WATER : 2000 AD

THE SCENARIO FOR ARID RAJASTHAN

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CHAPTER I

INTRODUCTION

Water is a scarce commodity in the arid areas. The axiom is true for the arid zone of India also, which covers about 12 per cent of the country's total geographical area. The most acute problem of water within the arid zone is, however, faced within the hot arid belt of Rajasthan which accounts for about 61 per cent of the country's arid zone and is spread over eleven western districts of the State (Fig. 1).

a) The problem :

A dominantly sandy terrain, the disorganised drainage network over major part, deep and often saline groundwater and high rates of evaporation make the problems more acute. Spatially, the eastern margin of the desert receives more rainfall than the western margin and hence, has a better drainage network and a better prospect of water availability. Yet, the demand for water is increasing steadily, as human and livestock populations are increasing, more and more land is being brought under irrigated agriculture and newer industries are being set up. Since water is limited such trend is forcing people to even use 'marginal' quality water in some areas. This again triggers off a chain of degradation processes involving the land and also affects human and animal health. To alleviate the problems, new tube-wells are being sunk and water has been canalized from the wetter north into the desert's westernmost part.

Yet, short-sighted planning and poor execution of works, like the construction of minor irrigation reservoirs at wrong sites, dumping of industrial effluences in the ephemeral stream beds or profuse irrigation without proper soil drainage are adding more to the problems. The problem of water is, therefore, multi-dimensional. Bringing water into the arid zone, or sinking more tube-wells alone, cannot solve the problems. Tackling of the problem requires, first, quantitative information on the availability and uses of water, as also an analytical approach to the environmental impact of different water uses and monitoring of the effect of different uses.

b) Objective :

Out of the above two categories, information on the availability and uses of water is most needed in formulation of water budget that can help in proper planning of future water uses. Fortunately, there is fragmentary information on several facets

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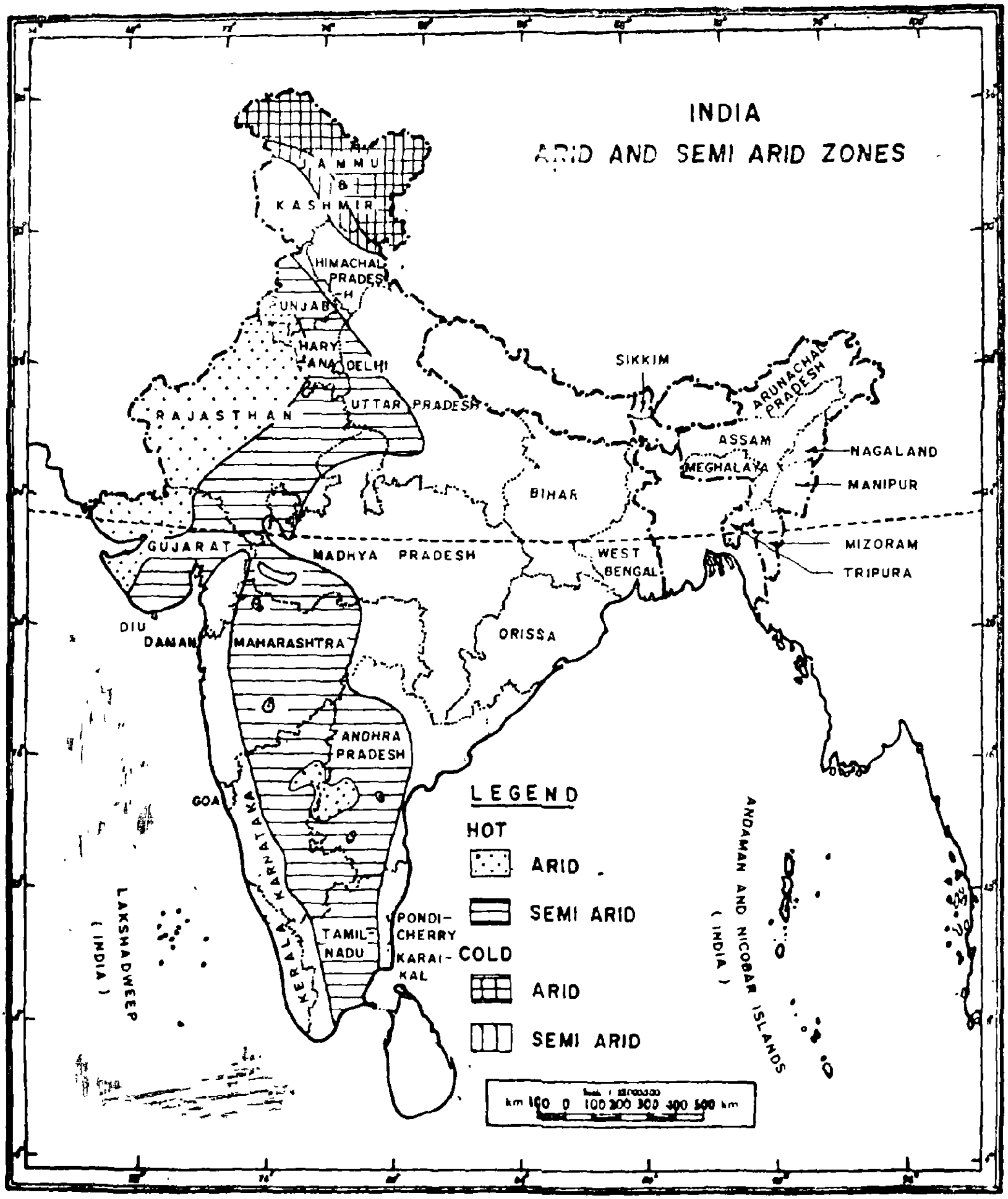
1: 22 million Outline Map of India with
State Boundaries printed 1987



Based upon Survey of India Outline Map printed in 1987

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line

The boundary of Meghalaya shown on this map is as interpreted from the North Eastern Areas (Reorganisation) Act 1971 but has yet to be verified.

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of the availability of water and its exploitation level in the arid Rajasthan. For example, the Rajasthan Ground Water Department has calculated the ground water reserve within the different districts of arid Rajasthan, alongwith the levels of its exploitation. The Central Arid Zone Research Institute (CAZRI) has, on the other hand, calculated the potentials of surface water storage in the region, alongwith the yearly basin outflow from the only integrated drainage basin of the region – the Luni basin. Yet, information on many other facets, like water use by different crops within the districts, are not available. The present study attempts to fill up the missing links along the data string that are required for water budgeting of the arid Rajasthan. This would then provide an integrated view of the presently available water and its use and finally indicate the future trend.

CHAPTER-II

CLIMATE

The mean annual rainfall in arid Rajasthan varies from about 500 mm in the east along the Aravallis to less than 100 mm in the west in Jaisalmer district (Fig. 2).

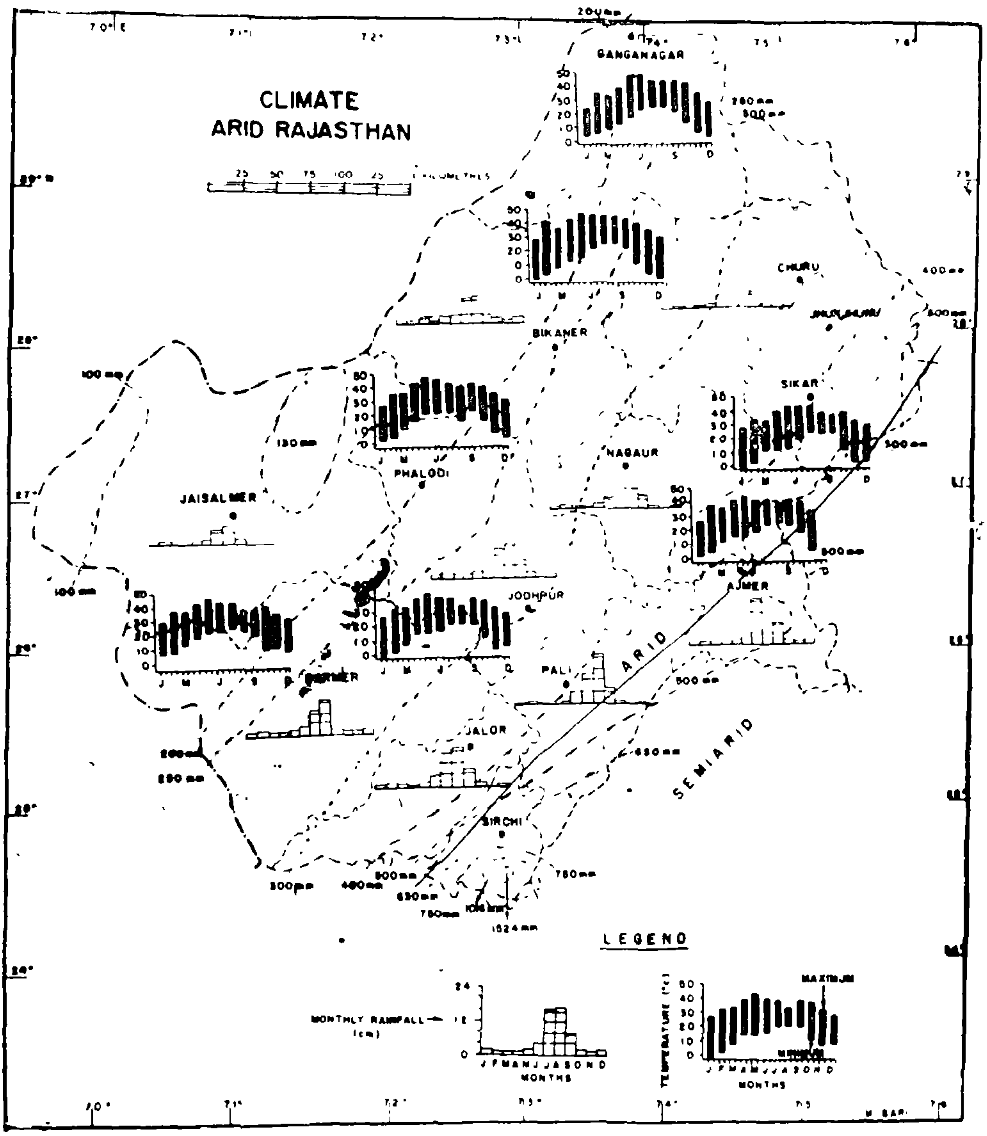


Fig. 2

Added to this decreasing rainfall gradient westward there is an increasing gradient of year to year variability in rainfall. It is less than 40 per cent in Sikar and Jhunjhunu districts in the east, and more than 70 per cent in the western part of Jaisalmer district. The main rainy season is from June to September, when 90 to 95 per cent of the total annual rainfall is received. The winter rainfall accounts for the rest 5 to 10 per cent, and is associated with the western disturbances. The annual average total rainfall, received in the eleven arid districts of Rajasthan is 50123.7 million cubic metre (MCM) which constitutes 86.6 per cent of the total 'inflow' of water into the region. The rest 13.4 per cent (7786.0 MCM) of the inflow is through canal system in Ganganagar district (Table 1).

Table 1. Average annual rainfall (MCM) in the arid Rajasthan

District	Tehsil	Rainfall
BARMER	Barmer	3,176.4
	Sheo	1,402.5
	Siwana	696.2
	Pachpadra	956.7
	Chohtan	1,121.0
	Total	7,352.8
BIKANER	Bikaner	2,645.6
	Lunkaransar	1,453.8
	Kolayat	1,799.2
	Nokha	1,019.8
	Total	6,918.4
CHURU	Churu	587.8
	Ratangarh	571.3
	Sujangarh	1,062.3
	Sardarshahar	1,077.0
	Rajgarh	757.5
	Taranagar	542.7
	Dungargarh	788.9
	Total	5,387.5
GANGANAGAR	Ganganagar	236.0
	Karanpur	157.8
	Padampur	170.4
	Raisinghnagar	282 7
	Hanumangarh	354.5
	Total	1,201.4
JAISALMER	Jaisalmer	5,117.6
	Pokaran	1,651.4
	Total	6,769.0

JALOR	Jalor	804.5
	Sanchor	1,144.1
	Bhinmal	1,601.6
	Total	3,550.2
JHUNJHUNU	Jhunjhunu	611.7
	Chirawa	520.2
	Khetri	824.4
	Total	1,956.3
JODHPUR	Jodhpur	977.4
	Phalodi	1,771.1
	Bilara	1,459.4
	Shergarh	1,010.8
	Osian	1,069.7
	Total	6,288.4
NAGAUR	Nagaur	1,469.0
	Didwana	585.9
	Parbatsar	856.0
	Merta City	937.4
	Nawa	706.6
	Total	4,554.9
PALI	Pali	123.6
	Jaitaran	504.5
	Desuri	800.6
	Sojat	772.1
	Bali	1,377.5
	Total	3,578.3
SIKAR	Sikar	666.6
	Neem ka Thana	604.2
	Ramgarh	604.5
	Sri Madhopur	691.2
	Total	2,566.5
ARID RAJASTHAN (11 districts)	Total	50,123.7

CHAPTER III

SURFACE WATER RESOURCES

a) Hydrological zones :

Arid Rajasthan could be divided into the following three broad hydrological zones (Fig. 3):

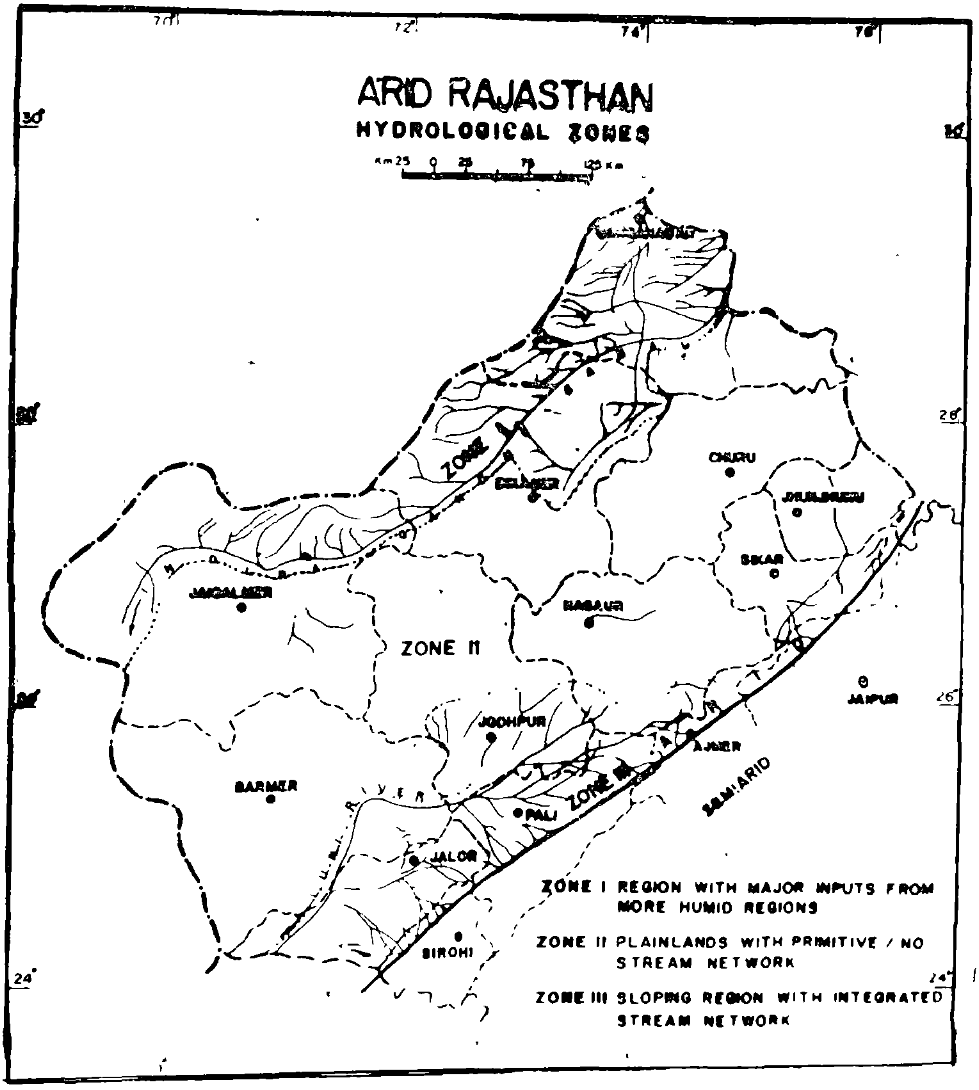


Fig. 3

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 repetative micro-hydrology. Churu, Jhunjhunu, Sikar, Nagaur, Jodhpur and parts of Bikaner, Jaisalmer and Barmer districts come under this category.

Zone - III :

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

The areas occupied by these regions in arid Rajasthan are 15 per cent, 52 per cent and 33 per cent, respectively.

Zone I : The water resources of zone I are primarily the canal water. The canal systems are the Gang Canal, the Bhakra Canal, the Ghaggar Canal and the Indira Gandhi Canal. On the basis of average from 1982 to 1986 it has been calculated that the canal water supplied in this zone is at the rate of 5.24 m/ha (6.958 ft/acre). Thus, the canal water available in the three districts of zone I is as follows:

Part of district	*Water available in Million Cubic Metres (MCM)*
Ganganagar (60%)	6.49
Bikaner (50%)	7.14
Jaisalmer (25%)	5.03

Zone II : In this zone the water resources are in the form of *Tanka, Nadi, Khadin* etc, which contain water from 2 to 12 months after the monsoon rains. The estimated surface water resources in the districts within this zone ara as follows :

Whole or part of district	*Water available (MCM)*
Ganganagar (40%)	11.19
Bikaner (50%)	26.16
Churu	22.82
Jhunjhunu	8.04
Sikar	10.48
Nagaur	53.18
Jodhpur	20.66
Jaisalmer (75%)	38.38
Barmer	19.64

Zone III : The maximum water resources within arid Rajasthan are available in zone III due to its well integrated drainage systems, shallow and rocky surfaces and better rainfall status. The districtwise water resources in this zone are as follows:

District	*Water available (MCM)*
Jalor	71
Pali	869
Jhunjhunu	96 Basins of Shekhawati tract
Sikar	96

Thus, the surface water resources in the 11 arid districts of Rajasthan are 1361.21 MCM (Table 2).

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	—	33.30
Churu	—	22.82	—	22.82
Jhunjhunu	—	8.04	96.00	104.04
Sikar	—	10.48	96.00	106.48
Jaisalmer	5.03	38.38	—	43.41
Jodhpur	—	20.66	—	20.66
Nagaur	—	53.18	—	53.18
Pali	—	—	869.00	869.00
Barmer	—	19.64	—	19.64
Jalor	—	—	71.00	71.00
Total	18.66	210.55	1132.00	1361.21

b) Runoff estimates :

In case of micro-catchments the percentage of runoff increases with decreasing catchment size, because of the reduced infiltration losses. Small watersheds (less than 5 ha) can produce runoff amounting to 10 to 15 per cent of rainfall. In case of the sandy loam soils, an almost level surface (0.5 per cent slope) produced 13.3 to 32.1 per cent runoff, while catchments with 5 per cent slope produced 36.1 to 45.4 per cent runoff and those with 10 per cent slope produced 2.65 to 44.3 per cent runoff, depending upon the micro-catchment area (200-400 sq. metres). Studies at the Central Research Farm of CAZRI at Jodhpur indicated that on an average about 30.5 per cent runoff could be generated from an average annual monsoon rainfall of 263 mm.

In the Luni basin of arid Rajasthan the annual precipitation is highly variable, ranging from 600 mm in the southeast to 300 mm in the northwest. About 52 per cent area of the basin has rugged mountainous terrain, composed of igneous and metamorphic rocks with shallow to moderately deep colluvial and alluvial sediments.

Studies in different subcatchments of the basin, covering 104 to 1520 sq. km. area, indicated that the runoff volume diminishes with downstream travel. Runoff volumes of 58.7 to 62.5 per cent of the rainfall recorded in the hilly terrain was reduced to 14.3 to 20.7 per cent at the outflow locations. This decrease is due to high transmission losses in the beds and banks of the alluvial channels and failure of the lower runoff from desert plains to counter balance the losses.

The rhyolite basins in the 250 to 400 mm rainfall zone, when put under grazing, produced 1.2 to 11.0 mm runoff annually, depending upon the grazing intensities. The runoff coefficients for such environments vary from 10 to 15 per cent of rainfall.

The interdune basins located in the 150 to 250 mm rainfall zone and having sandy loam to loamy sand textures can generate 10 to 13 per cent of rainfall as runoff under undisturbed conditions. This is evident from the high density of water bodies in such regions.

To sum up, the average run-off generation from arid Rajasthan is between 10 and 15 per cent of rainfall, as much of the terrain is sandy. However, due to the spatial variations in rainfall and terrain type, deviations from this average value are expected. In the less than 200 mm rainfall zone the dominantly interdune areas can generate 10 to 15 per cent of rainfall as run-off, if these are in undisturbed condition and have adequate vegetation cover. The rocky/gravelly surfaces, on the other hand, can generate between 20 and 25 per cent. In the 200 to 400 mm rainfall zone the micro-catchments in the plains with sandy loam to loamy sand can generate as much as 30 to 40 per cent as run-off, although the larger catchments can generate between 15 and 20 per cent. The rocky/gravelly surfaces in this zone can generate between 20 and 30 per cent of rainfall as run-off. In the more than 400 mm rainfall zone the hills and rocky uplands are able to generate 40 to 60 per cent as run-off, while the alluvial and other sandy plains can generate between 20 and 30 per cent.

CHAPTER-IV

GROUND WATER UTILIZATION

a) The pattern of utilization :

The utilization of groundwater for domestic, livestock and irrigation purposes has been constantly increasing in the arid districts of Rajasthan, especially because of the absence of perennial surface water sources over most part and a rapid growth of human and livestock population which are largely depndent on groundwater for their survival. Because of the increasing trend of groundwater exploitation it has become necessary to assess the quantity and quality of usable water from different aquifer systems in the region.

An attempt has been made here to estimate the groundwater balance in each district of arid Rajasthan and to find out the stage of groundwater development, taking into consideration the recharge through rainfall and utilization for irrigation and domestic purposes. The district wise assessment of groundwater resources is based on the data provided by Ground Water Department, Government of Rajasthan. These data have been further projected for the years 1990, 1995 and 2000, on the basis of anticipated rate of groundwater development, as suggested by the "Group on the estimation of groundwater resource and irrigation potential from groundwater in Rajasthan" (1985). Accordingly, the following growth rates have been considered for the various districts of arid Rajrsthan :

Growth rate (%)	*District (s)*
4	Ganganagar, Jalor, Pali, Sikar
3	Jhunjhunu, Nagaur
2	Jodhpur
1	Barmer, Bikaner, Churu, Jaisalmer

The data on utilizable recharge are considered to be constant over the years for each district, as these have been normalised on the basis of average rainfall of the districts.

The present status of groundwater resources has been worked out on the basis of recharge generated by the rainfall of 1987 and net groundwater draft for irrigation and domestic purposes for the post-monsoon period of 1987-88. It has been worked out that the development of grounwater is considerably low, i.e. below 5 per cent in Jaisalmer, Bikaner and Churu districts, whereas it is moderate, i.e. between 25 per cent and 45 per cent in Nagaur, Ganganagar, Barmer and Jodhpur districts. In case of Jhunjhunu, Sikar, Jalor and Pali districts the development of groundwater

Table 3. Ground water potential in arid Rajasthan (Based on June 1988 data)

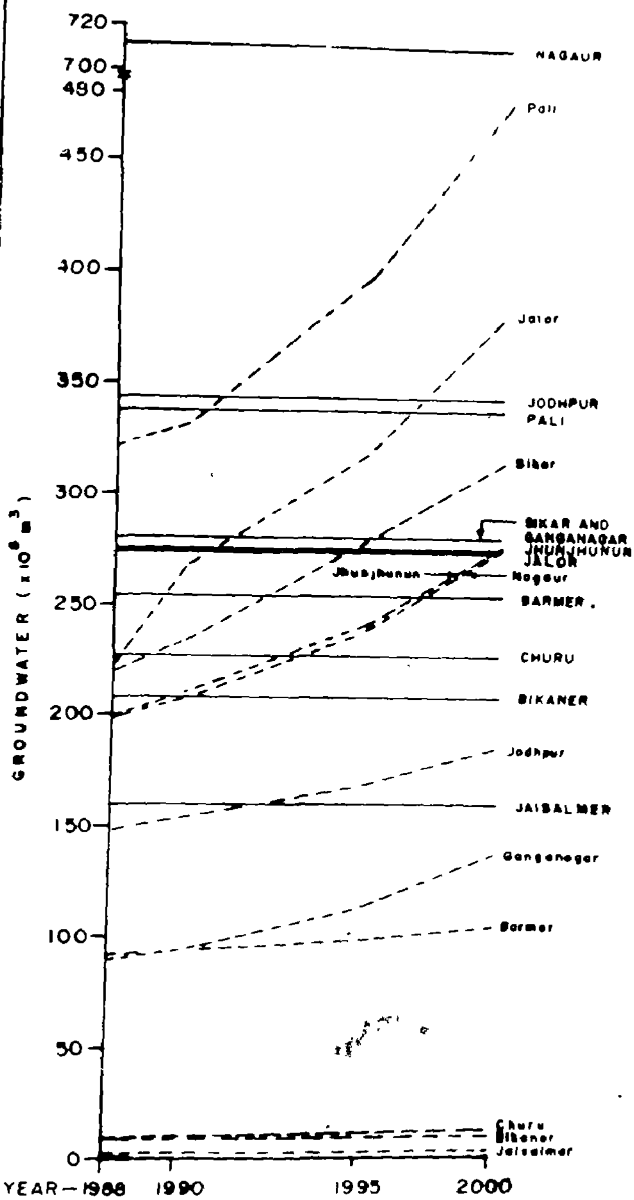
District	Utilisable recharge (MCM)	Net ground water utilised (MCM)	Balance ground water (MCM)	Ground water developed (%)
Barmer	252.25	92.67	159.58	36.74
Bikaner	208.17	8.87	199.30	4.26
Churu	227.25	1 .04	217.21	4.42
Jaisalmer	159.70	2.22	157.48	1.39
Jalor	274.06	222.79	51.27	81.29
Jhunjhunu	275.76	200.86	74.90	72.84
Jodhpur	345.11	149.00	196.10	43.18
Nagaur	712.35	199.09	513.26	27.95
Pali	339.52	312.81	26.71	92.13
Sikar	280.76	220.33	60.43	78.48
Ganganagar	280.00	90.00	190.00	32.14
Total	3354.93	1508.68	1846.24	44.97

has shown considerable growth i.e. between 70 per cent and slightly more than 90 per cent (Table 3, Fig. 4). The trend of utilization of groundwater is a reflection of the irrigation practices in the different districts. In Jaisalmer, Bikaner and Churu districts groundwater is principally utilised for domestic purposes. Therefore, the development of groundwater in these districts does not exceed 5 per cent level. In Nagaur, Ganganagar, Barmer and Jodhpur districts large areas are under well irrigation. This, alongwith the utilization for domestic consumption, has led to moderate rate of groundwater development. In Jhunjhunu, Sikar, Jalor and Pali districts, however, the exploitation of groundwater has reached a very high level due to enormous withdrawal through a large number of energised wells and low to medium duty tube-wells for irrigation purposes.

It is also important to note that in a number of development blocks the growth rate has already exceeded the annual recharge and as such these blocks have attained 'over-exploited', 'gray' or semi-critical and 'dark' or critical stages of groundwater development (Table 4).

Table 4. Development Blocks with excessive ground water development in arid Rajasthan

a. *Over-exploited blocks* (Overall annual draft exceeds recharge)	b. *'Dark' or critical blocks* (Groundwater development is over 85%)	c. *'Grey' or semi-critical blocks* (Groundwater development varies between 65% and 85%)
1. Dhorimanna (Barmer district)	1. Saila (Jalor district)	1. Chirawa (Jhunjhunu district)
2. Bhinmal (Jalor district)	2. Udaipur (Jhunjhunu district)	2. Osian (Jodhpur district)
3. Sri Madhopur (Sikar district)	3. Rohat (Pali district)	



UTILISABLE GROUND WATER RECHARGE (——) AND NET GROUND WATER UTILISED (- - -) IN DIFFERENT DISTRICTS OF ARID RAJASTHAN

Fig. 4

Information on groundwater resources in all the districts is also available. It has been estimated that the total groundwater resources in arid Rajasthan was 4544.6 MCM, as per 1984 assessment. This, however, includes the net annual rechargeable groundwater (Table 5). The total groundwater resources in the region is being periodically assessed by Rajasthan Groundwater Department on the basis of new information generated about the aquifers. Hence, the groundwater potential figures (Table 3) may not tally well with the total groundwater resources figures (Table 5) for all districts. It has also been calculated that about 81863.1 sq.km. area is suitable for groundwater recharge (Table 5).

Table 5. Groundwater resources in arid Rajasthan and net area suitable for groundwater recharge (Based on 1984 data)

District	Area (sq.km)	Net area suitable for groundwater recharge (sq.km)	Total ground water (MCM)
Barmer	28387.0	11139.7	319.0
Bikaner	27231.0	2977.0	146.7*
Churu	16829.0	6126.2	251.1
Ganganagar	20629.0	2078.2	327.3
Jalor	10640.0	6086.2	612.7
Jaisalmer	38401.0	14320.0	143.2*
Jhunjhunu	5929.0	5103.9	356.4
Jodhpur	22860.0	12140.9	510.7
Nagaur	17718.0	8520.6	655.7
Pali	12391.0	6703.5	672.5
Sikar	7732.0	6666.9	549.3
	208747.0	81863.1	4544.6

Source : Report of the Group on the Estimation of Groundwater Resource and Irrigation Potential from Ground water in Rajasthan (1985).

*Figures not compatible with the annual utilisable recharge in Table 3.

b) Subsurface water potential zones along the buried streams in arid Rajasthan :

Geomorphological interpretation of the terrain with the help of remote sensing, especially the aerial photographs and satellite imagery, has indicated that hidden within the desert plains of Rajasthan there are several courses of former streams which could be the potential sources of groundwater at shallow to moderate depth. Unfortunately, there is very little available data on the actual potentials of and recharge to these Quaternary aquifers, although along some of the courses tube-wells and dug wells are known to exist.

The streams were in flow during a previous wetter climatic phase, but became gradually dry and buried under their own debris and aeolian sand as the present arid phase set in. However, whenever there is rainfall in the catchment water collects along those buried courses, since the sand and gravelly deposits in them act as good aquifer. Some of the buried streams which are known to be potential are the buried segments of the Mitri in Pali and Jalor districts, the dry valley of the Jojri in the Merta alluvial plain in Nagaur district and the buried courses of the Saraswati in the extremely dry western part of Jaisalmer district.

The Saraswati river, which is quoted in the ancient Indian scriptures as a mighty one, has been identified by many scholars with the present dry bed of the Ghaggar in Haryana and Rajasthan and with the Raini, the Wahinda and the Hakra (Nara) in Pakistan. The present dry bed of the Ghaggar is visib'e on the satellite imagery of the northern part of Rajasthan and adjoining part of Pakistan as a continuous, wide belt with dark grey tone, running from Suratgarh through Anupgarh (India) to Fort Abbas and Ahmedpur East (in Pakistan). However, another be't of discontinuous patches with dark gray tone was noticed south-westward from Anupgarh to Sakhi in India. This former valley is then traceable through Khangarh and Islamgarh in Pakistan and then Dharmi Khu, Ghantial, west of Ghotaru and Shahgarh, Babuwali and Mithrau (in India) and then through Rajar and Mihal Mungra (in Pakistan) to the present Hakra channel and beyond. Several westward shifts took place from this course and the remnants of the major shifted courses are now known in Pakistan as the Wahinda and the Raini. The Hakra-Nara course in Pakistan was the last major shifted course of the river and it survived well within the historical period. From visual interpretation of the Landsat images it is also clear that Sutlej, a mightier Himalayan stream than the Saraswati, used to contribute to the Saraswati at several points in the Sub-Himalayan and Punjab plains, over the period of time. The river has shifted its course several times in such a way that its original south-flowing course in the plains has now given way to a west-flowing course. The survival of the Saraswati depended to a large extent on the perennial supply of water of the Sutlej.

The course of the Saraswati to the west of Jaisalmer is estimated to have a reserve of about 3000 MCM water. It has also been qualitatively found that the buried segments associated with lineaments often become the good sites for water exploration. Such situations exist especially in Pali and Jalor districts in the south, and Churu and Jhunjhunu districts in the north (where the Kantaliya river dies out on the sandy plain, but its dry courses associated with lineaments have been found to be potential).

Inspite of such qualitative information, data on the actual aquifer conditions and recharge to them are still very meager.

CHAPTER-V

WATER USE BY PLANTS

a) Crops of arid Rajasthan :

Despite aberrant weather conditions all types of crops are grown in the arid Rajasthan. However, crops and area under each crop are highly influenced by the amount of rainfall and water resources available for irrigation. As an illustration, the area occupied by each crop during 1985-86, which was a major drought year and hence reflects the minimum water use in the region, is shown in Table 6. Gangangar is the only district where all crop components exist due to the availability of canal irrigation. Mungbean, moth bean and wet season pulses are grouped under *Kharif* pulses. Similarly in *Rabi* season pulses other than chick pea (gram) are grouped under *Rabi* pulses. Sorghum and lucerne are the prominent fodder crops of *Kharif* and *Rabi* seasons under irrigation. In *Kharif* season, sorghum, pigeon pea, peanut (groundnut), maize, rice, cotton, chillies and fodder crops are under irrigation, while pearl millet, *Kharif* pulses, clusterbean, castor, sannhemp and sesame are grown as rainfed crops. Pearl millet occupies the maximum area, followed by *Kharif* pulses during *Kharif* season. In winter, wheat and mustard occupy more area, followed by chick pea and barley. Sugarcane is largely grown in Ganganagar district and in small areas of Sikar district. Tobacco is the cash crop of Sikar, Jhunjhunu, Churu and Barmer districts.

b) Water requirement of crops :

Crop water requirement is the depth of water needed to meet the water loss through evapotranspiration of a well-managed crop for achieving full production potential under the given growing environment. The water requirement of rainfed crops was computed using Thornthwaite water balance equation. In case of irrigated *Kharif* and *Rabi* crops, water requirement was worked out by multiplying reference evapotranspiration (ET) with the crop coefficient (Kc), to account for the effect of crop characteristics on crop water requirement. The monthly values of ET for 11 districts (Table 7) were computed using modified Penman method. The climatic data, needed in Penman method, were available for the period 1955 to 1986 for Jodhpur, Bikaner, Jaisalmer, Barmer, Ganganagar, Nagaur, Pali and Churu stations only. For other three districts, values were extrapolated, considering the altitude constants. The higher ET values (Table 7) in all the districts indicate a harsh climatic condition in the region.

Table 6. Area (,000 ha) under *Kharif* and *Rabi* crops in arid Rajasthan (1985-86)

Crops	Barmer	Bikaner	Churu	Jaisalmer	Jalor	District Jhunjhunu	Jodhpur	Nagaur	Pali	Sikar	Ganganagar
	hectares										
a) *Kharif crops*											
Pearlmillet	1080.5	262.3	474.1	112.9	375 6	265.3	643.5	586.1	150.5	279.0	77.8
Sorghum	2.3	0.9	0.1	0.2	4.0	1.0	4.4	70.6	93.7	0.1	8.8
Pigeon pea	—	—	—	—	—	—	—	—	—	—	0.3
Other *Kharif* pulses	157.3	262.2	364.1	0.1	53.3	90.9	176.6	220.5	29.3	111.0	50.6
Cluster bean	0.1	—	0.1	—	0.2	0.1	0.2	0.1	0.2	0.2	—
Sesame	6.9	13.7	1.0	—	29.7	0.2	55.4	155.9	115.4	1.2	0.2
Castor	0.1	—	—	—	1.8	—	—	—	0.3	—	—
Peanut	—	6.1	—	—	—	0.1	0.1	10.7	3.1	1.0	36.6
Sann-hemp	—	—	—	—	0.1	0.1	—	—	—	0.1	0.2
Maize	—	0.1	—	—	0.3	—	—	0.5	33.7	0.3	1.2
Small millets	—	—	—	—	1.8	—	—	0.1	0.9	—	—
Rice	—	—	—	—	—	—	—	—	—	—	24.4
Chillies	—	0.1	—	—	1.5	0.7	10.9	1.1	2.1	0.7	1.8
Cotton	—	2.8	—	—	1.7	0 1	1.7	2.7	15.7	0.1	232.7
Kharif fodder	1.0	1.0	0.2	0.2	1.5	0.2	1.5	2.0	2 5	1 0	7.0
Total (A)	1248.2	549.2	839.5	113.5	471.3	358.6	893.8	1050.3	447.4	394.8	440.7
b) *Rabi crops*											
Wheat	12.5	11.8	1.6	—	37.0	26.7	27.9	31.9	48.3	38.8	285.8
Barley	1.0	0.1	3.2	—	2.0	8.1	0.4	8.6	8.7	17.8	9.6
Chick pea	0.1	13.5	163.7	—	0.1	81.0	0.2	2.3	3.0	70.6	534.5
Other *Rabi* pulses	—	0.1	—	—	0.2	—	—	—	—	—	0.6
Mustard	2.8	15.3	2.0	—	36.8	18.6	14.8	28.6	15.7	15.3	180.5
Coriander	0.5	—	—	—	—	0.1	0,1	0.1	—	—	0.1
Potatoes	—	—	—	—	—	—	—	—	—	—	0.1
Sugarcane	—	0.1	—	—	—	—	—	—	—	0.1	4.0

Tobacco	—	—	0.2	—	—	0.3	—	—	—	0.1	—
Rabi fodder	0.1	2.0	0.2	—	0.2	0.1	0.2	1.0	0.2	0.5	8.0
Total (B)	17.0	42.9	170.8	—	76.2	135.0	44.6	72.5	76.9	143.2	1023.3
Double crop area	16.9	21.8	37.0	—		128.2	21·4	40.2	75.7	142.7	299.8
Net cropped area	1248.3	570.2	973.4	113.3	508.9	365.4	916.5	1082.6	448.6	395.4	1173.2

Source : Statistical Abstract, Govt. of Rajasthan

Table 7. Monthly reference evapotranspiration (ET mm) of arid Rajasthan

Month	Barmer	Bikaner	Ganganagar	Jaisalmer	Jodhpur	Nagaur	Pali	Churu	Jalor	Jhunjhunu	Sikar
January	132	90	66	114	135	105	120	78	120	84	90
February	153	132	99	159	168	138	165	114	126	123	117
March	210	183	147	219	213	195	207	171	216	174	174
April	258	249	186	300	282	246	285	219	228	234	237
May	315	318	225	336	333	315	315	276	291	294	291
June	282	330	219	354	330	330	312	312	280	296	282
July	210	258	219	318	231	234	240	234	231	216	210
August	180	231	192	279	186	210	213	207	213	180	171
September	195	219	180	270	186	195	216	189	213	171	168
October	189	174	144	254	177	165	177	153	198	165	150
November	138	120	90	174	144	114	135	102	138	105	105
December	114	84	66	120	129	99	126	72	120	120	105
Total	2376	2388	1833	2897	2514	2346	2511	2127	2374	2161	2100

Water requirement for rainfed crops and irrigation requirement for irrigated *Kharif* and *Rabi* crops are given in Tables 8 to 11. In Jaisalmer district the area under *Rabi* crops is presently negligible, but the introduction of canal will help to bring more area under irrigation by 2000 AD. Therefore, water use has also been calculated for *Rabi* crops. Water requirement for rainfed *Kharif* crops and irrigated *Kharif* and *Rabi* crops are shown for each crop in Tables 12 to 14.

c) Water use by plants (including crops, grasses, shrubs and trees) :

Although no correct estimate of the total water use by the plants in arid Rajasthan is yet available, the present minimum water use in the region has been calculated on the basis of estimates of water use by different crops and plants, the average annual precipitation in the region and the plant cover in 1985-86 which was a major drought year. The results indicate that the minimum water use by the crops alone in the region is 21976.9 MCM (including irrigation requirement), while the total mininum water use by all the plants, including crops, is 47,704.5 MCM (Table 15).

Table 8. Water use (mm) by rain-fed crops during *Kharif* season

District	Pearl millet	Kharif pulses	Cluster bean	Sesame	Castor	Sannhemp	Smaller millet
Barmer	187	163	192	189	192	–	–
Bikaner	180	147	184	181	—	—	–
Churu	231	193	237	233	—	—	—
Ganganagar	136	114	138	136	—	136	—
Jaisalmer	130	110	130	130	—	—	—
Jalor	253	208	261	253	261	253	208
Jhunjhunu	261	212	270	261	—	261	—
Jodhpur	255	216	259	255	—	—	—
Nagaur	223	191	229	223	—	—	191
Pali	283	230	288	283	288	—	230
Sikar	291	227	298	291	—	291	—

Table 9. Water use (mm) by irrigated *Kharif* crops

District	Sorghum		Pigeon pea		Peanut		Maize		Cotton		Chillies		*Kharif* forages		Rice	
	RF*	IR**	RF	IR	RF	IR	RF	IR	RF	IR	RF	IR	RF	IR	RF	IR
Barmer	189	220	—	—	—	—	—	—	—	—	—	—	189	80	—	—
Bikaner	181	308	—	—	187	451	185	364	192	750	192	608	181	132	—	—
Churu	233	200	—	—	—	—	—	—	—	—	—	—	233	49	—	—
Ganganagar	136	239	138	194	139	351	137	391	144	575	144	561	136	136	162	2338
Jaisalmer	130	370	—	—	—	—	—	—	—	—	—	—	130	281	—	—
Jalor	253	167	—	—	—	—	250	324	263	677	263	581	253	17	—	—
Jhunjhunu	261	95	—	—	266	215	—	—	271	502	271	361	259	—	—	—
Jodhpur	255	134	—	—	262	244	260	314	266	661	266	424	255	25	—	—
Nagaur	223	216	—	—	227	313	225	361	232	655	232	649	223	60	—	—
Pali	283	117	—	—	291	245	286	254	293	644	293	537	283	—	—	—
Sikar	291	53	296	90	298	162	292	174	304	430	304	371	249	—	—	—

*RF = Rainfall

**IR = Irrigation

Table 10. Water use (mm) by *Rabi* crops (First approximation)

District	Wheat	Barley	Chick pea	Other *Rabi* pulses	Mustard	Coriander	Potatoes	Sugarcane	Tobacco	*Rabi* fodder (Lucerne/ Berseem)
Barmer	553	553	290	—	292	420	—	—	490	954
Bikaner	442	442	234	220	223	—	—	1900	—	811
Churu	370	370	217	—	192	—	—	—	450	715
Ganganagar	305	305	166	150	232	300	350	1800	—	720
Jaisalmer	543	543	—	—	289	—	—	—	—	—
Jalor	476	476	266	230	259	—	—	—	—	947
Jhunjhunu	422	422	225	—	215	320	—	—	440	800
Jodhpur	532	532	293	—	310	417	—	—	—	1000
Nagaur	469	469	245	—	237	343	—	—	—	809
Pali	451	451	290	—	303	419	—	—	—	916
Sikar	390	390	214	—	207	300	—	1800	430	800

Table 11. Water use (mm) in waste and fallow lands, forests and grasslands

District	Waste and fallow lands	Forest	Grasslands
Barmer	193	198	212
Bikaner	189	194	208
Churu	243	250	268
Ganganagar	147	150	162
Jaisalmer	131	134	144
Jalor	259	266	286
Jhunjhunu	273	280	301
Jodhpur	261	268	288
Nagaur	231	237	255
Pali	292	299	322
Sikar	304	312	335

Table 12. Water requirement (MCM) of rainfed crops

District	Pearl millet	*Kharif* pulses	Cluster bean	Sesame	Caster	Sann hemp	Small millets	*Kharif* forages	Sor-ghum	Pea nut	Maize	Cotton	Chill-ies	Rice	Pigeon pea	Total
Barmer	2020.5	256.4	0.2	13.0	0.2	—	—	1.9	4.3	—	—	—	—	—	—	2296.5
Bikaner	472.1	385.4	—	24.9	—	—	—	1.8	1.6	11.4	0.2	5.5	0.1	—	—	903.0
Churu	1095.3	702.6	0.2	2.3	—	—	—	0.5	0.2	—	—	—	—	—	—	1801.0
Ganganagar	105.8	57.7	0.1	0.2	—	0.3	—	9.5	12.0	50.8	1.6	335.0	1.4	39.5	0.4	614.3
Jaisalmer	146.8	0.1	—	—	—	—	—	0.3	0.3	—	—	—	—	—	—	147.5
Jalor	950.2	110.8	0.4	75.2	4.5	0.3	3.7	3.8	10.1	—	0.7	4.5	3.9	—	—	1168.1
Jhunjhunu	692.4	192.6	0.3	0.5	—	0.3	—	0.5	2.6	0.1	—	0.1	2.0	—	—	891.4
Jodhpur	1640.9	381.6	0.6	141.3	—	—	—	3.8	11.3	0.3	0.1	1.7	28.9	—	—	2210.5
Nagaur	1306.9	421·2	0.2	347.6	—	—	0.2	4.5	157.5	24.4	1.1	6.2	2.5	—	—	2272.3
Pali	425.0	67.4	0.5	326.6	0.9	—	2.0	7.1	265.2	9.1	96.3	45.9	6.0	—	—	1253.0
Sikar	812.0	252.1	0.5	3.4	—	0.2	—	2.5	0.3	2.9	1.0	0.5	2.1	—	0.1	1077.6

Table 13. Irrigation requirement (MCM) of *Kharif* crops

District	Sorghum	Pigeon pea	Peanut	Maize	Rice	Cotton	Chillies	*Kharif* forages	Total
Barmer	5.1	—	—	—	—	—	—	0.8	5.9
Bikaner	2.8	—	27.6	0.4	—	21.4	0.3	1.3	53.8
Churu	0.2	—	—	—	—	—	—	0.1	0.3
Ganganagar	21.2	0.5	128.4	4.6	570.3	1337.8	5.5	9.5	2077.8
Jaisalmer	0.8	—	—	—	—	—	—	0.6	1.4
Jalor	16.7	—	—	0.9	—	11.6	8.7	0.3	28.2
Jhunjhunu	1.0	—	0.1	—	—	0.2	2.7	—	4.0
Jodhpur	5.9	—	0.2	0.1	—	11.0	46.0	0.4	63.6
Nagaur	152.6	—	33.6	1.8	—	17.4	7.1	1.2	213.7
Pali	109.6	—	7.7	85.6	—	100 9	11.1	—	314.9
Sikar	0.05	0.02	1.6	0.6	—	0.7	2.6	—	5.6

Table 14. Irrigation requirement (MCM) of *Rabi* crops

District	Wheat	Barley	Chick pea	Pulses	Mustard	Coriander	Potatoes	Sugarcane	Tobacco	*Rabi* forage	Total
Barmer	68.0	5.5	0.3	—	8.2	2.2	—	—	0.17	0.48	85.4
Bikaner	52.0	0.4	31.5	0.2	34.0	—	—	2.9	—	16.2	137.2
Churu	6.0	11.8	355 2	—	3.8	—	—	—	0.78	1.43	379.0
Ganganagar	780.3	29.4	887.3	0.9	418.8	0.15	0.53	71.3	—	5.8	2194.5
Jaisalmer	—	—	—	—	—	—	—	—	—	—	—
Jalor	176.3	9.5	0.1	0.4	95.2	—	—	—	—	18.9	300.4
Jhunjhunu	112.8	34.3	182.3	—	40.0	0.24	—	—	1.32	0.8	371.8
Jodhpur	148.6	2.0	0.48	—	46.0	0.25	—	—	—	2.0	199.3
Nagaur	149.7	40.6	5.7	—	67.7	0.34	—	—	—	8.1	272.1
Pali	217.5	39.1	8.9	—	47.7	0.13	—	—	—	11.0	324.3
Sikar	151.3	69.4	151.0	—	31.6	0.15	—	1.3	0.76	4.0	409.5
Total	1863.5	242.0	1622.8	1.5	793.0	3.5	0.53	75.5	3.0	68.7	4673.5

Tabie 15. Water use (MCM) by plants in arid Rajasthan (1985-86)

District	Av. annual precipitation	Water use (1) by *Kharif* crops	Irr. Req. (2) cf *Kharif* & *Rabi* crops	Total water requirement (1+2)	Pastures	Waste & fallow land	Forests	Total
Barmer	7352.8	2296.5	91.3	2387.8	452.2	2577.0	40.6	5457.6
Bikaner	6918.4	903.0	191.0	1094.0	120.0	3873.0	124.9	5211.9
Churu	5387.5	1801.1	379.3	2180.4	128.0	1603.4	12.8	3924.6
Ganganagar	1201.4	614.3	4272.3	4886.6	39.4	1191.6	82.4	6200.0
Jaisalmer	6769.0	147.5	1.4	148.9	165.5	4711.6	22.3	5048.3
Jalor	3550.2	1168.1	400.0	1568.1	51.8	1237.2	48.0	2905.1
Jhunjhunu	1956.3	891.4	203.3	1094.7	130.6	408.0	96.6	1729.9
Jodhpur	6288.4	2210.5	262.9	2473.4	350.3	3166.3	13.8	6003.8
Nagaur	4554.9	2272.3	485.8	2758.1	191.7	1366.2	36.1	4352.1
Pali	3578.0	1253.0	639.2	1892.2	305.8	1790.1	219.4	4207.5
Sikar	2566.5	1077.6	415.1	1492.7	156.6	909 6	105.4	2663.7
Total	50123.7	14635.3	7341.6	21976.9	2091.9	22833.4	802.3	47704.5

CHAPTER-VI

WATER BUDGET

Based on the available information on rainfall, surface water resources and water use by different trees, shrubs, grasses and crops, it is possible to calculate the approximate water balance for the amount received through precipitation and other external surface sources like canal.

In its general form the water balance equation of a region may be expressed as:

$$(P + Qsi) - (Et - Qso - Quo + ds) \qquad ...(1)$$

where,

P is average precipitation,

Qsi is average surface water inflow (canal),

Et is average evapotranspiration (considered as water use),

Qso is average surface water outflow (stream),

Quo is average deep percolation loss, and

ds is average change in storage.

The change in storage (ds) is calculated as

$$ds = dso + dsr \qquad ...(2)$$

where,

dso is average change in water held by the soil, and
dsr is average change in surface storage (reservoirs).

The total inflow (57909.7 MCM) consists of rainfall (50123.7 MCM or 86.6 per cent of the total) and canals from the Punjab-Haryana plains (7786.0 MCM or 13.4 per cent of the total). Out of this total receipt 501.2 MCM (0.9 per cent) is considered as deep percolation, which is calculated on the basis of 1 per cent of the total rainfall. The *nadis, tankas, khadins* and irrigation reservoirs store upto 1342.6 MCM (2.3 per cent), while the vegetation component, consisting of natural as well as planted species (including crops), use 48804.5 MCM of water (84.3 per cent of the total). That leaves about 12.5 per cent or 7238.7 MCM water for soil storage. However, the dominantly sandy nature of the soil in the region has a potentiality to hold about 17706 MCM of water (Table 16).

Table 16. Potentials of water held (MCM) in soils of arid Rajasthan

District	Saturation level per solum									Total
	50 mm	90 mm	40 mm	140 mm	160 mm	230 mm	220 mm	20 mm	5mm	
	Dune complex	Sandy plain	Shallow hard pan	Fine sandy loam/loam	Medium sandy loam	Clay loam/ silty clay loam	Saline soils	Shallow gravelly soils	Hills and rocky areas	
Jaisalmer	846.0	1043.0	50.0	200.0	501.0	504 0	43.0	28.0	12.5	3227.5
Bikaner	646.0	926.0	14.6	—	512.0	201.0	85.0	4.4	—	2389.0
Barmer	512.0	1179.0	82.0	—	—	126.0	72.0	37.0	2.4	2010.4
Churu	446.0	472.0	21.0	130.0	151.0	—	37.0	1.8	00.0	1258.8
Jodhpur	148.0	1035.0	112.9	313.0	62.0	116.0	41.0	33.0	2.3	1862.3
Jalor	124.0	234.0	9.0	150.0	80.0	507.0	90.0	9.0	2.7	1205.7
Nagaur	62.0	573.0	14.0	446.0	390.0	464.0	24.0	30.0	8.0	2006.0
Jhunjhunu	29.0	344.0	—	102.0	—	97.0	—	2.6	2.2	576.8
Sikar	20.0	449.0	2.7	21.0	206.0	36.0	9.0	5.8	2.2	751.7
Pali	2.7	54.0	14.0	120.0	76.0	776.0	164.0	7.3	0.7	1214.7
Ganganagar	101.0	112.8	—	557.3	—	432.1	—	—	—	1203.2
Total	2936.7	6421.8	319.3	2039.3	1978.0	3259.1	565.0	158.9	28.0	17706.1

Although the above equations are used for water balancing these were found inadequate for calculating the net utilisation of water, received from rainfall and other surface sources on the one hand and extraction of ground water on the other. The total available water for the region is then a sum of rainfall, surface water inflow and net ground water extraction. For a good rainfall year, as during the 1980's, this was estimated to be 59418.4 MCM. The utilization of the amount could be split up into basin outflow, deep percolation, water use by plants, human and livestock consumptions, industrial use, evaporation from the surface storages and soil storage. Since the concept is slightly different from the traditional 'water balance' concept, we shall call it water budgeting. Unfortunately, the lack of reliable data on all the above aspects makes it difficult to provide an approximate water budget for the region during an average rainfall year as in the 1980's. For 1985-86 the water use by plants was calculated as 47704.5 MCM, when the net sown area was about 37 per cent of the total area due to drought (Table 15). For an average rainfall year, therefore, the water use marginally increased to 48804.5 MCM, as a first approximation. The estimated demand for human and livestock consumption as well as industrial use, during mid - 80's were then calculated on the basis of present trends and considered as utilization. Together, these three components accounted for 505.9 MCM water. Moreover, the evaporation losses from the surface storages (including canals) was considered to be 886.1 MCM. The basin outflow was considered as 342 .0 MCM and deep percolation as 501.2 MCM. Subtracting these figures from the available water (59418.4 MCM) led ultimately to a residue of 5291.7 MCM which could be considered as soil storage (Table 17; Fig. 5).

Table 17. Present water budget (MCM) for arid Rajasthan

District	Rainfall	Surface water inflow	Ground water extraction	Basin outflow*	Deep percolation	Water use by plants	Human consumption	Livestock consumption	Industrial use	Lvaporation from catchment storage	Soil storage
Barmer	7352.8		92.7	3429.0	73.5	5557.6	18.3	37.2	0.3	12.9	
Bikaner	6918.4		8.9		69.2	5311.9	14.4	24.2	0.7	17.3	
Churu	5387.5		10.0		53.9	4024.6	18.2	24.9	0.3	15.1	
Ganganagar	1201.4	7786.0	90.0		12.0	6300.0	30.6	25.5	2.9	7.4	
Jaisalmer	6769.0		2.2		67.7	5148.3	5.6	19.0	0.1	25.3	
Jalore	3550.2		222.8		35.5	3005.1	15.2	17.2	0.3	46.9	
Jhunjhunu	1956.3		200.9		19.6	1829.9	19.7	13.7	4.9	68.6	
Jodhpur	6288.4		149.0		62.9	6103.8	26.3	31.1	3.0	13.7	
Nagaur	4554.9		199.1		45.5	4452.1	25.8	35.7	—	35.1	
Pali	3578.3		312.8		35.8	4307.5	20.6	23.5	3.8	573.5	
Sikar	2566.5		220.3		25.6	2763.7	22.1	20.6	0.2	70.3	
Total	50123.7	7786.6	1508.7	3429.0	501.2	48804.5	216.8	272.6	16.5	886.1	5291.7

Total receipt = 59418.4 MCM   Total utilization = 59418.4 MCM

* Outflow in good rainfall years

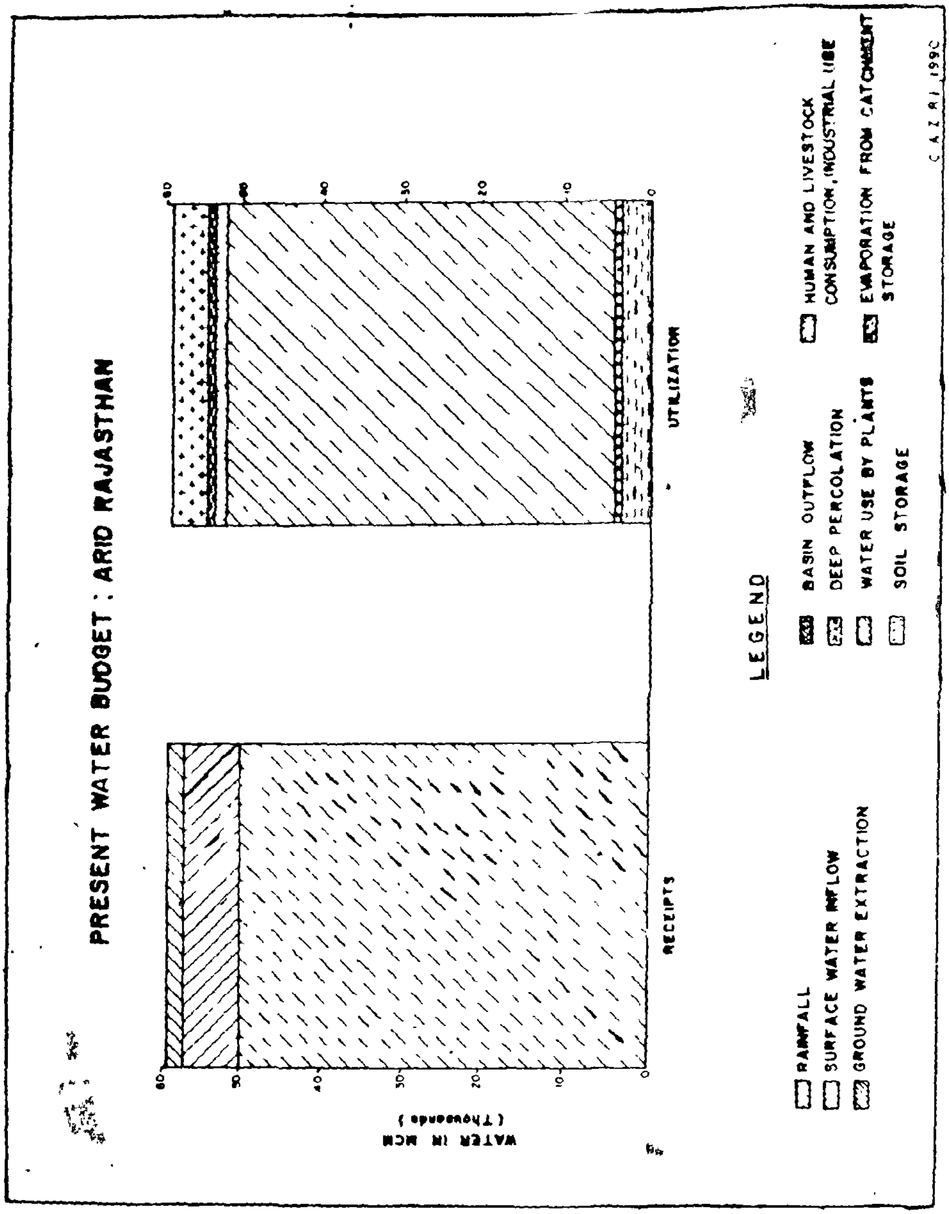

PRESENT WATER BUDGET : ARID RAJASTHAN
WATER IN MCM
(Thousands)
0
10
20
30
40
50
60
RECEIPTS
UTILIZATION
LEGEND
RAINFALL
SURFACE WATER INFLOW
GROUND WATER EXTRACTION
BASIN OUTFLOW
DEEP PERCOLATION
WATER USE BY PLANTS
SOIL STORAGE
HUMAN AND LIVESTOCK CONSUMPTION, INDUSTRIAL USE
EVAPORATION FROM CATCHMENT STORAGE
C A Z R I 1990

Fig. 5

CHAPTER-VII

SALT BALANCE IN ARID RAJASTHAN: A CASE STUDY IN THE LUNI BASIN

The Luni river and its tributaries, covering an area of 34,866 sq. km., form the only integrated drainage system in arid Rajasthan. The annual average rainfall in the basin ranges between 600 mm in the southeast and 300 mm in the northwest. Typical of the desert climate, the rainfall is characterized by rapid onset and short duration, is infrequent, localised and variable within the basin. The PET varies from 1660 to 2063 mm/yr. The eastern part of the basin is hilly and rocky, composed mainly of igneous and metamorphic rocks, whereas the western part is covered with alluvium and sand, ranging from less than 1 m to more than 40 m.

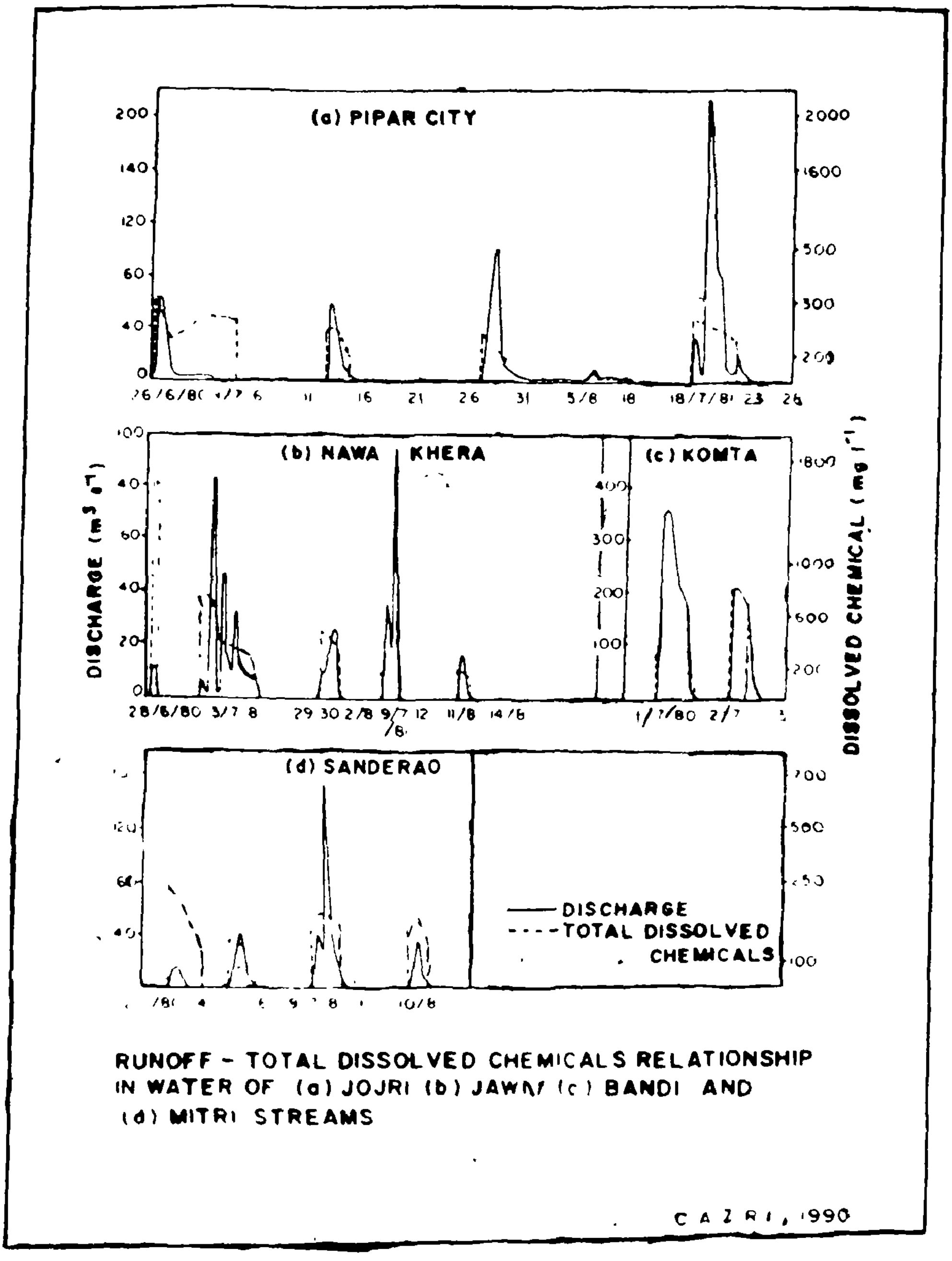
a) **Rain water composition** :

As an example three raingauging stations, a) Pachpadra (sandy aeolian plain with moderate to high wind activity), b) Rohat (alluvial plain with cultivated fields and moderate vegetation cover) and c) Pawa (in hilly region, with thorny forest vegetation) were considered for rainwater analysis. In the hilly and forested areas least amount of salt (0.01 g/l) is added through the rainwater, whereas the maximum salt is added in the high wind regime and sandy/saline areas (0.72 g/l).

b) **Stream water composition** :

The stream waters in the Luni basin were alkaline in nature (pH ranges from 7.7 to 8.6) and their EC varied between 231 and 27,684 $\mu s\ cm^{-1}$ (0.03 and 16.61 g/l). The Jojri, Upper Luni, Bandi, Khari and Sagi waters were found to be dominated by Ca^{2+} and SO_4^{2-}, whereas other streams were dominated by Na^+ and Cl^- ions.

Within a single flow event the salt concentrations were higher on the rising limb of the hydrograph, compared to the falling limb, with a low conductivity after the peak flow (Fig. 6). This is attributed to the flushing of the soil surface in which higher concentrations of chemicals are washed out by the initial phase of storm runoff. Weathering, leaching and evaporation lead to accumulation of highly soluble salts in surface soils during the time interval between two runoff events. In the Luni basin this interval is of the order of 8 to 10 months. Thus, the recycling of salts in the landscape had a serious effect on the quality of the stream waters in the region.



(a) PIPAR CITY
(b) NAWA
KHERA
(c) KOMTA
(d) SANDERAO
DISCHARGE (m³ s⁻¹)
DISSOLVED CHEMICAL (mg l⁻¹)
DISCHARGE
TOTAL DISSOLVED CHEMICALS
RUNOFF - TOTAL DISSOLVED CHEMICALS RELATIONSHIP IN WATER OF (a) JOJRI (b) JAWAI (c) BANDI AND (d) MITRI STREAMS
CAZRI, 1990

Fig. 6

From the salt balance study in the Luni Basin, it can be concluded that the stream water quality in the Indian arid zone deteriorates due to the presence of salts in the precipitation and flushing of the soil surface through quick and overland flows. Salts are accumulated near the soil surface by evaporation and are brought up from deeper depths through capillary action in drier and hot months. Geology, landscape and flow volume are the controlling factors on the amount of total dissolved salts and composition of individual ions.

During floods a large amount of water infiltrates to a greater depth, which brings more salts to the soil surface in the subsequent drier months and results in in high salt contents in stream waters in flows of the following year*.

*Source : Choudhari, J.S. and Sharma, K.D. 1984. Stream salinity in the Indian arid zone. *Journal of Hydrology*. 71 : 149-163.

CHAPTER-VIII

TRENDS OF POPULATION AND LAND USE CHANGES

a) The changing population :

The arid zone of Rajasthan is experiencing rapid increase in its human and livestock population. For example, according to the Census of India the human population increased by 37.29 per cent between 1971 and 1981. This is much higher than the Rajasthan state's average of 32.38 per cent. The country as a whole experienced an increase of 24.75 per cent during the same period. The livestock population registered an increase of about 7 per cent between 1983 and 1987 livestock censuses. The livestock density of 119 heads per sq. km. is, however, too high and it puts a serious pressure on the scarce resources of the desert, especially during the droughts like that in 1985-86, leading to high rates of mortality also. The human population density of 65 per sq.km. is also high for the desert, although the figure is low as compared to the state's population density of 100 per sq.km. Considering the present trend of population growth the expected human and livestock population in 1990 to 2001 have been calculated (Tables 18, 19; Fig. 7).

Table 18. Human population (in million) in arid Rajasthan (present and projected figures)

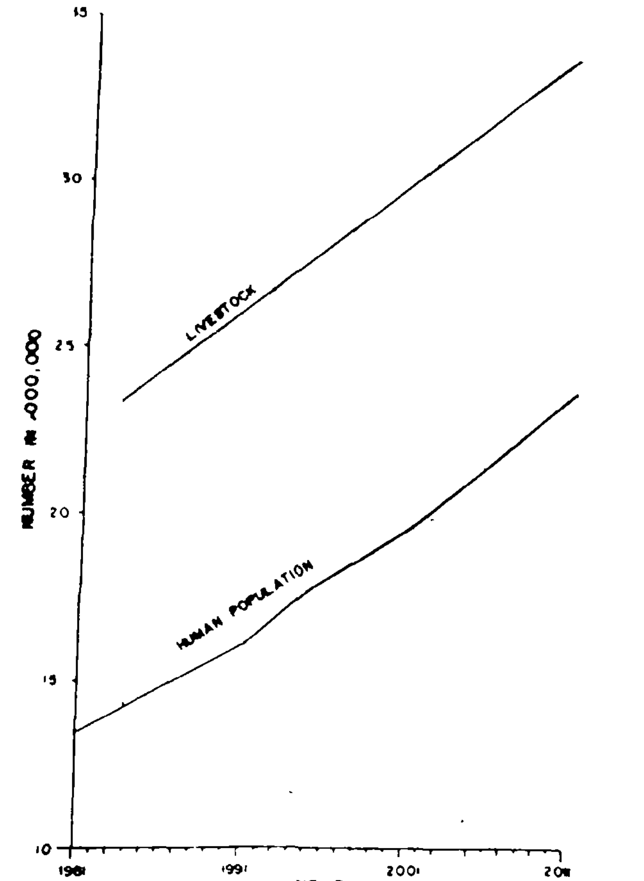
	Year				
District	1981*	1991	1995	2001	2011
Barmer	1.119	1.351	1.505	1.669	2.028
Bikaner	0.849	0.997	1.109	1.228	1.487
Churu	1.179	1.400	1.546	1.702	2.041
Ganganagar	2.030	2.512	2.821	3 149	3.862
Jaisalmer	0.243	0.286	0.317	0.351	0.423
Jalor	0.903	1.067	1.177	1.293	1.547
Jhunjhunu	1.211	1.450	1.599	1.757	2.101
Jodhpur	1.668	2.016	2.253	2 505	3.058
Nagaur	1.629	1.969	2.179	2.404	2.895
Pali	1.275	1.501	1.646	1.800	2.135
Sikar	1.377	1.619	1.781	1.953	2.328
Total	13.483	16.168	17.933	19.811	23.905

*Source : Census of India : Rajasthan (1981); Govt. of India.

Table 19. Livestock population (in million) in arid Rajasthan (present and projected figures).

District	1983	1987	1992	1997	2002
Barmer	3.184	3.393	3.657	3.920	4.184
Bikaner	2.075	2.213	2.385	2 556	2.728
Churu	2.130	2.271	2.447	2.624	2.800
Ganganagar	2.185	2.329	2.510	2.691	2.872
Jaisalmer	1.631	1.736	1.871	2.005	2.142
Jalor	1.476	1.572	1.694	1.816	1.938
Jhunjhunu	1.176	1.255	1.353	1.442	1.547
Jodhpur	2.666	2.843	3.063	3.284	3.506
Nagaur	3.056	3.256	3.508	3.765	4.014
Pali	2.012	2.144	2.310	2.477	2.643
Sikar	1.759	1.879	2.025	2.170	2.317
Total	23.350	24.891	26.823	28.750	30.691

Source : Statistical Abstract (1987-88); pp 12 & 14; Animal Husbandry Department, Govt. of Rajasthan, Jaipur.

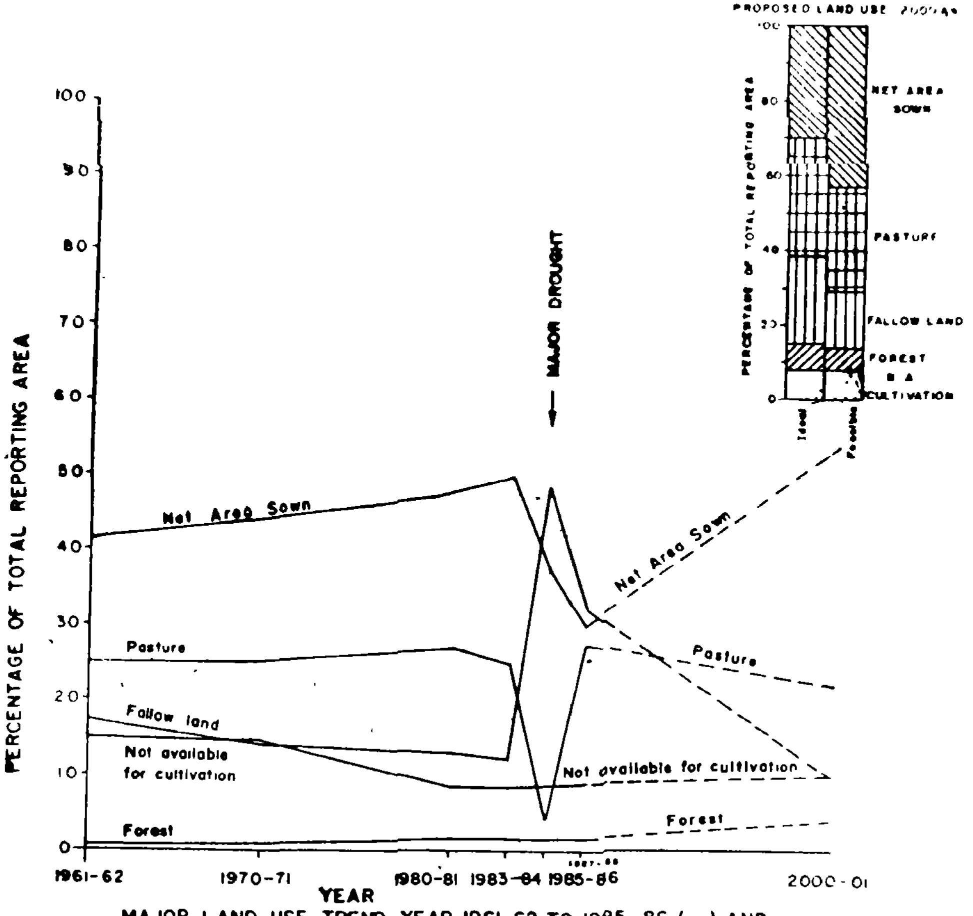


PROJECTED TREND OF HUMAN AND LIVESTOCK POPULATION INCREASE (1981-2011) IN ARID RAJASTHAN

Fig. 7

b) The land use changes :

As the population increases, so does the pressure on the land and water. This is reflected in the changing land utilization pattern within the region (Table 20). The net sown area increased steadily from 41.3 per cent of the total reporting area in 1961-62 to 49.9 per cent of the total in 1983-84. Consequently, the fallow lands decreased from 17.3 per cent to 13.7 per cent during the same period. The pressure on marginal lands also increased, so that the lands not available for cultivation declined from 14.9 per cent in 1961-62 to 8.6 per cent in 1983-84. Fortunately, the figures for pasture land oscillated between 25.5 per cent and 26.3 per cent, thanks to the traditional belief in keeping permanent pastures *(oran)* in every village area for the livestock. The figures, however, change considerably during the major drought years, as in 1985-86 and 1987-88 (Table 20, Fig. 8).



MAJOR LAND USE TREND, YEAR 1961-62 TO 1985-86 (—) AND PROJECTED TREND UPTO 2000-01 (---) IN ARID RAJASTHAN

Fig. 8

Table 20. Land use changes in arid Rajasthan

	Percentage of total reporting area								
	1961-62*	1970-71*	1980-81*	1983-84*	1985-86*	1987-88*	2000-01 (Projected)	2000-01 (Suggested)	
								Ideal	Feasible
Net area sown	41.3	44.2	47.2	49.9	37.4	29.9	54.0	30.0	43.0
Pasture	25.7	25.5	28.8	26.3	4.3	27.3	22.0	31.5	28.0
Fallow land	17.3	14.5	14.2	13.7	48.2	31.9	10.0	23.5	15.0
Forest	0.8	0.8	1.4	1.5	1.6	1.7	4.0	6.0	5.0
Area not available for cultivation	14.9	15.0	8.4	8.6	8.5	9.2	10.0	9.0	9.0

*Source : Statistical Abstracts and Revenue Records of Govt. of Rajasthan

Considering the present trend of land utilization it is expected that 54.0 per cent of the reporting area of arid Rajasthan will be under net sown area during 2000-01, while the pasture land will decline to 22.0 per cent and fallow land to 10.0 per cent. It is also presumed that the area not available for cultivation might increase marginally to 10.0 per cent, as a result of faulty uses of water, especially in irrigated areas, consequent salinity-alkalinity build-up in soil, and due to high reactivation of marginal sandy areas. The afforestation programme, if continued in right earnest, may lead to a coverage of 4 per cent of the total reporting area.

As the area under crops will increase, so will the demand for water. The expected area under *Kharif* crops during the year 2000 AD, assuming a very good rainfall year, has been calculated as 56 per cent of the total area (Table 21). The areas under the *Kharif* and *Rabi* crops will also increase gradually as irrigated agriculture spreads in the Indira Gandhi Canal Command area (Indira Gandhi Nahar Project).

Table 21. Expected area (,000 ha) under *Kharif* and *Rab'* crops in arid Rajasthan during 2000 AD (considering good rainfall).

Crops	District										
	Barmer	Bikaner	Churu	Ganganagar	Jaisalmer	Jalor	Jhunjhunu	Jodhpur	Nagaur	Pali	Sikar
Pearlmillet	1800.0	569.0	776.6	235.7	127.5	533.3	333.9	943.8	844.3	330.7	388.8
Kharif pulses	274.9	525.2	590.2	207.1	85.0	210.2	114.6	722 3	312.6	112.3	205 3
Cluster bean	1.6	17.7	10.6	1.8	33.9	0.5	1.0	2.5	1.0	4.0	4.5
Pigeon pea	0.2	2.9	0.4	0.6	5.6	—	—	2.5	—	—	0.1
Sorghum	2.6	5.9	0.9	15.0	5.0	4.0	1.0	4.0	80.1	95 7	0.2
Peanut	0.6	14.8	2.2	40.0	22.6	1.5	0.2	2.1	10.7	3.2	1.5
Cotton	0.6	11.8	1.7	232.7	22.6	3.0	0.1	2.0	3.0	16.0	0.2
Chillies	0.3	2.9	0.4	1.2	5.6	1.5	1.0	12.0	1.2	2.1	1.0
Kharif forage	1.3	5.9	0.9	7.6	11.3	1.5	0.2	1.5	2.0	2.5	1.0
Rice	—	—	—	24.3	—	—	—	—	—	—	—
Maize	—	—	—	2.0	—	0.3	—	1.0	0.5	33.7	0.4
Sesame	115.7	20.0	2.9	0.5	—	51.3	0.3	112.0	218.9	209.2	2.0
Castor	0.2	—	—	—	—	3.0	—	—	—	0.5	—
Sannhemp	—	—	—	0.5	—	0.2	—	—	—	—	0.1
Smaller millets	—	—	—	—	—	3.1	—	—	0.2	1.0	—
Total (A)	2093.8	1176.3	1387.5	769.0	319.2	813·4	452.3	1805.8	1474.4	810.9	605.1
Wheat	16.0	53.2	7 8	300.1	56.5	35.8	29.4	35.6	31.9	48.2	38.8
Barley	1.4	8.9	5.0	10.5	17.0	2.1	9.0	0.5	8.6	8.7	17.8
Chick pea	1.6	29.6	165.0	535.0	56.5	0.5	85.1	4.2	2.3	2.5	70.6
Mustard	4.7	29.6	4.3	200.9	101.7	38.5	25.7	20.4	28.6	20.0	20.3
Coriander	0.5	—	—	0.2	—	—	—	0.1	0.1	0.5	0.1
Potatoes	—	—	—	0.2	—	—	—	—	—	—	—
Sugarcane	—	—	—	4.0	—	—	—	—	—	—	—
Tobacco	—	—	0.2	—	—	—	0.3	—	—	—	0.2
Rabi fodder	0.5	.9	0.9	8.6	11.3	1.5	0.5	0.2	1.0	1.0	0.5
Horti. crops.	0.3	5.9	0.9	15.2	11.3	—	—	0 2	—	—	—
Total (B)	25.1	133.0	184.1	1074.7	254.3	78.4	150.0	61.3	72.6	80.9	148.2
Double cropped area	18.7	193.5	40.0	305.6	197.8	52.2	130.2	40.8	40.2	75.7	142.6
Net cropped area	2100.2	1205.8	1531.6	1737.9	375.7	839.5	472.2	1826.3	1506.8	816.1	610.7

CHAPTER-IX

FUTURE DEMAND FOR WATER AND SUGGESTED USES

a) The demand in different sectors :

The future demand of water for human and livestock consumption, irrigation and industries have been calculated (Table 22). While the demand for human consumption may increase from 196.85 MCM in 1981 to 289.23 MCM in 2001 AD, the demand for livestock consumption may increase from 249.00 MCM to 332.50 MCM during the same period. The maximum demand for water will, however, be in the case of irrigation, from 5178 MCM in 1981 to 6265 MCM in 2001, while the industrial demand may increase marginally, from 16 MCM to 18 (Fig. 9).

b) Proposed action plan for CCA in the Indira Gandhi Nahar Project, Stage II, area :

The command area of the Indira Gandhi Nahar Project (IGNP), falls within six districts of Rajasthan namely, Jaisalmer, Bikaner, Churu, Jodhpur, Jaisalmer and Barmer (Table 23). However, 85 per cent of the area falls within the districts of

Table 22. Expected water demand (MCM) in arid Rajasthan by 2011 A.D.

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 (@ 0.3 m per ha**)	5178.00	5696.00	5900.00	6265.00	6892.00
Industry	16.00	17.00	17.50	18.00	21.00
Total	5639.85	6239.06	6487.32	6904.73	7638.02

* lpd : litres per day, ** m : metres

Table 23. Proposed irrigated area in the Indira Gandhi Nahar Project, Stage II, during 2000 A.D.

District	Culturable command area (ha)
Ganganagar	30,000
Churu	42,200
Bikaner	2,95,200
Jaisalmer	5,65,200
Jodhpur	64,200
Barmer	15,200
Total	1,012,000

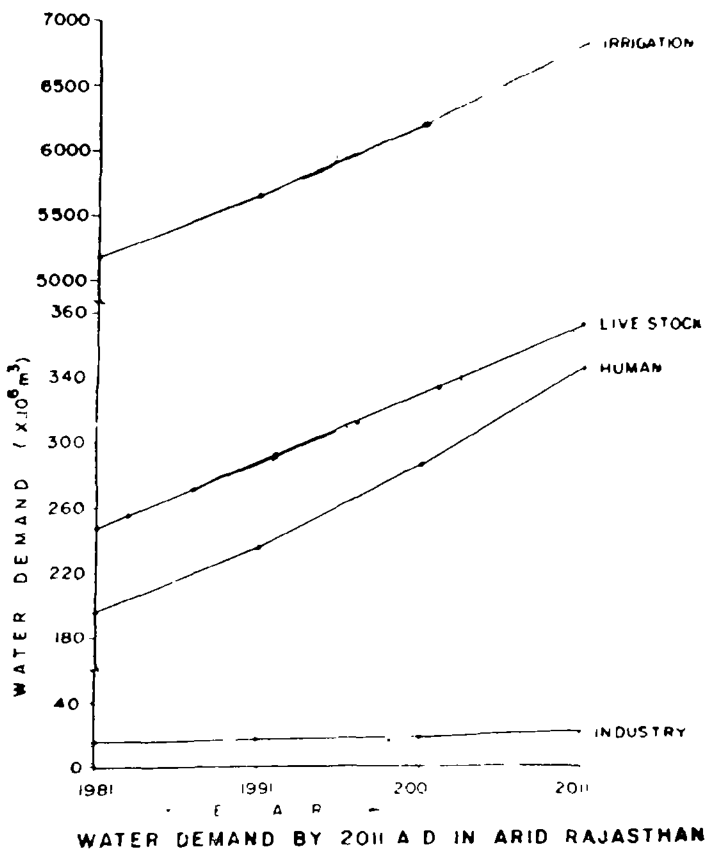


Fig. 9

Jaisalmer and Bikaner. Command area development work is still in progress in the stage II.

According to the present thinking, the water allocation for the IGNP, Stage II, is likely to be 4932 MCM. The water for irrigation is likely to be 4131 MCM and that for drinking purpose and other requirements about 801 MCM. Detailed studies on cropping pattern, crop water demand and crop yield are needed for providing realistic information on cropping plan, etc. However, if irrigation intensity is kept at 80 per cent level, as recommended by the Rajasthan State Government, the provisional cropping pattern may include 30 per cent area under *Kharif* crops and 43 per cent area under *Rabi* crops. Pearl millet, pulses, cluster bean, pea nut, cotton, wheat, chick pea, mustard and barley could be the major crop components. About 3 per cent area may come under perennial grasses, while horticultural crops, including grafted 'Ber' *(Z. mauritiana)* and citrus, may cover 2 per cent area (Table 24).

Table 24. Provisional cropping for the Indira Gandhi Nahar Project area, Stage-II, during 2000 AD (80% irrigation intensity)

Crop	Percentage area	Area in ha
Kharif		
Pearl millet	6	60,720
Pulses	6	60,720
Pigeon pea	1	10,120
Cluster bean	5	50,600
Pea nut	4	40,480
Cotton	4	40,480
Sorghum	1	10,120
Til	1	10,120
Fodder	2	20,240
Sub-total	30	3,03,600
Rabi		
Wheat	12	1,21,440
Barley	5	50,600
Chick pea	12	1,21,440
Mustard	12	1,21.440
Fodder	2	20,240
Sub-total	43	4,35,160
Grafted Ber (*M. mauritiana*)	1	10,120
Citrus	1	10,120
Perennial grasses	3	30,360
Sub-total	5	50,600
Total	78%	7,89,360

The soils in the command area are presently not developed and lack in nutrients. During the initial five years or so, the cultivators will, therefore, go in for traditional crops. With the gradual improvement in soil fertility, micro-level climatic changes and efforts of agricultural extension services, the cropping pattern will change. Imposition of any pre-conceived optimum cropping pattern on the cultivators, on the other hand, may become counter-productive. Cropping pattern in the irrigated commands are known to have changed gradually under the influence of agro-economic conditions. Development of new crop varieties, prices of agricultural commodities, social needs, demand-supply position in the national and international markets, etc., bring about periodical changes in the cropping pattern. Consequently, the irrigation demands in the system are not fixed, but change with the cropping pattern and crop characteristics. Since the water availability for the IGNP, stage II, is likely to be limited, emphasis should be on the practising of extensive irrigation, rather than intensive irrigation.

c) Problem areas within the IGNP, Stage II, and the need for water management :

While proposing the provisional cropping pattern for the command area of stage II, the average soil depth has been taken as more than one metre. However, the entire command area is underlain by a hydrological barrier at varying depths. Lenses or layers of gypsum, gypsiferous clay, bentonite, *kankar* pan, etc., are the major types of barrier. Preliminary estimates indicate that in the flow command area about 5 per cent land has such barrier within 5 m of the ground level, especially in the command area of Dattor branch canal (21000 ha), Sagarmal Gopa branch canal (10220 ha) and Sakaria and Awai distributaries (3550 ha). In case of the lift canal schemes such areas are mainly confined to the Phalodi (23660 ha), Kolayat (12230 ha) and Pokaran (675 ha) schemes. Together, these constitute about 17 per cent of the total lift command area. It is estimated that the hard pan barrier at 5 to 10 m depth is in 247510 ha area (163540 ha under flow and 83970 ha under lift schemes). With the introduction of irrigation, the average annual rise in water table is expected to be of the order of 25 cm per year. Under such circumstances the essentiality of a proper drainage system needs hardly to be over-emphasised. The areas having hard pan at 5 m or less depth (approximately 72000 ha) need, however, to be treated as the most vulnerable to waterlogging and salinity. Enough care is also required for the areas having barriers at 5 to 10 m depth (247510 ha). The following suggestions are made :

i) The areas highly vulnerable to waterlogging and salinity should be used for cultivation of grasses, with utmost control on water application through sprinkler irrigation.

ii) Drip and sprinkler irrigation systems would be of help in preventing or delaying the process of rise in groundwater table in the vulnerable areas. As per the present rates, the cost of providing sprinkler irrigation with adequate storage capacity for each individual cultivator would be around Rs. 10,000 per ha.

iii) The principle of volumetric sale of water should be introduced and strictly enforced. Water should be delivered to the lined tanks only, from where it may be pumped out with wind or solar energy, so that only the most needed quantities are purchased, no flooding is done and optimun utilization of this scarce resource is ensured. Similar experiment in China has proved successful. Although the construction of such small ponds will add to the cost, considering the problem of ecological imbalance, this possibility should be explored.

iv) The most vulnerable areas having barrier at 5 m or less depth need to be surveyed and monitored in detail. Inverted wells should be constructed in the critical areas for effective drainage.

v) The areas under sand dunes should be stabilized through grasses and trees. Because of the higher water availability a number of plant species could be grown to serve the dual purpose of sand stabilization and economic return. Among the timber producing tree species *Hardwickia binnata*, *Tecomella undulata* and *Acacia nilotica* could be propagated on dune slopes, while *Azadirachta indica*, another timber producing species, could be grown in the flat interdunes having better moisture status. Trees like *Bauhina racimosa* (under favourable moisture regime) and *Cordia rothii* have values in cottage industries. *Colophospermum mopane* is a fast growing tree, having topfeed value, *Acacia senegal* is a gum producing species and has top-feed value also, while *Acacia tortilis* has good fuel value. Therefore, planting of the above trees will not only help in stabilizing the sand, but also provide some economic return. Apart from the above, the naturally occurring *Calligonum polygonoides* shrubs on the dunes have very good fuel value as well as sand binding capacity. The species should, therefore, be protected wherever it is possible to do so.

Among the grasses *Saccharum munja* is important for cottage industries, while *Lasiurus sindicus*, *Cenchrus cilliaris* and *Cenchrus setigerus* have nutritious fodder value. These could be propagated along the dune slopes and on lower sandy undulations. The last one has a higher moisture demand and is better adapted to gentler slopes. *Vetiviera zizanoides*, a grass that prefers medium to heavy textured soil and has importance in cottage industries, could be grown in the waterlogged interdunes. *Citrullus colocynthis*, a creeper having medicinal value and having demand in local soap making industries because of its non-edible oil production, is also a good sand binder and grows well on dune slopes.

All the above species should be given due consideration.

The provisional cropping pattern, as proposed in Table 24, is for areas where hard pan barrier is at depths of more than 10 m. Considering an allocation of 4132 MCM water for irrigation and irrigation efficiency of 0.65 (65 per cent), the net irrigation water available for consumptive use at field will be 265.4 mm or 2654 cubic metre per ha. Any variation in the availability of water will, therefore, require adjustment in the cropping pattern. With lower availability of water the areas under crops requiring less water would be increased. The areas under crops like pea nut and cotton in *Kharif* and wheat and fodder crops in *Rabi* would be reduced proportionately.

d) Deficit irrigation approach :

To maximise yield per unit application of water, the seasonal water requirement has to be minimised by optimally programming the date and depth of all seasonal irrigations in such a way that yield reduction would be proportionately lesser than the reduction of water below the gross amount needed to meet fully the crop water requirement of each hectare of area to be cropped. This implies that small quantity of water would be applied over a larger area rather than a large quantity of water over a small area.

Integrated dryland farming-supplemental irrigation system will improve the rainwater use efficiency in rainfed crops. Protective irrigation to rainfed crops during

Kharif would be much more effective against famines than the intensive irrigation to crops over a small area (Table 24).

e) **New irrigation technology :**

As has been mentioned earlier attention has to be given in the region on new irrigation technologies like sprinkler and drip irrigation, since these systems make the best use of every drop of available water by drastically reducing the conveyance and deep percolation losses. The feasibility of using sprinkler system on individual farm should, however, take into consideration the prevailing wind velocity in the region and the cost of infrastructure development, like storage tank construction. The drip system, on the other hand, is neither for all farmers, nor for all crops. It has particular promises for high-value, widely-spaced vegetables and plantation crops on porous soils of the water scarce regions.

f) **The demand for ground water :**

Part of the demand will be met by ground water. Yet, the ground water exploitation level has already reached a critical limit in many districts, although in many others the exploitation level is low (Fig. 4). The projection of ground water recharge, draft and balance for the years 1990, 1995 and 2000 have been estimated, taking into consideration the ground water assessment data for the year 1988. It has been recalculated that in Jaisalmer, Bikaner, Churu, Barmer, Ganganagar, Jodhpur and Nagaur districts the utilization of groundwater would be well within the limits of recharge through rainfall, while in Jhunjhunu district the recharge would be almost equal to the utilization in 2000 AD. In Jalor and Pali districts the trend of exploitation will, however, exceed the recharge from 1990 onwards. Therefore, these districts are likely to experience the adverse effect of over-exploitation (Fig. 4, Tables 25-27).

Table 25. Projected groundwater potential in arid Rajasthan for January 1990 (with the present trend of utilization)

District	Utilisable recharge (MCM)	Net ground water utilised (MCM)	Balance ground water (MCM)	Ground water developed (%)
Barmer	252.25	94.06	158.19	37.29
Bikaner	208.17	9.00	199.17	4.32
Churu	227.25	10.19	217.06	4.48
Jaisalmer	159.70	2.25	157.45	1.41
Jalor	274.06	266.16	47.90	97.12
Jhunjhunu	275.76	209.90	65.87	76.12
Jodhpur	345.11	153.47	191.63	44.47
Nagaur	712.35	208.05	504.30	29.21
Pali	339.52	331.57	7.94	97.66
Sikar	280.76	233.55	47.21	83.19
Ganganagar	280.00	95.40	184.60	34.07
Total	3354.93	1613.60	1781.32	48.10

Table 26. Projected ground water potential in arid Rajasthan for January 1995 (with the present trend of utilization)

District	Utilisable recharge (MCM)	Net ground water utili·ed (MCM)	Balance ground water (MCM)	Ground water developed (%)
Barmer	252.25	98.77	153.48	39.15
Bikaner	208.17	9.45	198.72	4.53
Churu	227.25	10.69	216.55	4.70
Jaisalmer	159.70	2.36	157.34	1.48
Jalor	274.06	319.39	-45.33*	116.54
Jhunjhunu	275.76	241.38	34.38	87.54
Jodhpur	345.11	168.82	176.29	48.92
Nagaur	712.35	239.25	473.10	33.59
Pali	339.52	397.89	-58.37*	117.19
Sikar	280.76	280.26	49.77	99.83
Ganganagar	280.00	114.48	165.52	40.88
Total	3354.93	1882.74	1521.45	56.21

*Figures indicate utilization of more water than is being recharged and hence, tapping of the non-rechargeable source.

Table 27. Projected ground water potential in arid Rajasthan for January 2000 A.D. (with the present trend of utilization)

District	Utilisable recharge (MCM)	Net ground water utilised (MCM)	Balance ground water (MCM)	Ground water developed (%)
Barmer	252.25	103.70	148.55	41.15
Bikaner	208.17	9.92	198.25	4.76
Churu	227.25	11.23	216.02	4.93
Jaisalmer	159 70	2.48	157 22	1.55
Jalor	274.06	383.26	-109.20*	139.89
Jhunjhunu	275.76	277.59	-18.30*	100 67
Jodhpur	345.11	185.71	159 40	53.81
Nagaur	712.35	275.14	437.21	38.63
Pali	339.52	477.47	-137 95*	140.62
Sikar	280.76	336.31	55.55	119.79
Ganganagar	280.00	137.38	142.62	49 06
Total	3354.93	2200.19	1249.37	65.58

*Figures indicate utilization of more water than is being recharged and hence, tapping of the non-rechargeable source.

g) Suggestions on groundwater monitoring and development :

The management of groundwater resources in arid regions require special attention due to the fact that it occurs under complex hydrometeorological and hydrogeological environments. Groundwater forms the most reliable resource for human and livestock consumption in this region. Therefore, its exploitation for domestic purposes is among the maximum priority agenda in almost all the districts. The utilization of groundwater for irrigation has also been increasing due to the spreading network of electricity. Under the circumstances it is important to review the groundwater assessment in each district annually and to suggest the limit for safe yield. Artificial recharge methods, suitable to the particular sites, should also be adopted so that proper groundwater balance can be maintained. Better irrigation methods need to be adopted, so that there is minimum water loss through evaporation and seepage. A comprehensive legislation for utilization of groundwater resources should be framed and the people should be educated regarding proper utilization of groundwater resources.

h) **Other suggestions for better utilization of water :**

There is, thus, a great need for proper planning, so that the available water could be utilized in a better way. If the population growth rate could be restricted to 1.9 per cent over what it was in 1981, the total population might come down to 18,606,562 in 2001. Considering the rate of consumption of water as 40 lits/day, the suggested demand for water consumption during 2001 will be 271.6 MCM.

For the livestock the average area needed to sustain each cattle unit is 0.5 ha. If the pasture land could be kept at 20.3 per cent of the total area, fallow land at 6.7 per cent and half of the area not available for cultivation is taken as 4.5 per cent, then the total area under pasture and natural vegetation cover could be expected around 31.5 per cent of the total or 6,559,600 ha. The theoretical sustainable cattle unit then becomes only 13,119,200. The present livestock population is, however, about 25,000,000. If this limit could be maintained upto 2001 through selective prunning, then the suggested water demand for livestock at the rate of 30 litres per day is 273.8 MCM in 2001.

Similarly the area under crops needs some proper thinking. As we have noted earlier, about 54 per cent of the total area will be under the category of net sown area during 2000-01, if the present trend of land utilization continues, while 22 per cent area will remain for pasture. The fallow land may cover only 10 per cent of the total area. Much of the area of the desert is, however, ideally suited for pastoral and silvi-pastoral systems. Proliferation of the area under crop means more demand for water and encroachment on the marginal lands. Under such circumstances and without an assured supply of water the prevailing wind regime hastens the process of land degradation. The well-maintained pasture lands, on the other hand, help in checking the land degradation and in feeding the large number of domestic animals. Considering all the factors, it is felt that the ideal utilization would be 30 per cent land under net sown area and about 31.5 per cent land under pasture. About 23.5 per cent land could be kept as fallow. However, it is difficult to achieve this status because of the prevailing socioeconomic and demographic situations. Under the circumstances, the next best option to maintain the ecological balance and to minimise the water use, would be to check the net sown area to 43 per cent level, while about 15 per cent land area could be kept as fallow. The pasture land should be increased to 28 per cent of the total (Table 20).

The pace of research and development work on efficient conservation of water need also to be accelerated. This includes improving the designs of low-cost traditional water harvesting systems like *tankas*, *nadis*, *khadins*, etc., and designing of suitable structures for conserving water without much evaporation loss. The possibilities of injecting the surface water into shallow subsurface aquifers for storage without appreciable deterioration of quality for future reuse, need also to be examined. Such experiments in the *Takyrs* (saline depressions) of the Karakum desert of the USSR and in the sami-arid sandy plains of the *Sahel* region of Africa are claimed to have limited success.

CHAPTER X

EPILOGUE

The year 2000 AD is only a decade ahead of us now. With the ever increasing demand for water it is high time that serious rethinking is done for better conjunctive use of this scarce resource of our arid region.

If we recapitulate the statements on present water budget (Table 17), the present total receipt of water is about 59418.4 MCM. Out of this receipt the plants use as much as 48804.5 MCM water (or 82.1 per cent), while the human and livestock consumptions account for 489.4 MCM (0.8 per cent). The industrial use is a meager 16.5 MCM. About 3429.0 MCM water (5.8 per cent) goes out as basin out flow during the good rainfall years, while 886.1 MCM water (1.5 per cent) is evaporated from surface storages. That leaves about 5291.7 MCM water (8.9 per cent) for soil storage and 501.2 MCM (0.8 per cent) for deep percolation.

Now, considering that it is possible to implement the feasible land utilization that has been suggested for 2000-01 (Table 20), the approximate water demand for plants is likely to be as follows :

Land use category with percent area	*Water demand MCM*
Net sown area (43%)	25198.0
Pasture (28 %)	14644.0
Waste and fallow lands (24%)	9665.0
Forest (5%)	2507.0
Total :	52014.0

Similarly, if the growth rate of human and livestock populations could be checked to the limits suggested, the demand for water will be 271.6 MCM and 273.8 MCM, respectively.

If the contribution through canals does not increase, the total receipt of water through rainfall and surface water inflow is likely to remain unchanged at 57909.7 MCM level, but the contribution from ground water will perhaps reach the level of 2200.2 MCM, if the utilization pattern is as suggested in Table 27. Therefore, the total available water will be 60109.9 MCM.

Now, if deep percolation and basin out flow are considered to be unchanged at 501.2 MCM and 3429.0 MCM respectively and the evaporation loss from surface storages as 886.1 MCM, then the sum of total utilization becomes 57393.7 MCM, thus leaving only 2716.2 MCM for soil storage (Table 28, Fig. 10), which is most unlikely. The dominantly sandy terrain absorbs much more water than has been left as residue from this calculation (Table 16). In other words, there is a likelihood of a shortfall of water to the tune of 2500 MCM or more. Therefore, the alternative approaches are : a) restricting the basin outflow and soil storages through improved and ecologically sound rain water harvesting techniques, b) exploration and tapping of new ground water sources which could be annually recharged, so that there is less stress on non-rechargeable ground water reserve, and c) application of improved technologies for crop growth, which ensure minimum uses of water. This again calls for better coordination between research institutions and development agencies and people's active participation in proper utilization of the scarce water resources.

Table 28. Present water budget and a eonservative cstimate of water budget for 2000 AD in arid Rajasthan.

Details	Water budget (MCM)	
	Present	2000 AD
A. *Receipts*		
Rainfall	50123.7	50123.7
Surface water inflow	7786.0	7786.0
Groundwater extraction	1508.7	2200.2
Total receipt	59418.4	60109.9
B. *Utilization*		
Basin outflow	3429.0	3429.0
Deep percolation	501.2	501.2
Water use by plants	48804.5	52014.0
Human consumption	216.8	271.6
Livestock consumption	272.6	273.8
Industrial use	16.5	18.0
Evaporation from catchment storages	886.1	886.1
Soil storage	5291.7	2716.2
Total utilization	59418.4	60109.9

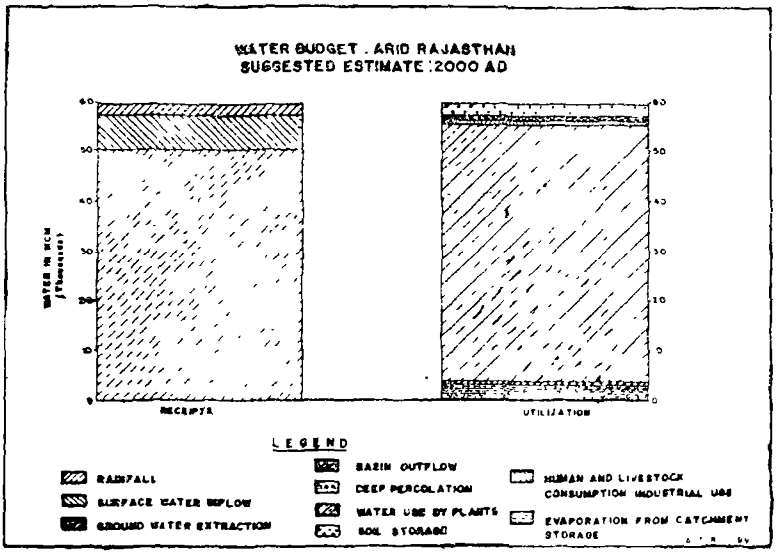


Fig. 18

This scenario is not very encouraging. However, we do not propose to draw any pessimistic conclusion. The situation, though grim, could be faced with appropriate planning and technological applications. These have been highlighted in this endeavour.