SR-2/1999-2000

STATUS REPORT ON HYDROLOGY OF ARID ZONES OF INDIA

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1999-2000

PREFACE

The arid zone is characterized by low mean annual rainfall coupled with high coefficient of variability, large amplitude of fluctuations of diurnal and annual temperatures, strong wind regimes and high potential evaporation. There are 2.86 lakh sq. kms. of such lands in the Rajasthan, Gujarat, Punjab and Haryana states of India. A substantial portion (about 60%) of this arid zone lies in the Rajasthan State and includes the Thar Desert. The problem of hydrology and water development planning in arid zones are often very different from those in more humid areas.

This report is not intended as a definitive book on the subject, it is only a interim contribution to this field while some other organizations like WMO, FAO, & CAZRI are the agencies those are publishing regular reports for this area.

Concerning the technical contents of the report, the aim is to describe the characteristics of the main hydrological elements of arid regions of India as - Indian Arid land, Geology of arid land, Rainfall, Soil pattern, Ground water, Dunes-land forms, and climate changes. Human factors in arid land development have also been described here. A list of recent publication on this region has also been included. In last, some recommendations and conclusions based on the integrated analysis of climatic and biophysical land resources have been described.

This report entitled " **Status Report of Hydrology of Arid Zones of India**" is a part of the work program of **Hydrological Information System Division** of the Institute for the year 1999-2000. This study was carried out by **Dr.(Mrs.) Rama Mehta, Sc. B.**

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ABSTRACT

The development of our dryland is growing at an increasing pace through sometimes with unforeseen and unwanted consequences. The quality of the resources base and the health of socio-economic base of our country, arid zones are affected by decisions usually made with limited information and partial knowledge trial in this direction.

This report is a collection of scattered information about the hydrology of arid regions in India. This report is divided nearly 14 categories, in which the Indian arid land, Geology, Rainfall, Desertification of arid lands, position of ground water in arid and semi-arid regions, and Dunes-land farms have been described. A list of recent publication has also been given. The effects of human beings in the development of arid land have been described in category nine. The distribution of soil pattern in various states and their major constraints for water conservation and crop production are presented in Table 7. Effect of wind erosion, water erosion and salinity/Alkalinity on fertility status of soil have also been given in different tables. Some recommendation and conclusions based on the integrated analysis of climatic and biophysical land resources have also been discussed.

1.0 Introduction

India is one of the few countries, which conceived the problems of the desert and desertification at the stage of their offing. In the post-independence era of accelerated socio-economic development of the country with the help of modern science and technology, the uniqueness of the environmental vigour of this region and the need for development of specialized technologies has been recognized right from the beginning. The main emphasis in the First five-year Plan was on the control of deserts in our country. On the recommendation of the UNESCO Advisory Committee on Arid zone Research, the government of India established a Desert Afforestation Research Station at Jodhpur in 1952 and later expanded it as the Desert Afforestation and Soil Conservation station during 1957. The station was further recognized and elevated as a Central Arid Zones Research Institute (CAZRI) in 1959. The administrative control of this institute was transferred to the Indian Council of Agricultural Research in 1966.

The natural resources of arid and semi-arid regions – particularly soil and water – are limited, and are often in a delicate environmental balance. Arid and desert lands occupy one third of the landmass and sustain approximately one sixth of the world population over fifty countries. The problem of arid zone is so great and so far reaching that it is not possible for any of these countries concerned, or for the rest of the world to ignore it. Other problems in the development of arid zones may arise from the sudden availability of modern technology to societies unprepared for it. Traditional farming methods by irrigation from groundwater in parts of the Near East were based on animal source of power. Over the centuries, the balance between rate of water withdrawal and natural recharge was achieved without substantial use of groundwater storage and field efficiency was relatively high. Electrical or engine-driven pumps have increased the capacity of wells. The absence of effective controls on drilling and pumping has resulted in groundwater mining with the consequences of decreasing yields, deteriorating water quality, saline intrusion in coastal areas and wastage of water.

Arid zones have a long history of human settlement. Low and fluctuating rainfall, high solar radiation, low atmospheric humidity, strong and regime and dominance of dunes and sandy plains among the landforms are the characteristic natural features of the hot arid zone, which occupies 2.86 Lac km^2 or 8.7% of the geographic area of the country. Although many definitions of aridity and semi-aridity appear in the literature none can be considered entirely satisfactory and the terms " arid" and "semi-arid" remain somewhat imprecise. The term applied herewith to those parts where rainfall will not support regular rain-fed farming. This definition encompasses all the seasonally hot arid and semi-arid zones classified by means of rainfall, temperature and evaporation indices (Walton, 1969)

Arid zone problems are characterized by their complexity, high degree of variability of controlling factors and of course by the painstaking condition of physical environment.

2.0 Literature Review

Arid zones in their broadest sense may be defined as the zones experiencing chronic water deficit. However, there are large areas in India with water shortage at one time or another. The monsoon regime leaves the major part of the country dry for a period varying from 2 to 11 months on an average, but the inter-yearly variations are quite important. Whereas, the normal dry season, when rains are not expected, goes unnoticed, the extension of the dry spell beyond the time of onset of the normal monsoon season poses a severe threat to water management and agricultural operations. The word drought in its most usual sense implies dryness. This dryness may be rigorous or mild in its intensity, long or short in its duration, seasonal or periodic in its occurrences and if seasonal. The word drought is related to the term aridity for it is the dryness that in its extremely intense form and long duration contributes to the aridity. Several degree of aridity may be recognized. The extremely arid zones are the ones not experiencing any rain for more than a year at a stretch. Only a very small portion of the Thar Desert in the extreme western Rajasthan in India and Sind in Pakistan belongs to this category. In other cases, there may be a few sporadic showers, but of very low intensity and duration so that no month may be characterised as humid. Subsequent degrees of decreasing aridity may be recognized on the basis of the number of dry months. Meher - Homji (1997) have made an attempt together the information on dry season, aridity, Desertification and drought related problems in the Indian sub-continent. They have briefly reviewed the spatial complexity and the temporal variability.

Dhir et.al (1997) have presented a soil map of arid zone of Rajasthan based on updated soil survey information and refinement of boundaries from dry season (April – June). They have used the latest version of soil taxonomy in the classification. A book review by Atar Singh and Bawa (1991) has given about "Research and Management of Arid Rainfed Areas". This book is a compilation of much of the information already published in CAZRI annual progress reports and lacks critical evaluation and interpretation of the data.

Wind erosion is a major problem in the arid sandy tract of northwest India, especially in west Rajasthan. Venkateswarlu and Kar (1996) have studied the Wind erosion and its Control in Arid Northwest. Fig.1 shows the part of the Thar or the great Indian Sand Desert, along with the adjoining sandy arid areas of Punjab, Haryana and Gujarat states. According to the data compiled recently by the Min. of Agriculture, Govt. of India, 10.46 million ha of land in India is affected by wind erosion. Out of the total, Rajasthan accounts for 93.8% (9.81 million ha), followed by Haryana (5.1%).

Since actual measured PET data are not readily available in most arid and semi-arid regions, especially in historical climate data sets, it becomes necessary to use formulae, which can estimate PET from available climatic data. Mahalashmi et.al. (1993) have given a test of two empirical Evapo-transpiration formulae for semi-arid regions. In practice, the only available data for most locations in the arid and semi-arid regions are maximum and minimum temperatures and rainfall, often readily available only as weekly means. Many simplified, empirical formulae for estimating PET which require fewer climatic elements than Penman's formula have been published. (Linacre 1977, Fitzpatrick 1963, Swan & Volume 1986, Hargreaves & Samani 1986, & Cahoon et.al. 1991). The major limitation to the use of these empirical formulae is that their application is limited to the climates, seasons or environments similar to those used to derive them.

Saha and Usha (1992) have been made study about the role of rural women in decision-making processes of various socio-economic activities. In decision-making processes especially in agriculture, livestock and socio-religious matters, women were consulted by the heads of households. By and large, little differences in decision-making processes between different groups establish homogeneous character of the population. Singh et.al. (1993) have given the KAP study regarding common diseases among rural women inhabiting some semi arid areas of Rajasthan. During this study, they interviewed around 391 elderly women inhabiting semi arid areas of Rajasthan and the information is gathered on their knowledge, attitude and practices of common diseases.

3.0 Indian Arid Lands

For the classification of the arid and the semi-arid zones in India, a number of formulae based on combinations of climatic parameters, e.g. precipitation and temperature; precipitation and evaporation; precipitation and relative humidity; and number of dry days; have been applied to 78 representative stations but none of these formulae gives perfectly satisfactory results in classifying all the stations according to their vegetation types. Another logical approach would be to delimit the bioclimatic zones purely on the basis of phytogeographic criteria e.g. floristic, morpho-ecological or ephormonic, agronomic and vegetational. Floristic statistics such as the number of species per area have been used in combination with climatic characters to give an indication of the bioclimatic degrees of aridity-humidity. However, due to distinctive activities of man, the natural vegetation is usually deformed, so it is often difficult to rely solely on the vegetational indicators of arid, semi-arid and humid climatic conditions.

The entire area stretching from the Sahara to the Thar appears to be a meteorologically homogeneous one. Physiographic and anthropogenic conditions of the region are comparable to identical phase in contiguous host arid zone of India. In the Indian desert, before the aridity set in, the streams were alive and carried sufficient silt into the sea. Thereafter aridity set in, the runoff decreased but these streams now flow sub-terraneously along dead channels. The confluences of the main channels form salt basins. This process is still in progress as new salt basins are being formed on lower reaches on the smaller tributaries. The desert region can be divided into two parts: the great desert and the little desert. The great desert extends from the edge of the Rann of Kutch beyond the Luni river northward. The whole of

Rajasthan - Sind frontier runs through this. The little desert extends from the Luni between Jaisalmer and Jodhpur upto northern west. A zone of absolutely sterile country, consisting of rocky land cut-up by limestone ridges lies between the great and the little deserts.

The study of the geomorphology of the southern arid zone has shown that two cycles of erosional surface are present, one of which is responsible for the accordance of the summits in this area which consist of domes, whalebacks, flat domes, inselbergs, koppies, pediments and pediment passes. The region comprises a vast stretch of quatenary alluvial plain and wind sorted sands. Its mean elevation in the east at the foot of Aravalli mountains is generally 350 to 450 m above sea level and from here the plain slopes in an easterly and south- westerly directions to an elevation of about 100 m in the west and 20 m in the south-west towards the Rann of Kutch.

In India about 3.2-million km^2 area is under arid zone of the hot Thar Desert. It is roughly 12% of country's total geographical area, and is spread over 7 states, namely Rajasthan, Gujarat, Haryana, Maharashtra, Karnataka, Andhra Pradesh and portions of Jammu & Kashmir. The Indian arid land lies between 24^0 and 28^0 N latitudes and 70^0 and 76^0 E longitudes. However, most (90%) of the Indian arid zone is located in northwestern India. About 62% of extremely arid region is predominantly located in 11 districts (Barmer, Bikaner, Churu, Jaisalmer, Jodhpur, Jalore, Jhunihunu, Ganganagar, Nagaur, Pali and Sikar) of western Rajasthan. (Table1).

Table 1: State-wise distribution of arid and semi-arid areas in India

State	Arid area (km)	Semi-arid area (km)	Arid area (%distribution)	Semi-arid area (%distribution)
Hot				
Rajasthan	196,150	121,020	61	13
Gujarat	62,180	90,520	20	9
Punjab & Haryana	27,350	58,650	9	6
Maharashtra	1,290	189,580	Neg.	19
Karnataka	8,570	139,360	3	15
Andhra Pradesh	21,550	138,670	7	15
Tamil Nadu	-	95,250	-	10
Uttar Pradesh	-	64,230	-	7
Madhya Pradesh	-	59,470	-	6
Cold				
Jammu & Kashmir	78,300	13,780	-	-
Total	387,390	970,530	-	-

It has been widely recognized that the crucial problem of Indian arid zone is a growing imbalance between increased population pressure and declining land productivity. Other problem in the development of arid zones may arise from the sudden availability of modern technology to societies unprepared for it.

3.1 Arid regions of Rajasthan

Arid region of Rajasthan has less than one per cent of its area under forest cover. The report of National Commission on Agriculture (1976) estimated the per capita availability of fuelwood for the entire state of Rajasthan at 208 kg per annum. On the assumption of a per cent decline in per capita consumption every year from 1985 onwards (assumed by the commission) the per capita demand of fuelwood in arid Rajasthan was estimated at 175 kg per capita per annum by 2000 AD. In view of the meager area under forests it was noted that the region would be severely deficit in fuelwood, (Anantha Ram and Bhati 1988). However, while estimating the deficit, the contribution of ones own farm to the fuelwood supply, a sample survey was conducted in 1989 in a cluster of two villages in Sikar district of Rajasthan to study the sources of fuelwood supply and consumption pattern of fuelwood along with other fuels for cooking purposes. (Anantha Ram et.al. 1990)

About 62% of this area are in western Rajasthan. The climate is characterized by extreme temperature ranging from 0^0C in winter to 45^0C in summer with erratic annual rainfall varying from 152 mm in western Rajasthan to about 600 mm in eastern districts. About 80% of rainfall occur from July to September.

The topography of Western Rajasthan is not a result of superficial or biogenic agencies but is attributed to geological processes largely in the nature of sheet movements, rapid changes in the drainage system, enormous accumulation of loose rocky materials, deepening of water-table and consequent famishing of vegetation, and thereby accentuation of desertic conditions. A thick sedimentary sequence ranging in age from early palaeozoic to middle Ecocene is exposed in the western Rajasthan desert.

3.2 Arid Regions of Andhra Pradesh

A major proportion of the Indian arid region is confined to northwestern parts of the country spreading through Gujarat, Rajasthan and Haryana. In peninsular India, the arid regions stretched from Bellary and Tumkur districts of Karnataka State to Anantapur district in Andhra Pradesh. Anantapur is the driest district in the state situated in the middle of peninsular India and has the unique distinction of being subjected to rain shadow effect both during the southwest and northeast monsoon season. The geographical area of the district is 19,13,492ha out of which net area sown is 8,77,473ha with only 41,341 ha being sown more than twice. A total area of 1,79,948 ha is under irrigation through major and minor irrigation projects, tubewells and tanks. Among the rainfed crops, groundnut, kodomillet, sorghum and pearlmillet are extensively grown. The area under groundnut in the district is 28.2 per cent of the area under groundnut in the state while the productivity is 79% of the state average productivity.

Red loamy soils with depth ranging from 10 to 30 cm are generally found in the district. The field capacity and wilting point of these soils at Anantapur are 16.6 and 3.6 percent respectively. There are few pockets of black soils particularly in the northern parts of the district. Some important observations made on the moisture regime, aridity and droughts in Anantapur region are presented and discussed in relation to crop production by Victor et. al. (1991)

4.0 Geology of Arid Zones in India

The great Thar desert of India occupies an area of about 150,000 sq. kms. And it extends westward in a northeast southwest trend in the northwestern India from (a) the western part of Aravalli Range to the vegetated flood plain of the Indus river basin in Pakistan, and (b) Southwesterly, from the state of Punjab in India into the Rann of Kutch. Physiographically, low and isolated hills and hillocks and sandy dunes of widely varying wavelength and amplitudes, lying over monotonous, flat sandy alluvium dominate the region. The solid geology of the western part of Rajasthan and a part of Gujarat is covered by a thin veneer of wind blown sand sheet and this obscures the detailed study of the bed rock geology by direct observation over the greater part of the area. But a comprehensive account of the geology underlying the sand body can be worked out from (1) the isolated exposures jutting out of that sea of sand, (2) The peripheral geological set up around the sandy body, and (3) subsurface drilling data.

In the eastern and central part of the sand body, surface geology is characterised by the sub-horizontally bedded rocks of quaternary, Tertiary and Marwar Supergroup sequence (7 early cambrian) but these rocks are at places, associated with older rocks. In and around Jodhpur, Barmer and Pokaran, Malani group of rocks dominates. In the central part of the western fringe of the sand body occur consolidated and well-preserved Mesozoic-Tertiary sequences (locally also permo-carboniferous) both as outcrops in the low hills and as subsurface formations.

The sand in general is well rounded and the average medium grain size of the samples comes to about 0.148mm. The average grain sizes vary widely in different parts of Thar Desert, for example, (1) 0.1 to 0.15 mm in central Gujarat plain, (2) 0.125 mm in Punjab and (3) 0.15 mm in western Rajasthan. These compare well with the average grain diameter of 0.14 to 0.15 mm found in the Porali plain of Southern Pakistan.

Geomorphologically , CAZRI has already established three categories of aeolian sand bodies and these are based on field determination of age and degree of stabilization. These are:

1. Old dissected dunes of indeterminate type and sand shields.
2. Stabilized parabolic, longitudinal and transverse dunes and

3. Active small scale barchen, shrub – capped and low longitudinal ridge dunes.

4.1 Land Degradation in the Arid Zone

Land degradation is a combined effect of several naturals and anthropogenic land degradation processes such as wind erosion/deposition, water erosion, salinisation, and physical disintegration, chemical, biological and natural. Among natural process climate and neotechtonic activities play an important role in the land degradation. However, anthropogenic factors, such as cultivation on marginal lands, cutting of shurbs and trees, over grazing and use of highly saline and sodic waters for growing crops are the principal causes of degradation/desertification of different fragile arid ecosystems depending upon their degree of inherent vulnerability.

A case study of Sikar district in Rajasthan has been discussed by Surendra Singh et.al. (1996). In Sikar district, almost all the above land degradation processes, particularly anthropogenic are actively operating and resulting in the degradation/desertification of different landforms/ecosystems. In the northwestern, western and southwestern parts due to less than 350-mm rainfall and presence of coarse to medium textured aeolian landforms (ecosystems) wind erosion/deposition is the major process of land degradation. Whereas in the central, north-eastern, eastern and south –eastern parts of the district due to more than 350 mm rainfall and presence of fine to very fine textured fluvial landforms (ecosystems) and impeded drainage conditions, water erosion and salinity/alkalinity are the major processes of land degradation.

The special distribution of the grazing lands of different classes of degradation is shown in Table 2. An estimate of the area occupied by these is as follows:

Table 2. The extent and distribution of degraded pasturelands.

Condition of pasture land	Total grassland area (%)
Desertified	24
Highly degraded	44
Moderately degraded	19
Good to excellent	13

5.0 Traditional Forms of Water use in Arid Zones

5.1 Runoff Control

Runoff control methods may be generally classified as follows:

- Terracing on side-long slopes to intercept dispersed runoff, with one or more contoured walls of stone behind which downwashed sediments gradually accumulate to form narrow strip fields;
- Cross-terracing in small hillside drainage channels, where a series of fields are formed from sediment retained behind the terrace walls, primitive provision for spill being provided at the lower end of each field;
- Groups of terraced fields located in small valley bottoms, and watered by long estch-water channels which intercept the runoff on the surrounding hills and conduct it to the cultivated areas;
- Water-spreading on terminal deltas by either "wild flooding" or using ad-hoc measures for guiding the waters, such as semi-permanent checks, bunds or spurs to give some initial direction to the floods;
- Primary spate irrigation systems, whereby terraced field complexes of tens or hundreds of hectares which flank the main channels or valley bottoms, alluvial plains or deltas are watered by diverting flood flows into them.
- Storage dams, sometimes with canals constructed in rock now mainly defunct.

In addition to using runoff for agriculture the traditional dwellers in these lands also divert it to cisterns to meet both domestic and stock watering needs.

5.2 Use of Flash Flood

Spate Irrigation is one of the important traditional ways of using flash floods for agriculture in arid lands. However, it can only be practiced where floods can be expected to occur reliably every year. Clearly, introducing additional storage into their hydrological systems would bring about improvement in the operation of spate irrigation schemes. This would be required to serve two functions:

- Detention storage for flood control to damp out duration discharge peaks;
- Seasonal carry-over storage to hold water that is in excess of immediate requirements until it is needed to make up for deficits in future inflows.

In temperature climates both these storage functions are simultaneously fulfilled by conventional reservoirs. The hydrological environment in arid zones is such however, that it is usually best to separate these functions when storage is required for the efficient utilization of ephemeral runoff.

A better form of storage to make efficient use of arid zone runoff may be the unconsolidated alluvium typically associated with the ephemeral watercourses of these zones, which are often extensive and usually have water tables, which lie at shallow depths. The total volume of good quality water stored in these aquifers is in some cases one or two orders of magnitude greater than the long term mean annual runoff of their associated ephemeral watercourses. Hence, in general, a rational approach to irrigation development based on major ephemeral channel systems in arid zones is the adoption of a conjunctive use strategy, which utilizes the sporadic flood runoff, and the shallow groundwater of the underlying alluvium. The basic elements of such an approach being:

- Spate breakers to control the level of flood peaks;
- Weir structures to regulate flow in the channel both for direct diversion to cultivated sears and for managing recharge;
- Wells and ancillary equipment to draw on groundwater storage during periods when there is no flow in the ephemeral channels.

6.0 Rainfall in Arid Zones

The semi arid and arid zones are characterized by low to medium mean annual rainfall coupled with high coefficient of variability, large amplitude of fluctuations of temperatures, strong wind regions and high potential evaporation/ evapo-transpiration. It is well known that west Rajasthan and the adjoining parts of the Punjab, East Rajasthan, North Gujarat have mean annual rainfall between 10 cm. - 50 cm. (IMD). It is however a less known fact that the annual number of rainy days over these areas also varies between 50 and 10. More than 90% of this annual rainfall occurs during the short period - end of June or beginning of July to middle of September. The potential evaporation over these parts varies from 160 cm. to 200 cm. (Rao et.al. 1971) .

The average annual rainfall of the region varies from 150 to 500 mm with a coefficient of variation as high as 60 - 70% . The distribution of rainfall is also erratic, occurring mostly in the period July to September. Due to the paucity of rainfall, the surface water resources are also scarce. In the extreme south- west there is an organized drainage emanating from the western slope of the Arravali that covers about 30,000 km.

In response to rain the actual flow is limited to a few days only. In the Northwest there is another small stretch under the influence of Ghaggar river. In the rest of the major part of the tract, points of runoff are there and water from them is intercepted or collected right from historic times onward. These, depending upon rainfall are able to meet the human and livestock needs from few days to months, after which people have to depend upon ground water.

The annual rainfall in the dryland areas varies from less than 200 mm to 750 mm as against the potential evapotranspiration varying from 1400 to 2000 mm. In the north- western and central states about 80 to 85 % rainfall is received in summer season (July to Sept.) and only 5 to 10 % is expected in winter season (Nov. to March). In the southern states about 55 to 60 % rainfall is received during June to September and 30 to 35 % during November to January. In other words, the rainfall is bimodal. The average of rainfall of summer and winter seasons at some of the research centers is reported in Table 3.

Table 3: Average summer/winter rainfall (mm) at some dryland research center

Station	Rainfall (mm)		Station	Rainfall (mm)	
	Summer	Winter		Summer	Winter
Agra	530	60	Jodhpur	310	37
Anantpur	590	62	Ludhiana	530	75
Bellary	320	202	New Delhi	465	60
Bhilwara	291	185	Rajkot	590	30
Bijapur	600	50	Solapur	535	150
Sardarkrishi - Nagar	405	217	Hissar	320	45

The rainfall is highly erratic and variable, both in magnitude and direction. The coefficient of variance of annual rainfall is as high as 66 % at Jaisalmer (Rajasthan), 40% at Hissar (Haryana), 34% at Karnal (Haryana), 32% at Sardarkrishi Nagar (Gujarat), 30% at Solapur (Karnataka) and 25% at Anantpur (Andhra Pradesh). The rainfall is often intense and it produces run-off, particularly from sloping lands.

Throughout the Rajasthan, rainfall, the major source of water supply is highly deficient, variable and unpredictable in its reliability. Impressionistic views reveal and emphasize decline in the overall rainfall , increase in its variability in different areas, marked fluctuations in seasonal behaviour pattern. A closer, comprehensive and critical analysis of the available rainfall records and data of district, tehsil and other stations can enlighten further on this spatio-temporal phenomena and base for futuristic planning.

The accepted traditional classification of Rajasthan on rainfall zonal basis of (a) Arid zone with - 500 cm. or less; (b) Semi-arid zone with, 500 to 650 cm. (c) Sub-humid zone with 650 to 750 cm. and (d) Humid zone with 750 cm. or more with their respective district components.
(Appendix -1, Water environment in India, Gupta and Shukla, 1992)

6.1 Rainfall Characteristics Analysis of Sikar (Rajasthan) region of India

Sikar district comprising of 7732 km^2 area is located in between 27^0 10' to 28^0 12' N and longitude 74^0 40' to 76^0 15' E in the extreme northeastern part of arid Rajasthan. District Jaipur in southeast, Nagaur in southwest, Churu in northwest, Jhunjhunu in northeast of Rajasthan state and Mahendergarh district of Haryana state board it. The district experiences both arid and semi-arid climate and is characterized by scanty, erratic rainfall, extreme temperatures and high evaporation rates. The mean annual rainfall is 453.6 mm varying from 377 mm in north to 502 mm in east during monsoon season from June to September. The mean maximum temperature in summer season range from 37^0 to 42^0C, which occasionally reaches upto 47^0C. In winter season mean annual temperature is 8^0C and decreases upto 4^0C. The annual evapotranspiration ranges from 1500 to 2000 mm. The Mean annual rainfall and coefficient of variation of Sikar district has been shown in Fig.2.

The average annual rainfall varies from 377mm at Fatehpur in the northwestern to 502 mm at Neem-kathana in the northeastern parts of the district. An average annual rainfall in Lachhmangarh, Sikar, Danta Ramgarh, and Sri Madhopur tehsil is 435, 467, 455 and 486mm, respectively.(Fig. 2). About 90 to 95 % of the annual rainfall occurs during June to October. However, the highest annual recorded rainfall during the period 1901- 1990 varied from 858mm in 1977 at Fatehpur to 1234 mm in 1917 at Neem-ka-Thana (Table 4). The lowest annual rainfall varied from 90 mm at Neem-ka-Thana (year 1905) to 156 mm at Lachhmangarh during the drought period of 1978. The average number of rainy days with rainfall of 2.5mm or more in a year varied from 22 at Fatehpur and Lachhmangarh to 33 at Neem-ka-Thana.

The coefficient of variation (c.v.) of annual rainfall was highest at Fatehpur (49%) in the northwestern parts of the district and lowest at Danta Ramgarh (35%). The C.V. values for Lachhmangarh and Sikar, Neem-ka-Thana and Sri Madhopur were 42, 36, and 38 % respectively (Table 4).

Table 4: Mean annual and extreme rainfall and its variability

Station	Normal annual rainfall (mm)	Number of rainy days	St.Deviation (mm)	Coefficient of variation (%)
Danta Ramgarh	455	28	161	35
Fatehpur	377	22	186	49
Lachhmangarh	435	22	184	42
Neem-ka-Thana	502	33	181	36
Sikar	467	30	195	42
Sri Madhopur	486	28	183	38

and

Station	Extreme of annual rainfall (mm)					
	Highest			Lowest		
	Amount	Year	% of normal	Amount	Year	%of normal
Danta Ramgarh	887	1975	195	129	1972	28
Fatehpur	858	1977	228	110	1972	29
Lachhman garh	942	1977	217	156	1978	36
Neem-ka-Thana	1234	1917	246	90	1905	18
Sikar	1093	1977	234	155	1967	33
Sri Madhopur	1124	1917	231	131	1918	27

Source: India Meteorological Department, Pune and Laboratory analysis.

6.2 Rainfall Characteristics Analysis of Kutch (Gujarat) region of India

Kutch is one of the low crop productivity districts of the Gujarat state where more than 85% of the net sown area is under rainfed agriculture. The district lies between 22^0 45' and 24^0 15' N latitude and 68^0 15' and 71^0 10' E longitude with an area of 45,652 sq. km. The district has a long coastal belt and also border with Pakistan. It has live stock population of about 1.71 millions and human population of 10,50,161 (Census of India 1981)

The annual rainfall across the district varies from 338.4mm to 451.9mm about 90 % of which is received in Kharif season i.e. June to Sept. Both , the quantum of rainfall across the district and the pattern of distribution within the season are highly variable.

Singh et. al. (1991) have given the rainfall characteristics analysis of Kutch district (Gujarat), India based on the rainfall data of 12 stations for the period 1901 to 1989 revealed that the rainfall has decreasing trend from SW region to NE region. Fig. 3. Show the mean annual rainfall and its coefficient of variation over Kutch region.

7.0 Ground Water in Arid Lands

The tracts under the direct influence of integrated drainage or those that get recharged through sub-surface flow have reasonably good potential, much of which is already being exploited. Such regions cover nearly 30 % of the arid zone. In the rest of the arid zone the ground water is too little, too deep and also not quite potable. However, even in this tract the people through a conjunctive use of surface and ground water are able to sustain themselves through with considerable difficulty.

Arising out of the aridity , the surface and ground water are both scarce and uncertain. Further these are of poor quality both for domestic and agricultural purposes. Dunes and sandy soils that are highly prone to humid erosion cover a large part of the area. At other places soils are shallow or saline.

Traditionally such rainwater is stored in various sources and reservoirs like lakes, tanks, canals embankments and dams but, as in India as whole, in Rajasthan also much of rainfall amount flowing through various river systems goes un-utilized as surplus runoff. Proper harvesting of this potential needs careful planning, efficient management and fruitful implementation. Fig. 4. Show the Districtwise groundwater conditions in Rajasthan for June 1988.

In terms of Ground water, the future seems to be rather gloomy for nearly one-third of the Rajasthan, because they're almost 85-90% of the entire quantity of ground water available has been consumed. This dark zone of ground water includes nearly 86% of the district of Alwar, 64% of Ajmer, 58% of Chittorgarh, 63% of Jaipur, 47% of Jalore, 59% of Jhunjhunu, 63% of Pali, 48% of Udaipur and 36% of the district of Bharatpur.

7.1 Quality Classification of Groundwater of Western Rajasthan

Groundwater in western Rajasthan is inherited by diversity of quality problems. Occupying largely the area of Indian Thar Desert, the region is characterized by arid climate conditions and thus the groundwater is often deep and saline. It also contains high sodium causing thereby problem of sodicity.

An integrated classification of quality of groundwater based upon EC (electrical conductivity), SAR (sodium adsorption ratio) and RSC (residual sodium carbonate) values of 4145 water sampies has been made to evaluate water quality for irrigation in 11 district of western Rajasthan by Gupta (1991). It is observed that groundwater are sodic in character due to high SAR or RSC values. The SAR ranges from 0.15 to 176.8 with an average value of 13.9. In districts Barmer, Bikaner and Jaisalmer more than 33.3 % waters have SAR more than 18. High RSC generally occurs in low to medium salinity water and ranges from nil to 68.8 meL^{-1} with an average value of 3.1 meL^{-1} . The districts viz., Jhunjhunu, Nagaur and Sikar have high RSC in ground waters. Based upon salinity, SAR and RSC distribution, the whole region has been divided in six saline-sodic zones (Fig. 5.) as follows:

Zone I: Low Salinity, low to medium SAR and high RSC water ($C_1S_1A_2$): Such waters occur in Jhunjhunu and Sikar districts covering an area of 5,928 and 7,732 sq. km, respectively. RSC in these waters is considerably high. More than 40 % waters in these districts have RSC more than 2.5 meL^{-1} and at many places its value exceeds 10 meL^{-1}. Use of these waters for irrigation requires proper management practices.

Zone II: Medium Salinity, Low SAR and low RSC waters ($C_2S_1A_1$): These waters are observed in extreme north of the region covering Ganganagar district. The district has an area of 20,629 sq. km. The average salinity of groundwater is 3.5 dSm^{-1}, SAR less than 10 and RSC less than 2.5 meL^{-1} . These waters could be used for irrigating semi-tolerant crops without any harmful sodic effects.

Zone III: Medium Salinity, medium SAR and low RSC waters ($C_2S_2A_1$) : Groundwater in Jodhpur and Pali districts fall in this zone. The two districts cover an area of 22,860 and 12,300 sq.km. respectively.

Zone IV: Medium Salinity, medium SAR and high RSC waters ($C_2S_2A_2$) : These waters are characterized by both SAR and RSC problems. Nagaur district covering an area of 17,718 sq. km falls in these zones of water quality. Owing to high SAR and RSC, the groundwater in the district, have potential sodicity hazard. At many places in the district, the RSC of groundwater is more than 10 meL^{-1} and SAR is more than 26.

Zone V : High salinity, medium SAR and low RSC waters ($C_3 S_2A_1$): Such waters have high salinity (>5.0 dSm^{-1}) in more than 33.3 % (one third) samples but average value of SAR is less than 18 and RSC is below 2.5 meL^{-1}. Groundwater in district viz. Churu and Jalore covering an area of 16,860 and 10,640 sq. km. respectively fall in this zone. The medium SAR values, which are usually associated with high salinity, may develop moderate alkaline conditions in soils.

Zone VI : High salinity, high SAR and low RSC waters ($C_3 S_3A_1$): This zone is occupied by Barmer, Bikaner and Jaisalmer districts occupying extreme western part of the region. The three district cover an area of 28,387; 27,231 and 38,384 sq. km, respectively and have mostly arid climate. More than 33.3 % water in this zone have high EC(>5.0 dSm^{-1}) and high SAR (>18). The average EC of groundwater ranges from 4.7 dSm^{-1} in Jaisalmer district to 6.07 dSm^{-1} in Barmer district. Similarly, average SAR ranges from 14.7 in Bikaner district to 20.6 in Marmer district. Nearly 30% waters in these two districts have been found to contain RSC higher than 2.5 meL^{-1}. These waters also have high salinity and high SAR. Occurrence of high SAR and RSC along with salinity is responsible for alkalinity development in soils in part of Barmer district as observed by Joshi and Dhir (1989).

Utter lack of people's foresight and imbalanced planning and management of water resources coupled with a sense of responsibility in the people seems to have degraded the land and water resources in the state too far. India has no established system for the conservation and development of these rare resources of nature.

Ground water in hard rocks like quartzite, schist, dolomite limestone etc. occurs under unconfined or water-table conditions. The ground water movement in such aquifers is through joints, fractures, foliation, lineations etc. These formations generally do not yield high discharge. The coarse textured younger alluvial sediments form potential aquifers. But wherever the clay horizons exist, they do not form productive aquifers. In older alluvium formations granular zones may act as productive aquifers. When granular zones sandwiched between two clay horizons, confined to semi-confined conditions may prevail.

Hydrogeology of phreatic aquifers has been studied in Sikar district in Rajasthan from 281 wells selected randomly so as to represent the area as a whole. Quaternary alluvium is the most extensive water bearing formation in Sikar district. It overlies the metasedimentaries, as confirmed by the various bore hole data and occupies 6552 km^2 area (84.5%) of the district. Hard rock as hydrogeological formations cover relatively smaller area 1197 km^2 (15.5%) and are mainly restricted in the eastern part of the district. The salient characteristics of different type of aquifers and their extent, depth to water and quality of ground water for district Sikar have been given alr e dy

7.2 Isotope Technique in groundwater of arid region

Water management assumes a greater importance for the water thirsty lands of the arid zone and demands a comprehensive approach to development planning. Rainfall is known to be scarce and irregular in desert regions. Direct recharge to groundwater is small and occurs by flood flows through channel bottoms. Water that unrelated to the contemporary hydrometeorological situation then assumes importance. Such water can originate in far away mountainous fringe areas or might be paleowaters. Non-meteoric fossil brines also play their role in the arid basin hydrology.

Isotope techniques for water resources studies involve the use of one method or a combination of methods e.g. environmental isotope approach, injection followed by monitoring of radiotracers and logging with the help of sealed radiation sources.

Some Isotopic studies in arid basin Hydrology

1. Surface and Groundwater Inter-relationship in Jowai Reservoir Region, Rajasthan

The studies involved the use of enriched oxygen-18 as a tracer. Water samples were taken from Jowai reservoir and from groundwater at different distances downstream along the course of the river. The results indicate the zone of influence of the reservoir on the groundwater regime and also a trend of decreasing surface water inputs with increase in distance from the source region.

2. Determination of Aquifer characteristic by use of Radiotracers in Sikkar Basin, Rajasthan

The investigations were conducted using radiotracers (82 Br, 132 I, 51 Cr, 3H) for study of transmission characteristics of quaternary sandy deposits in Sikar to determine the filtration velocity in the formations after correcting the radioactive decay, distortions to hydrodynamic field caused by borehole construction and diffusion of the tracer. Values of filtration velocities so obtained range from 0.01 to 2.3×10^{-5} cm/sec. The stratification observed by core analysis, the filtration velocity confirms natural gamma and electrical logs. Coefficient of permeability evaluated at various horizons gave an average value of 1.99 m/d and a transmissivity value of $85 m^2$ against the corresponding values of 2.62 m/d and 112 m^2 from pumping tests.

In another experiment using two well technique, tracer activity distribution curve showed three peaks corresponding to effective porosity values of 3.2% 8.4% and 10.9% against an average values of 6.1% obtained by boulten method.

3. Environmental Isotope approach for study of Groundwater in Semi Arid regions of Rajasthan and Gujarat

The δD , $\delta^{18} o$ relationship for Gujarat and Rajasthan , we have

$\delta D = 6.4 \quad \delta^{18} o \sim 0.6$ (Gujarat)

$\delta D = 3.3 \quad \delta^{18} o \sim 18.6$ (Rajasthan)

The rainfall is evaporated to a larger extent in Rajasthan as compared to Gujarat and may be due greater aridity in Rajasthan. For Sikar basin in Rajasthan, the groundwater sampled from eastern region (200 mg/l of TDS) have δ D variation from ~25%, to –65% showing large isotopic variations due to erratic recharging events ~ a characteristic feature of arid zones. Depth profiling of groundwater in these areas shows that the deeper water (60-m bgl) is enriched in δ -values as compared to shallow water. This is contrary to recharge during Pleistocene period, when a depletion in stable isotopic values has been observed in several arid regions. It could be attributed to recharge under different climatic setting during 1000 – 2000 BC when dry conditions prevailed (Harappen civilization). In the alluvial tracts of Gujarat, relatively fast replenishment of groundwater is observed in recharge areas. The origin of this groundwater has been traced in artesian aquifers located at 300 to 500 m bgl near Dhananj village in Mehsana.

4. Dating of Groundwater of Rajasthan and Gujarat

The data generated by the geophysics group of TIFR Bombay, showed that the apparent silicon-32 ages for groundwater (500 – 2000 year old) in arid to semi-arid are in good agreement with C-14 ages.

This can be seen from the following data:

Well location	Water Depth (m)	Uncorrected age (years)	
		32 si	14 c
Palana, Rajasthan (Tube well)	168	2000	5000
Palana (Open well)	66	2000+1000	5000
Vijaipur, Gujarat (Tube well)	116	1500	2280
Balod, Gujarat (Tube well)	65	600	2600

WMO – IAEA Network.

7.3 Isotope study of Groundwater in Jaisalmer

Jaisalmer district lies between $26^0 4'$ and $28^0 8'$ north latitudes, and between $69^0 30'$ and $72^0 20'$ east longitudes. The district lies in the very arid part of the Thar Desert (Porwal and Mathur, 1993). The average annual rainfall at Jaisalmer is 165 mm. The study area lies in the western part of the district and extends from Austere to pillar No. 724 on the international border (Fig. 6). It is known as Shahgarh Bulge area is strategically important because of its location along the international border. The area is covered with sand dunes which are either bare, or have scrubby vegetation. Since there is no some hand pumps of shallow depth are used for drinking water. The hydrogeological formation is alluvium. Near the pillar 724 along international border, a free flow of water was observed. In order to understand the ground water recharge process in Shahgarh area of arid Jaisalmer district, Singh D. et.al. (1996) have made an environmental isotopic study based on measurement of D, ^{18}O and ^{3}H contents were carried out on shallow groundwater. Very low rainfall, sandy terrain and very little vegetation characterize the area. Water level in the scattered shallow wells and handpumps varies from 10 to 30 m. Stable isotope analysis of the water samples indicates very high depletion of the heavy isotope contents and suggests quite old origin of these waters. The ^{3}H contents are very low. A ^{3}H tracer injection experiment at Mehsana indicated negligible recharge due to modern precipitation. The ground water is potable to brackish, the TDS ranging from 200 to 1500 mg/l. A higher fluoride content was observed in two wells.

8.0 Dunes - Land Forms

Most spactacular amongst the land - forms are the dunes. These are present in 58% area of the region. The area of occurrence of dunes lies in the northern and western half of the region but even here it is not a contiguous feature and does have interludes of dune-free corridors as the area from Pokran through Bikaner. A variety of dune formations such as coalesced parabolic, longitudinal transverse, barchan and obstacle have been recognized. Amongst these, parabolic and coalesced parabolic dunes are dominant. The dunes are very variable in height- the common range being 10 to 80 meters and those occurring in Jodhpur and Barmer . The dunes are highly sandy and contain only 1.8% to 4.5% clay and 0.4% to 1.3% silt. The inter-dunes and associated plains are also light textured, through with some more of silt and clay. These have a varyingly developed strata of old surface having well developed calcrete of ten with some well-rounded rock fragments underneath or exposed at the surface.

The stabilized sand dunes in the extreme northwest also show an increase of sand piling by 1 to 2 meters on the flank and 3 to 5 meters on the crest. The distribution of dunes is being mapped by GSI but information on dune sand thickness is largely lacking. Observation or estimation under the projects could supply these data. The resulting knowledge about dune systems should be very helpful for human populations in dealing with dune landscapes.

9.0 Human Factors in Arid Land Development

The Indian desert is relatively densely populated. Therefore, the pressure of man and livestock on the land farms is very severe. In the olden days human population used to live in balance with the natural environment, but the modern needs, and to some extent the developmental endeavours being taken up in the desert region, have disturbed the delicate ecological balance.

9.1 Productivity in Arid Zones

In general, the arid lands have very low productivity. In spite of low productivity, Rajasthan sustain a fairly high population of livestock. Paradoxically, along with the reduction in the grazing area during the last two decades, the livestock population has registered a phenomenal increase.

The pressure on the grazing lands by livestock results in the depletion of vegetation resources and in certain habitats of the desert, the natural successional trends have been reversed. Due to severe depletion of flood species, the livestock productivity has declined and has induced their migration and nomadism in the human population.

A general approach to improve the productivity of arid lands is to bring irrigation water, chiefly for raising crops. Incoming of water into a desert affects the ecosystem adversely. It is evident that in Anupgarh Shakha area, the water table is rising at an average rate of 1.52 mt. per year. At some places the rate is as much as 3 mt. also. In Ghaggar flood area water table has risen 6 - 9mt. On the basis of water table changes in the Shri Ganganagar district, estimates are that the problem will attain a critical limit with present rate of rise in static water level in different zones. Besides the perched water-table rise along with subsurface gypsum bed is also creating severe water logging hazard.

For collecting rainwater for subsequent irrigation, village ponds, dams across former channels have been constructed in many parts of the Thar Desert. These human efforts have also resulted in deteriorating the desert ecosystem. They have pushed up the water table and spread the salinisation. Salinity due to construction of tanks has developed in a small development block. Evidence shows that prior to 1958, an area of 8.3 sq.km. of once productive lands has been salinised beyond use. Since 1958 salinity has spreads within this block laterally and during this period an additional area of 15.6 sq. km. has been affected.

9.2 Water Conservation and Dryland Crop Production in Arid and Semi-Arid Regions

Out of 328 mha geographical land area of India, about 143 mha is under cultivation. More than 70 % of the cultivated area is under rainfed crops. Assuming the full utilization of the available surface and ground water resources for irrigation, about 50% of the land area will still continue to remain under rainfed agriculture. Therefore, for sustainable agriculture and for reducing the imbalances between irrigated and dry farming regions, dryland areas must continue to receive priority in development programs.

According to Indian Agricultural Atlas, the dryland areas include the zones having an annual rainfall upto 750 mm (Fig. 7). Such areas fall within the arid and semi-arid climate of the tropics and cover parts of the states of Punjab, Haryana, Rajasthan, Uttar Predesh, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh. About 51 mha land area of India falls under this category (Shafi & Raja, 1987) and produces most of the coarse grains, pulses, oilseeds, cotton and dry fodder. With traditional farming, the production of these commodities is, however, low and risky. With the new dry farming technology, generated by various dry land research centers in different agroclimatic zones, it is likely to at least double the production from its present level. (Oswal, M.C.;1994))

The hot desert of India covers about 12% of the total geographical area of the country. Crops often experience drought at some stage of growth and as a result, yields are generally low. The adverse effects of drought on crop yield are further accentuated due to the poor fertility status of the soils. To increase the productivity of such areas, the only course left is to plant trees along with crops/grasses. The plantation of multipurpose trees in arid regions helps to reduce wind erosion hazards, and makes crop production possible where cropping would otherwise be extremely difficult (Puri et.al. 1994) . They said that the yield and yield attributing parameters of barley increased under these tree species compared to those from areas devoid of trees. Boilogical yield was also higher under the tree than that in the open area. The soil under different tree canopies was rich in organic carbon content, moisture availability and nutrient status (N,P and K). These trees improved the productivity of Barley due to enhanced moisture and nutrients.

9.3 Stabilization of Farm Income and Employment under Water Scarcity Conditions

The agriculture of Rajasthan, where irrigation facilities are comparatively scarce, depends primarily on rainfall. Drought and famine have assumed more or less a well-established cyclical pattern of recurrence in the state. During drought year, farmers face great difficulties. Pandey and Upadhyay (1970) observed that drought situation results in substantial loss of production and productivity, employment of labour in general and employment of hired labour in particular, and fall in income. Bharara (1980) noticed that in arid zone of Rajasthan, on an average, crop loss per cultivating household varied from 35% in an average year to 52% in mild drought year to 82% in drought year to 100% in severe drought year as compared with no loss in a good/surplus year. Naidu (1985) found that the acreage of cereals declined by 16% and production by 13% during the drought year (1982 – 83) compared to preceding year in the state of Andhra Pradesh. Patel et.al. (1987) observed that only about 25% of the total casual labourers could get full employment during the drought year (i.e. 1987) , relative to 60% during the normal year (i.e. 1986). It is thus necessary that farmers of the drought prone areas of the country in general and of Rajasthan in particular adopt crops and cropping patterns which can help them in withstanding to some extent the vagaries of the monsoon and can provide them with some income and employment even in the event of failure of rainfall. Gupta and Verma (1993) have carried out this study in a village Naga – Ki – Dhani in Jaipur district of Rajasthan. Twenty-five farmers in proportion to their number in each size group were selected randomly for the study. Out of these 25 farmers, 11 were from small (0 – 2 ha), 8 from semi-medium (2 – 4 ha) and 6 from medium (4 - 10 ha) groups. Since there was no farmer in the sample village having holding size of 10 ha and above, hence no farmer was selected in large group.

Linear programming techniques was used as an analytical tool in the present study. The specific model used in the study is based on the models developed by Sirohi and Gangwar (1968) , Verma (1972) and Sirohi et.al. (1980). The model used in the study included in all 46 activities (processes) and 57 resource constraints. Following four optimum crop plans were developed for each of the three size groups of farms.

P_0 = Existing plan,
P_1 = Optimum plan with existing resource supply.
P_2 = Optimum plan with existing resource supply and maximum area restriction on important crops.
P_3 = Optimum plan with cash borrowing.
P_4 = Optimum plan with cash borrowing and maximum area restriction on important crops.

The results of optimum plans showed that use of improved varieties of crops developed specifically for water scarcity conditions, would certainly increase the farm income. The employment opportunities under optimum plans developed with cash borrowing did not increase significantly over plans with existing resource supply. However, working capital available with the farmers during drought year would not allow full use of whatever little irrigation water available in the open wells. Hence it is suggested by the author that credit in adequate amounts should be made available to the farmers during drought years.

10.0 Climatic changes in Arid Zones

Climate plays a key role in determining the development of arid zones of the world and changes in climate dictate the changing pattern of life in these regions. Although instrumental data available for about a century do not show any trend in the climate of the Rajasthan desert. Historical, archaeological and fossil studies do indicate that the area undergone a number of changes in climate and evidences have been found of what were once well developed human civilization in the area. In the light of such findings, changes in climate, in the future, need to be studied in the framework of the past, which may provide the " ground truth" for future work.

Rajasthan experiences highest air temperature during April through middle of June or till the southwest monsoon burst over the region. The mean temperature at Sikar was 31.9^{0}C and varied between 21.9^{0}C and 39.7^{0}C in the district. Maximum air temperature normally decreases from northwest to south and southeastern parts of the district. (Fig . 8).

The Humidity and Evapo-transpiration of the district Sikar in Rajasthan have been given here. During the monsoon season, the relative humidity is very high and range from 76 to 83%. For the rest of the period, the air is generally dry with relative humidity falling below 50%. (Table 5).

Table 5: Climatic normals of Sikar (latitude 27^0 37^1,longitude 75^0 08^1 E MSL 432)

Weather Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	*
Max. temp.	22	26.2	31.5	36.4	39.7	39.1	34.7	33.1	33.7	33.1	29.1	21.9	31.9
Min temp.	5.8	8.2	14.5	19.6	24.3	27.5	26	24.7	23.1	17.1	10.4	6.7	12.3
Rel.hum-idity(%) 0830h	75	67	56	50	49	60	76	83	77	64	64	72	66
Rel.Hum-idity(%) 1730h	50	45	43	37	38	42	57	67	64	53	53	54	50
Rainfall (mm)	8.4	7.8	6.7	3.1	15.7	43.7	163	148	55.1	6.0	3.4	5.8	467.
Wind speed (kmph)	6.1	6.2	7.9	8.0	9.4	11.6	9.2	7.8	7.3	5.1	4.3	4.9	7.3
No. of days with dust storm	0.0	0.1	0.1	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7
No. of days with tunder	0.4	0.2	0.4	0.4	1.3	1.6	1.9	1.9	0.9	0.6	0.1	0.1	10.0
Pot. Evapo-trans. (mm)	52	74	127	167	215	214	156	133	134	144	68	48	1532

Source: India Meteorological Department, Pune and laboratory analysis, '*' stands for annual values.

10.1 Potential evapo transpiration

The annual potential evapo-transpiration (PET) over the region is very high and it ranges between 1500 and 1600 mm/year (Fig. 9). The PET at Sikar was 3 times higher than the rainfall received in the area. At other station also, the PET rates were 3.1 to 4.8 times higher than the amount of annual rainfall received. Such high evapo-transpiration is due to high temperatures, low humidity and high wind conditions prevailing in the region for most of the time except during the monsoon period. Studies for long range prediction of weather through numerical methods are already being initiated through another INDO-US collaboration, so far dealing with monsoon prediction. The paleoclimatic information could thus supplement these studies and provide information for verification of their models.

Sedimentology has been developed as an extremely important tool for understanding quaternary climatic history. We need trained personnel and sophisticated equipment for mineralogical and chemical analysis of sediments. In India, such expertise and instruments are scarce.

The distinctive hydro-climatic features of arid zones are:

- High levels of incident radiation
- Generally high diurnal and seasonal temperature variations
- Low humidity a short distance inland from the sea
- Strong winds with frequent dust and sand storms
- Sporadic rainfall of high temporal and spatial variability
- Even greater variability of short-duration runoff events in ephemeral drainage systems
- Generally high infiltration rates in channel alluvium
- High sediment transport rates and
- Relatively large groundwater and soil moisture storage changes.

10.2 Remote Sensing in Landuse Planning of Arid environment

Systematic information on landuse/land cover in the form of maps and statistical data is a pre-requisite for rational landuse planning on a district, regional and national level. Data available on landuse/ land cover in the country are inadequate and unreliable because they were collected and compiled by conventional methods which are less accurate and time consuming.

The landuse/ land cover mapping of Jodhpur district in Western Rajasthan was completed using IRS – 1A (LISS – 1) FCC imagery and landuse classification system standardised by National Remote Sensing Agency (NRSA) , Hyderabad (1980). The salient features of the biophysical conditions and present status of landuse / land cover categories for rational land use planning of the district have been highlighted by Singh et. al. (1993)

Satellite remote sensing using IRS – 1A (LISS –1) False Colour Composites (FCCs) of Kharif and rabi seasons for the year 1988-89 in conjunction with ground truth enabled to identify and to map different landuse / land cover categories at levels I and II in Jodhpur district comprising an area of 22,85,000 ha of arid northwestern Rajasthan. The extent of different landuse / land cover categories from IRS FCC products and revenue record has been computed and tabulated by Singh et.al. (1993) in Table 6. It has been observed that the area mapped from IRS FCC products for all the landuse / land cover categories is less than that of revenue record due to the small scale and poor resolution of the remotely senses data. The suitable cropping patterns, plant species and soil and water conservation measures have been suggested for the rational landuse planning of different landuse/ land cover categories of the district.

Table 6: Lansuse/ Land covers categories statistics, Jodhpur district, Rajasthan, 1988-89

Categories Level I & II	Category I Area (ha)	Category II Area (ha)	% of total geographical area
Build-up land	8800	8800	0.39
Agricultural land	1723358		
Kharif cropland		1057375*(61%)	
Rabi cropland		48711 (2.83%)	
Kharif and Rabi cropland		24289 (1.41%)	
Net area sown		1081796(62%)	47.34
Fallow land		641562 (37.2%)	28.08
Forest	4336		
Degraded forest scrub land		4336	0.19
Wastelands	439452		
Salt affected land		17383	0.76
Gullied/ ravinous land		7383	0.32
Land with or without scrub		168867	7.39
Sandy area (desertic)		236600	10.35
Barren rocky/stony waste / sheet rock area		9219	0.40
Water Bodies	8740		
River/stream		8350	0.37
Lake/reservoirs/tank/canal		390	0.02
others	100314		
Grassland/grazing land		99219	4.34
Mining area		1095	0.05
Total		2285000	100.00

Remote sensing techniques can be used to undertake the detailed investigations in conjunction with ground truth on the following aspects of the Indian arid zones.

1. Mapping of sand seas, its dunes and their drift direction; and desert related morphological features; the identification of the Thar dessert as a geomorphic entity and its creep towards the fertile area.
2. Biomass monitoring on a continuing basis so that the long term trends can be identified.
3. The estimation of rain by cloud data from mateorological satellites using techniques such as clouds indexing etc. At some suitable areas cloud seeding experiments need to be tried.
4. Ground Water assessment and exploitation. Geological Survey of India has collected immense amount of data about wells and bore holes for some districts of Rajasthan. It may be possible to integrate this data into some of the regional features pertaining to the ground water geology of the area and try to understand the regional behaviour of ground water.

11.0 Soil Patterns in Arid Lands

The soil of dryland areas of India can be grouped under (I) desert soils, (ii) alluvial soils, (iii) black soils, and (iv) red soils. The distribution of these soils in various states and their major constraints for water conservation and crop production are presented in Table 7.

Soil surface crusts, formed due to impact of rainfall, hinder the rapid intake of rainfall in the soil, enhance runoff and reduce rainwater conservation, besides hampering emergence of seedlings and establishment of crops. Presence of hard pan/calcium carbonate concretion, hinders movement of water and ramification of plant roots and reduces water storage capacity of soils. Shallow soil depths do not allow normal root ramification, reduce feeding zone of roots and restrict plant growth and water storage capacity of the soil profile. Soil cracks allow free entry of atmospheric air into soil, resulting in rapid evaporation of water from the soil. Heavy texture poses problems for tillage and the soil does not come to workable condition easily. Such soils remain waterlogged for a long time after heavy rains, resulting in poor aeration of the soil and plant growth.

In general , soils of hot dryland areas are deficient in available nitrogen, low to medium in phosphorus and zinc, and medium to high in potassium. Sub – soil salinity is not uncommon in these soils (Oswal & Khanna 1983).

Table 7: Soils of arid and semi-arid regions and their major constraints.

Soil	Area represented	Major Constraints
Desert	Western Rajasthan, Parts of Haryana	Low water holding capacity (WHC 10-15 CM/M), High infiltration rates and erodibility, presence of calcium-carbonate concretions in root-zone.
Alluvial	Parts of Rajasthan, Punjab, Haryana, U.P., Delhi and Gujarat	Soil crusting, hard pan at plough-depth, WHC 15-25 cm/m.
Black	Maharastra, Western Madhya Pradesh, Parts of Karnataka, Andhra Pradesh and Gujarat	Soil cracking, heavy texture, poor drainage, WHC 25-35 CM/M.
Red	Parts of Andhra Pradesh, Karnataka and Madhya Pradesh	Soil crusting, shallow depth, sub-soil compaction, WHC 15-20 cm/m.

Source: Oswal (1994)

The central and southern part of the arid Rajasthan is made up of medium and fine textured soil developed in-situ or from alluvial parent material. The region is almost devoid of any signs of deflation or of aeolian sand. These soils are well aggregated and have a good moisture retention capacity. These soils as those of dunes and sandy plains are somewhat of alluvial parent material.

In the desert state of Rajasthan, the problem of environmental pollution is less acute then the land-water resources degradation. The fact that Rajasthan possesses 10% of the total geographical area of the country and 5% of its total population but it has only 1% of the water resources of the country. Thus abundance of land and acute scarcity of water in the state have become a focal point for research.

On the entire geographical area of the state, nearly two-thirds i.e. 61.9% is desert and 13.10% is mountainous terrain and plateau which is not available for cultivation. As most of this area is desert and very dry, negligible agricultural activity is possible and even vegetation like shurbs find it difficult to survive. According to Dhabaria the wind erosion has led to the expansion of the Thar Desert, depletion of forests and denudation among the Aravallis have played havoc with the ecology of the region. The environmental crisis there is really acute. (Gurjar, 1990)

Effect of Wind erosion/deposition on fertility status of soils: Analysis of physico-chemical properties and fertility status of soils (Table 8) revealed that they are dominantly coarse textured, variable in colour, slight to strongly calcareous pH ranges from 7.6 to 9.0. Electrical conductivity ranges from 0.08 to 0.754 dSm-1 of degraded lands and 0.11 to 0.83 dSm-1 of non-degraded lands. The organic carbon is now in moderately and severely degraded soils, 0.138 and 0.062 per cent, respectively. The available potassium (K_2O) is low in the ,moderately and severely degraded soils (191 and 122 kg/ha, respectively) than non-degraded soils (280 kg/ha). The available (PO) is low in moderately and severely degraded soils (11.0 and 5.5 kg/ha) then non-degraded soils (16 kg/ha).

The fertility data (Table 8) indicate that moderately and severely degraded soils (W2 , W3) have very low content of organic carbon, available PO and available K2O in comparison to slightly degraded and non-degraded soils.

Table 8: Effect of wind erosion/deposition on fertility status of soils

Parameter	Non-degraded soil	Slightly degraded soil (W1)	Moderately degraded soil (W2)	Severely degraded soil (W3)
Texture	Fs-ls	ms-fs	ms-fs	cs-fs
Colour	10YR 5/4-10YR 6/4	10 YR 6/3-10YR 6/4	10 YR 6/3-10YR 6/4	10YR 6/2-10YR 6/4
Calcareousness	eo-e	eo-e+	eo-e+	eo-es

PH	7.4 – 8.4	8.1 – 9.0	7.6 – 8.4	8.1 - 8.4
EC (dSm)	0.11– 0.83	0.74 – 0.19	0.13 – 0.75	0.08 – 0.85
Organic Carbon (%)	0.21– 0.28 (0.20)	0.13 – 0.24 (0.157)	0.076- 0.333 (0.138)	0.039–0.12 (0.062)
Available Potassium (kg/ha)	201 – 450 (280)	90 – 326 (200)	106 -371 (191)	45 – 213 (122)
Available Phosphorus (kg/ha)	12-20 (16)	6 – 14 (12.5)	10 (11)	3 – 8 (5.5)

Source : Field survey and laboratory analysis through CAZRI, 1996.

Effect of Water erosion on fertility status of soils: The physico-chemical properties and fertility status of soils affected by water erosion (Table 9) indicate that there is not much difference in pH and EC of non degraded and degraded soils, ranging from 7.4 - 8.4 to7.7 – 9.2 and to 0.11 – 0.83 to 0.084 – 0.754 dSm, respectively. The organic carbon is low in moderately and severely degraded soils (0.159 and 0.109%, respectively) as compared to non-degraded soils (0.292%). There is slight variation in the available potassium of moderately and severely degraded soils (112.5 and 110.0 kg/ha, respectively) as compared to non-degraded soils (280 kg/ha). Similarly the available phosphorus content is low in moderately and severely degraded soils (10 and 4 kg/ha) in comparison to non-degraded soils (20 kg/ha)

Table 9: Effect of Water erosion on fertility status of soils

Parameter	Non-degraded soil	Slightly degraded soil (V1)	Moderately degraded soil (V2)	Severely degraded soil (V3)
Texture	ls-cs	ls-cs	fs-gl-e	fs-sl-e
Colour	10YR 6/4-10YR 5/3	10 YR 6/3-10YR 4/3	10YR 5/5-10YR 5/4	10YR 6/4-10YR 5/4
Calcareousness	eo-e	eo-es	eo-es	eo-e+s
PH	7.4 – 8.4	7.7 – 8.4	7.8 – 8.4	8.4 - 9.2
EC (dSm)	0.11– 0.83	0.96 – 0.235	0.084–0.75	0.084-0.48
Organic Carbon(%) Available	0.21– 0.65 (0.292)	0.08 – 0.198 (0.243)	0.078- 0.28 (0.159)	0.056-0.17 (0.109)

Potassium (kg/ha)	201.3– 866 (280)	157.5 –292.0 (221.6)	61.8- 196.8 (112.5)	67.5-19.03 (110)
Available Phosphorus (kg/ha)	12-28 (20)	12 – 28 (14)	4 – 14 (10)	3 – 7 (4)

Source : Field survey and laboratory analysis through CAZRI 1996.

Effect of Salinity/ Alkalinity on fertility status of soils: Morphological characteristics, physico-chemical and fertility status of degraded and non-degraded soils is given in Table 10. The electrical conductivity and pH of saline/alkaline soils varies from 8.2 to 21.2 dSm and 8.4 to 10.8, respectively. The mean value of organic carbon in slightly degraded soils is 0.280 per cent, whereas in moderately and severely degraded soils it is 0.260 and 0.180 % , respectively. The mean value of available phosphorus in non-degraded soils is 20 kg/ha in moderately and severely degraded soils is 10 and 6 kg/ha, respectively. Similarly, the mean value of potassium in non-degraded soils is 280 kg/ha and in moderately and severely degraded soils is 350 and 260 kg.ha, respectively.

Table 10. Effect of salinity/alkalinity on fertility status of soils.

Parameter	Non-degraded soil	Slightly degraded soil (V1)	Moderately degraded soil (V2)	Severely degraded soil (V3)
Texture	fs-cl	fs-sl	sl-l	ls-cl, sicl
Colour	10YR 6/4- 10YR 5/3	10 YR 6/2- 10 YR 6/4	10 YR 6/4- 10YR 4/3	10YR 6/4- 10YR 6/2
Calcareousness	eo-e	-e+1	-e+2	-e3-e4
PH	7.4 – 8.4	8.4 – 10.0	8.4 – 9.0	7.6 - 8.8
EC (dSm)	0.11 – 0.83	1.38 – 3.8	4.00 – 7.50	8.20 – 21.20
Organic Carbon (%)	0.211 – 0.65 (0.292)	0.20 – 0.350 (0.280)	0.198 - 0.38 (0.260)	0.200 – 0.39 (0.180)
Available Potassium (kg/ha)	201.25– 866 (280)	101.2–347.8 (280)	200 - 400 (350)	216 – 380 (260)
Available Phosphorus (kg/ha)	12-28 (20)	12 – 28 (15)	10 - 18 (10)	4 – 18 (6.2)

Source : Field survey and laboratory analysis through CAZRI 1996.

12.0 Problems of Desertification in Arid Zone

The United Nations Environment Program has defined desertification in February 1990 as " land degradation in arid, semiarid , and dry subhumid areas resulting from adverse human impact". This definition replaces the 1977 definition adopted at the United Nations Conference on Desertification in Nairobi, Kenya. The old definition said that desertification is the " diminution or destruction of the biological potential of the land and can lead ultimately to desert-like conditions". The direct cause of desertification was believed at that time to be a combination of drought and human actions. The 1990 definition omits hyperarid regions because there can be no human - induced land degradation in the absence of humans, and there are no humans in most of the hyperarid zone.

The principal desertification processes are (1) degradation of the vegetative cover, (2) accelerated water and wind erosion, and (3) salinization and water logging.

These process affects the three major land uses in arid areas: irrigation agriculture, rainfed cropland (dry farming), and pastoralism on rangelands. Rangeland desertification is primarily a matter of degradation of the vegetative cover through overgrazing and cutting of woody vegetation. Rangeland area was calculated as the difference between the total land in the arid, semiarid and dry subhumid regions, as given by Hopkins and Jones (1983).

Dregne, H.E. (1996) has discussed the disputes that have risen about what desertification is, its extent and severity, and the challenges that are faced in attempting to control the phenomenon.

Dregne (1991) gives the amount of irrigated land, rainfed cropland, and rangeland in the drylands of the world in Table 11. All of the land lies in the arid, semiarid, and subhumid climatic zones except for a small amount of irrigated land in the hyperarid zone of the Sahara Desert in Africa.

Table 11: Lansuse in the drylands of the world, by continent.

Continent	Irrigated land	Rainfed land	Rangeland	Total
Africa	10.4	79.8	1342.3	1432.5
Asia	92.0	218.2	1571.2	1881.4
Australia and New Zealand	1.9	42.1	657.2	701.2
Europe	11.9	22.1	111.6	145.6
North America	20.9	74.2	483.1	578.2
South America	8.4	21.3	390.9	420.6
Total	145.5	457.7	4556.3	5159.5

*** all the above figures are in million hectares.

About three percent of the drylands is irrigated, 9 percent is rainfed cropland, and 88 % in rangeland. The most extensive land use (rangeland) is the least productive.

Asia has, by far, the largest amount of irrigated land and also is the leading continent in area of rainfed cropland and rangeland. In addition, it has the dubious distinction of having the highest or nearly highest percent of degraded land in the three land use categories. While there is considerable variation among continents in the degradation of their irrigated lands and rainfed croplands, all except Australia have highly degraded rangelands. Australia is unique because it has large areas where the forage is highly unpalatable and the pastoral lands lack good water supplies.

Desertification affects the agricultural and non- agricultural lands alike. Rainfall pattern, landform history, morphological and pedological characteristics of the land, characteristics of vegetation and prevalent land utilization pattern determine the extent and magnitude of the problem. The key role is, however, played by man and the domesticated animals. Mismanagement and /or overuse of the land and water resources lead to the degradation of those resources and accelerate the natural processes. Consequently, the problem spreads to newer areas. In the arid western part of Rajasthan, desertification is manifested through the features of accelerated wind erosion/ deposition, water erosion, salinity/alkalinity, water logging (Shankarnarayan & Sen 1985, Venkateshwarlu et. al. 1992)

Desertifacation problem in western Rajasthan, as caused by accelerated and natural processes and manifested through degraded features like sand sheets, drifting sand, active dunes, deflation hollows, rills, gullies , soil crust, salt entrustations, impeded drainage conditions, poor vegetation cover, low plant density and low biomass production under different rainfall zones, has been highlighted by Singh et.al. (1994) . It is taking place in western Rajasthan through wind erosion/ deposition, water erosion, salinity/alkalinity, waterlogging, and degradation of vegetation. Increasing anthropogenic, technogenic and zoogenic activities has accelerated these processes. It has resulted in the depletion of biological productivity of the region. In the less than 300 mm rainfall zone, wind erosion/ deposition is more serious and widespread due to low rainfall and highly vulnerable sandy terrain. Salinity / alkalinity and waterlogging resulted mainly due to faulty methods of irrigation and presence of impervious strata. Overgrazing and indiscriminate felling of trees resulted in the degradation of vegetative cover and decrease in biomass production. In the more than 300 mm rainfall zone, water erosion and wind erosion/ deposition are the serious problems affecting the biological productivity of different ecosystems. In case, these problems continue unchecked, large acreage of agricultural land will be affected in future. Based on this integrated information, suitable action plan may be formulated for combating desertification.

Using the 1990 UNEP definition of desertification (as " land degradation in arid semiarid and dry sub humid areas, resulting from adverse human impact") , Singh et.al. (1992) have made an attempt to map the desertification hazards in western Rajasthan (Fig.10). The first stage involved the mapping of dominant land uses in different rainfall zones. Mapping of dominant and associate processes of desertification and their severity for desertification status followed this. . This method is found to be useful for mapping the problems of desertification under Indian conditions. The units chosen are flexible and easily understandable to different users. Remote sensing plays a major role in such mapping and could be supplemented by sample field surveys.

13.0 Recommendations & Conclusion

Based on the integrated analysis of climatic and biophysical land resources it has been observed that arid and semi-arid zones of north-western and south-western parts of India due to less rainfall dominated by sand dunes , interdune plains and sandy undulating older alluvial plains.

Fencing

These sand dunes and sand deposits should be protected from biotic interference through the fencing with locally available thorny brushwood or five strands barbed wire fixed on angle iron posts spaced at 6 m apart.

Transplanting/revegetation

The transplantation of tree, grass and shurb species could be done by raising the nursery of 6 to 9 month old drought hardy seedlings, like Acacia tortillas, Acacia nubica, Cercidium floridum, Calligonum polygonoides and Prospopis Cineraria should be transplanted at a spacing of 5x5 m in the strips of micro wind breaks. This is to be done after first effective monsoon shower.

In between the tree and shrub species, the record slip of locally available indigenous perennial grasses such as Panicum antidolate, Panicum turgidum, Lasiurus sindicus and Cenchrus ciliaris may be planted to check the wind erosion/ deposition.

Gully erosion control

The gullies of different depth, width, shape and size have developed along the hills and rocky/gravelly pediments. Using measures like contour buntings, contour furrows, anicuts and check dams across the slopes and nullahas could control the gully erosion. To reduce velocity of surface runoff, small reservoirs should be constructed in the upper reaches and their water could be used for irrigation. The silvipasture and hortipasture systems will be very useful in the gullied areas.

Bank erosion control

The bank erosion due to lateral shifting of the courses of rivers and their tributaries could be controlled by using the measures like construction of spurs, check dams and anicuts at 200 m distance and pucca wall at the turning points. The high bunds along streams alongwith thick tree vegetation belts can check the bank cutting.

Development of Surface Water

The first priority should be given for the maintenance of the existing sources and later on all possible new resources could be tapped. At present most of the natural resources such as water, fuel, fodder and other associate components are gradually declining. So far very few soil and water conservation works have been executed in these areas and that too have been carried out in fragmentary and piecemeal manner and they have not yielded the desired benefits. This may be due to the lack of people's participation. Hence to check further deterioration of the natural resources, watershed development approach and specific sites for surface water resources development have been suggested.

Nadi renovation

Joras/nadis are small embanked dugout ponds used for rainwater harvesting to mitigate the drinking water shortage in these areas. Before the water supply schemes came into existence, the water of these joras/nadis was the only source being used by both, human beings and animals, for drinking purpose. The high evaporation and seepage losses, sediment deposits in the beds and water pollution are the major problems, limiting their proper utilization. Hence there is a need to renovate these structures by means of desilting, construction of silt traps and plantation of trees, shurbs and grasses in their catchment areas.

Control of seepage and evaporation losses

The large amount of water nearly 40% is lost from the joras/nadis due to seepage and using following measures could control evaporation and these losses.

(i) The seepage losses from nadis could be minimized by clay lining and janta emulsion. These measures have been proved useful to check the seepage losses from water bodies without any deterioration to their water quality by pollution.

(ii) Minimizing the surface area of nadis and increasing the depth could reduce the evaporation losses.

(iii) Shading and floating materials on water surface such as foamed rubber, polystyrene and polyethylene sheets could also check evaporation losses. These materials have been found useful and economical for this purpose.

Development and management of Ground Water

The younger and older alluvial aquifers have better groundwater potential. Thus, it is necessary that in these areas further exploitation of groundwater should be completely stopped and here no new well or tubewell should be allowed to dug or drilled. It has been observed that some areas have lowering of groundwater level. Using artificial recharge methods such as the subsurface barriers, percolation tanks, injection wells, contour and field bunding should check it.

Water for Irrigation

It has been observed that the large area of these lands having sandy soils is under well irrigation, where large amount of water goes as waste due to seepage in the unlined channels. The techniques such as lining with bentonite, tank silt with bhusa, janta emulsion or polyethylene sheets suggested by scientists of CAZRI could save 60 to 70 % water losses. Using drip and sprinkler system of irrigation could also check such water losses.

In the fine textured alluvial plains of Patan-Raipur region, a large quantity of groundwater is being used with unscientific methods of irrigation, resulting wastage of water and creating waterlogging conditions as well as salinity problem. Hence, proper management and judicious use of water for irrigation will control such problems and more area could be brought under irrigation. In case the water holding capacity of these soils is increased by using the FYM and tank silt, the frequency of irrigation will be reduced and groundwater could be saved and used for irrigating more area of these plains.

Evaporation losses

The high wind velocity prevailing in this region is resulting in high evaporation losses. Moreover, the transit losses of water in open field channels are also very high. In order to check such losses and to save sufficient quantity of groundwater, it is suggested that water from one end to the other end of field could be transported through the cement pipes of 15 to 20 cm diameter.

The soil conservation measures like contour bunding, gully plugging and vegetative cover on the mine spoils to check wind and water erosion is needed. The buried pediments, flat older alluvial plains and younger alluvial plains badly dissected into deep gullies need suitable soil conservation measures like checkdams, anicuts, earthen bunds, contour furrowing and contour bunding. The grass and tree cover on bunds and in the areas of upper catchment to check the further water erosion is absolutely necessary. The interflueves of these lands could be developed into silvipasture, hortipasture and agrohorticulture systems. The bank cutting of streams is reducing the cultivated lands, particularly at the meandering and confluence points. These sites, therefore, need masonry structures for regulating the runoff and to control bank dissection and creation of new wastelands.

Inaugurating a two –day national seminar on ground water management strategies in arid and semi-arid regions in the BM. Auditorium, Jaipur on 24th June 2000. Mr. Sethi (Union Minister for Water Resources) said that the indiscriminate and unregulated use of water had led to the depletion in ground water level and it had reached a state of crisis. Against the desirable per capita annual availability of 1,850 cubic meters of water in the country, the current availability is only 1,700 cubic meters; and taking into account the population growth , the availability would fall to about 1,450 cubic meters by 2025. The Minister pointed out that the time had come to squarely focus on the issue of proper management of water resources so as to ensure availability in a sustained manner.

He said the Central Ground Water Board had carried out extensive artificial recharge studies in many States and they had led to the development of area specific techniques which had demonstrated a high degree of efficiency in the collection of rain water and recharge of ground water. Mr. Sethi favoured the introduction of rooftop rainwater harvesting for improving the drinking water availability in arid and semi-arid areas.

Noted activist, Mr. Anna Hazare, speaking on the occasion, said the absence of people's initiative in water management had led to the Government taking over the work and added that the technical flaws in official schemes often rendered them ineffective. He called upon the Gram Sabhas to take up the conservation and management of water as a major component of their work. Over 200 Scientists, Hydrologists, experts and Non-Government Organizations from, are attending the two-day meet across the country.

Land use in arid and semi-arid areas in India is primarily conditioned by combination of natural, social, economic, technical demographic and political constraints can only be identified for finding out methods of their circumvention, other constraints, especially pertaining to social, economic, demographic and technology essentially involve existence of organization which would help facilitate interaction of factors promoting gradual removal of constraints. The existing infrastructure of voluntary organizations and institutional financing agencies could be profitably incorporated into the organizations.

Agarian development process itself is a difficult task. Any attempt at identifying delineating and removing constraints may not always result into success stories. A continuous evaluation, monitoring and feedback system with maximum participation of rural population would go a long way in solving the problem of poverty, hopelessness and despair in arid areas.

14.0 List of Recent Publications on Arid/Semiarid Regions

1. Abdulrazzak, M. J. and Sorman, A. U.,1994. Transmission losses from ephemeral stream in arid region. ASCE Journal of Irrigation and Drainage Engineering, 120(3): 669-675.

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19.Long, R. B., 1987. Aggregate marginal returns from western irrigated agriculture. Water Resources Bulletin, 23(6): 1117-1124.

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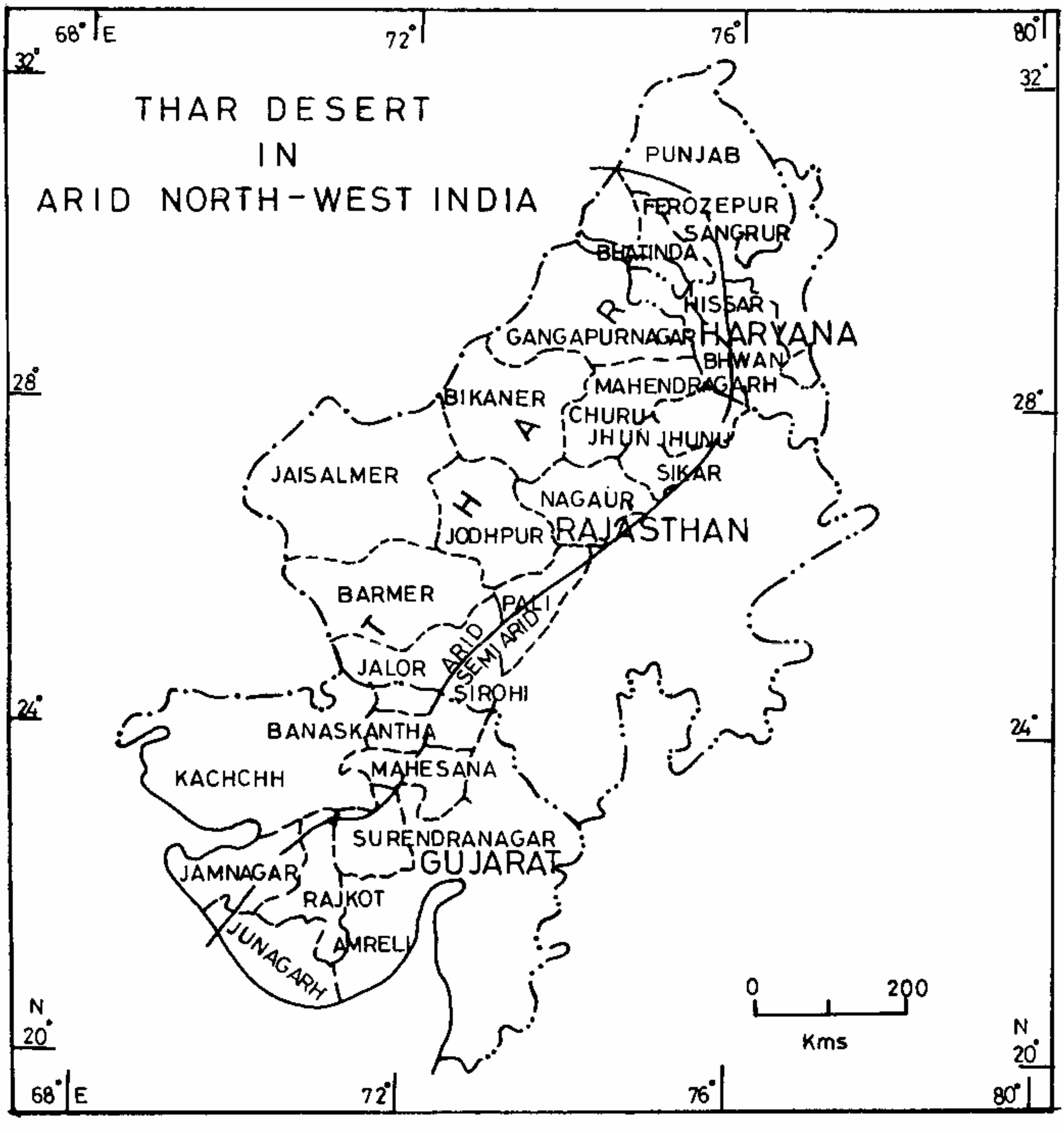
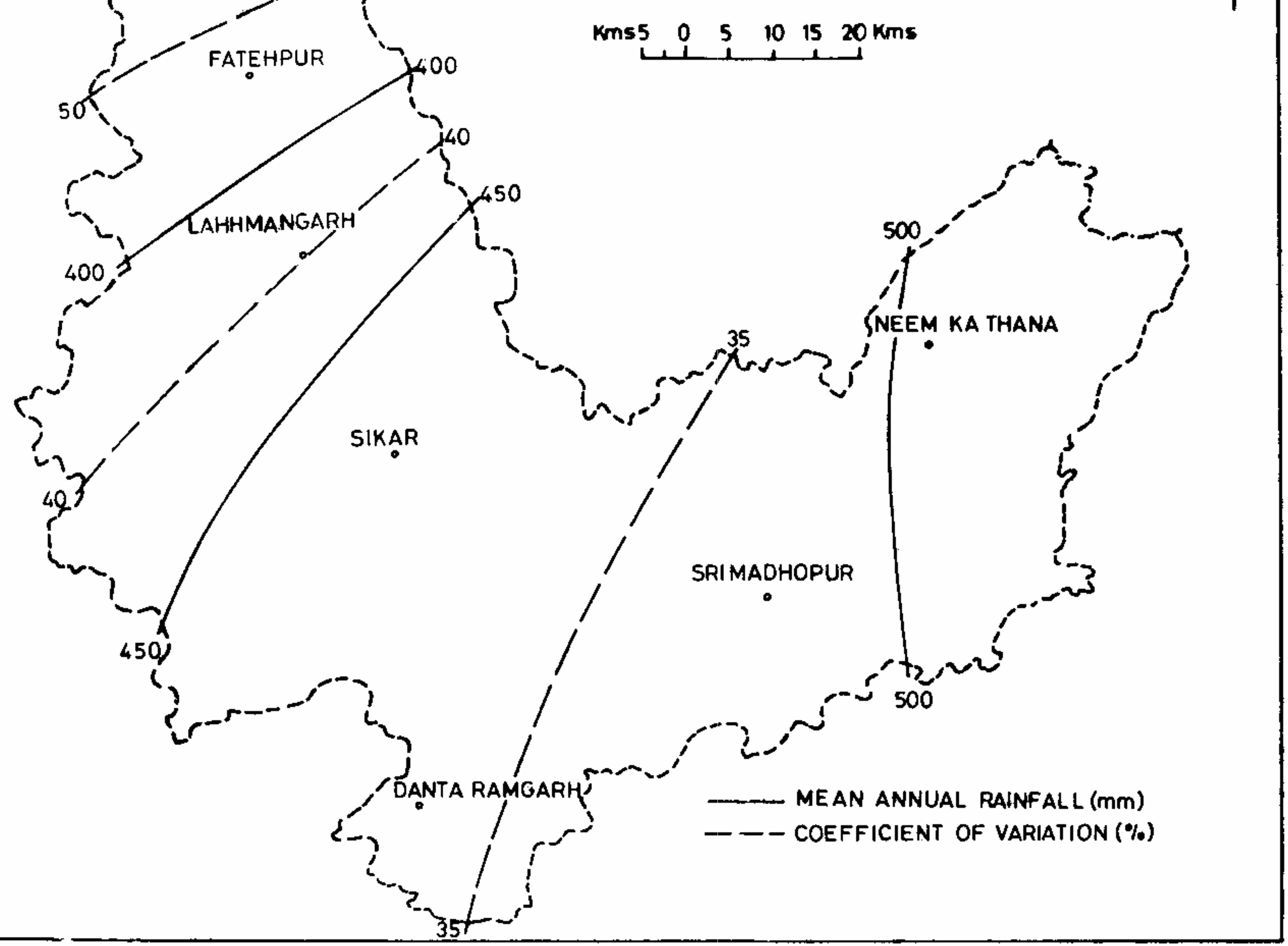


FIG. 1. THAR DESERT IN ARID NORTH WEST INDIA

Fig 2 SIKAR DISTRICT

MEAN ANNUAL RAINFALL AND COEFFICIENT OF VARIATION



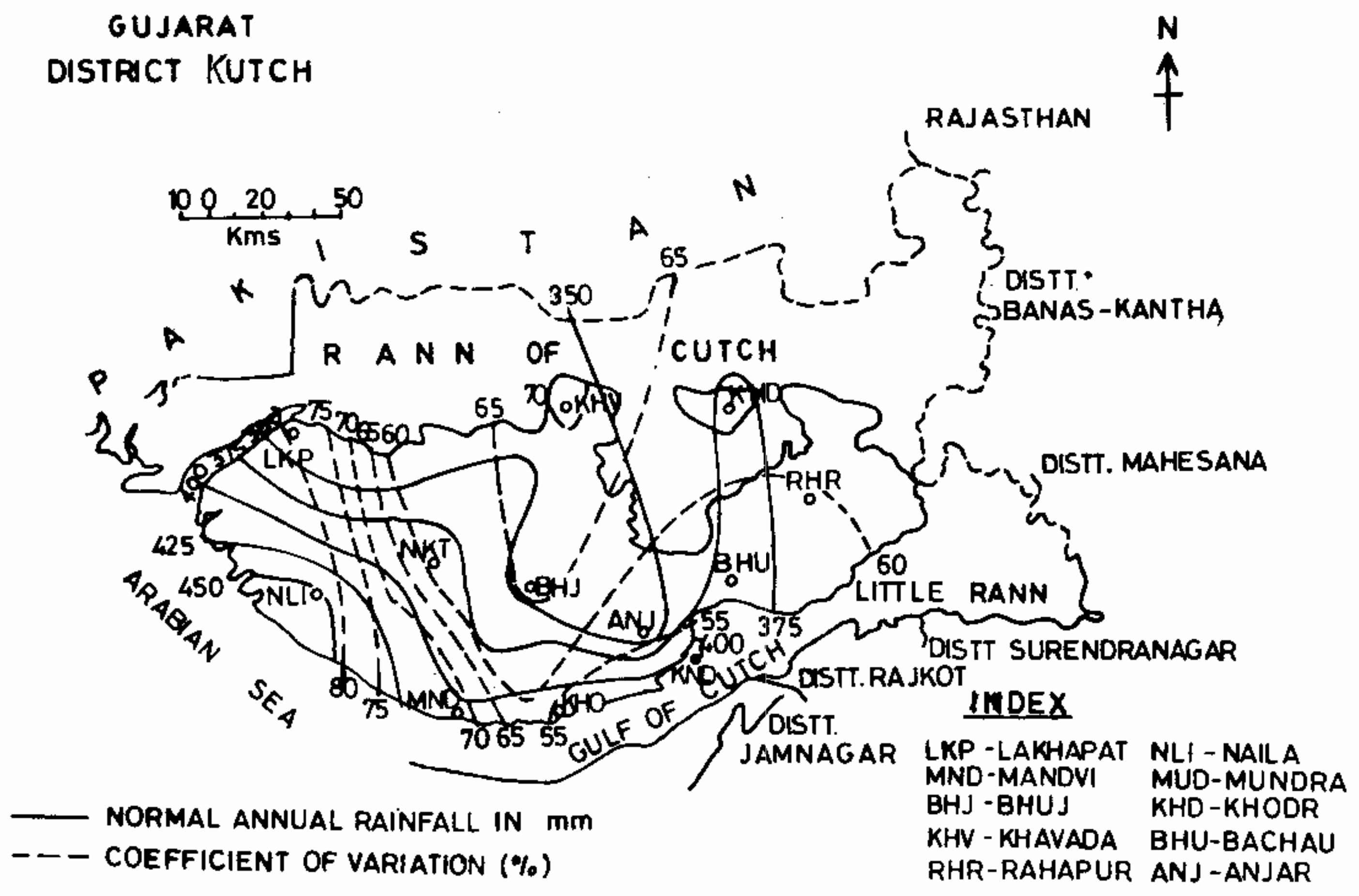


FIG.3. MEAN ANNUAL RAINFALL AND ITS COEFFICIENTS OF VARIATION OVER CUTCH REGION

DISTRICTWISE GROUND WATER CONDITIONS IN RAJASTHAN
JUNE 1988

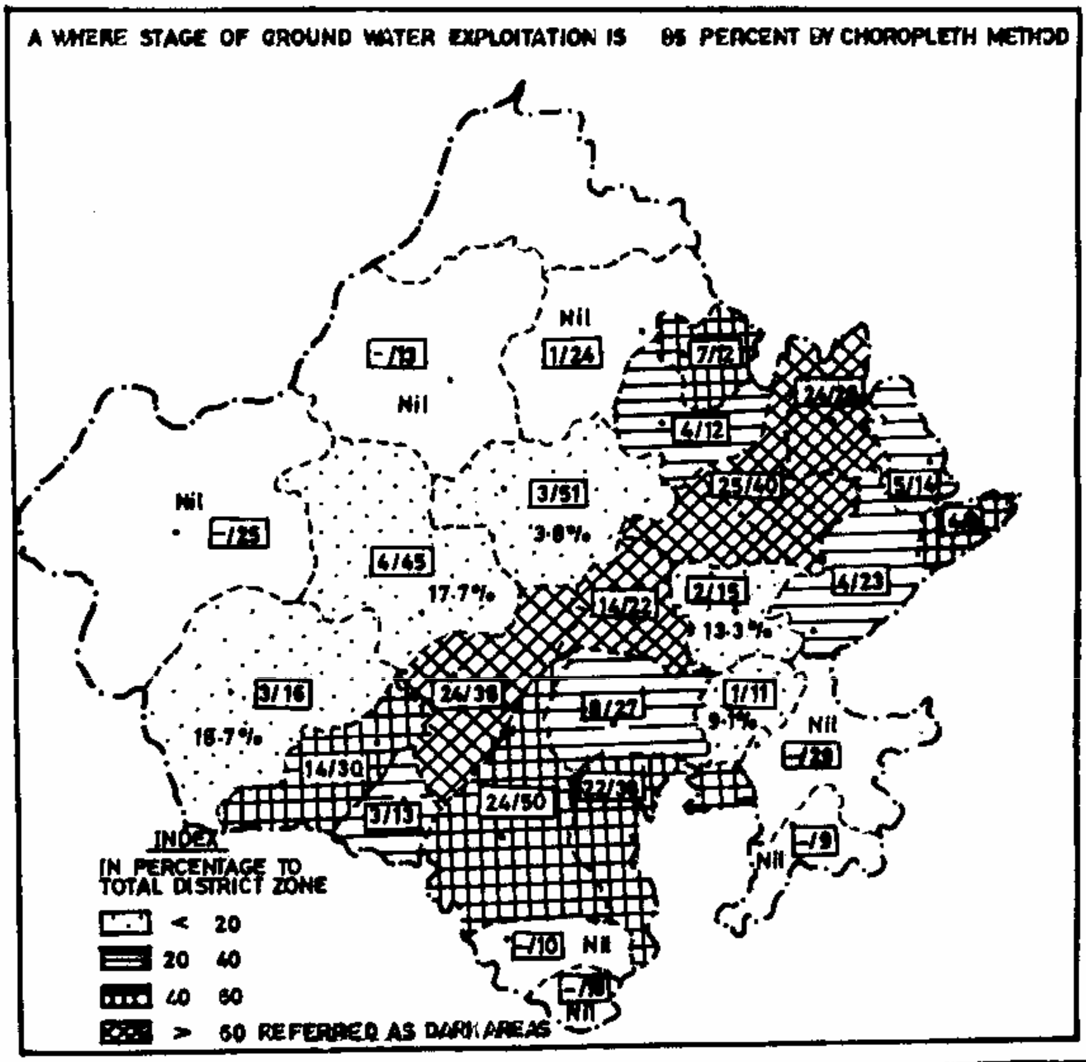


FiG 4

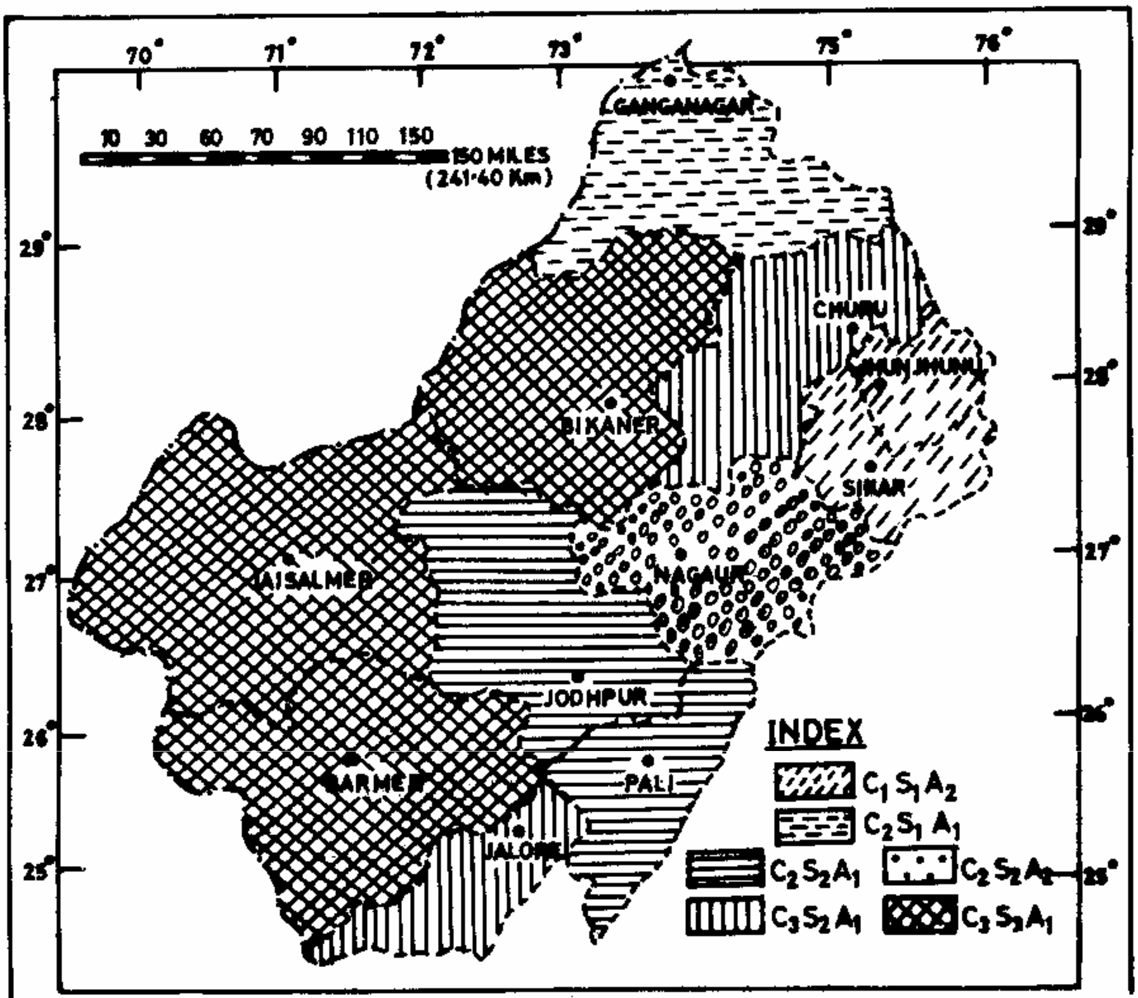


FIG. 5: SALINE SODIC ZONES OF GROUND WATER IN WESTERN RAJASTHAN

EC(dSm^{-1}): $C_1 < 3$; C_2 3–5; $C_3 > 5$

SAR: $S_1 < 10$; S_2 10–18; $S_3 > 18$

RSC(meL^{-1}): $A_1 < 2.5$; $A_2 > 2.5$

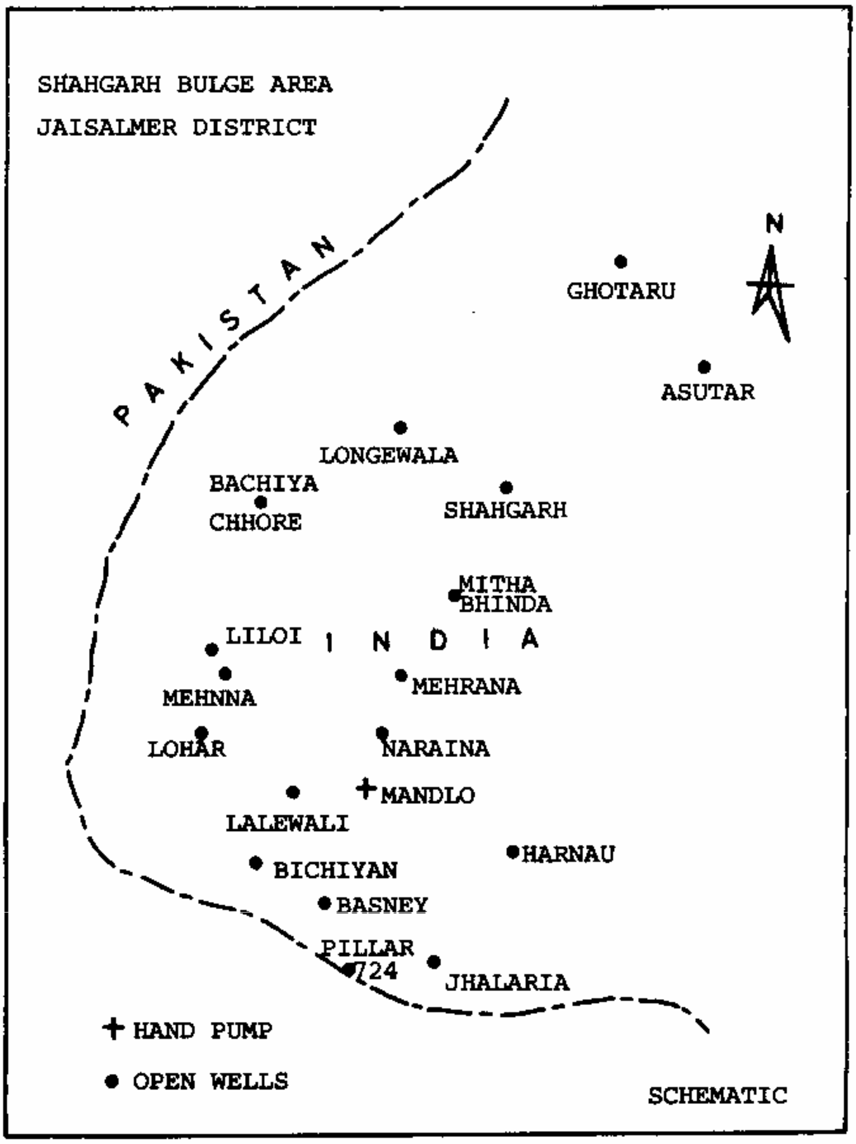


FIG. 6 . SHAHGARH BULGE AREA, JAISALMER DISTRICT

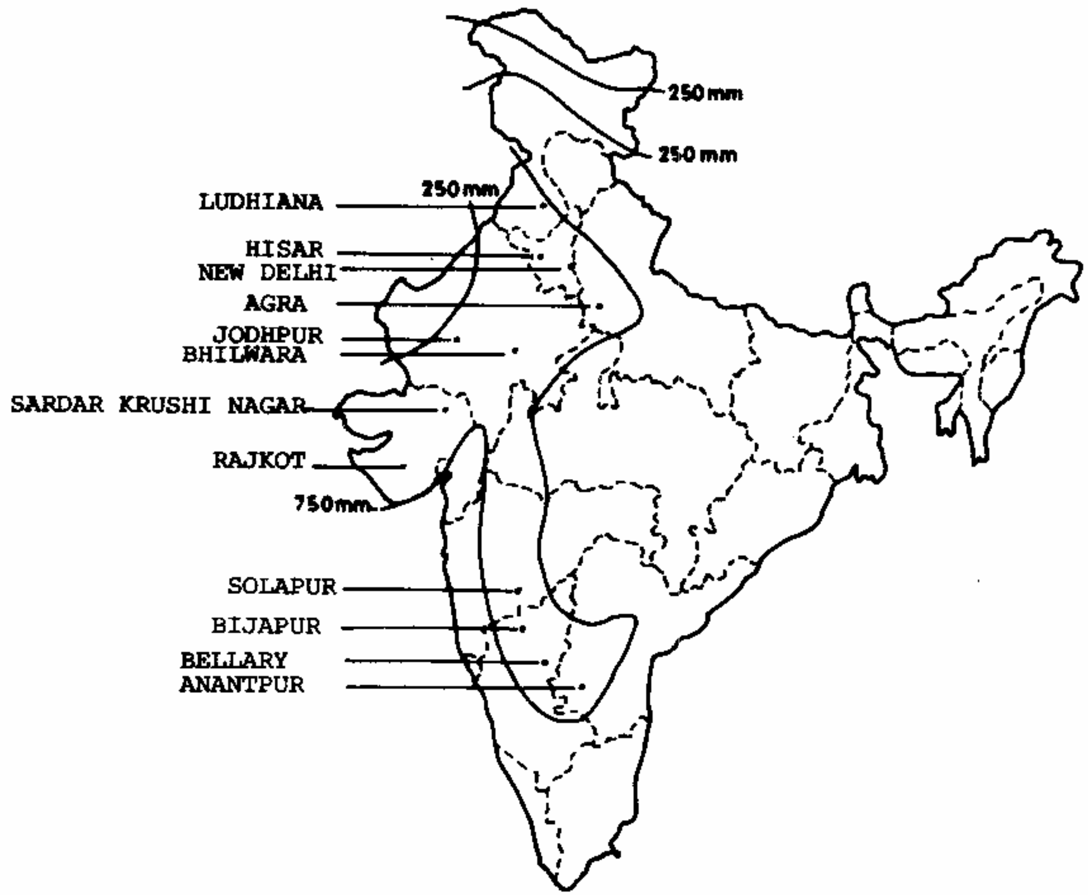


FIG. 7 . DRYLAND AREAS OF HOT ARID AND SEMI-ARID REGIONS OF INDIA

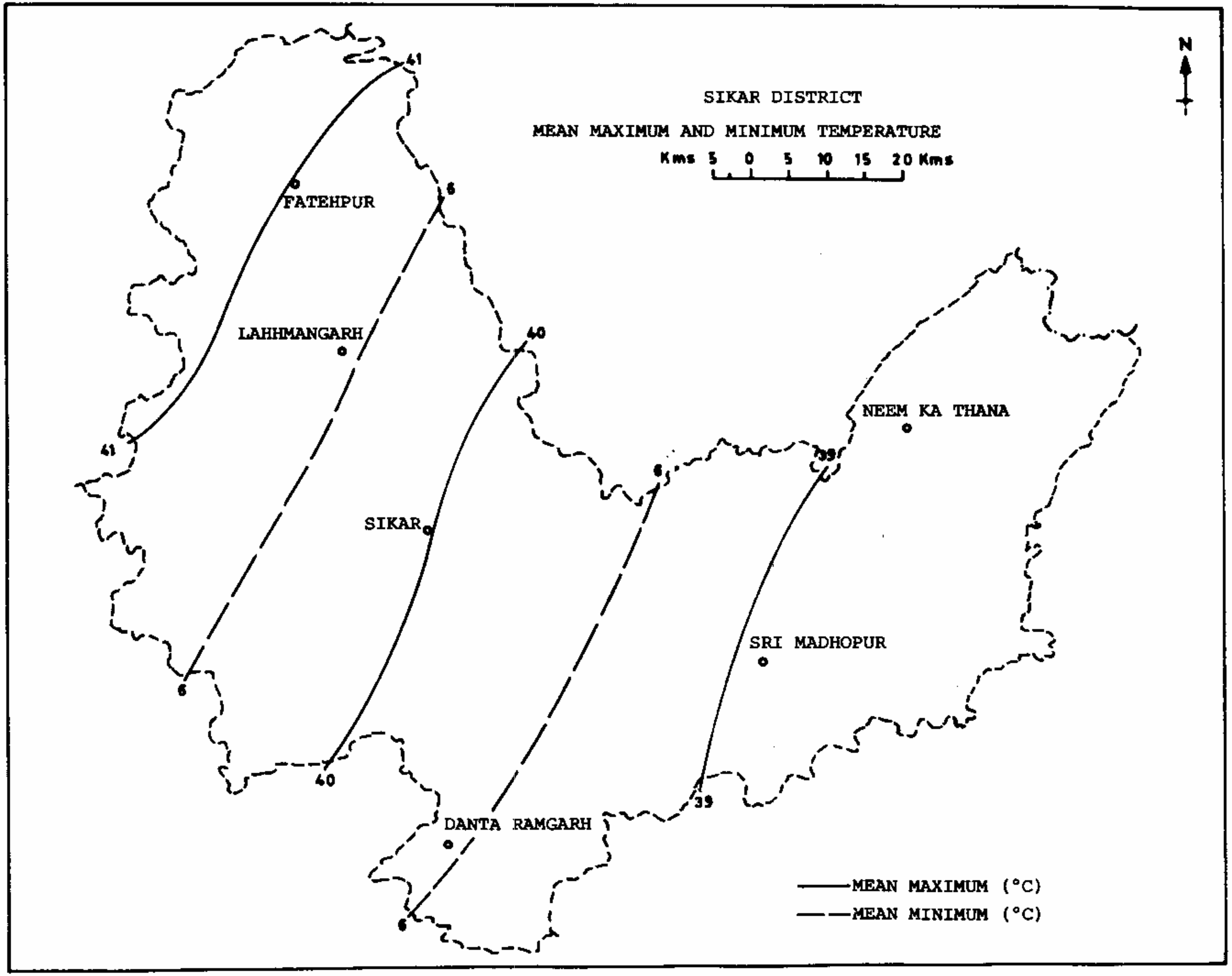

SIKAR DISTRICT
MEAN MAXIMUM AND MINIMUM TEMPERATURE
Kms 5 0 5 10 15 20 Kms
N
FATEHPUR
LAHHMANGARH
SIKAR
NEEM KA THANA
SRI MADHOPUR
DANTA RAMGARH
41
41
6
6
40
40
6
6
39
39
MEAN MAXIMUM (°C)
MEAN MINIMUM (°C)

FIG. 8

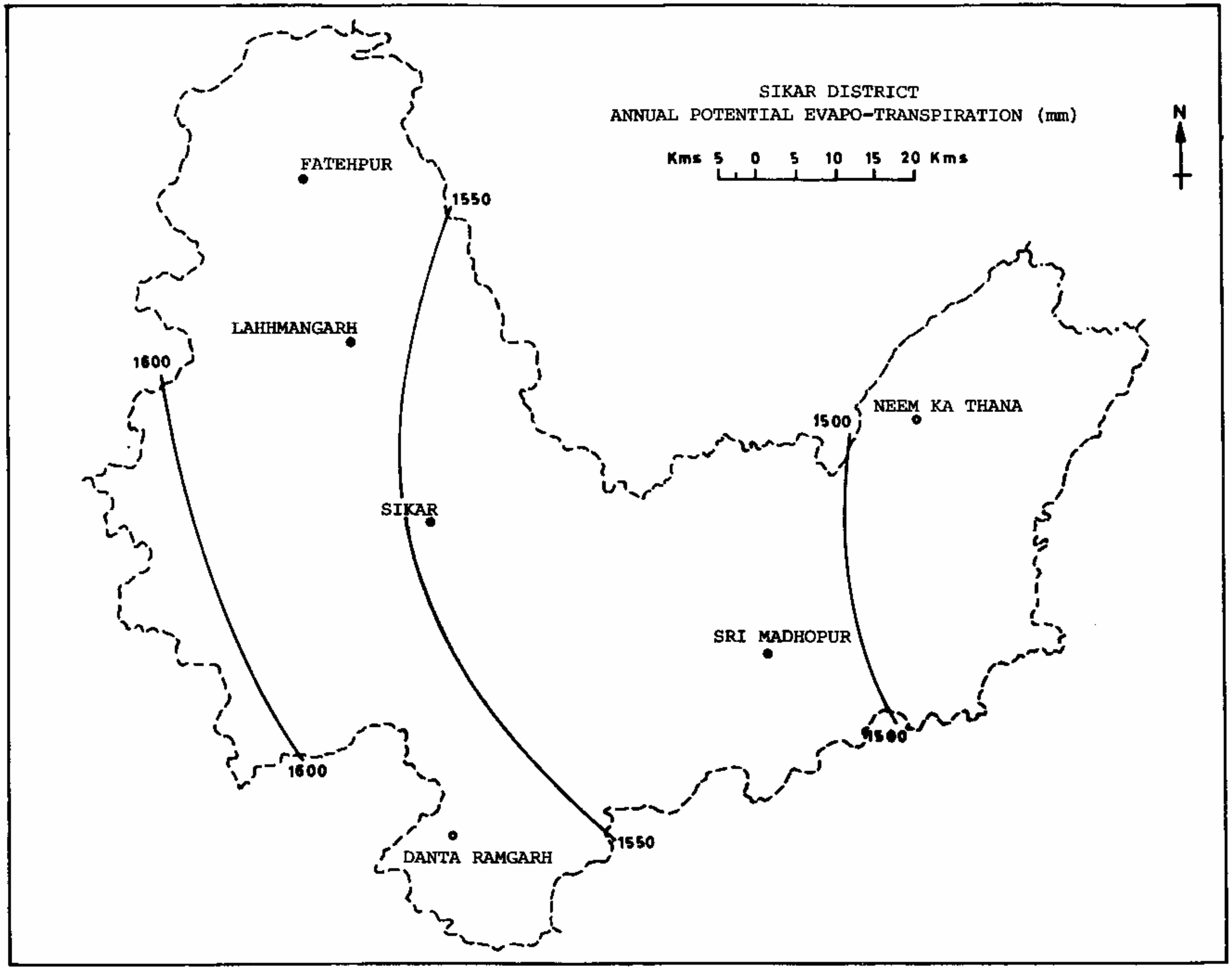

SIKAR DISTRICT
ANNUAL POTENTIAL EVAPO-TRANSPIRATION (mm)
Kms 5 0 5 10 15 20 Kms
N
FATEHPUR
LAHHMANGARH
SIKAR
DANTA RAMGARH
SRI MADHOPUR
NEEM KA THANA
1600
1600
1550
1550
1500
1500

FIG. 9

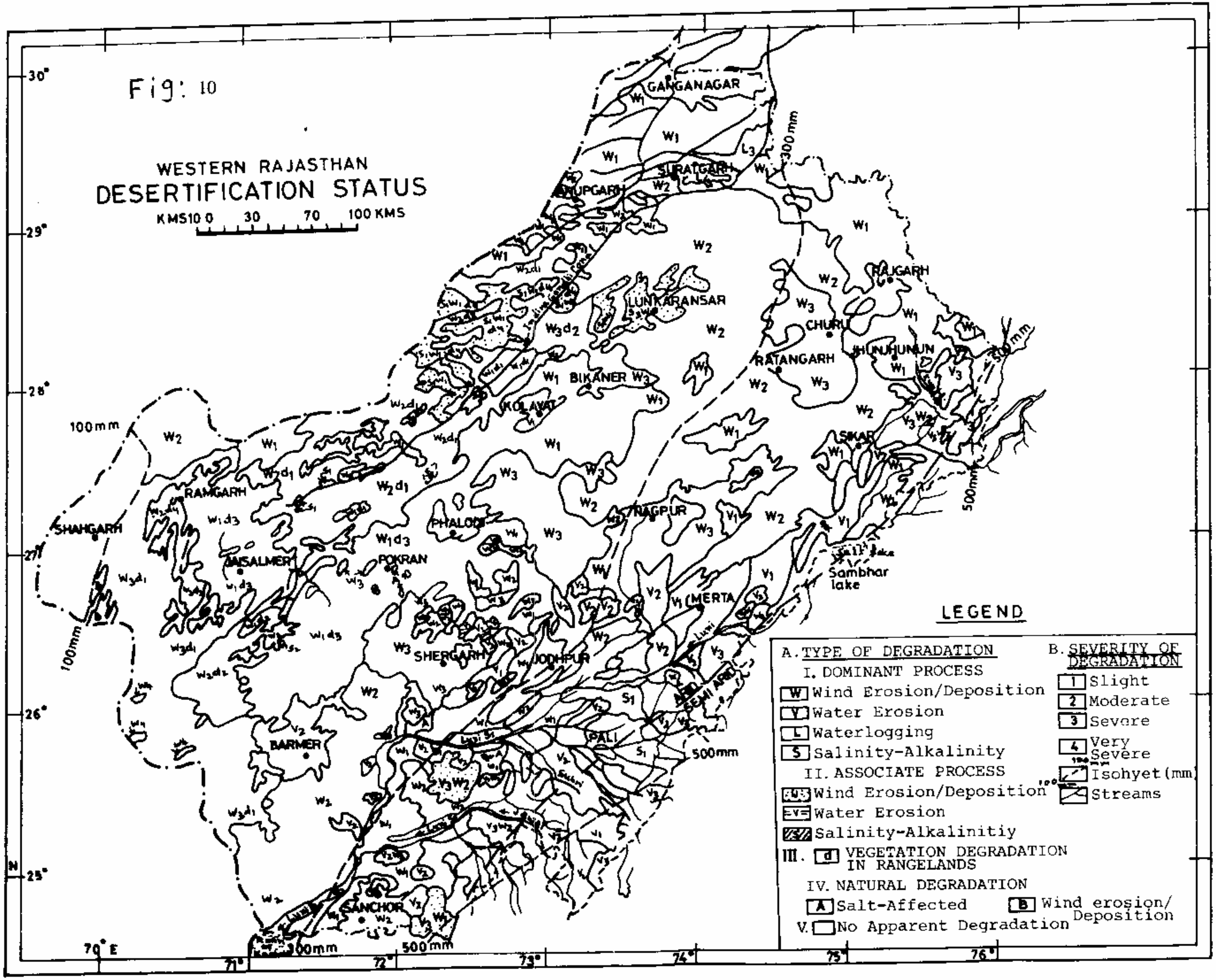


Fig: 10
WESTERN RAJASTHAN
DESERTIFICATION STATUS
KMS10 0 30 70 100 KMS
GANGANAGAR
SURATGARH
ANUPGARH
RAJGARH
LUNKARANSAR
CHURU
JHUNJHUNUN
RATANGARH
BIKANER
KOLAYAT
SIKAR
RAMGARH
SHAHGARH
PHALODI
NAGPUR
JAISALMER
POKRAN
Sambhar lake
MERTA
SHERGARH
JODHPUR
PALI
BARMER
SANCHOR
100mm
300mm
500mm
30°
29°
28°
27°
26°
25°
N
70° E
71°
72°
73°
74°
75°
76°
LEGEND
A. TYPE OF DEGRADATION
I. DOMINANT PROCESS
W Wind Erosion/Deposition
V Water Erosion
L Waterlogging
S Salinity-Alkalinity
II. ASSOCIATE PROCESS
Wind Erosion/Deposition
Water Erosion
Salinity-Alkalinitiy
III. d VEGETATION DEGRADATION IN RANGELANDS
IV. NATURAL DEGRADATION
A Salt-Affected
B Wind erosion/ Deposition
V. No Apparent Degradation
B. SEVERITY OF DEGRADATION
1 Slight
2 Moderate
3 Sevare
4 Very Severe
Isohyet (mm)
Streams

Director: **Dr. K.S.Ramasastri**

Study Group

Ms. Rama Mehta, Scientist 'B'