 ha) increases the demand for irrigation water. This is being met through mining of groundwater resources. The free power in agriculture continued for many years, and the existing pump horse power based pricing of electricity encourage over-pumping and inefficient and often wasteful use of groundwater.

The total utilizable groundwater in the state was estimated to be 8034.7 million cubic metres, against which the total groundwater draft for various uses was estimated to be 11,599 million cubic ha metre. Hence, even at the aggregate level, groundwater is over-developed. The gross groundwater irrigated area in the state is 2.962 million hectares. This accounts for 54.2 per cent of the total irrigated area in the state. Out of the 32 districts in the state, groundwater is over-exploited in 21 districts, with the level of average annual abstraction exceeding the average annual recharge.

5.4.1 Response to Groundwater Depletion

The state's response to over-exploitation has largely been through launching of water harvesting and artificial recharge schemes based on local water resources. But, the fact that all the basins in Rajasthan are "closed", with no surplus water flowing out of the region as waste (Kumar et al., 2008a), these schemes have not been effective in improving the overall water situation in the state's river basins. The Tarun Bharat Sangh (TBS) had done exemplary work in mobilizing community action to address water scarcity problems by helping them to plan and build thousands of traditional water harvesting/recharge systems such as the *Johads* in Arawari basin in Alwar district of Rajasthan. Here again, the schemes had only led to redistribution of water within the basin affecting the downstream reservoirs and communities dependent on them adversely, leading to conflicts between the state irrigation bureaucracy and the NGO. Many other NGOs in Rajasthan are also using small water harvesting as a major instrument to deal with water scarcity and groundwater depletion in the region. The work of other NGOs in the state falls in similar lines. Overall, village becomes the decision making unit for the NGO interventions, and the concept of river basins remains un-touched territory.

While the fact remains that agriculture takes lion's share of the groundwater pumped in a water-scarce state like Rajasthan, there are no organizations working on promoting water productivity in well irrigated farming. The power of the idea of enhancing irrigation water productivity in agriculture is largely unexplored in well-irrigated areas. Interestingly, in the command areas of IGNP, government has been promoting the use of micro irrigation systems by subsidizing the construction of *diggies,* which enables farmers to use pressurized irrigation systems.

5.5 Water Institutions in Rajasthan

The major state level government agencies, concerned with water resources in the state, are the Rajasthan State Water Resources Department; Rajasthan State Groundwater Department; Rajasthan State Public Health Engineering Department; and the State Pollution Control Board. The state water resources department is concerned with planning, design, execution and management of surface water systems in the state, including major, medium and minor irrigation schemes. The state groundwater department is concerned with planning and evaluation of groundwater in the state. The state pollution control board monitors water quality of selected natural streams, lakes, reservoirs and wells and also enforces pollution control norms.

The central Ground Water Board (CGWB), which is a national level institution, under the Ministry of Water Resources, Government of India, is concerned with survey, investigation, estimation, planning, and regulation & management of groundwater in the country. CGWB has its western regional office in Jaipur. They are undertaking periodic monitoring of groundwater levels and quality in the state through a network of observation wells.

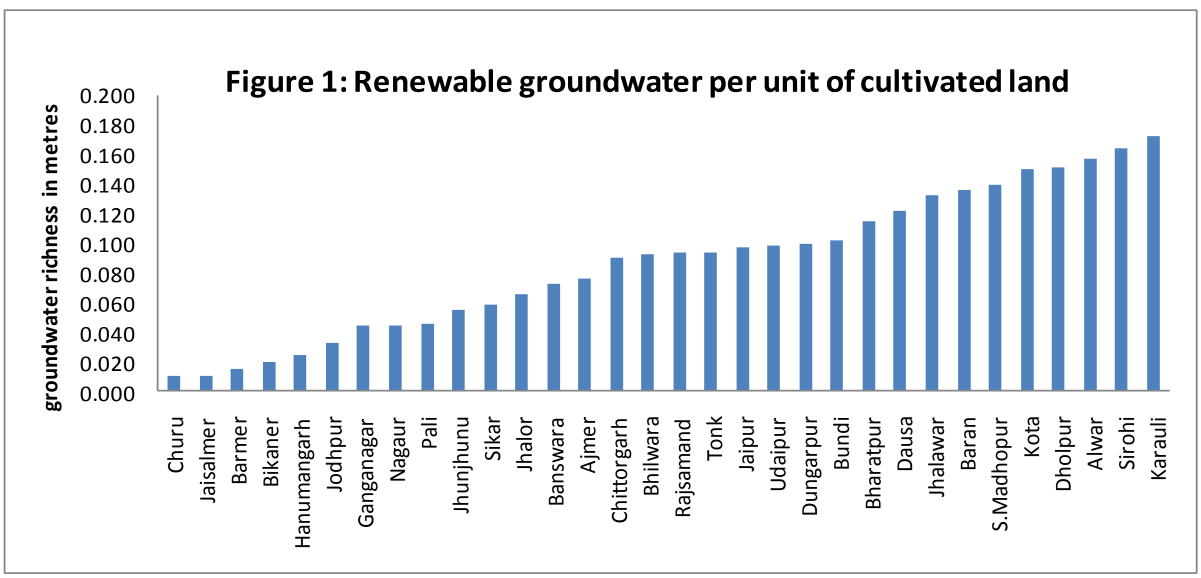
In addition to the government agencies, there are two major research institutions working on water resources in the state. They are: Central Arid Zone Research Institute (CAZRI), Jodhpur under ICAR, and Institute for Development Studies, Jaipur. CAZRI undertakes research on several water issues, and water management technologies for the arid region of the state including that for drinking water supplies. The major NGOs working in Rajasthan are Sewa Mandir, Udaipur, People's Education and Development Organization (PEDO), Dungarpur; N. M. Sadguru Water and Development Foundation; and Tarun Bharat Sangh, Alwar. Among these NGOs, the ones which are most active in the state are Sewa Mandir and Tarun Bharat Sangh. They are heavily involved in implementing water management projects, focusing mainly on interventions for augmenting water resources and water supplies.

There is a paucity of institutions within the civil society which are undertaking research on water management issues in Rajasthan. The only exception is the Hanumana Trust in Alwar, which works on water management issues in agriculture.

6. Presentation of Results

6.1 Groundwater resources availability district-wise

The estimates provided by the Central Ground Water Board shows that the largest amount of renewable groundwater resources is in Alwar district (79,036 ha m), followed by Jaipur (60,695 ha m). The resource availability is poorest in Rajasamand, Jaisalmer and Churu are 9,415 ha m, 6,009 ha m and 12,898 ha m, respectively (Figure 1). The groundwater resources per unit of arable land,

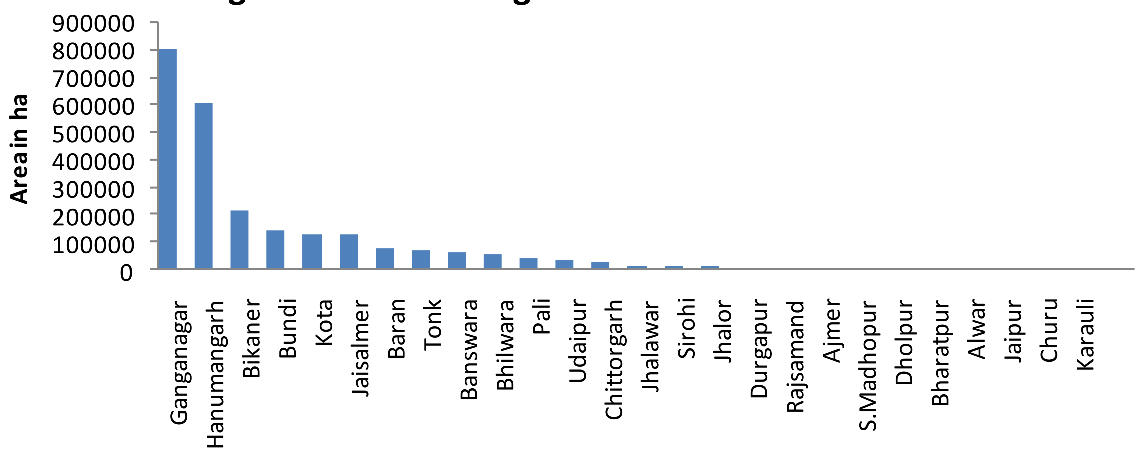


which is reflective of the relative availability of the resource to use for irrigation, shows that groundwater is most plenty in Karauli and S. Madhupur. Alwar has a groundwater richness of 0.157 m, where it is 0.098 for Jaipur. But, we must keep in mind the fact that the very fact that resource is available in plenty might have driven agricultural growth in some districts, leading to expansion of net sown area, thereby reducing the relative availability of the resource. In fact the net cultivated area as a percentage of the geographical area is very high in Jaipur and Alwar.

6.2 Surface irrigation: district-wise

Data on area irrigated by canals in Rajasthan shows that Ganganagar has the largest area under surface irrigation (8.0385 lac ha), fully contributed by canals. This is fully contributed by the Indira Gandhi *Nehar Yojna*, which brings in water from Sutlej River to the western arid districts of the state. Ganganagar is followed by Hanumangarh district with a total area of 6.11 lac ha and Bikaner with 2.188 lac ha. It is important to remember here that groundwater in the entire Ganganagar district is saline, and not usable for irrigation. None of the districts have area irrigated by tanks, which is the second largest contributor to surface irrigation in the state. Figure 2 shows the total area irrigated by surface sources in different districts of Rajasthan. The figure only shows the names of districts which have some area under irrigation, and excludes those which have no surface irrigation, viz., Dausa, Nagaur, Jhunjhunu, Jodhpur and Sikka.

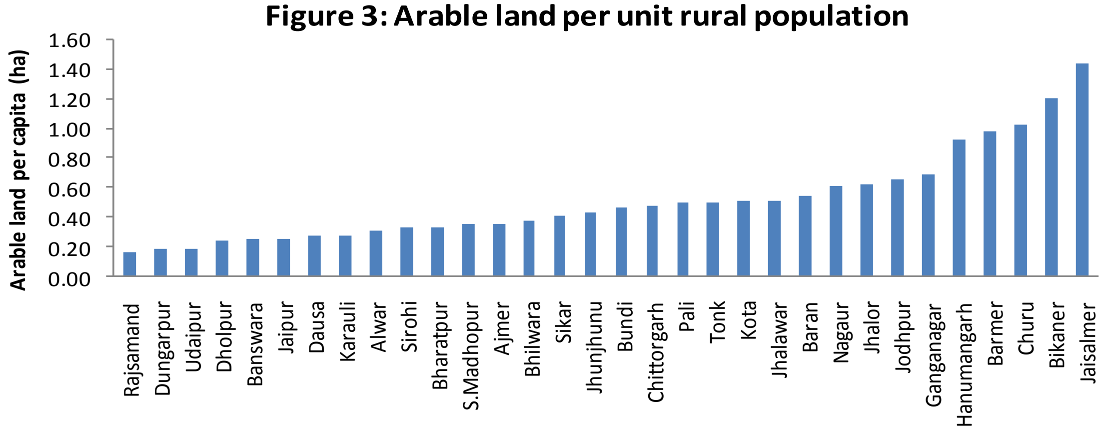
Figure 2: Surface irrigated area in different districts



6.3 Cropped Land per unit of rural population

Per capita gross cropped area in relation to rural population is a strong indicator of how important is agriculture for the state or the importance that agriculture can play in the future growth of the countryside. Our analysis using gross cropped area and rural population shows that

Figure 3: Arable land per unit rural population



Jaisalmer has the highest per capita arable land (1.41 ha), followed by Bikaner (1.2 ha) (Figure 3). These districts fall in the very low rainfall receiving, sand dune affected, highly arid western Rajasthan, which is sparsely populated. Also, large tracts of these districts are covered by sand dunes (80-100 per cent), and desert soils. In fact, it is the sparse population, due to historical scarcity of water, poor quality of land and hostile environment, which pushes the per capita arable land figures upwards. But, in spite of the large cultivated land, due to these hostile environments prevailing in these districts due to the agro-climate and scarcity of water, productivity levels are very low. Since the groundwater in these districts is saline, the only way to bring the cultivable area under production is through import of surface water, like what is being done in Ganganagar and Bikaner.

Rajasamand, Dungarpur and Udaipur are the districts having lowest per capita arable land, and these are districts having large amount of forest land. These are districts receiving highest rainfall in the state.

6.4 Intensity of groundwater use per unit of Cultivated Land and Population

6.4.1 Gross Groundwater Irrigated Area & Irrigated Area per Capita

It has been found that adoption of MI systems in India is largely confined to farmers with individual wells with energizing devices (Kumar *et al*., 2008b). The only exception is Bikaner in Rajasthan, where canal irrigators have large storage systems in their fields. The very large land holdings of the farmers in this area had increased the physical feasibility and socio-economic viability of this system. Hence, one of the pre-requisites for large-scale adoption of micro irrigation systems by farmers is the presence of energized wells and large area under well irrigation.

Jaipur has the highest groundwater irrigated area in the state (309507 ha). Jaipur is followed by Jhunjhunu (265589 ha), and Alwar (250996 ha). In terms of per capita well irrigated area, Jhalore stands at the top with 0.147 ha per capita of irrigation. But, Jaipur has only the 12th position, and Alwar has the 8th position. One reason is the high population of the district. Jhunjhunu, which is second highest in terms of gross well-irrigated area, is second in terms of per capita well irrigation also.

Table 2: Gross and Per capita Groundwater Irrigated Area in Different Districts of Rajasthan

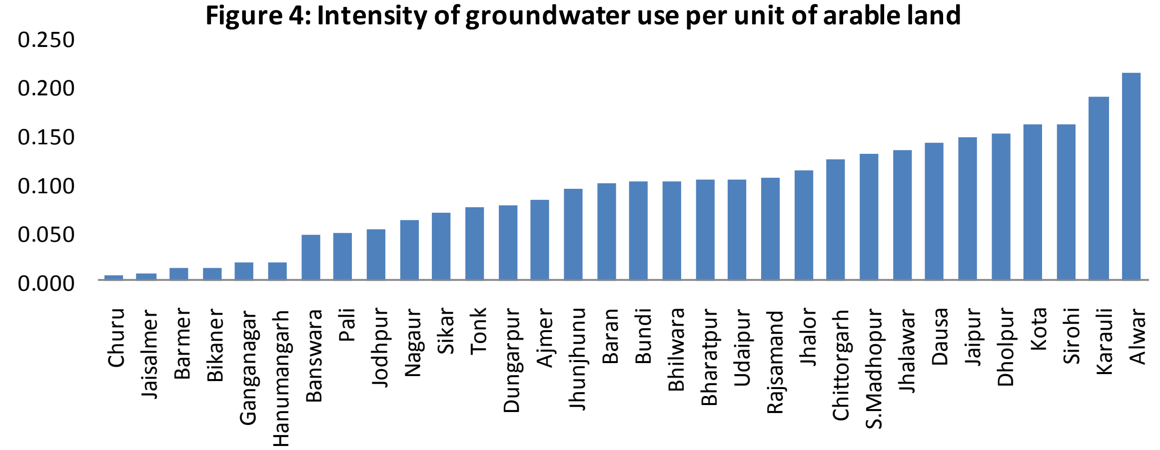
Sr. No	Name of District	Population	Groundwater Irrigated Area	Per Capita Well Irrigation (Ha)
1	Ganganagar	1789423	0	0.000
2	Hanumangarh	1518005	0	0.000
3	Jaisalmer	508247	0	0.000
4	Jodhpur	2886505	3510	0.001
5	Dholpur	983258	3594	0.004
6	Bharatpur	2101142	8436	0.004
7	Bikaner	1674271	8157	0.005
8	Banswara	1501589	18310	0.012
9	Kota	1568525	30835	0.020
10	Durgapur	1107643	25635	0.023
11	Churu	1923878	44864	0.023
12	Udaipur	2633312	81666	0.031

13	Ajmer	2181670	70522	0.032
14	Karauli	1209665	42182	0.035
15	Baran	1021653	42336	0.041
16	Rajsamand	987024	42497	0.043
17	Nagaur	2775058	130308	0.047
18	Pali	1820251	102179	0.056
19	Jaipur	5251071	309507	0.059
20	Dausa	1317063	80038	0.061
21	Bundi	962620	61551	0.064
22	Barmer	1964835	126946	0.065
23	Bhilwara	2013789	142434	0.071
24	Alwar	2992592	250996	0.084
25	Chittorgarh	1803524	154355	0.086
26	Tonk	1211671	107180	0.088
27	Sawai Madhopur	1117057	98962	0.089
28	Sikar	2287788	220593	0.096
29	Sirohi	851107	103634	0.122
30	Jhunjhunu	1913689	265589	0.139
31	Jhalore	1448940	212401	0.147

6.4.2 Intensity of Groundwater Use

Intensity of groundwater use in relation to arable land is a better indicator of how important is the resource for agriculture than the total amount of groundwater draft as the latter does not take into consideration the size of the arable land for which groundwater is needed for irrigation and the population, which demand the water. Figure 4 shows that groundwater use intensity is highest in Alwar (0.215m), immediately followed by Karauli (0.19 m), Kota and Sirohi. Jaipur has the 6th position vis-à-vis groundwater use intensity (0.148m). Alwar has the highest position in terms of aggregate groundwater withdrawal also (1080 MCM). Jaipur stands second in terms of aggregate groundwater draft (920 MCM). The other districts such as Karauli and Kota record high intensity use because of the much smaller area under cultivation in these districts.

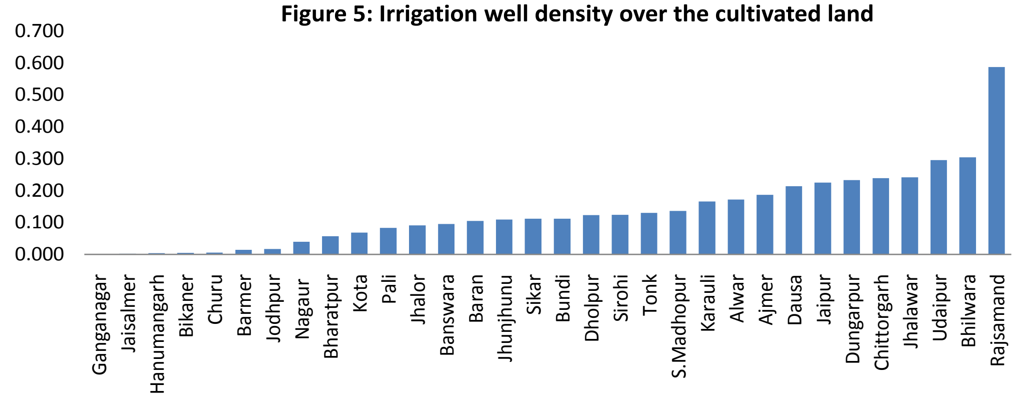
Figure 4: Intensity of groundwater use per unit of arable land



6.5 Density of groundwater abstraction structures

District-wise estimates of density of groundwater abstraction structures are presented in Figure 5. Density of groundwater abstraction structures ranges from nearly zero to 0.58 per ha. Well density does not mean much when the geological formations change and when the types of abstraction mechanisms change (Kumar, 2007). We have already seen that the geological formations display wide heterogeneity in Rajasthan. Also, the types of abstraction structures vary from open dug wells in the consolidated formations, to dug-cum-bore wells to bore wells (in consolidated formation with deep water table conditions) to tube wells in deep alluvial areas with deep water table conditions. The tube wells are generally the highest yielding groundwater structures and drilled in alluvial and semi consolidated sedimentary sandstone and limestone formations. The dug wells are the common groundwater abstraction structures in the crystalline hard rock areas of south and east Rajasthan, and also in alluvial areas when water level is very shallow. Further, in hard rock areas with deep water table conditions, farmers move from dug

Figure 5: Irrigation well density over the cultivated land



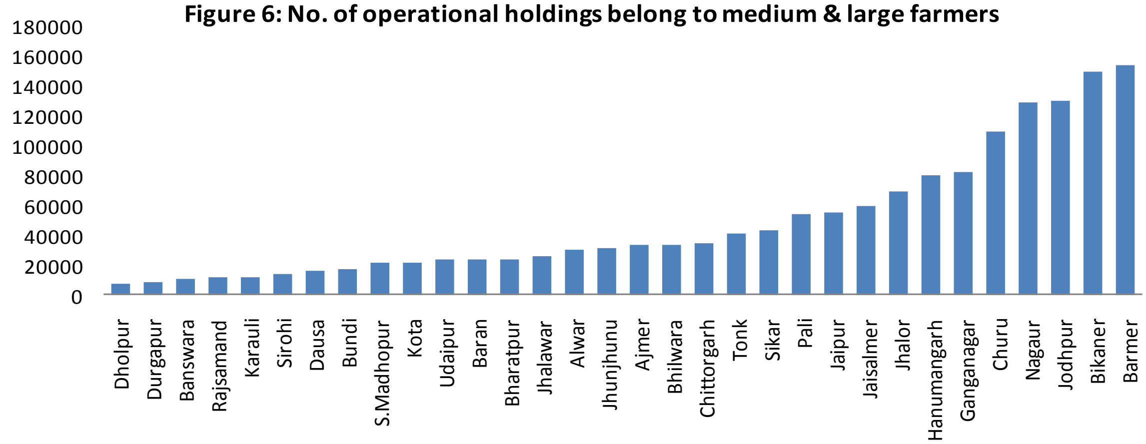
wells to dug-cum bore wells and deep bore wells.

Zero values for irrigation well density does not mean that wells do not exist in an area or groundwater is not used in an area, as there are wells drilled for meeting domestic and industrial water supply needs also. Nevertheless, irrigation being the largest user of groundwater in semi arid and arid regions in India (Kumar, 2007), irrigation well density is also an indicator of the importance of groundwater for the rural communities. The chart shows that irrigation well density is highest in Rajsamand district (0.58 per ha), followed by Bhilwara, Udaipur, Jhalawar, Chittorgarh, Dungarpur and Jaipur (0.225 per ha). While Alwar has the highest intensity of groundwater use, it does not have the same position when it comes to density of irrigation wells, which is only an average of one in every 5.8 ha of cultivated land. At the same time, while Rajsamand, Bhilwara and Udaipur are not among the top districts in terms of intensity of groundwater use, it has very high density of wells. This mismatch is because of the difference in well yields. In Udaipur and Rajsamand, which are underlain by consolidated crystalline formations, wells are low yielding, and as a result, more numbers of wells are required to cover a unit area of irrigated land.

6.6 Stage of groundwater development

Map 4 shows the stage of groundwater development in different districts of Rajasthan. It shows that Jhunjhunu experiences the highest degree of over-exploitation of groundwater with the total draft equal to 200 per cent of the annual recharge. The stage of over-exploitation in Jaipur is as high as 186.6 per cent. It can be seen that those areas which are underlain by alluvium and semi consolidated sandstone and limestone aquifers experience very high intensity of groundwater use, and have high degree of over-exploitation. Whereas those which are underlain by crystalline rocks, since there is not much static groundwater resources, the chances of over-exploitation beyond a certain level is impossible as wells would dry up under over-draft conditions. The most poorly developed groundwater resources are in Ganganagar, with a stage of development of only 45 per cent. One reason for this phenomenon in spite of the very low potential of fresh groundwater could be the presence of canal water.

Figure 6: No. of operational holdings belong to medium & large farmers



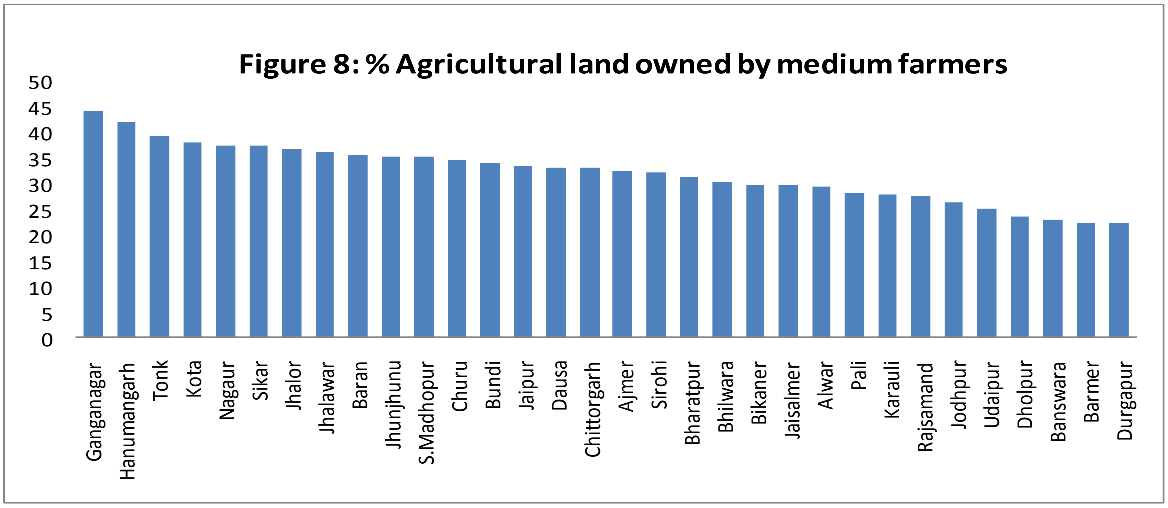
6.7 Large holding pattern in different districts

Figure 6 provides the number of operational holdings belonging to large and medium farmers. As the Figure indicates, Barmer has the largest number of large farmers. This is followed by Bikaner, Jodhpur, Nagaur and Churu. However, these are very hot and arid districts, with very poor water endowment and very poor irrigation facilities, and hence the rural areas have very sparse population. As a result, most farmers have large plots of land.

Further analysis was done wherein we looked at the percentage area of operational

Figure 7: % Area of operational holdings with the large farmers

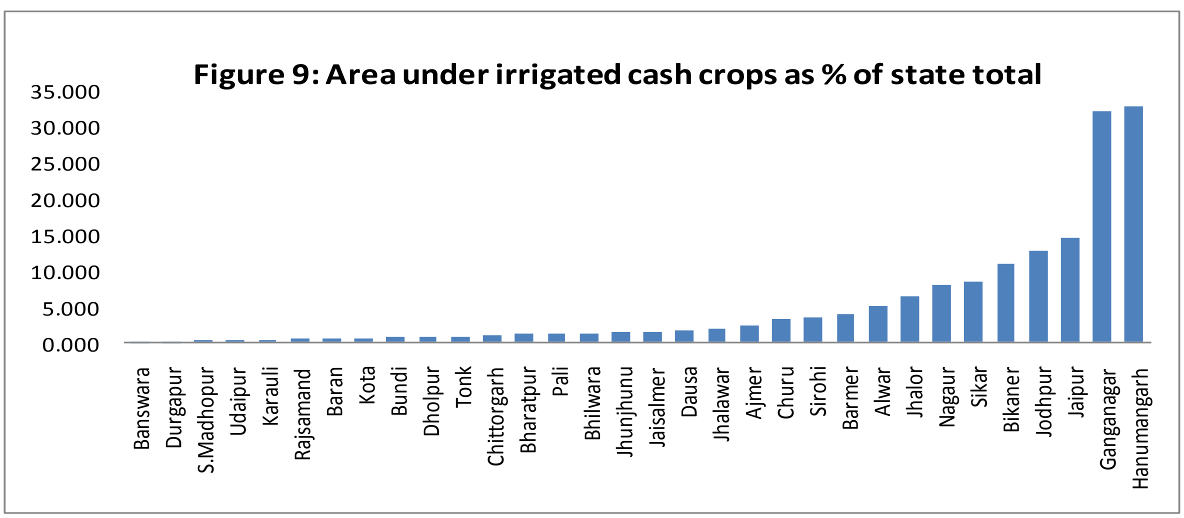
holdings belonging to large and medium farmers. The results are presented in Figures 7 and 8, respectively. Unlike many other Indian states, in Rajasthan large farmers occupy large portion of the agricultural land. It is as high as 72 per cent in Barmer. Bikaner, Jaisalmer, Jodhpur, Churu and Ganganagar also have very large percentage of the agricultural land in the hands of large farmers. But, these districts used to be highly water-scarce districts, and also had problems of poor land quality. Among these, Ganganagar and Bikaner are now receiving water from Indira Gandhi Nehar Yojna, and irrigated agriculture is now prospering in these areas. Relatively water rich Jaipur and



Ajmer have 22.8 per cent and 21.3 per cent area in the hands of large farmers.

6.8 Aggregate and Percentage Area under Cash Crops

Area under cash crops in each district as a percentage of the total cash crop area in the state was estimated and presented in Figure 9. The district of Hanumangarh has the largest area under irrigated cash crops (152427 ha), followed by Ganganagar (149988 ha) and Jaipur (67,617 ha). Jaipur has the 3rd position, and Alwar has the 9th position. In terms of percentage of state total, it is 32.89 per cent in Hanumangarh, and 32.36 per cent in Ganganagar. These cash crops include vegetables,



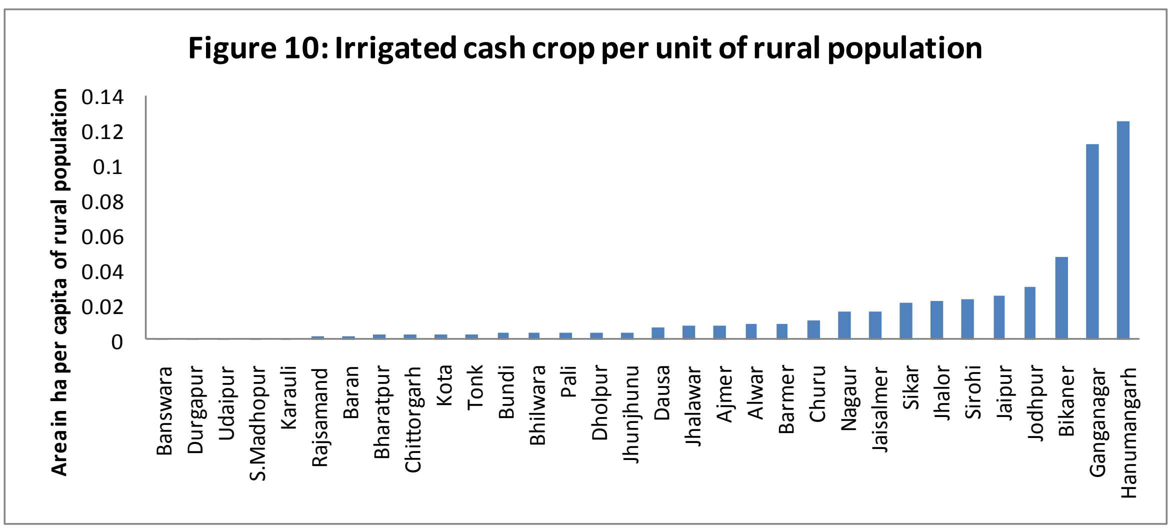
fruits, groundnut, castor and cotton (different varieties). These figures are important, as the initial feasibility of micro irrigation in any district would depend largely on the area under crops that are amenable to these technologies in that region. But, if we look at the actual area under cash crops which are under well irrigation, Jaipur will be in the first position, as in the two other districts, canals are the only source of irrigation. The reason for considering well irrigated crops is that it is practically difficult to bring canal irrigated crops under MI systems, as it would require special storage systems for water.

6.9 Area under Cash Crop per unit of Rural Population

Cash crops such as vegetables, cotton and fruits are highly amenable to well irrigation. These are crops which actually would benefit from micro irrigation, particularly drip irrigation. Area under irrigated cash crops in per capita (rural population) terms is highest in Ganganagar, followed by Hanumangarh and Bikaner (Figure 10). Here, in addition to Hanumangarh and Ganganagar, we can ignore Bikaner also, as this district is also mainly irrigated by canals.

Jaipur, which has the highest position in terms of groundwater irrigated area and 12th position in terms of per capita well irrigated area (0.05 ha), occupy the 5th position in terms of irrigated cash crop per unit of rural population (0.025 ha per capita of rural population). Alwar has the 13th position vis-à-vis per capita area under cash crops. While this could mean low level of efficiency in the use of groundwater in these groundwater irrigated districts, it also means that there is tremendous potential for shifting to high valued cash crops in the region using well irrigation.

But, there are large differences in cultivated area between districts. Hence, in order to capture the dominance of cash crops in district's agriculture, it is important to get the figures of total cash crop area as a percentage of the gross cropped area. The analysis shows that Jaipur has highest percentage area under cash crops (7.85%), after Ganganagar and Hanumangarh.



7. Findings

- Rajasthan displays high degree of heterogeneity in groundwater resources. Almost all the geological formations of various origins are found across the country are found in Rajasthan. Unconsolidated, semi consolidated and consolidated aquifers are found.

- Geologically, the unconsolidated formations cover recent alluvium, brown sand, clay, silt and gravel, pebble, calcareous concretion, older alluvium, laterite, silt, sand , ferruginous concretion and cobbles. Semi-consolidated formations include clay-stone, sandstone, grit, silt stone, conglomerate, and limestone. The consolidated formations encountered are basalt with inter-trappean clay, sandstone, limestone, dolomite and shale, slate, quartzite, schist, gneiss and marble; and phyllite and granite. The aquifer characteristics differ in quantity and quality. While some aquifers are high yielding, some are low yielding.

- Among the 31 districts, Alwar has the highest groundwater potential, assessed in terms of the annual renewable groundwater resources (790 MCM per annum), followed by Jaipur with 607 MCM of water. Ganganagar has the lowest fresh groundwater potential.

- The "groundwater richness", expressed in terms of groundwater resource availability per unit of arable land (net sown area) is highest in Karauli. Alwar has the third position, but Jaipur has only the 14th position in "groundwater richness". But, the fact that groundwater resources availability is relatively higher in these districts (Alwar and Jaipur) might have driven agricultural growth in these districts, thereby increasing the net sown area. Also, these districts have very little of forest land, unlike the districts of South and South eastern Rajasthan, favouring the expansion of cultivated land.

- Arable land per unit of rural population is highest in Jaisalmer (1.44ha), followed by Bikaner with 1.20 ha per head of rural population. Jaipur has the 26th position with 0.26 ha per capita of rural population, and Alwar has 23rd position. One reason for the very high arable land availability in the hyper-arid districts of Jaisalmer, Churu and Bikaner is that historically, these districts are sparsely populated due to hostile environments (sand dunes, extremely low rainfalls, and high temperature and aridity) and poor quality of agricultural land. Contrary to this, better natural resource endowment in districts like Alwar and Jaipur make them densely populated. Hence, though the per capita arable land is high among many districts of north Rajasthan, productivity is very low in many of these districts. Productivity is also low in the districts of south Rajasthan.

- Groundwater use intensity, expressed in terms of total groundwater draft per unit of arable land, is highest in Alwar (0.215 m), follo**w**ed by Karauli. Jaipur has the 6th position in terms of groundwater use intensity. In spite of 14th position in groundwater richness, groundwater use intensity is 6th highest for Jaipur. This means, the degree of exploitation of groundwater in Jaipur is much higher than that of many of the "groundwater rich" districts. One of the reasons for heavy dependence on groundwater is the poor availability of surface water in these districts.

- Groundwater-irrigated area, in terms of gross area irrigated by wells, is largest for Jaipur, followed by Jhunjhunu and Alwar. Irrigation is through tube wells (in alluvial areas) and bore wells and open wells in hard rock areas. Well density (expressed in terms of no. of wells per unit of arable land) is highest in Rajasamand, followed by many districts from South Rajasthan, which are fully underlain by hard rock formations. Jaipur has the 6th position in well density. Though well density in Alwar is much lower when compared to some of the high well density areas, it has high intensity of groundwater use. This indicates that the wells here are high yielding.

- Surface water irrigation is highest in Ganganagar, followed by Hanumangarh and Bikaner. These districts receive water from IGNP canals. Surface irrigated area is extremely low in Alwar and Jaipur, with them occupying 23rd and 24th positions, respectively.

- Degree of groundwater over-exploitation is highest in Jhunjhunu (200 per cent), followed by Jodhpur (199) and Jaipur (186) and Alwar.

- Balmer has the maximum number of operational holding belonging to the large and medium farmers, followed by many of the hyper-arid districts in western and north western Rajasthan viz., Bikaner, Hanumangarh, Churu, Jaisalmer and Ganganagar. These also coincide with the districts which have very high arable land per capita of rural population. But, these districts do not have significant well irrigation. The total number of large and medium operational holdings is 55,611 in Jaipur and 29,834 in Alwar.

- The percentage area of operational holdings belonging to large farmers is highest in Ganganagar (44.3 per cent). Jaipur and Alwar have 14th and 23rd position, with 22.5 per cent and 6.9 per cent, respectively. The percentage of area of operational holdings belonging to medium farmers is highest in Balmer (72.1 per cent). Jaipur has 13th position (33.5 per cent) and Alwar has 28th position. But, if we exclude the districts having little well irrigation, Jaipur and Alwar will have a more dominating position with regard to number of large & medium farmers, and area belonging to large holdings. The adoption of modern farming practices and high valued and high risk crops is likely to be high in areas which have greater number of farmers with large operational holdings.

- Aggregate area under cash crops is highest in Hanumangarh, which occupies nearly 32.86 per cent of the total irrigated cash crops in Rajasthan state. The other district is Ganganagar, which has equally large area under irrigated cash crops. But, crops in these districts are irrigated by canals. Nearly 14.6 per cent of the total irrigated cash crop in the state is in Jaipur, and occupies 3rd position with 67,617 ha under fruits, vegetables and oil seeds. The district is well known for cultivation of chilly and ground nut. But, what is more important than the area under cash crops is the presence of pressurizing device for MI systems. That way, energized well irrigation schemes have great advantage over surface irrigation systems. Jaipur as the largest groundwater irrigated area by electric pump sets (3.09 lac ha). Alwar has a total groundwater irrigated area of 250996 ha, and nearly 5 per cent of the state's irrigated cash crops are in this district. One of the pre-requisites for bringing any crop under MI is the presence of well irrigation. The presence of these crops which are amenable to micro irrigation, large area under well irrigation, and access to market would make it ideal for promoting precision irrigation technologies.

- There are no civil society organizations in Rajasthan, which actually try and address the critical issues in managing groundwater through field interventions. The knowledge and information available with scientific institutions such as CGWB, western region can however be tapped for building the primary database for initiating projects in that region.

8. Conclusions

We have used several considerations for identifying the most suitable district for groundwater management intervention. They are: importance of agriculture for the district's rural economy; groundwater resource endowment in the district; significance of groundwater for the district's agriculture and the degree of dependence on groundwater for irrigation; seriousness of groundwater over-development problems; the physical and socio-economic feasibility for introducing MI systems. All these considerations are captured in some quantitative variables.

These variables are: 1] total availability of renewable groundwater; 2] groundwater richness; 3] groundwater use intensity; 4] groundwater irrigated area per capita; 5] degree of over-exploitation of groundwater; 6] the land holding pattern, particularly the percentage of operational holding area belonging to large and medium farmers and the aggregate number of large & medium farmers; 7] gross cultivated land per capita of rural population; 8] irrigated area under cash crops per capita of rural population and percentage of total area under irrigated cash crops of the state falling in the district; and 9] total area under surface irrigation in the district.

To integrate these complex considerations, values of these variables are computed for each district, compared and ranked. Based on the ranking, it appears that Jaipur and Alwar provide most favourable conditions for groundwater management interventions that use demand management concepts.

These districts have very high natural endowment of groundwater resources which is of good quality. These districts have large areas under cultivation. The districts also have well developed groundwater irrigation systems, in the form of electrified wells. The area irrigated by wells is very significant in the two districts together accounting for nearly 21 per cent of the total well irrigated area in the state. There are large numbers of wells, with average of one in every 4.4 ha in Jaipur and one in every 5.8 ha in Alwar. Jaipur has large number of farmers having large & medium operational holdings, an important factor which decides the feasibility of modern farming practices and high valued crops. Among the groundwater irrigated districts, Jaipur has the largest share of irrigated cash crops such as fruits, vegetables, groundnut, castor and cotton. Both the districts use groundwater intensively and also experience high degree of over-exploitation. Also, they are not served by surface irrigation systems.

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