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HYDROLOGICAL ASPECTS OF DROUGHT UP TO 1988-89 - A CASE STUDY IN RAJASTHAN

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE-247667 (U.P.)
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PREFACE

A most important factor in understanding hydrological droughts, it is a supply and demand phenomenon. To a hydrologist drought means below average availability of flow in streams and below average storages in reservoirs, lakes, tanks, ground water aquifers and soil moisture in soil column. The various hydrological variables which can be used to study hydrological aspects of drought include rainfall, groundwater, levels, surface water storages and soil moisture.

The problem of drought in the country has been recurrent in nature. In late 80's the country has faced drought for three years in succession. Reliable estimates indicate that the drought of year 1987 is ranked second in the century, the first one being in year 1918. It has been estimated by Central Water Commission that about 1/3rd of the geographical area of the country (107 M. ha.) spread over 99 districts, are drought prone.

The National Institute of Hydrology initiated drought studies in the year 1986 with the major objectives to lay emphasis on. hydrological aspects of drought and to develop suitable drought indices along with evolving short and long term drought management strategies. In this venture the institute has already carried out studies on various aspects of drought. In order to study the gravity of problem, studies have been taken up using the field data to evaluate impacts of drought. In this pursuit the Institute has chosen six states namely, Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra and Rajasthan. The present report covers the study of six districts of Rajasthan state. These districts are Ajmer, Jodhpur, Banswara, Barmer, Dungarpur and Udaipur.

The study includes various kinds of analysis of rainfall and groundwater level data for assessing drought impacts. Based on the analysis, inferences highlighting the hydrological aspects of the recent droughts have been drawn up.

The study has been carried out by Scientists Shri. Avinash Agarwal, Sc.'C', Shri. S. K. Goyal Sc.'B', Shri. R. P. Pandey, Sc.'B' and scientific staff Shri. Yatveer Singh, R.A. under the guidance of Dr.G.C.Mishra, Sc.'F'. The manuscript has been typed by Shri. Rajneesh Kumar Goel, L.D.C.

Satish Chandra

(Satish Chandra)
Director

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ABSTRACT

The occurrence of drought in India is not a recent phenomenon. In recent years the country faced three drought years in succession namely 1985, 1986, 1987. It has been reported intensity wise the drought of year 1987 ranks second in the 20th century, the first one being in the year 1918. Statistics on areal coverage indicate that out of the country's total geographical area of 328 m. ha., 107 m. ha., or about one third of the area and 29 percent of the population are affected by drought.

In view of severity of drought problem and less understanding the hydrological aspects associated with the droughts, the National Institute of Hydrology started studies in the year 1986 to better understand the drought impacts from hydrology point of view. In this venture the institute started collection, from field organizations, of the data concerning rainfall, and groundwater in selected areas, covering the period 1951 to 1989. Six states of Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Madhya Pradesh & Rajasthan were selected for the study. This report covers the analysis of rainfall, groundwater, and reservoir level data in respect of six selected districts Ajmer, Jodhpur, Banswara, Barmer, Dungarpur and Udaipur of State Rajasthan for the assessment of drought impacts.

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1.0 INTRODUCTION

1.1 General

In spite of all the inconveniences that drought causes all around the world, many drought phenomena are still insufficiently understood in terms of the characterization and impact assessment. There have been difficulties encountered in finding a generally accepted drought definition. The definitions currently in use are derived either on professional standpoints (meteorology, hydrology, geography etc.), or on the economic activity affected (agriculture, power, production, water supply etc.). A most important factor in understanding drought, often not included in definitions, that it is a "supply and demand" phenomena. A definition of drought which does not include reference to water requirement or demand can be regarded as inadequate. In general terms, the chief characteristics of drought is associated with a decrease of water availability in a particular period and over a particular area for specified use(s).

In India, the problem of droughts is recurrent. Estimates indicate that about one-third of the geographical area of the country (107 m. ha.) spread over 99 districts are affected by drought. In recent times, the country faced three drought years in succession namely, 1985, 1986 and 1987. It has been reported that intensity wise the drought of 1987 ranks second in the century, the first one being in year 1918. During the drought of 1987 about 50% of country's area was affected by drought with about 18% negative departure in monsoon rainfall all over India and about 45% negative departure in monsoon rainfall over the drought affected region (Upadhyay & Gupta, 1989). Sampath (1989) has reported that during 1987, 21 meteorological subdivisions out of 35 recorded deficient/scanty rains leading to drought conditions. A quick glance of food grains production figures indicates that during year 1987-88 the production was 138.41 million tonnes while in 1988-89 it was estimated to be about 172.0 million tonnes. The years 1985-86 through 1987-88 saw declining trend of food grains production which fell from 150.4 million tonnes in 1985-86 to 138.41 million tonnes in 1987-88. The fluctuation of food grain production clearly show dependability of agricultural activities on the rainfall.

The incidents of drought lead to reduction in stream flows, depletion of soil moisture storages, decline of reservoir and tank levels and fall in groundwater table. This in turn lead to reduced agriculture and fodder production. The drought characteristics and the associated problems vary from area to area depending upon the amount of variability of available water supplies and the demand of water for specified users.

1.2 Objectives of the Study

Inspite of repeated occurrence of droughts in the country, the hydrological aspects of droughts have not been studied to the desired extent. Such studies have a direct bearing on evolving strategies for planning judicious use of water resources.

The Institute, therefore, initiated studies to lay emphasis on Hydrological Aspects of Droughts in year 1985. Keeping in view the successive three drought years of 1985,1986 and 1987, in major parts of the drought prone areas of the country, study areas were chosen in six states namely: Andhra Pradesh, Maharashtra, Karnataka, Rajasthan, Gujarat and Madhya Pradesh.

Studies laying focus on hydrological aspects of drought for 1985-86 with two districts in each of chosen states and for 1986-87 with four districts in each of the states have been completed. The studies for year 1987-88 also been carried out in six districts each in six states and in view of wider aerial coverage in each state separate study reports, contrary to the earlier study reports which presented results of studies in all states in one volume.

The present report therefore presents the results of studies carried out in six selected districts of State Rajasthan for 1988-89. The districts included for studies are Ajmer, Jodhpur, Banswara, Barmer, Dungarpur and Udaipur. The report includes analysis of rainfall and groundwater level data for finding deficits in rainfall and its consequent effects on groundwater tables. The report is an attempt towards developing comprehensive hydrological drought indices for characterizing drought situations. List of offices and places from where data & other relevant information were collected in the state of Rajasthan are given in Appendix-II.

2.0 DESCRIPTION OF STUDY AREA

2.1 General

There are 99 districts spread over 13 states which have been identified as drought prone districts in the country and are shown in Fig. 2.1. This report covers the study of six drought prone districts of state Rajasthan namely; Barmar, Banswara, Ajmer, Udaipur, Jodhpur and Durgapur. The locations of the districts are shown in the state map shown in Fig. 2.2. Rajasthan state is situated in Northwestern part of India and lies between 23° 3' N and 30° 12' N latitudes and 69° 30' E and 78° 17' E longitudes. The area of the state is about 3,42,239 sq. km. The average rainfall of the state varies from 5 cm to 12.5 cm.

2.2 Population-Man & Cattle

The state of Rajasthan has the population 3,42,61 thousand as per census 1981 comprising 27051 thousand rural and 7210 thousand urban. The density of population per sq. km. as per census of 1981 is 100 for the state Rajasthan. The details of the population for cattle are given in Table. 2.1.

2.3 Land Use and Vegetal Cover

The details of district wise land use classification for the ending 1989-90 are shown in Table 2.2, 2.3 and Figure 2.3 for the state Rajasthan.

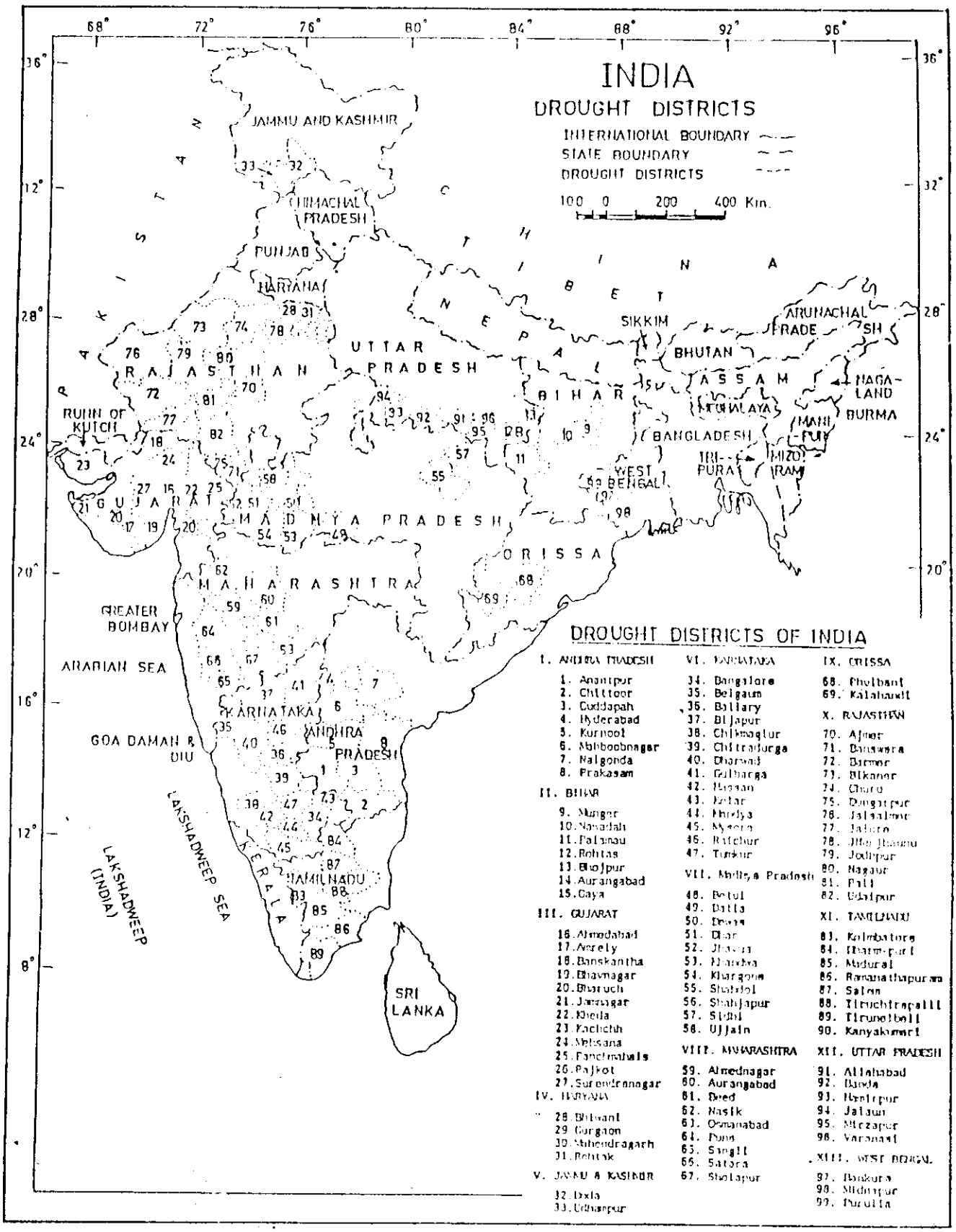


FIG.2.1 DROUGHT PRONE DISTRICTS IN INDIA

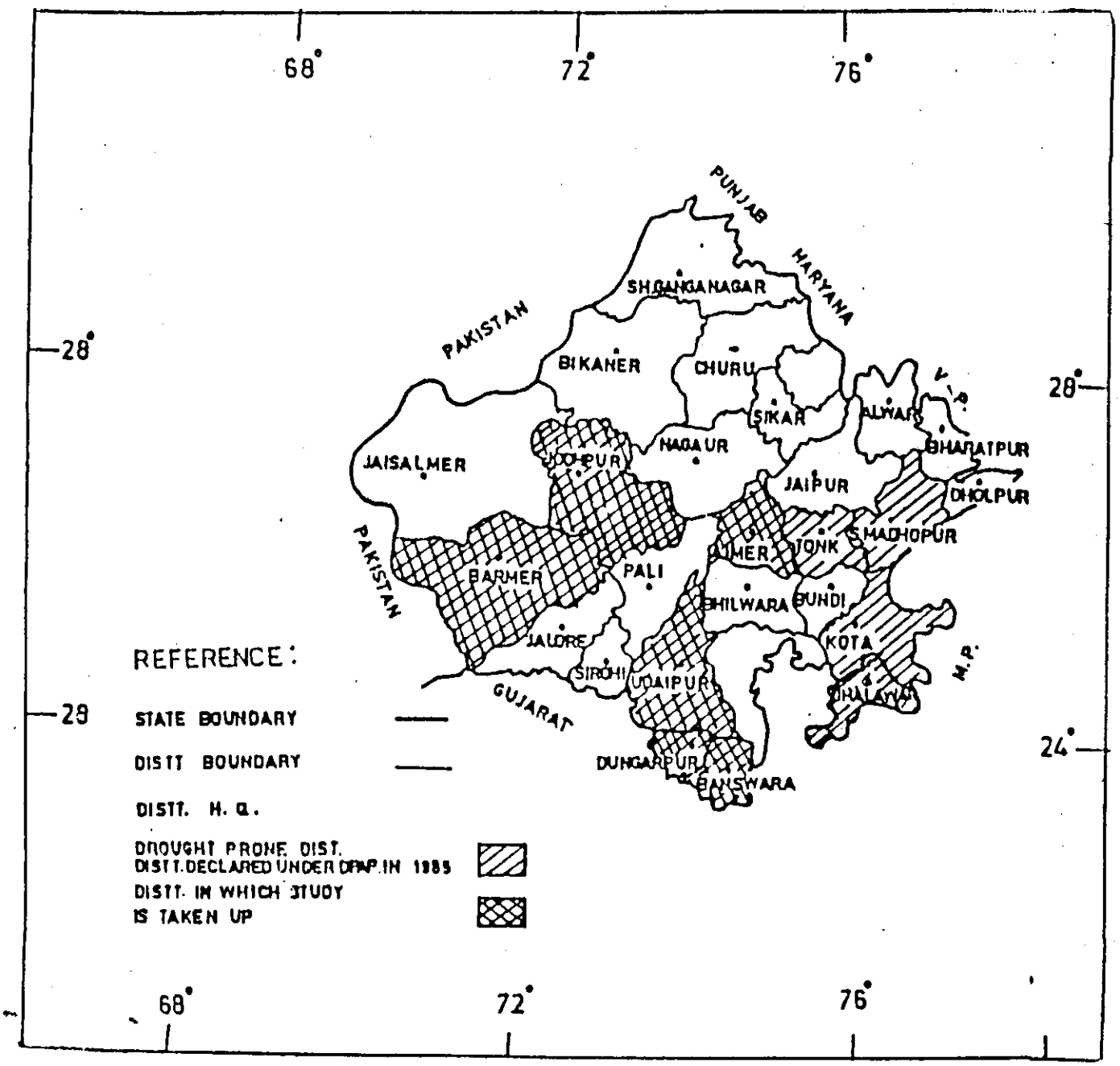


FIG. 2.2 : DROUGHT PRONE DISTTS. IN RAJASTHAN

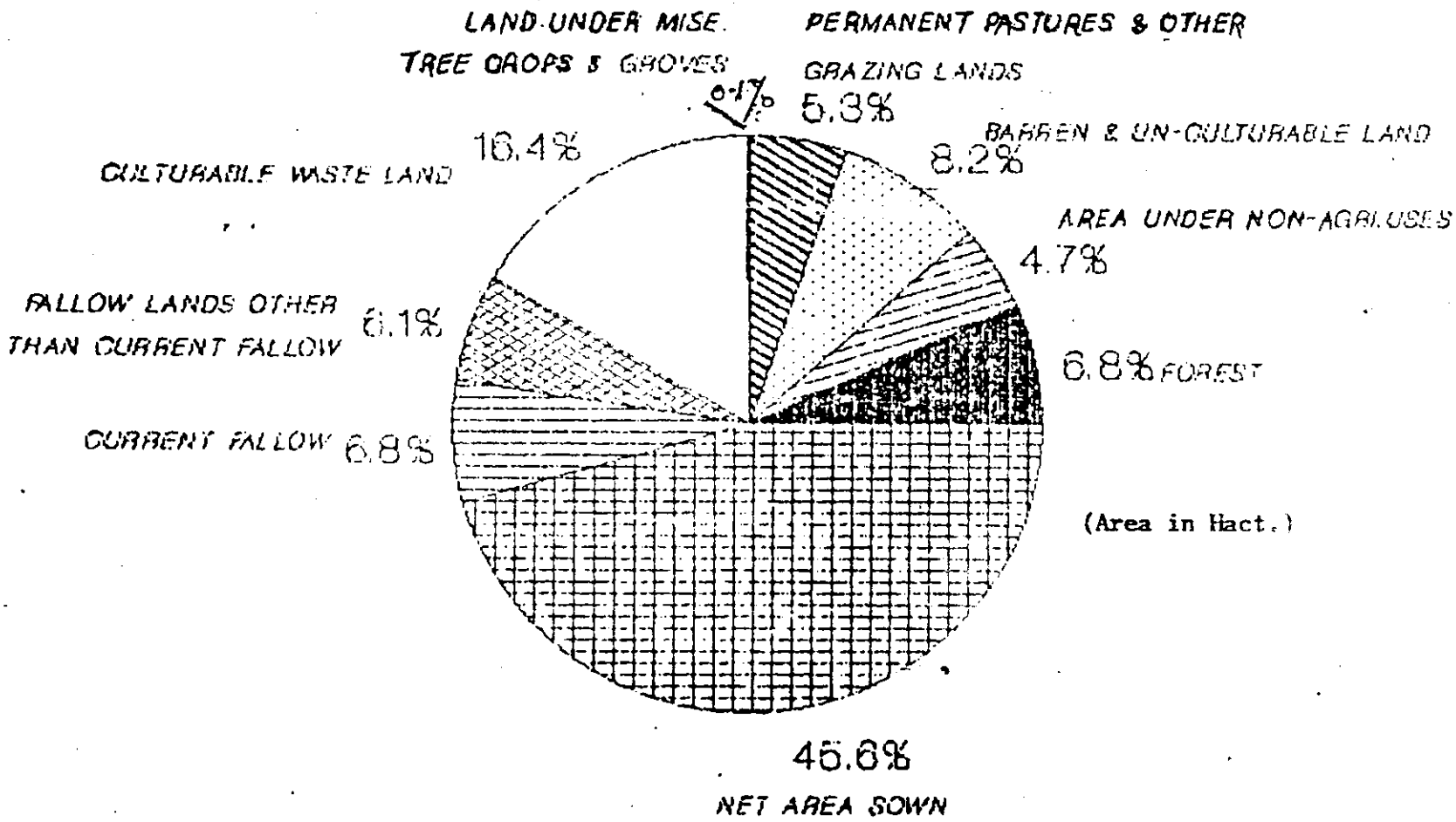


Fig.2.3: Land utilization in State Rajasthan, 1989-90.

Table 2.1: Live stock census 1983 (Provisional).

Sl.No.	Animal	Nos.
1.	Sheep	1,33,86,115
2.	Goats	1,54,09,451
3.	Camels	7,52,887
4.	Cattle & Buffaloes	1,95,00,876
5.	Others	4,36,641
	Total	4,94,85,970

Source: Desert Development Programme, Annual Plan 1987-88 Govt. of Rajasthan, Jaipur.

Table 2.2 : Land use classification for the state Rajasthan, 1989-90

Sl. No.	District Name	Reporting Area for land Utilisation statistics as per vill. papers	Classification of Reporting Area					
			Forest	Not available for cultivation			Other uncultivated	
				Area under	Barren	Total	Permanent	Land under
1.	Ajmer	842388	46839	43504	97936	141440	81421	380
2.	Alwar	766537	25255	41605	120544	162149	24461	562
3.	Banwara	506670	102459	8706	82215	90921	28737	299
4.	Barmer	2817332	24067	69145	130445	199590	208021	1283
5.	Bharatpur	506799	26099	25012	29094	58106	9110	230
6.	Bhilwara	1040025	59981	57473	166871	224344	119757	176
7.	Bikaner	2742655	74503	233125	43977	277102	45623	1241
8.	Bundi	581044	135770	36111	59334	95445	24797	249
9.	Chittorgarh	1035733	151500	41076	146959	188055	79548	276
10.	Churu	1686194	5637	72025	735	72760	46765	35
11.	Dholpur	300898	12904	16173	71265	87438	18952	1098
12.	Dungarpur	385593	61481	15044	73865	94909	39741	2303
13.	Ganganagar	2062848	61756	126065	4151	130216	15760	4059
14.	Jaipur	1399069	70575	82782	97406	180188	106544	1948
15.	Jaisalmer	3840160	16336	78844	364432	443276	107329	1692
16.	Jalore	1056583	18363	35254	87268	122522	48787	60
17.	Jhalawar	632235	105080	24962	38946	63908	51844	1227
18.	Jhunjhunu	591529	37149	16768	17833	36601	41291	125
19.	Jodhpur	2256405	6597	81209	144900	226109	120642	352
20.	Kota	1221850	325584	48320	92464	140784	53078	1277
21.	Nagpur	1764504	13234	81036	61874	142910	74844	78
22.	Pali	1233079	77459	55788	149915	205703	90473	1371
23.	S.Madhopur	1052731	239463	60014	106285	166299	61400	493
24.	Sikar	774942	52167	29169	23329	52498	45201	134
25.	Sirohi	517947	131261	25404	79568	104972	33366	224
26.	Tonk	718814	25428	34053	33559	67612	62921	248
27.	Udaipur	1913089	387186	179608	487526	667134	161224	1136
RAJ.STATE		34247653	2324233	1624295	2818696	4442991	1801637	22562

Table 2.3 : Agricultural land use classification for the state Rajasthan, 1989 - 90.

Sl. No.	District Name	Land Excluding Fallow lands	Fallow Land			Net Area sown	Total Cropped Area	Area sown more than once
		Culturable waste land	Total	Fallow lands other than current fallows	Current fallow	Total			
1.	Ajmer	73140	154941	61032	56132	117164	382004	426911	44907
2.	Alwar	12637	37660	18559	39916	58475	482990	654680	171682
3.	Banwara	18938	47975	29540	13368	42908	222408	308059	8565
4.	Barmer	261055	470359	361793	241406	623199	1500117	1530745	30628
5.	Bharatpur	4051	13391	9979	19590	29569	379634	452151	7251
6.	Bhilwara	187502	307435	56683	39615	96300	351965	465629	113660
7.	Bikaner	1060405	1107275	178903	157259	336162	947613	983602	35904
8.	Bundi	39685	64731	27026	45936	72962	212136	289688	77654
9.	Chittorgarh	199298	279122	23678	21634	45312	371744	535458	16378
10.	Churu	27094	73894	85516	123248	208764	1325139	1370209	4507
11.	Dholpur	1448	34498	14200	14302	28502	132556	167719	30162
12.	Dungarpur	26806	68850	24953	13367	38320	122033	157459	3542
13.	Ganganagar	82136	101955	76530	245595	322125	1448796	1774712	32791
14.	Jaipur	62081	170573	73099	116485	189584	780149	1000929	212780
15.	Jaisalmer	2915045	3024066	84101	31723	115824	240658	241172	50
16.	Jalore	26316	75163	103748	116023	219772	620663	726056	105357
17.	Jhalawar	66351	119422	16760	22734	39494	294331	369307	7497
18.	Jhunjhunu	6143	47559	16686	23739	40425	425785	496354	6655
19.	Jodhpur	78879	199873	369894	287759	657653	1166173	1194614	2844
20.	Kota	59345	113700	38048	82427	120475	521307	660103	13879
21.	Nagpur	16542	91464	68599	194733	263323	1257573	1298195	4468
22.	Pali	47077	138921	131637	129228	260865	560131	599933	3989
23.	S.Madhopur	30154	92047	30981	105255	136236	418186	499946	8120
24.	Sikar	11852	57187	40121	60415	100536	512554	592967	8041
25.	Sirohi	14727	48317	39798	26018	65816	147581	174334	2675
26.	Tonk	47233	110402	20509	77379	97888	417484	451726	3424
27.	Udaipur	239429	401789	69297	35164	104461	352519	480222	12770
RAJ.STATE		5628369	7452568	2081662	2340452	4422114	15605747	17902980	229728

2.4 Soils

The soils of state Rajasthan can be divided into eight broad groups. With more information available on the morphological characteristics of soils in different climatological and physiographical characteristics of soils in different climatological and physiographic units of the state, 12 basic soil associations have been established. Fig. 2.4 shows the details of soils in the state Rajasthan (Dept. of Agriculture, 1970).

2.5 Surface Water Availability

The details of storage built up, under construction and those under proposal in the state Rajasthan are given in Table 2.4.

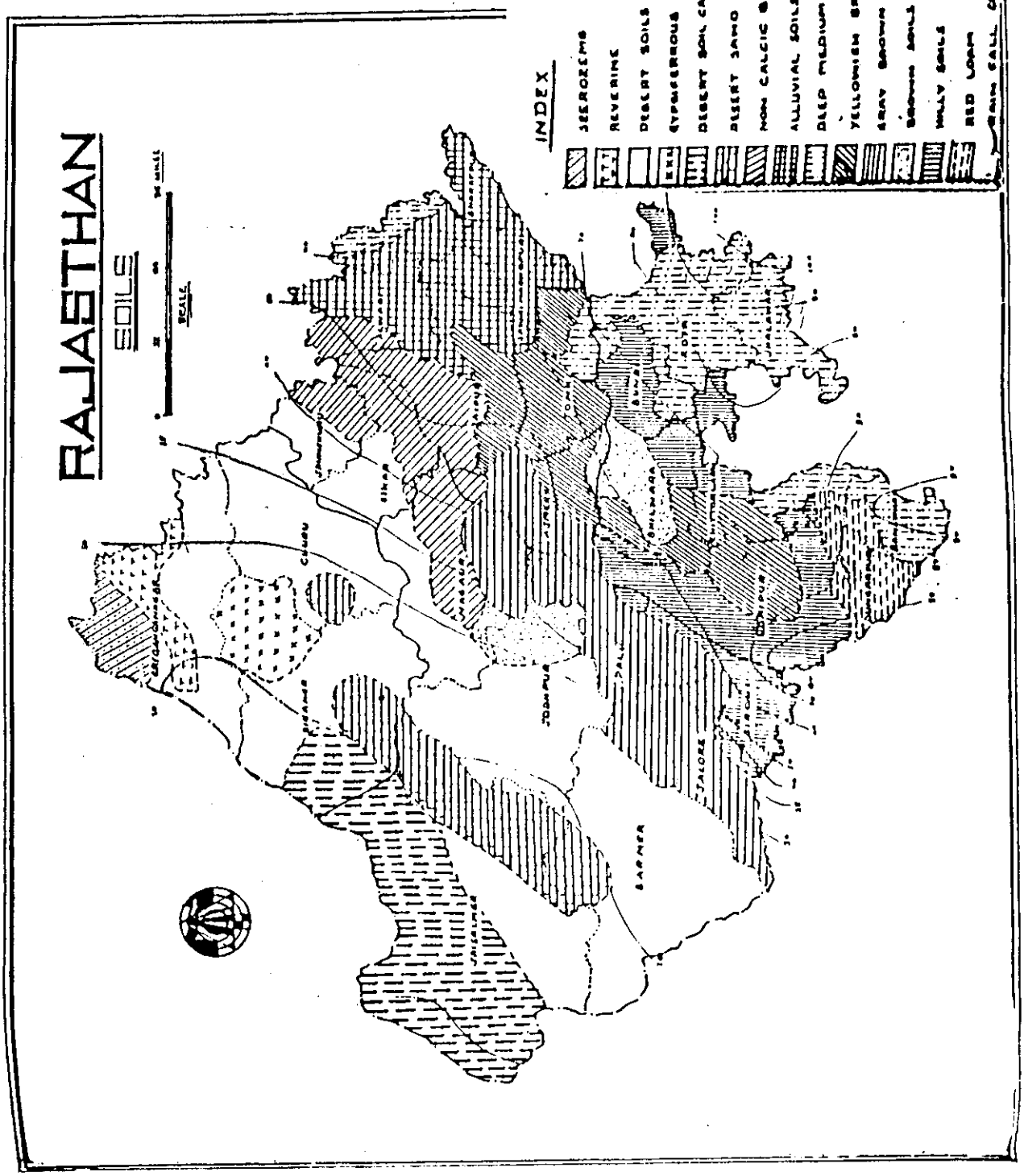


Fig.2.4 Soil Map of State Rajasthan

Table 2.4: Storages in the projects of state Rajasthan.

Sl.No.	Type of Projects	Gross storage in m.ha.m.	Live Storage in m.ha.m.
1.	Projects completed	0.5523	0.3589
2.	Projects under construction	0.2714	0.2313
3.	Total	0.8237	0.5902
4.	Proposed Projects	0.0546	0.0488

Source: C.W.C. Report on Water Resources of India, 1988.

2.6 Ground Water Availability

In the state of Rajasthan depth to water table ranges from 1.99 m (Ballop, District Bundi) to 122.2 m (Rama, District Jaisalmer). In general in the Eastern side of the Aravallis the depth to water is comparatively shallower than that in Western side. The attitude of the water table in the state varies between 721.15 m. above mean sea level(m.s.l.) (Dewair, District Udaipur) and 36.53 m. m.s.l. (Dewa, District Jalore). In the eastern side slope of water table ranges from 0.25 m/km to 3.3 m/km and in the Western side it ranges from 0.4 m/km to 10 m/km. (source: Report of C.G.W.B., Jaipur, 1985). The statement given in Table 2.5 shows the number of wells, Tube-wells, electrified wells, and diesel pump-sets in Rajasthan.

2.7 Water Use

The annual requirement of water in the state of Rajasthan for domestic purposes during 1981 was of the order of 0.0.72 m.ha.m. which has been estimated to increase to a level of 0.1332 m.ha.m. by 1991 (C.W.C., 1988). The water availability and water requirement figures for drought prone districts of the state Rajasthan are given in Table 2.6. The source wise gross and net irrigated area in various divisions of the state Rajasthan in 1989-90 is given in Table 2.7 and Table 2.8 and Figure 2.5 and Figure 2.6 respectively.

2.8 Crops & Fodder

The agricultural production of the state is dependent on rainfall. The principal crops of the state are Jowar, Bajra, Maize, Gram, wheat, oil seeds, cotton, sugar cane and tobacco etc. The details of crop wise area under different crops during the years 1989-90 are given in Figure 2.7. The details of crop wise irrigated area under different crops during the years 1989-90 are given in Figure 2.8.

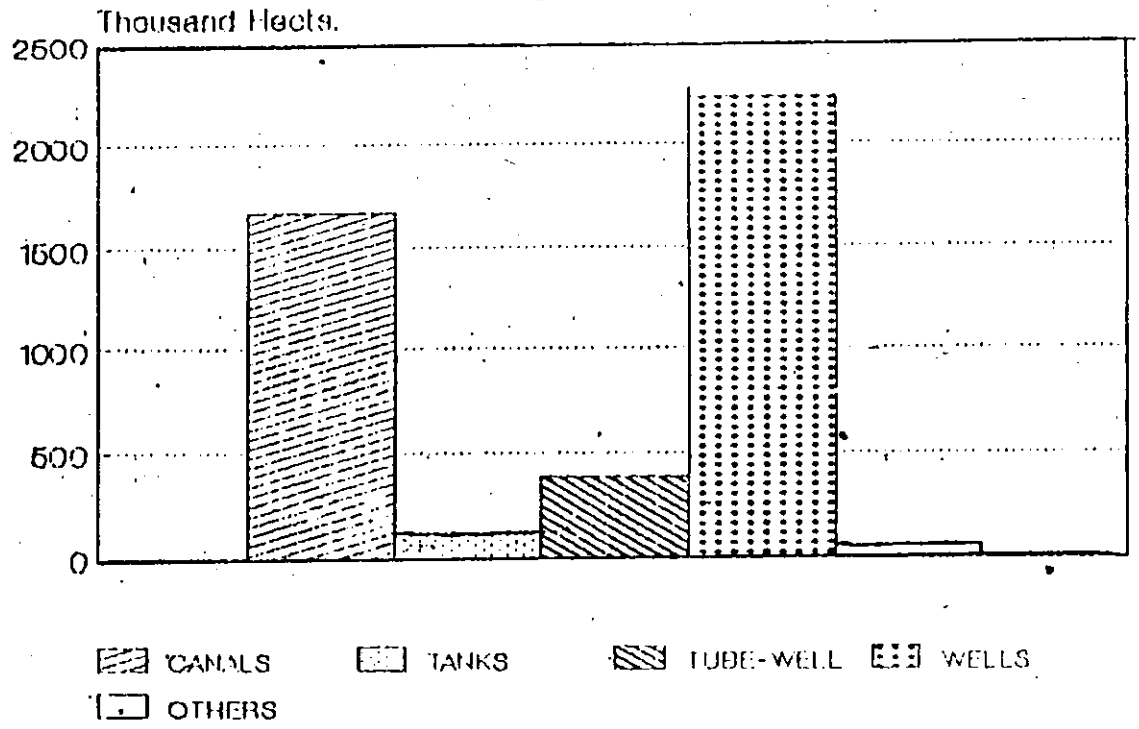


Fig. 2.5: Source wise gross irrigated area in Rajasthan, 1989 - 90.

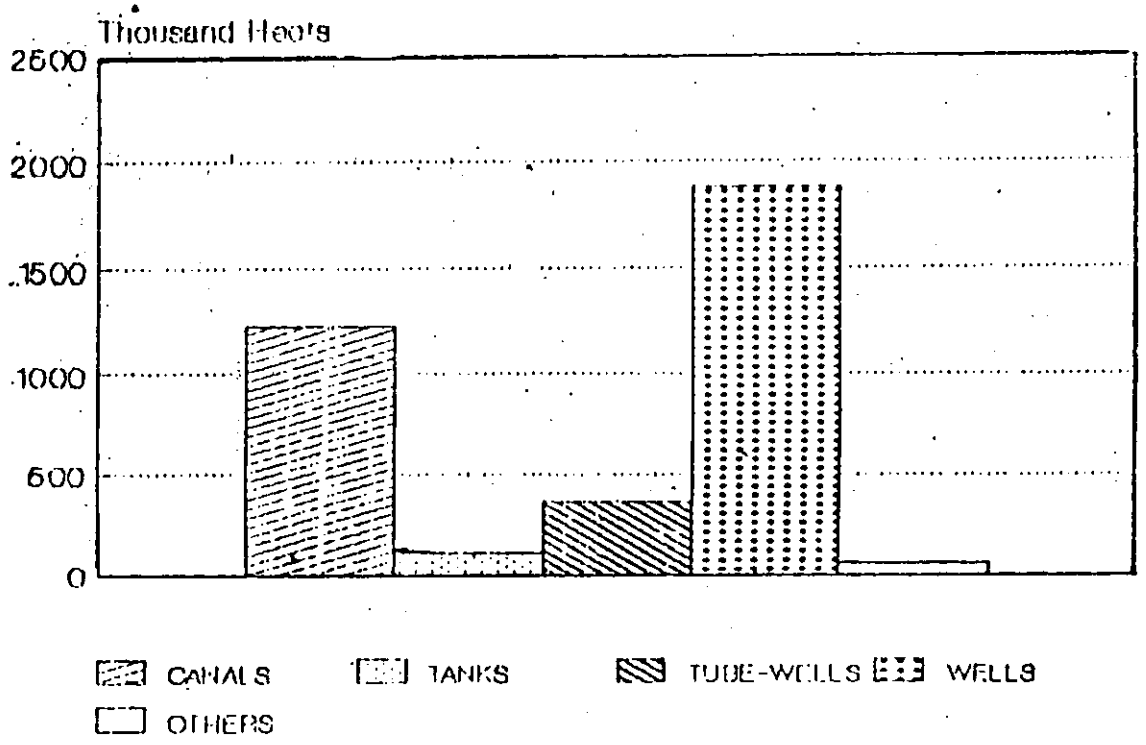


Fig. 2.6: Source wise net irrigated area in Rajasthan, 1989-90.

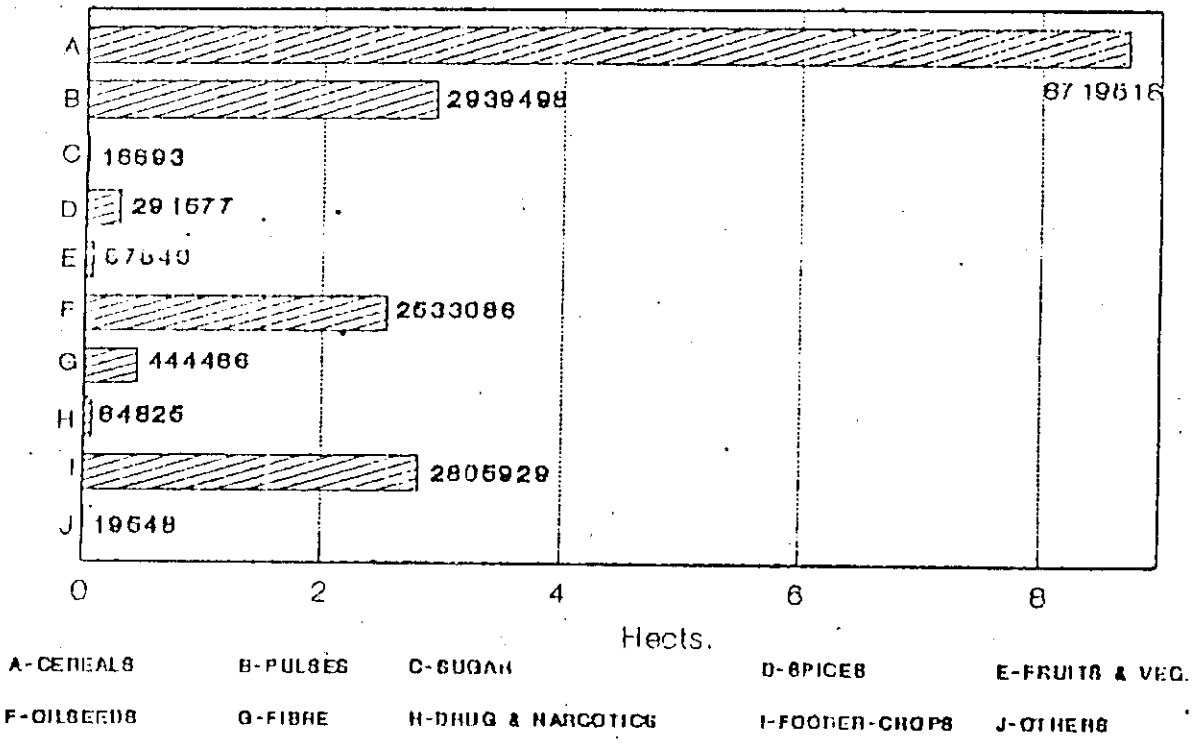


Fig. 2.7: Total area under different crops in 1989 - 90.

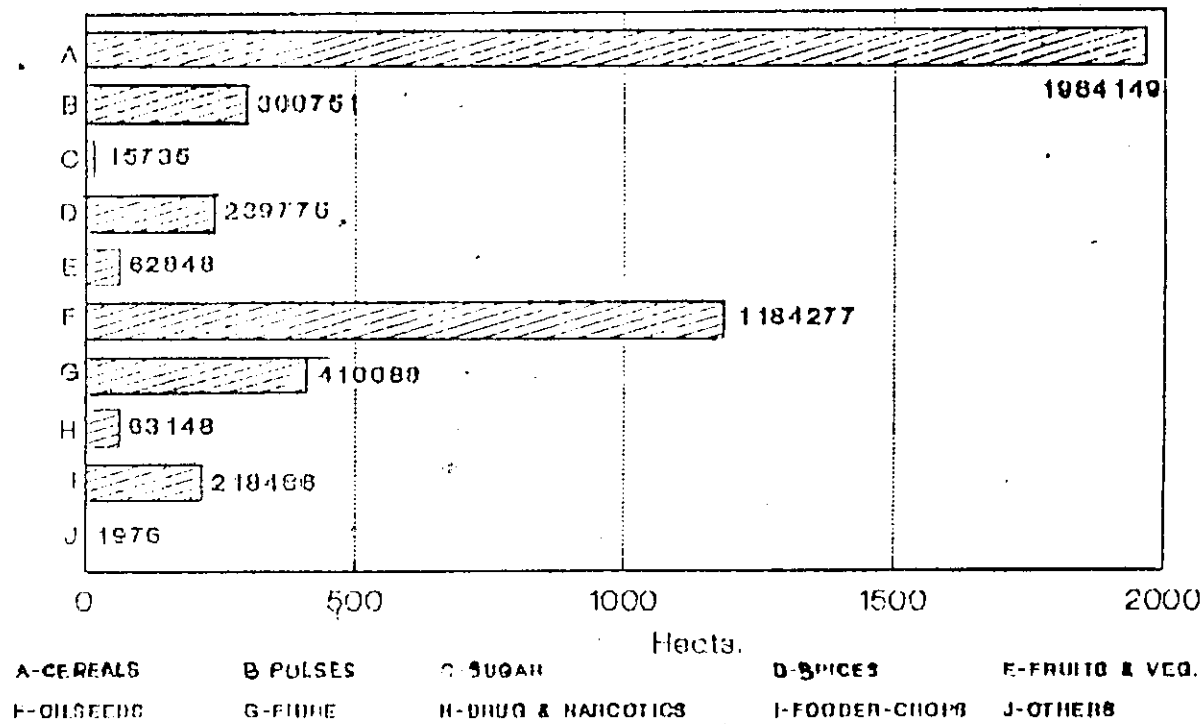


Fig. 2.8: Irrigated area under different crops in 1989 - 90.

Table 2.5 Statement Showing the No. of Wells, Tube-wells, Electrified Wells & Diesel Pump Sets in Rajasthan

Districts	Wells (1984-85) In use	Out of use	Tube-wells	1983 Diesel pump sets	Upto Jan.86 Electrified Wells
AJMER DIVISION					
Ajmer	50875	18648	46	3935	10989
Jaipur	106793	30673	152	28682	53398
Sikar	27938	8081	59	2640	22657
Jhunjhunu	9979	3058	103	2205	15495
Total-	205585	60460	360	37462	102539
BHARATPUR DIVISION					
Alwar	47096	12900	15990	53982	18756
Bharatpur	9472	12005	20763	22972	7905
Dholpur	13411	2494	4762	8434	1273
S.Madhopur	43611	8452	2451	21571	11964
Total-	113590	35851	43966	106909	39898
BIKANER DIVISION					
Bikaner	81	-	54	1	26
Churu	376	66	385	1	498
Ganganagar	-	-	4536	1754	4765
Total-	457	66	4975	1756	5289
JODHPUR DIVISION					
Jodhpur	13243	2179	583	4524	6601
Jaisalmer	73	-	100	3	23
Jalore	27801	6637	181	18213	10591
Barmer	4945	861	98	3256	2568
Nagaur	19282	9232	447	3009	11808
Pali	33728	9869	200	10032	13865
Sirohi	11458	1771	-	4765	6156
Total-	110530	30549	1609	43802	51612
KOTA DIVISION					
Kota	30979	6333	57	6024	6669
Bundi	16743	6245	21	3144	4103
Jhalawar	43924	6691	1	5321	7445
Tonk	35601	8253	-	5956	4605
Total-	127247	27522	79	20445	22822
UDAIPUR DIVISION					
Banswara	7042	11432	75	5842	3204
Dungarpur	10177	8567	76	3601	1985
Udaipur	91252	29563	25	7837	15542
Total-	108471	49562	176	17280	20831
BHILWARA DIVISION					
Bhilwara	84476	25438	6	3284	13207
Chittore	74223	4651	46	11123	23662
Total-	158699	30089	52	14407	36869
STATE-	824579	234099	51219	252061	279860

Table 2.6: Water availability (Cubic km.) and water requirement for drought prone districts of state Rajasthan.

Sl.No.	District	Water Availability		Total
		50% Dependability	75% Dependability	Requirement
1.	Amjer	2.37	1.88	0.65
2.	Banswara	2.15	1.60	0.15
3.	Barmer	0.39	0.39	0.33
4.	Bikaner	2.83	2.83	2.54
5.	Churu	0.20	0.20	0.15
6.	Dungarpur	1.05	0.69	0.19
7.	Jaisalmer	3.78	3.78	3.79
8.	Jalore	0.63	0.63	0.73
9.	Jhunjunun	0.22	0.22	0.21
10.	Jodhpur	0.73	0.47	0.49
11.	Nagour	0.39	0.39	0.43
12.	Pali	0.82	0.79	1.10
13.	Udaipur	2.74	2.18	1.18

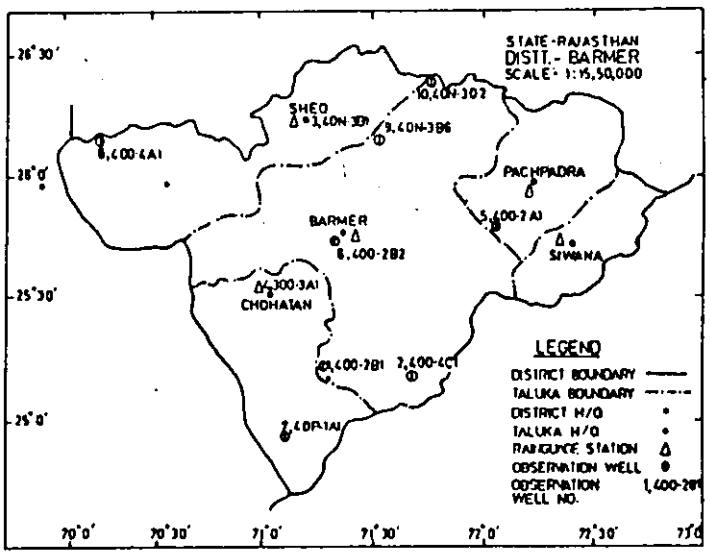
Source: CWC 1988.

2.9 Description of Districts

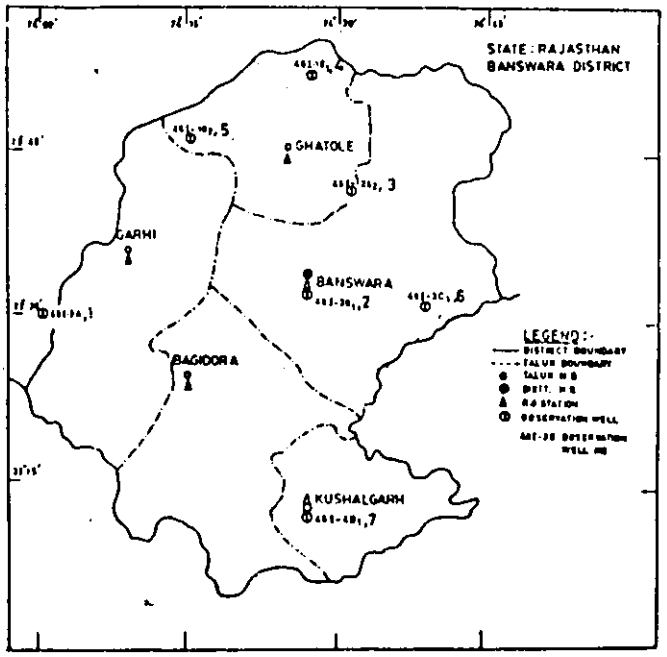
The details about the state in respect of physiography, climate, soils, land use,crops and water resources availability have been presented in the above sections. This section gives brief summary of various such details in respect of the districts chosen for study & the location of raingauges and groundwater observation wells selected in the districts of Ajmer, Jodhpur, Banswara, Barmer, Dungarpur and Udaipur are given in Figures 2.9 to 2.11 respectively.

2.9.1 Barmer

The Barmer district forms part of Rajasthan west region and this district as a drought affected one. The geographical location of the district is between 24°39/ to 26°-32/ north latitude and 70°5/ to 72°52/ east longitude. The district has an area of 28387 sq. km. The district consists of five tehsils, namely Barmer, Sheo, Chohtan, Siwana and Pachpadra and has 837 inhabited, 20 uninhabited villages and two towns as per 1971 census. The population of Barmer district is 1113823 and density of population 39 person per sq. km. as per 1981 census.



(a) DISTT. BARMER



(b) DISTT. BANSWARA

FIG. 2.9 : LOCATION OF RAINGAUGE STATION & GROUNDWATER WELL

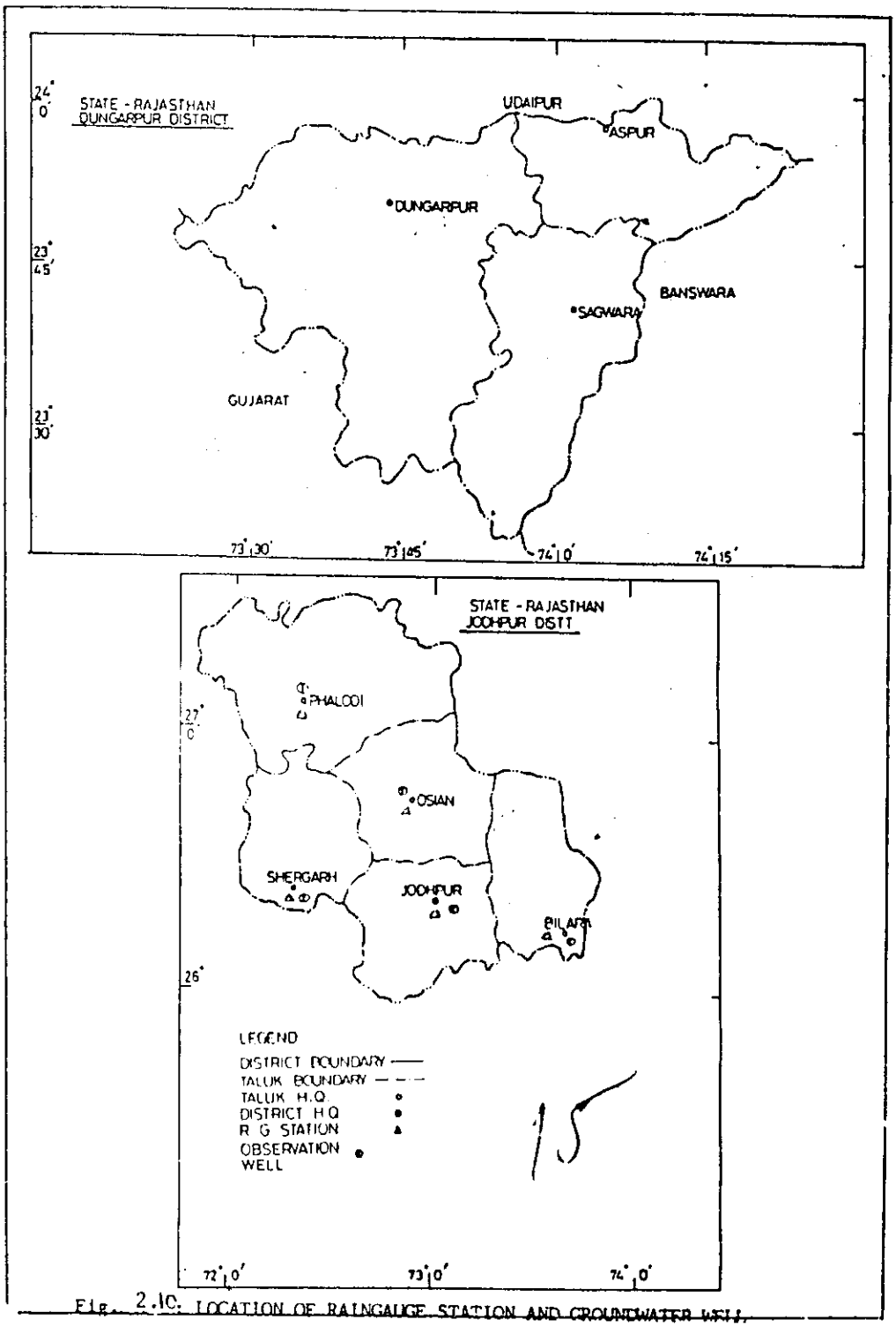
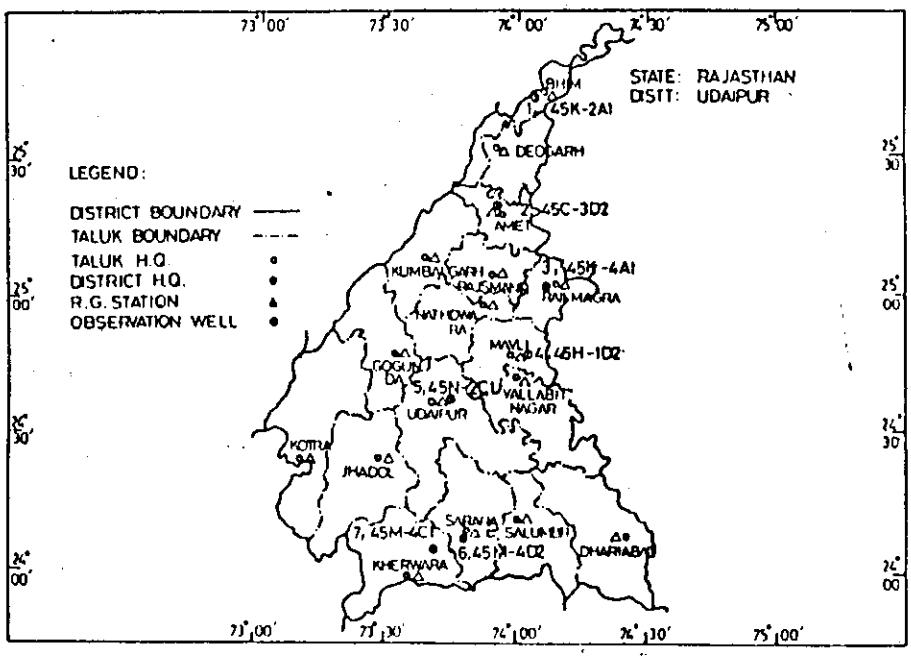


Fig. 2.10: LOCATION OF RAINGAUGE STATION AND GROUNDWATER WELL.



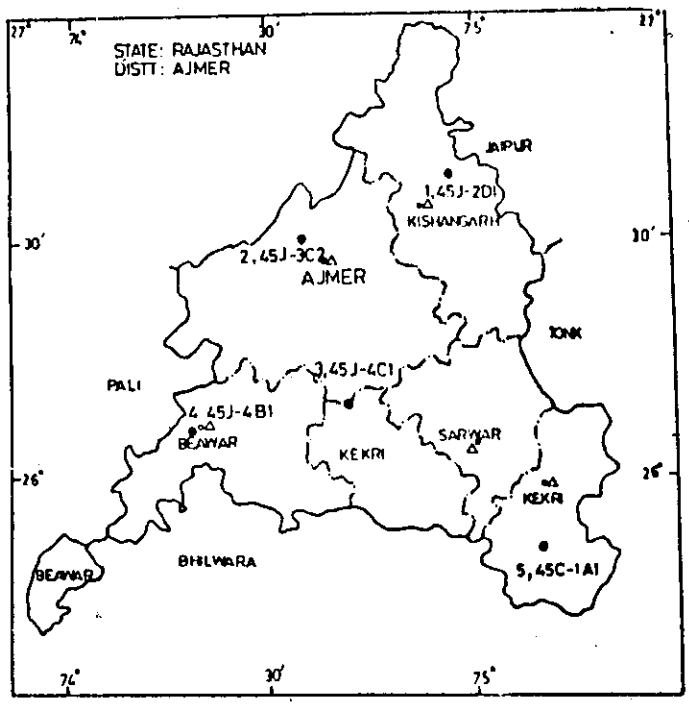


Fig. 2.11 : LOCATION OF RAINGAUGE STATION AND GROUNDWATER WELL

Table 2.7 : Source wise gross irrigated area in Rajasthan, 1989-90, Hectors.

Sl. No.	District Name	Canals							Tank
		Government					Private	Total	
		Rajasthan	Chambal	Gang	Bhankhara	Others			
1.	Ajmer	-	-	-	-	1793	-	1793	6879
2.	Alwar	-	-	-	-	3127	-	3127	285
3.	Banwara	-	-	-	-	50046	-	50046	4491
4.	Barmer	-	-	-	-	0	-	0	64
5.	Bharatpur	-	-	-	-	3401	-	3401	0
6.	Bhilwara	-	-	-	-	7484	-	7484	33329
7.	Bikaner	105965	-	-	-	0	-	105965	0
8.	Bundi	-	110365	-	-	15477	-	125842	5435
9.	Chittorgarh	-	-	-	-	3539	-	3539	16575
10.	Churu	-	-	-	-	0	-	0	0
11	Dholpur	-	-	-	-	8539	-	8539	64
12	Dungarpur	-	-	-	-	467	0	467	6022
13.	Ganganagar	384157	-	322446	389511	0	-	1096114	203
14.	Jaipur			-	-	3614	-	3614	1075
15.	Jaisalmer	751	-	-	-	0	-	751	0
16.	Jalore	-	-	-	-	24	-	24	0
17.	Jhalawar	-	-	-	-	6932	-	6932	446
18.	Jhunjhunu	-	-	-	-	6	-	6	0
19.	Jodhpur	-	-	-	-	0	-	0	0
20.	Kota	-	185241	-	-	21461	-	206702	7684
21.	Nagpur	-	-	-	-	336	-	336	0
22.	Pali	-	-	-	-	0	-	0	3820
23.	S.Madhopur	-	-	-	-	13490	-	13490	1040
24.	Sikar	-	-	-	-	397	-	397	0
25.	Sirohi	-	-	-	-	1338	-	1338	3845
26.	Tonk	-	-	-	-	16460	-	16460	6119
27.	Udaipur	-	-	-	-	14608	-	14608	24005
RAJ.STATE		490873	295606	322446	389511	172539	0	1670975	121381

Table 2.7 (Continued) : Source wise gross net irrigated area in Rajasthan, 1989-90, Hectors.

Sl. No.	District Name	Wells							Other sources	Total
		Tube wells			Pump-Sets			Total		
		By Electric	By Oil Engines	Total	By Electric	By Oil Engines	Total (Rehat Nal etc.)			
1.	Ajmer	126	0	126	17185	10576	33351	61112	164	7007
2.	Alwar	22831	105343	128171	94324	101225	6216	201765	2261	33561
3.	Banwara	34	0	34	1142	4536	1144	6822	4618	6601
4.	Barmer	0	0	0	22251	26006	2681	50944	0	51006
5.	Bharatpur	23553	103461	127014	4205	10892	42	15139	30098	175652
6.	Bhilwara	154	0	154	22466	10794	84800	118060	775	159802
7.	Bikaner	25	0	25	4	0	2	6	143	10613
8.	Bundi	214	19	233	10468	4583	18582	33603	2049	167162
9.	Chittorgarh	1988	0	1988	62140	31446	47671	141527	917	154546
10.	Churu	0	0	0	3382	0	3	3385	0	3385
11.	Dholpur	3600	38920	42570	2684	17869	387	20940	837	72950
12.	Dungarpur	214	0	214	3824	5105	5522	14447	1413	22563
13.	Ganganagar	1758	2816	4574	0	438	0	438	0	1101325
14.	Jaipur	155	1302	1457	256290	132488	43895	432673	28	436847
15.	Jaisalmer	55	0	55	249	0	34	283	3	1092
16.	Jalore	3316	0	3316	74527	99566	484	174577	283	1782
17.	Jhalawar	4	0	4	16937	12905	38982	68824	1756	7796
18.	Jhunjhunu	0	0	0	79725	8686	268	88679	0	8868
19.	Jodhpur	26585	528	27113	34887	19000	5397	59284	9	8640
20.	Kota	2051	1833	3884	29480	27610	10752	67842	8389	29450
21.	Nagpur	15599	209	15808	78346	22071	2784	193201	69	11941
22.	Pali	1529	0	1529	43717	31494	29173	104384	35	10976
23.	S.Madhopur	10981	15153	26134	38364	65735	6390	110489	369	15152
24.	Sikar	159	65	224	127100	15004	719	142823	0	14344
25.	Sirohi	0	0	0	26881	22162	2381	51424	1	5660
26.	Tonk	0	0	0	7747	13375	41964	63086	1021	8668
27.	Udaipur	342	0	42	31080	10048	50726	91854	1056	12186
RAJ.STATE		115273	269699	384972	1089675	703580	434356	2227611	56294	446123

Table 2.8 : Net Area Irrigated by Canals in each district of Rajasthan State for the year ending 1989-90, (Hectare).

Sl. No.	District Name	Canals							Tank
		Government					Private	Total	
		Rajasthan	Chambal	Gang	Bhankhara	Others			
1.	Ajmer	0	0	0	0	1732	0	1732	6230
2.	Alwar	0	0	0	0	2977	0	2799	260
3.	Banwara	0	0	0	0	47198	0	47198	4193
4.	Barmer	0	0	0	0	0	0	0	61
5.	Bharatpur	0	0	0	0	3344	0	3344	0
6.	Bhilwara	0	0	0	0	7165	0	7165	30664
7.	Bikaner	71087	0	0	0	0	0	71087	0
8.	Bundi	0	81480	0	0	13464	0	94944	4823
9.	Chittorgarh	0	0	0	0	3184	0	3184	16255
10.	Churu	0	0	0	0	0	0	0	0
11.	Dholpur	0	0	0	0	8527	0	8527	64
12.	Dungarpur	0	0	0	0	353	0	353	5013
13.	Ganganagar	250894	0	249396	281141	0	0	781431	203
14.	Jaipur	0	0	0	0	3606	0	3606	1075
15.	Jaisalmer	534	0	0	0	0	0	543	0
16.	Jalore	0	0	0	0	24	0	24	0
17.	Jhalawar	0	0	0	0	6310	0	6310	440
18.	Jhunjhunu	0	0	0	0	6	0	6	0
19.	Jodhpur	0	0	0	0	0	0	0	0
20.	Kota	0	135817	0	0	16471	0	152288	6169
21.	Nagpur	0	0	0	0	251	0	251	0
22.	Pali	0	0	0	0	0	0	0	3669
23.	S.Madhopur	0	0	0	0	13330	0	13330	1013
24.	Sikar	0	0	0	0	396	0	396	0
25.	Sirohi	0	0	0	0	1324	0	1324	3544
26.	Tonk	0	0	0	0	16353	0	16353	5901
27.	Udaipur	0	0	0	0	13304	0	13304	19262
RAJ.STATE		322515	217297	249396	281141	159319	0	1228668	108819

Table 2.8 (Continued): Net Area Irrigated by wells in each district of Rajasthan State for the year ending 1989-90, (Hectors).

Sl. No.	District Name	Wells						Other	Total
		Tube wells			Dug-Sets		Total		
		By Electric	By Oil Engines	Total	By Electric	By Oil Engines	Total (Rehat Mal etc.)		
1.	Ajmer	126	0	126	[illegible]	5626	33161	19572	159	57819
2.	Alwar	21709	99993	121702	[illegible]	92704	3965	[illegible]	2261	310774
3.	Banwara	32	0	32	927	4458	[illegible]	6568	4417	62408
4.	Barmer	0	0	0	19693	8564	1777	21034	0	21095
5.	Bharatpur	23232	101425	124657	4006	10615	42	14661	29719	172381
6.	Bhilwara	149	0	149	16549	6925	67392	91996	712	130656
7.	Bikaner	22	0	22	4	0	2	6	143	71258
8.	Bundi	203	19	222	7794	3302	16700	27796	1833	129684
9.	Chittorgarh	1825	0	1825	53178	[illegible]	[illegible]	128972	820	151056
10.	Churu	0	0	0	1737	6	3	740	0	1740
11.	Dholpur	3543	38197	41740	[illegible]	[illegible]	351	20585	789	71705
12.	Dungarpur	202	0	202	3710	[illegible]	[illegible]	12851	1307	19726
13.	Ganganagar	1080	1506	2586	0	[illegible]	0	139	0	784649
14.	Jaipur	155	1292	1447	[illegible]	[illegible]	40143	[illegible]	25	366073
15.	Jaisalmer	52	0	52	223	0	[illegible]	252	2	840
16.	Jalore	3309	0	3309	66792	90789	[illegible]	157862	234	161449
17.	Jhalawar	4	0	4	16244	[illegible]	[illegible]	65078	1590	74022
18.	Jhunjhunu	0	0	0	[illegible]	[illegible]	[illegible]	74896	0	74672
19.	Jodhpur	19889	503	20392	27330	[illegible]	[illegible]	44014	9	64415
20.	Kota	1700	1709	3469	23410	[illegible]	[illegible]	56991	7521	226418
21.	Nagpur	11695	209	11904	56253	[illegible]	[illegible]	78264	69	90528
22.	Pali	1399	0	1399	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92938
23.	S.Madhopur	10350	14712	25062	[illegible]	[illegible]	6184	[illegible]	367	144814
24.	Sikar	157	59	216	[illegible]	[illegible]	[illegible]	111998	0	114610
25.	Sirohi	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	1	45923
26.	Tonk	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	352	79692
27.	Udaipur	305	0	305	[illegible]	[illegible]	[illegible]	73080	856	113418
RAJ.STATE		101138	253684	354822	[illegible]	[illegible]	[illegible]	1891838	53823	3634970

The soils in the district are generally of five types viz. desert soils, red desert soils, sand dunes, saline soils of depressions and lithosols and regosols of hills. The land use in the district as classified from 1970-71 to 1979-80 forests is 13526.4 ha., land put to non-agricultural uses 55030 ha., barren and uncultivable land 145999.4 ha. and with the 2391144.3 ha. cultivable area. The total irrigated area in the district is 18087.3 ha. and the source wise distribution of 17934.5 ha. by ground water and 128.10 ha. by surface water and 4.7 ha. by other sources.

Luni is one main river flowing through the Barmer district. The catchment area of river basin in the district is 4328.0 sq. km.

As per CWC studies of 1982 the normal rainfall of the district is 266.7 mm. Normally there are 13.17 days in a year according to analysis of data from 1901 to 1980. There

are 10 raingauge stations located in the district and the density of raingauge station is 2952.1 sq. km. per raingauge station as per study of year 1982. The maximum annual rainfall in the district was experienced as 795.5 mm in year 1944. The south west monsoon gives about 91.7% of annual rainfall in the district. The coefficient of variation for annual rainfall has been reported as 55.14% for the district.

The ground water potential of the district as per S.G.W.B. data of one year is that the annual recharge of ground water is 385.037 M.CM., while the draft is 67.995 m.cm. and the surplus is 317.075 M.CM. in a one year.

As per CWC (1982) observation the district faced 67 years hydrological drought during the period 1901-1980.

2.9.2 Banswara

Banswara district is the second smallest district of Rajasthan state. The district has been identified as drought prone district. Banswara district, having an area of 5037 sq. km. is located between 23°-11/ to 23°-56/ latitudes and 74°-00/ to 74°-47/ longitudes. The district consists of five tehsils namely, Banswara, Ghatole, Garhi, Bagidora and Kushalgarh. The district has 1439 inhabited and 23 uninhabited villages. The population of the district as per 1981 census is 885701 of which the rural population constituted 93.7%. The density of population is 176 persons per sq. km. in the district.

The district has got four different verities of soils namely; Bhuri, Kali or black cotton soils, Lal soil & barangi soils. As per data from 1972-73 to 1976-77 the land use in the district include forests 92321 ha., barren and uncultivable land 94144 ha., land put to non agricultural uses 7511 ha.

It has been reported that the total irrigated area of the district is 15506 ha. as per 1969-77. The source wise distribution of irrigated area is 4522 ha. by surface water and 5003 ha. by ground water.

Through Banswara district the main river which flow is Mahi. The catchment area of Mahi river is 1632.5 sq. km. in the district.

According to CWC study of 1982 the normal annual rainfall of the district is 906 mm. The district gets 95.2% of the annual rainfall from the southwest monsoon as per analysis of data from 1901 to 1981.

As per C.G.W.B. data for the ground water potential is that annual recharge to ground water is 258.28 M.C.M., draft 36.56 M.C.M and surplus 221.72 M.C.M in one year.

2.9.3 Ajmer

The Ajmer district is located on the east region of Rajasthan state. This is one of the drought affected districts of the state. The district is situated between 25°-30/ to 26°-58/ North latitude and 73°-54/ to 75°-22/ East longitude. The geographical area of the district is 8479 sq. km. as per 1981 census. The district is divided in [illegible]

talukas namely, Ajmer, Kishangarh, Beawar, Sarwar and Kekri.

According to 1971 census there are 954 inhabited and 19 uninhabited villages and eight towns in Ajmer district. The total population of the district is 1431609 as per 1981 observation and average density of population per sq. km. in 1981 was 169 persons.

As per the information available, the soils in the district may be classified as sandy loam, loam, black cotton soil and rich alluvial soils. The land use details of the district as per data available from 1970-71 to 1979-80 include the forests 34601 ha., land put to nonagricultural uses 38243 ha., barren and uncultivable land 107696 ha. and cultivable area is 375134 ha. As per data from 1960-61 to 1979-80 the total irrigated area was 105547 ha. in the district. The source wise distribution includes 80287 ha. by groundwater and 25115 ha. by surface water and 145 ha. by other sources.

The Luni, Banas and Menda are the main rivers that flow through the district. The catchment area of the rivers in the district of the order of, Luni 1796 sq. km., Banas 5534 sq. km., and Menda 1149 sq. km.

As per CWC study of 1982 the district receives rainfall mainly from south west monsoon. The normal annual rainfall in the district is 469.3 mm. There are normally 24.6 rainy days in one year according to analysis from 1901 to 1980. About 91.7% of normal rainfall is received during the south west monsoon. The Twenty no. of raingauge stations are located in the district and the density of raingauge stations is one station per 422.5 sq. km. A maximum rainfall of 1209.5 mm was received in 1917 in the district and the coefficient of annual rainfall is 37.4% during the period 1901 to 1980.

As per Central Ground Water Board organization data the ground water potential in one year is that recharge to ground water is of the order of 1734.35 m.cm. while the draft is 256.21 M. CM. and surplus 1478.14 M.CM. The Ajmer district faced 14 years of hydrological drought during the period 1957-1980.

2.9.4 Udaipur

The district Udaipur is one of the drought prone district of Rajasthan state. The district having an area of 17279 sq. km., is located between 23°-46/ to 26°-02/ North latitudes and 73°-0/ to 74°-35/ East longitudes. It has got 17 tehsils namely, Bhim, Geogarh, Amet, Kumbhalgarh, Rajsamand, Railmagra, Nathdwara, Mavli, Gogunda, Vallabhnagar, Girwa, Kotra, Jodal, Sarada, Dhariyawas, Salumbar and Kherwara. The district has 3116 inhabited villages, 39 uninhabited villages and eight towns as per 1981 census.

The population of the district according to the 1981 census is 2351639 and density of population of the district is 136 persons per sq. km. as per 1981 analysis.

It has been reported that generally four types soils are found in the district namely, Sandy loam, clay loam, red clay, heavy clay. As per data from 1971-72 to 1980-81 the land use in district include forests 340358 ha., barren and uncultivable land 492397 ha. and land put to nonagricultural uses 234561 ha. and 674769 ha. with culturable area.

The total irrigated area of the district is 132149 ha. and the source wise distribution of irrigated area are 23928 ha. by surface water, 106516 ha. by ground water and 1705 ha. by other sources. The three main rivers Banas, Mahi and Luni flow through the district.

As per CWC analysis of 1982, the normal annual rainfall of the district is 620.24 mm. there are normally 30.39 rainy days in a year. Forty one number of raingauge stations are located in the district and the density of raingauge stations are 421.14 sq. km. per raingauge station as per data from 1901 to 1980. The south west monsoon gives about 92.5% of the annual rainfall and the coefficient of variation for annual rainfall is 39.53%.

As per C.G.W.B., the ground water potential data estimate, recharge to ground water is 1385.83 M. CM. and the draft 403.40 M. CM. and the surplus is 982.43 M.CM. As per CWC (1982) study the district faced 11 years of hydrological drought during the period 1957-80 except 3 years.

2.9.5 Jodhpur

The district Jodhpur is one of the drought prone district of Rajasthan state. The district having an area of 22,850 sq. km. is located between 26°0/ to 27°37/ north latitudes and 71°55/ to 75°52/ east longitude. It consists of five tehsils namely Jodhpur, Bilara, Shergarh, Phalodi and Osian. The district has 702 inhabited villages, 5 uninhabited villages and four towns as per 1971 census.

The population of the district according to the 1981 census is 16,50,933 and density of the population of the district is 73 persons per sq. km. as per 1981 census.

It has been reported that generally two types of soils are found in the district namely Desertic soils and Red desertic soils. As per data from 1970-71 to 1979-80, the land use in district include forests 1581 ha, barren and uncultivable land 106086 ha. and land put to nonagricultural uses 93767 ha and 19.08,098 ha with culturable area.

The total irrigated area of the district is 35,296 ha and the resource wise distribution of irrigated are 1705 ha by surface water, 32713 ha by ground water and 878 ha by other sources. Luni is the main river flowing through the district as per CWC analysis of 1982, the normal annual rainfall of the district is 319.5 mm. There are normally 18.0 rainy days in a year. Thirteen number of raingauge stations are located in the district and the density of raingauge stations are 1741.06 sq. km. per raingauge stations as per data from 1901 to 1980. The south west monsoon gives about 90.2% of the annual rainfall and the coefficient of variation for annual rainfall is 42.7%.

As per S.G.W.B. data the ground water potential data estimate recharge to ground water 465.42 and the draft 63.34 and the surplus 402.08. As per CWC (1982) study the district faced 45 years of hydrological drought during the period 1901-1980.

2.9.6 Dungarpur

The Dungarpur district is located on the East region of Rajasthan state. This is one of the drought affected districts of the state. The district is situated between 23°-20/ to 24°01/ North latitude and 73°-22/ to 74°-23/ east longitude. The geographical area of the district is 3770 sq. km. as per 1981 census. The district has three talukas namely, Dungarpur, Aspur and Sagwara. According to 1971 census there are 825 inhabited and 9 uninhabited villages and two towns in the district. The total population of the district is 680865 as per 1981 observation and density of population per sq. km. in 1981 was 181 persons.

As per the information available, the soils in the district may be classified as Red loam and rich alluvial soils. The land use details of the district as per 1970-71 to 1979-80 include forests 67235 ha., barren and uncultivable land 75980 ha. land put to non agricultural uses 14821 ha. and with the 119060 ha. culturable area.

As per analysis 1960-61 to 1979-80 average of 20 years the total irrigated area was 13583 ha. in the district. The source wise distribution include 4734 ha. by surface water and 8354 ha. by ground water and 495 by others sources. The Som and Mahi are the main rivers that flow through the district. The catchment area of the rivers in the district is of the order of Som 1076 sq. km. and Mahi 2199 sq. km.

As per CWC study of 1982 the district receives rainfall mainly from south west monsoon. The normal rainfall of the district is 713.7 mm. there are namely 33.8 rainy days in one year according to analysis from 1901-80. The district gets 94.3% of the normal rainfall from southwest monsoon. There are 13 raingauges stations located in the district with the density of one raingauge station per 314.2 sq. km. A maximum annual rainfall of 1226.2 mm was received in 1944 in the district and the coefficient of variation of annual rainfall is 33% for the period 1901 to 1980.

As per Central Ground Water Board Organization data the ground water potential in one year is that recharge to ground water is of the order of 297.37 M.CM. while the draft is 30.43 M. CM. and the surplus is 266.94 M. CM. The Dungarpur district faced 28 years of hydrological drought during the period 1901 to 1980.

3.0 RAINFALL ANALYSIS

3.1 General

As has already been described in chapter 2.0 six districts, namely Barmer, Banswara, Ajmer, Udaipur, Jodhpur and Dungapur from state of Rajasthan have been taken up for rainfall analysis in the present report. One representative raingauge station from each taluk in each of the six districts has been selected for the study. The locations of raingauges on the district maps have been shown in figures presented in chapter 2.0. The raingauge stations selected for the study are the ones which were selected by central water commission for carrying out studies for identification of drought prone areas in 1982. The analysis of rainfall data has been carried out with the data from year 1901-1989. The data from 1901 to 1989 have been extracted from CWC reports (CWC, 1982). The remaining data from 1981 to 1989 have been collected during visits of scientific teams to various central/state Govt. offices in the state Rajasthan.

3.2 Rainfall Departure Analysis

3.2.1 Seasonal Rainfall Departure

In order to compute the deficiency of rainfall on seasonal basis, seasonal rainfall departure analysis has been carried out. The data from period 1970-89 have been used for this analysis. Seasonal normals for the chosen six districts of Rajasthan have been calculated as the summation of normals for the months (June to September) as provided in CWC reports. Only four months i.e. June, July, August and September are taken into account while estimating seasonal normals as the Southwest monsoon is active for these four months in the state. The result of analysis are reported in Table 3.1. The graphical representation of seasonal deficiencies are shown in Figure 3.1. The major inference that are drawn from the seasonal analysis are; All the districts experienced continuous deficiency in seasonal rainfall in the range of 20 to 60% seasonal normal rainfall since 1985 except Banswara and Dungarpur. However in the year 1988-89 all the six selected district except Barmer and Udaipur experienced negative departures in range of 10% to 70%.

3.2.2 Monthly Rainfall Departure for the year 1988-89

In order to observe deficiency in monthly rainfall during the year 1988-89, monthly departures have been worked out for the same six districts. This analysis has been done for all the taluks and districts as a whole. Monthly rainfall values from June 88 to May 1989 along with monthly normals of representative raingauges of various taluks have been considered for the purpose. Monthly rainfall values for a district from June 1988 to May 1989 have been computed as weighted average rainfall of all the taluks considered for analysis in the district. It may be mentioned that in case of some districts/taluks monthly departure analysis has been limited to some months only due to data availability constraints.

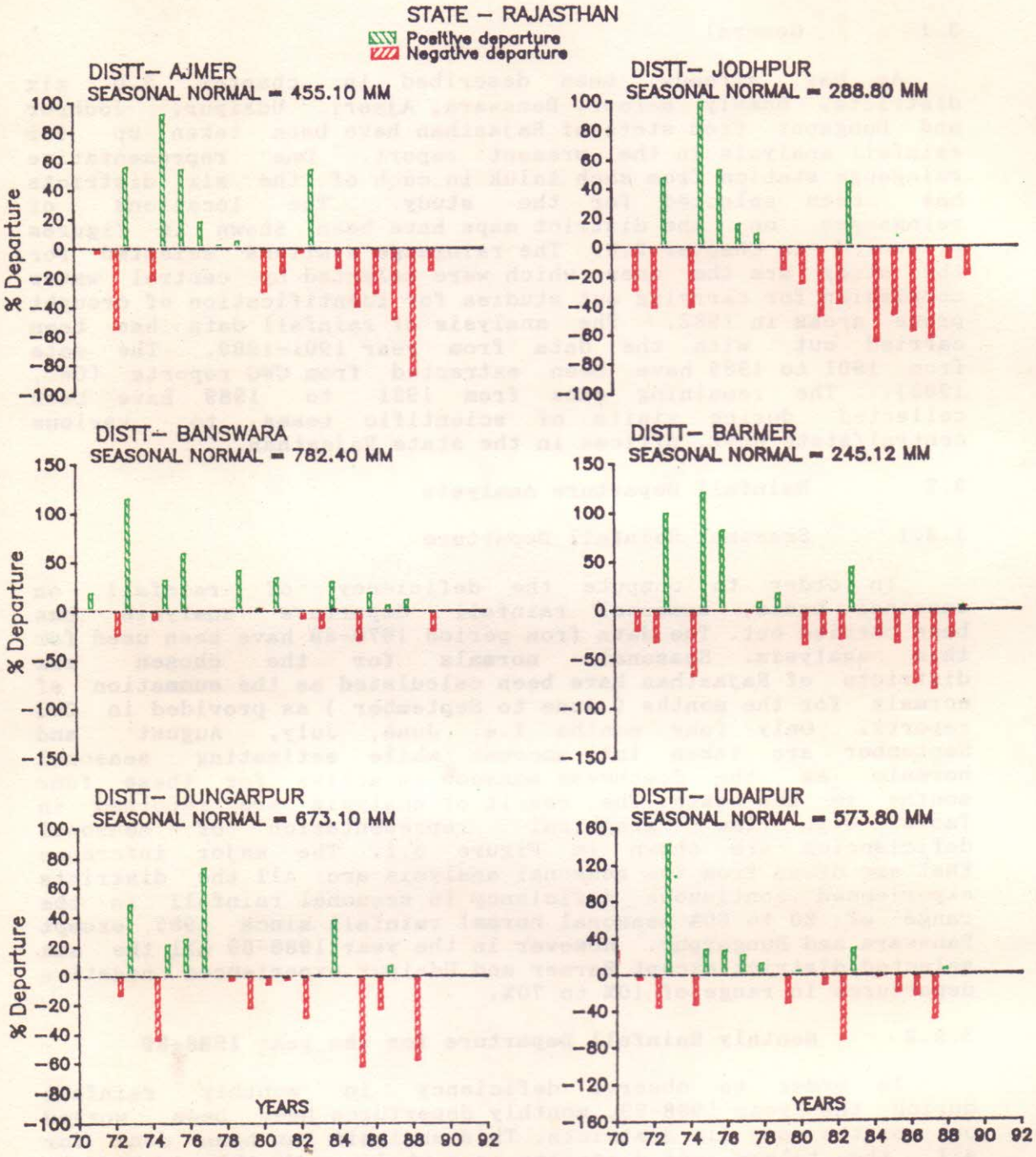


Fig.3.1:Districtwise seasonal rainfall departure.

Table 3.1 : Percent departure of seasonal rainfall for districts of Ajmer, Jodhpur, Banswara, Barmer, Dungarpur and Udaipur of State Rajasthan

Rajasthan	Districts of Rajastha, Percent departure					
	Ajmer	Jodhpur	Banswara	Barmer	Dungarpur	Udaipur
Seasonal Normal, mm	455.10	288.80	782.40	245.12	673.10	573.80
70	26.34	49.04	22.75	0.49	7.71	32.51
71	-2.91	-28.77	17.92	-20.43	1.57	-5.17
72	-54.68	-40.56	-24.39	-31.85	-13.43	-35.22
73	55.79	46.93	114.86	98.79	48.00	142.03
74	-21.28	-40.11	-8.41	-66.01	-44.08	-32.77
75	91.75	98.96	31.50	120.30	20.91	27.46
76	54.17	52.47	58.69	81.46	24.88	26.33
77	17.85	15.00	N.A.	-2.05	72.96	21.38
78	1.56	8.32	N.A.	7.91	-3.27	11.85
79	4.43	-14.87	40.83	17.16	-22.14	-31.14
80	-29.11	-24.16	1.87	-33.74	-6.00	3.37
81	-16.23	-46.40	33.37	-23.54	-3.07	-10.89
82	-2.68	-34.76	-7.28	-28.65	-28.93	-71.90
83	53.86	43.63	-17.07	43.66	0.34	28.63
84	-13.45	-64.57	29.50	-24.85	37.41	-2.29
85	-39.67	-45.37	-29.63	-32.68	-62.15	-19.60
86	-30.20	-57.19	18.27	-74.05	-22.93	-23.63
87	-47.88	-62.41	5.40	-80.70	6.67	-49.03
88	-86.66	-7.72	11.30	-27.27	-57.89	5.53
89	-14.72	-18.85	-20.11	3.45	0.41	0.27

The variations in rainfall month-wise (monthly rainfall and corresponding normals) have been plotted for all the six districts for water year June 1988 to May 1989 and are shown in Figure 3.2. The departure figures for two representative taluk of each of the six districts have shown in Figures 3.3. The results of monthly departure analysis for the districts as a whole are presented in Table 3.2.

Table 3.2 : Percent deficiency of rainfall in six districts of Rajasthan

Year/Month	Districts of Rajastha, Percent departure					
	Ajmer	Jodhpur	Banswara	Barmer	Dungarpur	Udaipur
1988 June	20.28	4.13	-38.74	-84.35	-100.00	22.96
1988 July	-100.00	36.32	- 12.72	-0.03	- 3.64	- 2.40
1988 Aug.	-100.00	- 37.71	109.19	- 8.04	-100.00	6.45
1988 Sept.	-100.00	- 47.47	- 32.12	-100.00	- 67.97	7.88
1988 Oct.	-100.00	- 99.69	- 4.05	-100.00	-100.00	- 99.34
1988 Nov.	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
1988 Dec.	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
1989 Jan.	313.20	- 19.95	-100.00	97.70	-100.00	43.32
1989 Feb.	-100.00	-100.00	-100.00	-100.00	-100.00	- 96.61
1989 March	-100.00	- 77.41	-100.00	- 92.03	-100.00	-100.00
1989 April	- 77.18	-100.00	-100.00	-100.00	-100.00	- 67.50
1989 May	-100.00	-100.00	-100.00	- 95.10	-100.00	-100.00

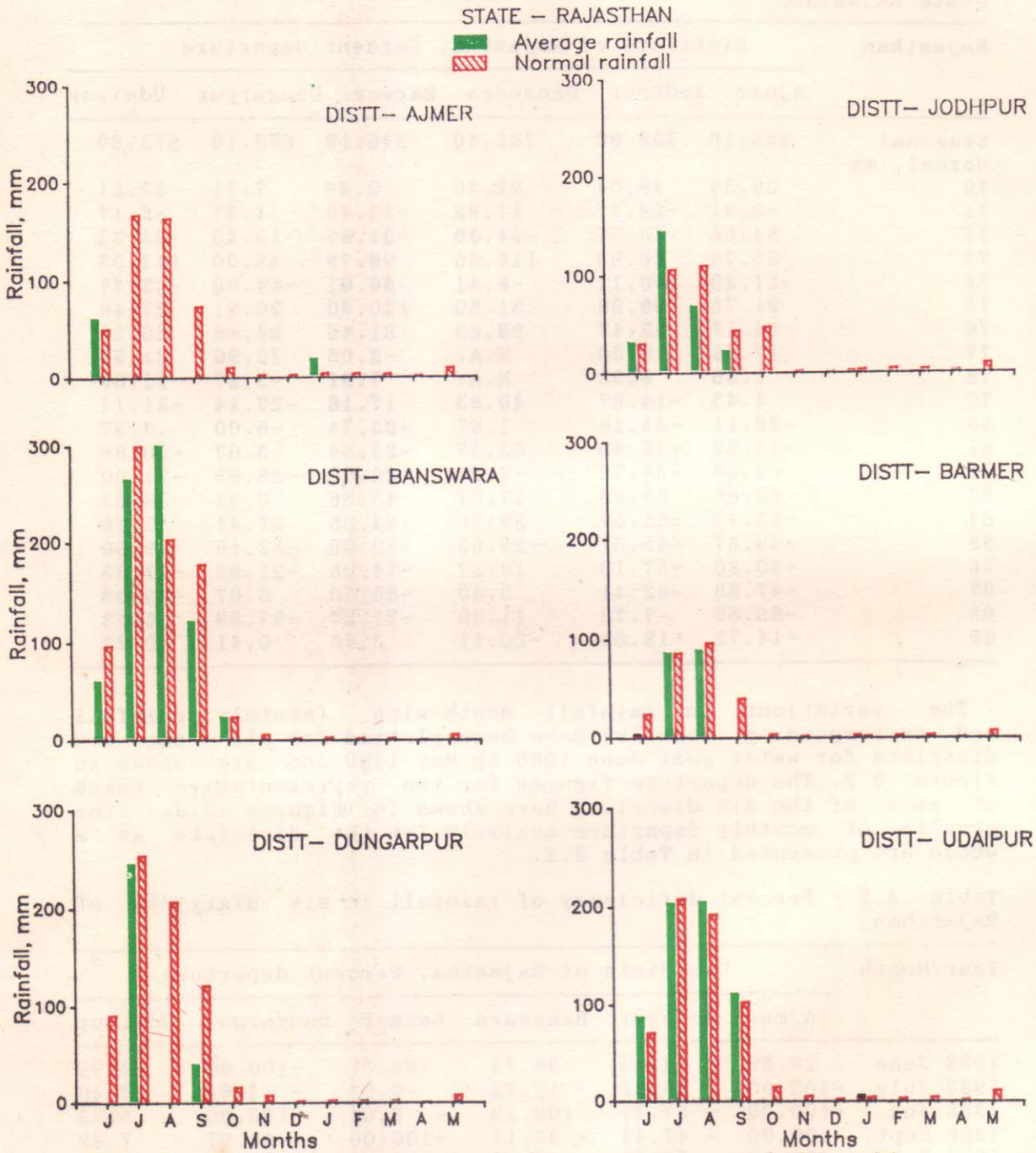


Fig3.2:Districtwise monthly rainfall departure for year 1988 – 89.

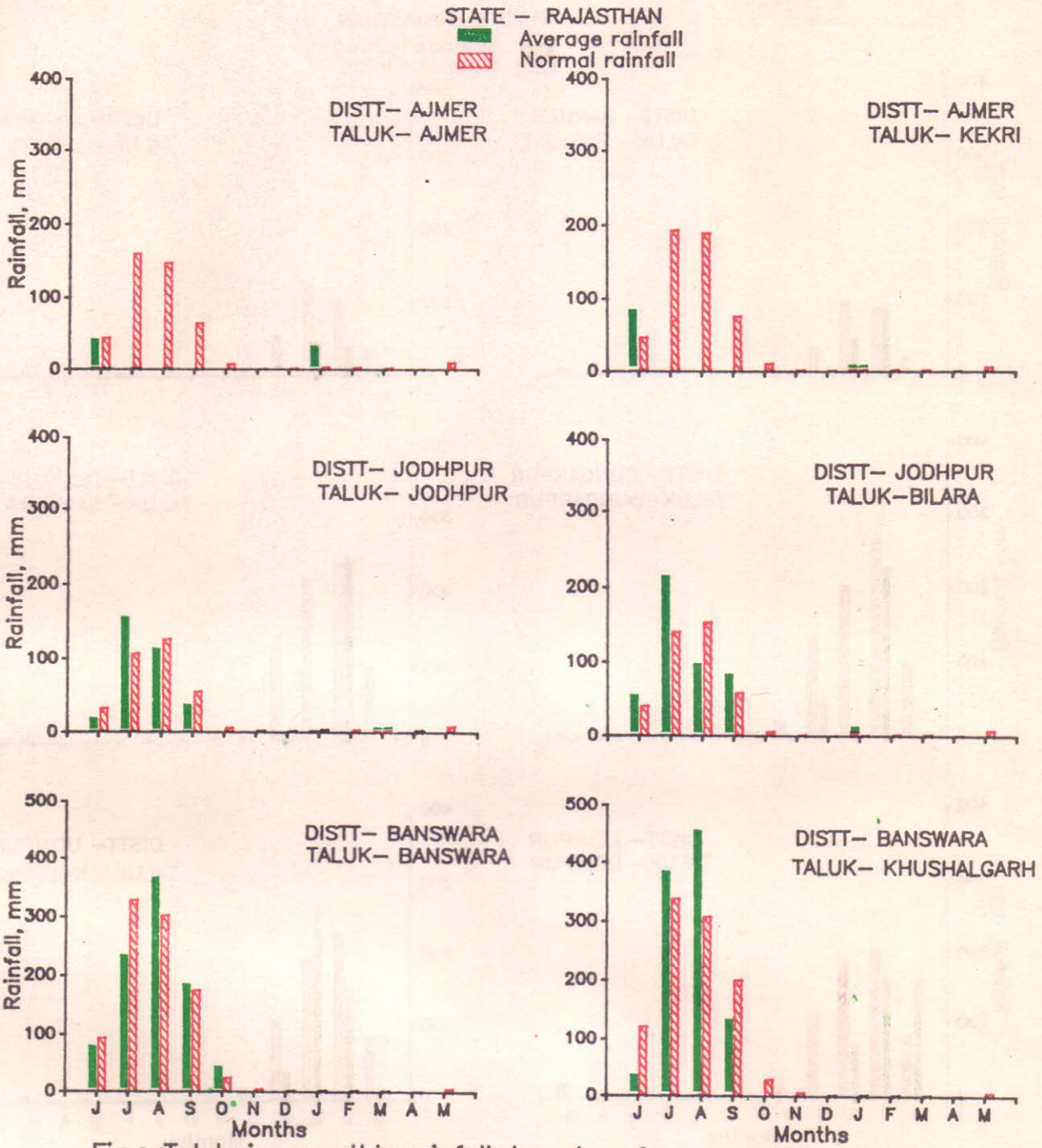


Fig.3.3 Talukwise monthly rainfall departure for year 1988– 89.

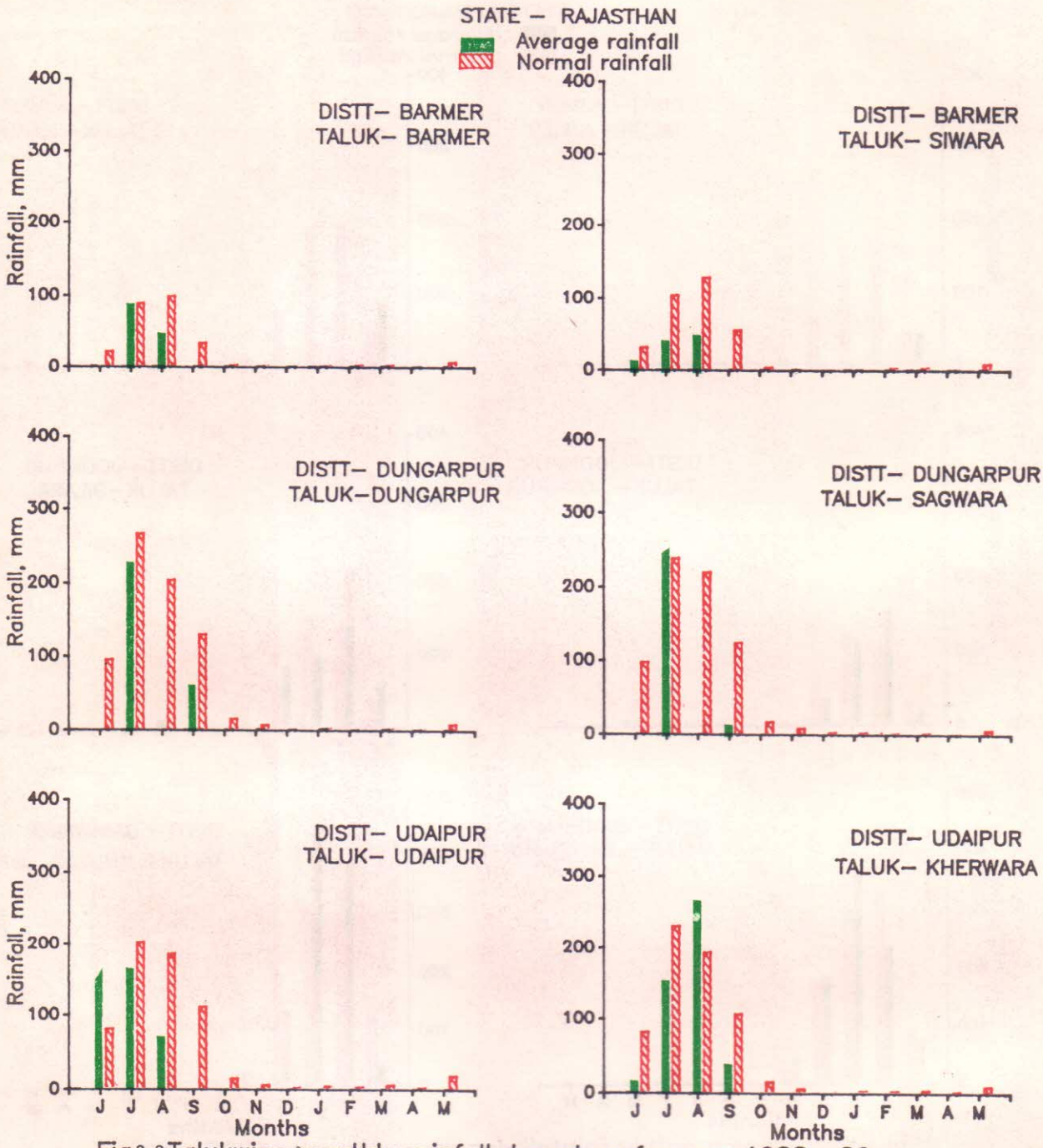


Fig3.3:Talukwise monthly rainfall departure for year 1988– 89.

Based on the Monthly departure values, two categories of monthly departures i.e. 20-50% & more than 50% have been made for driving monthly deficiency inferences. Table 3.3 gives description of districts in the state which experienced rainfall deficit during months of June 1988 to May 1989 in these two ranges viz 20 to 50% and more than 50%. The following inferences can be drawn from the results shown/presented in Figures 3.2 and 3.3, and Table 3.2.

In the state all the six selected districts i.e. in the monthly rainfall deficiency range 50% and above during Nov.88 to May 89, in continuation except Jan.89. However all the six districts had rainfall during monsoon months. This indicates that during monsoon months most of the districts experienced normal rainfall resulting in normal conditions. Similar type of results are also obtained from seasonal rainfall departure analysis.

3.3 Frequency of Rainfall

3.3.1 Probability Analysis of Annual Rainfall

The probability analysis of annual rainfall is useful to predict with reasonable accuracy the relative frequency of occurrence in different group intervals of annual rainfall. It is also possible to work out the percentage probability of occurrence of 75% of annual rainfall or more for identification of drought proneness of district/taluks/ tehsil.

Two taluks from each district and district as a whole have been selected for probability analysis of annual rainfall. The analysis has been carried out based on the data available from 1901 to 1988 and probability expressed both in number of years of occurrence and the percentage of years for each group interval. Group interval of 100 mm has been considered for the analysis.

The probability distribution curves has been drawn by plotting the values of percentage of cumulative probability in respect of various groups at their corresponding midpoint. The cumulative percentage have been worked out starting from the maximum rainfall group downwards adding the successive percentage.

Probability graphs for all the six districts and also for two selected taluks in each districts of the state have been shown in Figures 3.4 and 3.5 respectively. The range of annual rainfall at 75% probability level can be established using these graphs and such values for all the six selected districts and two taluks in each district are given in Table 3.3. In order to find drought proneness of the districts, the percentage probability of occurrence of 75% of normal rainfall of the district has been worked out and the results are given in Table 3.4. It can be seen from the table that all the districts have less than 80 percent of probability of getting 75% of normal. This indicates that the districts are not drought prone as per this analysis.

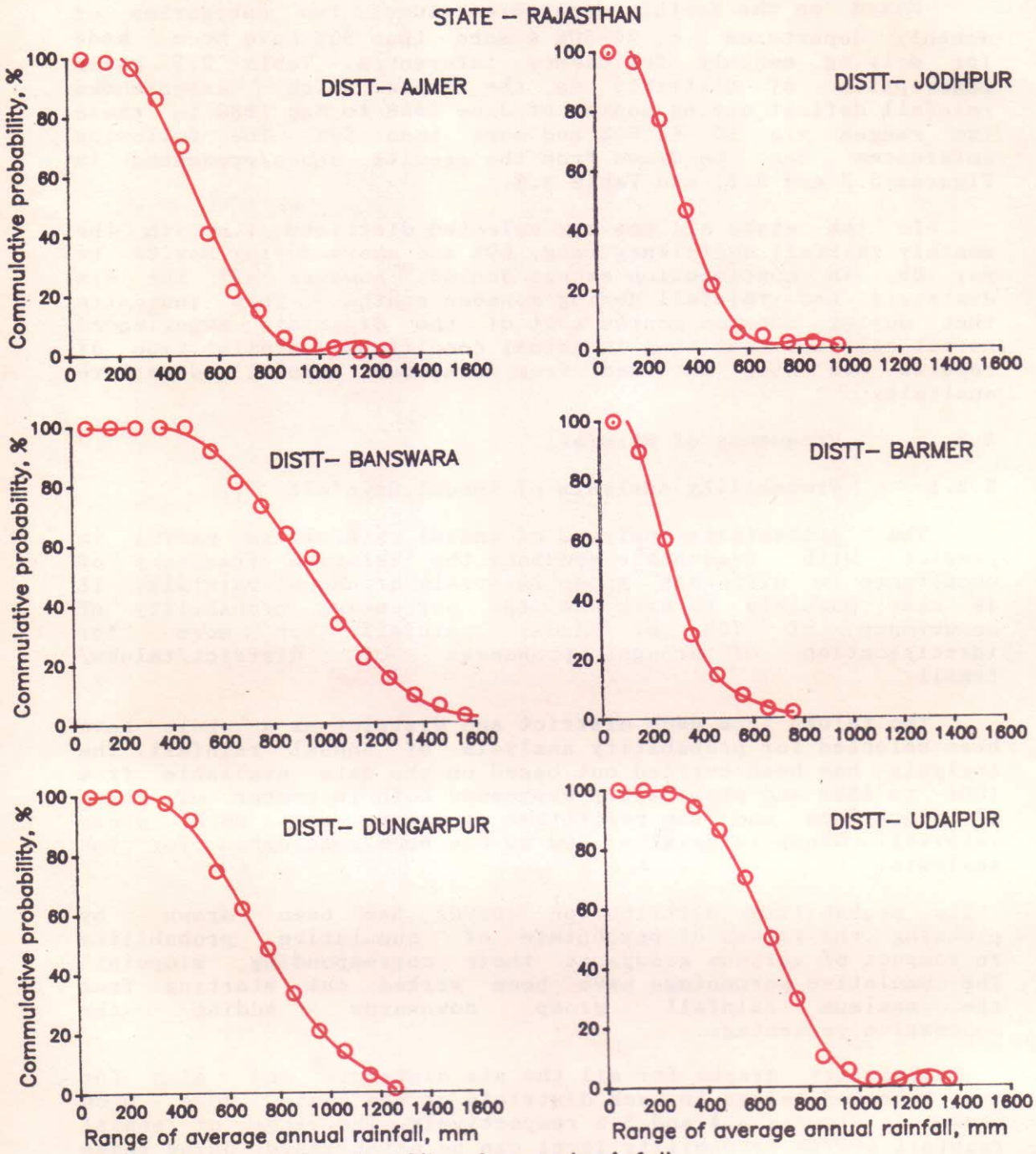


Fig3.4: Districtwise probability of annual rainfall.

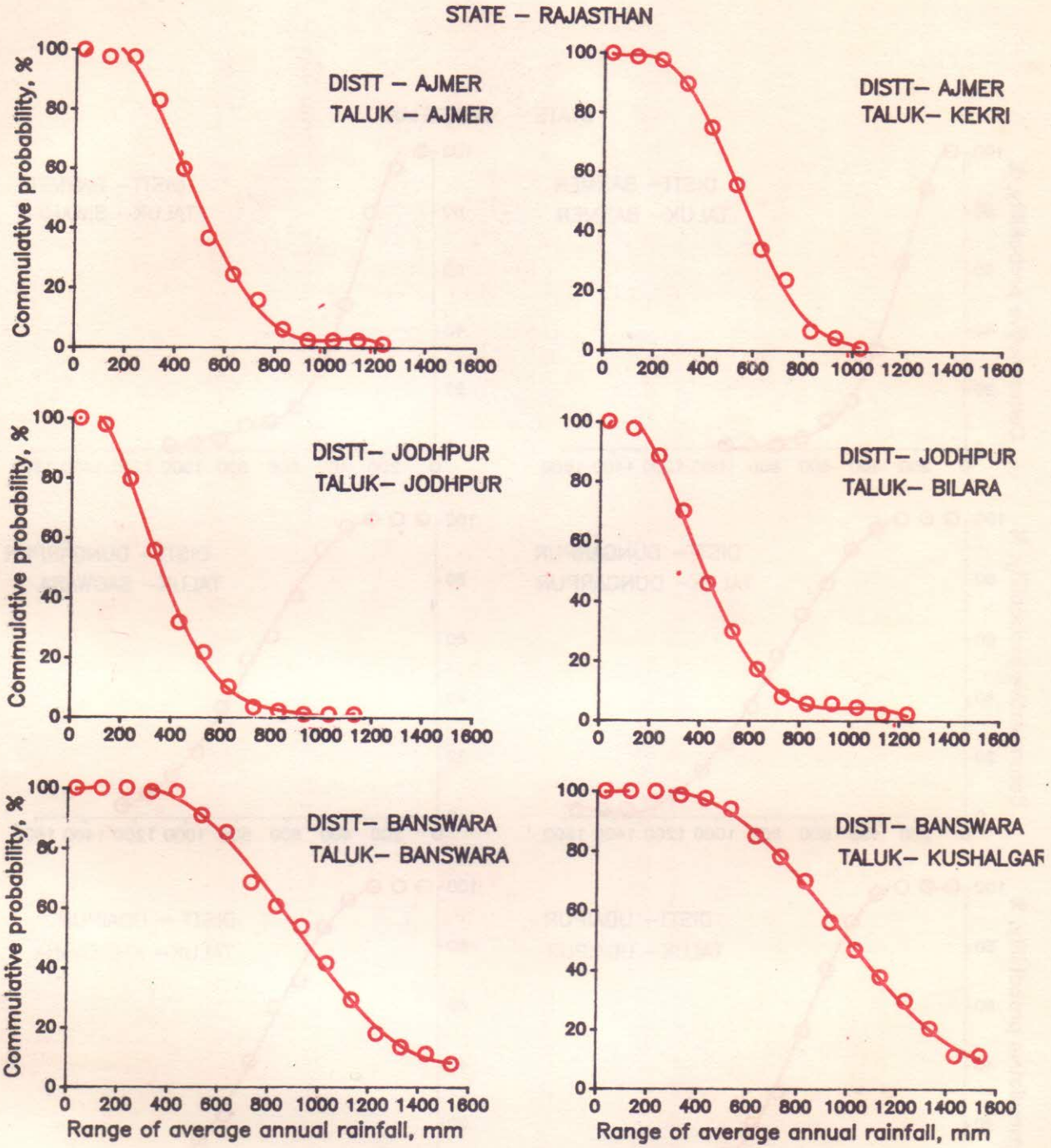


Fig.3.5: Talukwise probability of annual rainfall.

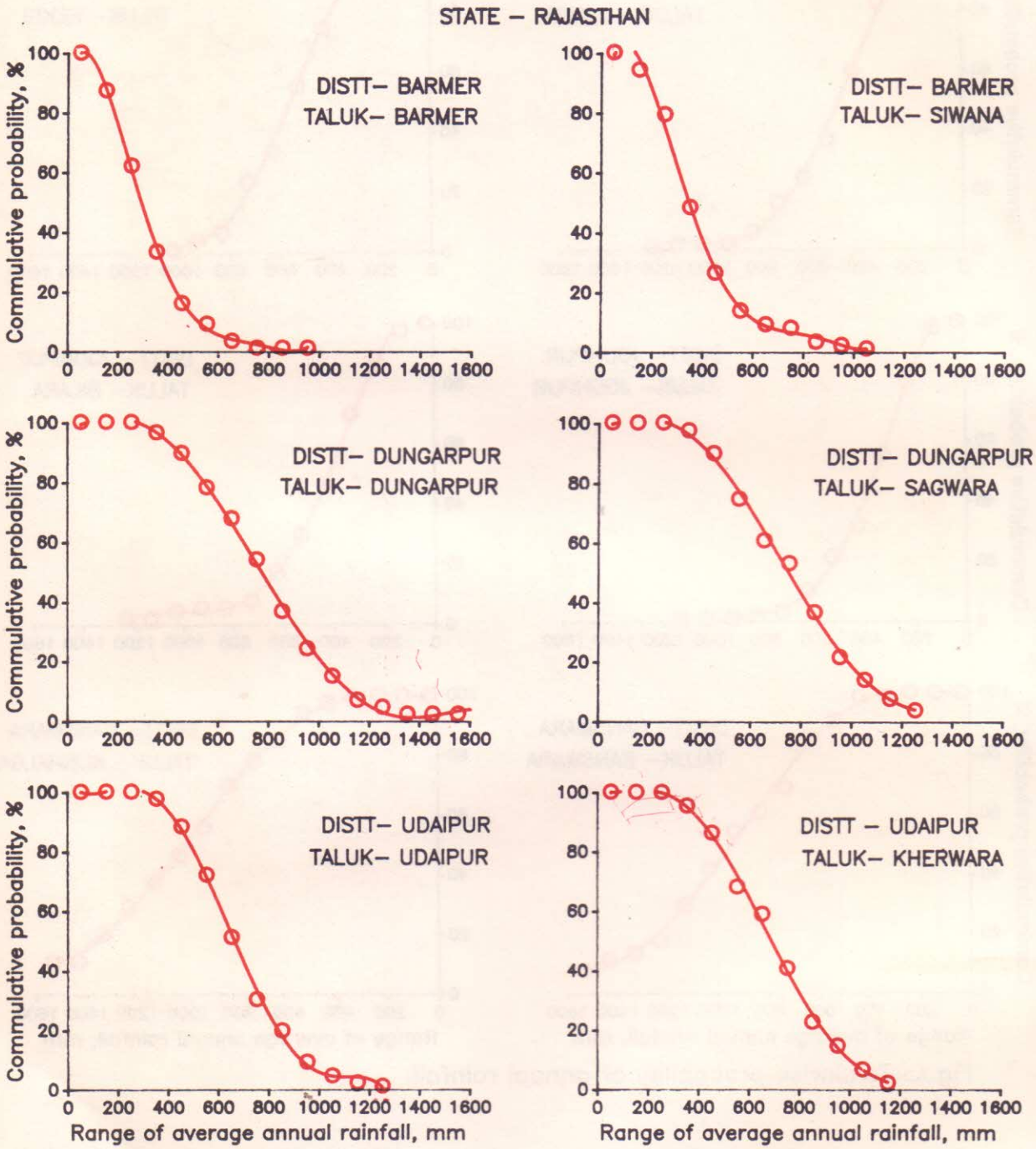


Fig.3.5: Talukwise probability of annual rainfall.

Table 3.3 : Monthly rainfall deficits as a whole in districts of Rajasthan during 1988-89.

Months	Group of range of deficiency in rainfall (expressed in percentage of normals)	
	20 - 50 %	50 % and above
June, 88	Banswara	Barmer, Dungarpur,
July, 88		Ajmer
August, 88	Jodhpur	Dungarpur, Ajmer
September, 88	Banswara, Jodhpur	Barmer, Dungarpur, Ajmer
October, 88	Nil	Barmer, Jodhpur, Dungarpur, Ajmer, Udaipur
November to December, 88	Nil	Barmer, Jodhpur, Dungarpur, Banswara, Ajmer, Udaipur
January, 89	Nil	Dungarpur, Banswara
February, to May, 89	Nil	Jodhpur, Dungarpur, Banswara, Ajmer, Udaipur, Barmer

Table 3.4 : Observations of probability distribution analysis for State Rajasthan.

Sl. No.	District	Name of Taluk	At 75% probability & above in mm)	75% of normal rain fall, mm	Probability of occurrence of rainfall equivalent to 75,%
1.	Ajmer	Ajmer	300-400		83
		Kekri	400-500		90
		District as a whole	400-500	333.8	82
2.	Jodhpur	Jodhpur	200-300		80
		Bilara	300-400		90
		District as a whole	200-300	216.6	81
3.	Banswara	Banswara	800-900		87
		Khushalgarh	700-800		88
		District as a whole	700-800	586.8	90
4.	Barmer	Barmer	100-200		82
		Siwana	200-300		97
		District as a whole	200-300	183.8	95
5.	Dungarpur	Dungarpur	500-600		83
		Sagwara	500-600		81
		District as a whole	500-600	504.8	81
6.	Udaipur	Udaipur	500-600		85
		Kherwara	500-600		82
		District as a whole	500-600	430.3	81

3.3.2 Probability of Occurrence of Rainfall Equivalent to 75% of Normal Rainfall

For identification of drought proneness of the district/taluk the percentage probability of occurrence of rainfall equivalent to the 75% of normal rainfall or more has also been worked out for the figures 3.4 and 3.5. As per I.M.D. criteria, an area would be classified as drought prone if probability of getting rainfall, equivalent to 75% of normal, is below 80% indicating that more than 20% of years, the area experienced scarcity of rain. Central Water Commission has carried out analysis and identified drought prone areas on this ground (CWC,1982). Using this criteria, inferences drawn from values in Table 3.4 are as below:

The probability values of occurrence of 75% normal rainfall in all districts are above 80% indicating that the districts are not drought prone based on this analysis as per I.M.D. criteria.

3.4 Excess/Deficit Rainfall Using Herbst's Approach

3.4.1 Model Description

Herbst's et al (1966) evolved a new method of drought analysis using monthly rainfall data, whereby it was possible to determine the duration and intensity of droughts and their months of onset and termination. The model uses the following steps to calculate indices to evaluate onset and termination of droughts.

A. Calculation of mean monthly rainfall,MMR

From the long record of monthly rainfall, the mean rainfall for all the months (i.e. mean monthly rainfall, MMR) is calculated:

$$MMR(J) = \sum_{I=1}^{NYR} \frac{RF(I,J)}{NYR} \qquad \text{--- (1)}$$

Where; MMR = Mean monthly rainfall; RF = Rainfall; NYR = Number of years of record and Suffix I and J denote years and months respectively.

B. Calculation of mean annual precipitation (MAP)

Mean annual precipitation (MAP) is calculated for entire period of record.

$$MAP = \sum_{J=1}^{NMN} MMR(J) \qquad \text{--- (2)}$$

Where; NMN = Number of months in a year

C. Calculation of Effective Rainfall

For calculation of drought criteria, the carry over effects from month to month is considered. For this purpose, the mean monthly rainfall for a month, say (J) is subtracted from the

actual rainfall for that month (J) so that deficit or excess for that month is obtained. This deficit or excess is multiplied by a 'weighting factor' for the next month (J+1) and the product whether negative or positive, is added algebraically to the rainfall figure of that month (J+1). This sum becomes the 'Effective rainfall' (ER) for that month (J+1).

The 'weighting factor' for a month used to calculate carryover effects is derived from an empirical formula as suggested by Herbst et al (1966).

$$W(J) = 0.1 * \left[1 + \frac{MMR(J)}{MAP/12}\right] \quad ...(3)$$

Where; W(J) = weighting factor for j^{th} month. The carry over for j^{th} month and corresponding effective rainfall is calculated as under:

$$CO(I,J) = ER(I,J-1) - MMR(J-1) \quad ...(4)$$

$$ER(I,J) = RF(I,J) + CO(I,J) * W(J) \quad ...(5)$$

Where; CO = Carry over factor. For the first month of first year of record, the effective rainfall has been assumed as equal to monthly rainfall. Thus for I = 1 and J = 1,

$$ER(1,1) = RF(1,1) \quad ...(6)$$

There upon the effective rainfall for each month of every year was calculated by allowing for the carry over effect of a surplus or deficit of rainfall in the preceding month. The process is continued to obtain the effective monthly rainfall for the full period of record.

D. Calculation of mean annual deficit

The difference of effective rainfall for a month and 'Mean Monthly Rainfall' for that month is obtained for full period of record and termed as 'Difference'.

$$DIFF(I,J) = ER(I,J) - MMR(J) \quad ...(7)$$

These 'differences' for various months of the record, if greater than or equal to zero, were reported as zero. Thus the 'Mean Monthly Deficits (MMD)' were based not only on those months in which a negative difference occurred, for positive differences (i.e., negative deficits) were taken as zero and thus also included in the computation.

$$MD(I,J) = 0.0 \text{ ; for } DIFF(I,J) > 0.0 \quad ...(8)$$

$$MD(I,J) = DIFF(I,J) \text{ ; for } DIFF(I,J) < 0.0 \quad ...(9)$$

In this way 'Mean Monthly Deficit' for each month of every year was calculated:

$$MMD(J) = \left[\sum_{J=1}^{NYR} MD(I,J)\right] * 1/NYR \quad ...(10)$$

The summation of Mean Monthly Deficits yields, Mean annual deficit (MAD) or,

$$MAD = \sum_{J}^{NYR} MMD(J) \qquad \ldots(11)$$

Where; MD = Monthly deficits or monthly differences; MMD = Mean monthly deficit; MAD = Mean annual deficit.

Mean annual deficit is used in testing for onset and termination of drought. The analysis includes establishment of another set of termination drought. This includes maximum parameters used for test of start and termination drought. This includes maximum of Mean Monthly Rainfall (MMR), the sum of two highest values of mean monthly rainfall, the sum of three highest values of mean monthly rainfall and so on up to the sum of mean monthly rainfall of all the months yielding a value equal to mean annual rainfall.

E Test to Determine onset of drought

From the given record, a month with a negative difference is found, while inspecting delete negative difference, the following two cases may arise.

Case (A) Delete negative difference < MMMR
Case (B) Delete negative difference > MMMR

Case (A) Delete negative difference < MMMR

If delete negative difference is less than MMMR, the difference of the next month is inspected and if negative is added to the negative difference of the previous month and compared with the second values on the sliding scale, (MMMR + x). If sum of these two delete negative difference exceed (MMMR + x), the drought is deemed to have started from the previous month. In this manner the absolute value of sum of all negative differences occurring from the first month over period of a year is tested sequentially against the twelv values of the sliding scale. If at any time the summed value of delete negative difference from the first to the J ,month exceeds the value MMMR+(J-1)x, drought is deemed to have started from the first month.

Case (B) Delete negative difference > MMR

In this case when the delete negative difference is greater than or equal to MMMR, the drought is deemed to have stated from this month.

F Tests to determine the termination of drought

Once the start of the drought is found, the program begins to search for a month with a positive difference. A precondition to be satisfied is that at least one of the two months following the initial month with a positive difference should also have a positive difference. Once this condition is met. then only the initial month is qualified for further testing for termination of drought. Thus for further testing for termination of drought a precondition to be

satisfied is that two consecutive months should have positive difference.

Once this condition is met, the following two tests are carried out for testing for termination of drought:

i) In this test the differences are algebraically summed up from the month, the drought started to the month of the termination test. If the sum became positive, the drought is deemed to have terminated otherwise second test is carried out for testing of termination.

ii) The second tests comprises of ten sequential tests. Firstly the actual rainfall values from the first to the third month of testing are summed up and compared with the sum of three highest values of mean monthly rainfall. If the sum of actual rainfall is higher the drought is considered to have been terminated. If the sum of actual rainfall is not exceeded, then the sum of actual rainfall of first four month is compared with the sum of the four highest values of mean monthly rainfall, and so on should the drought not yet have been terminated, up to a comparison of the sum of the rainfall of the rainfall of the twelve months following and including the month from which the test commenced, with the mean annual rainfall. By this stage either the drought had been terminated, in which case it was deemed to have ended in the month from which the multiple test had been initiated or the drought conditions prevailed over this period and test for the termination recommenced at the first month with a positive difference following that from which the previous unsuccessful test had proceeded.

Once a termination had occurred testing for the start of the next drought began at the first month with a negative difference following the month in which the drought ended.

(G) Evaluation of drought index

Drought intensity is evaluated by dividing the total deficits beyond the monthly mean deficit for the period of drought (D) by the sum of the mean monthly deficits for the same period.

$$\text{Drought Intensity (I)} = \frac{\sum_{J=IDST}^{IDEND} [MMR(J)-ER(J)]-MMD(J)}{\sum_{J=IDST}^{IDEND} [MMD(J)]} \quad \ldots(12)$$

Where; IDST = Month of start of drought; IDEND = Month of termination of drought.

In above equation if nominator is less than 0.0 (i.e., negative), then nominator is equalled to zero for calculation of drought intensity.

Severity Index : Severity Index is defined as product of drought intensity and drought duration

$$SI = I \times D \quad \ldots(13)$$

This analysis has been performed for all the six selected districts. Monthly rainfall data for the period 1951 to 1988 of selected raingauge stations located at taluk headquarters of each district have been used for analysis. A computer programme using the above approach is used for the analysis. The analysis has yielded the distinct spells of drought along with monthly and overall intensity of drought for all the spells. The graphical representations of the drought spells with intensity for all districts are shown in Figures 3.6.

The following inferences can be drawn from the analysis. The monthly rainfall data analysis, by using the Herbst program for the period 1951 to 1988 of six selected districts namely Ajmer, Jodhpur, Banswara, Barmer, Dungarpur and Udaipur shows that all the districts experienced 8 to 12 drought spells of the intensity ranging from 0.24 to 2.18 during the period. This shows that the districts are drought prone. Over the entire period of analysis the highest drought duration and severity index of 62 months and 7.19 respectively was observed during 1983 to 1988 in Ajmer district. All the six districts faced successive drought years in continuation from 1985-1988 leading to disastrous drought situation in these districts. It is clear from the analysis that in the year 1988 all the six districts show drought spells indicating that the year was a drought year which has also been indicated by other rainfall analysis.

The approach has yielded comparable results of drought analysis and has further scope for improvement taking into account the version of monthly weight age factors keeping in view the agriculturally more important months in the state.

3.5 Dry Spell Analysis

Agriculture is the worst sufferer of droughts as the ultimate effects of drought results in partial or total crop failure. Out of the various growing stages of crops, some are sensitive to moisture stress known as critical growing stages. Agricultural droughts are the result of occurrence of dry spells specially during critical growth stages of crops. Therefore the analysis of dry spells ($\geq$ 2 weeks) within monsoon season has significance specially for rain fed agriculture in the country. Therefore, an attempt has been made to identify the dry spells of two or more than two weeks duration during monsoon period (4th June to 15th September) by selecting one taluk from each of the 6 selected districts of state Rajasthan.

The criteria for selection of dry spells is that the daily rainfall should be less than or equal to 5 mm (as a day is assumed as rainy day if daily rainfall exceeds 5 mm) occurring continuously for at least two weeks (i.e. 14 days) or more. For counting number of spells the start of monsoon season has been assumed from fourth June of (beginning of 23rd standard week) every year. The duration and time of occurrence and number of such dry spells for all the 6 six districts of state Rajasthan have been presented in Appendix-III-A. The number of dry spells have been counted starting from the monsoon season of 1981 to 1988. The study has been carried out for one taluk in each district.

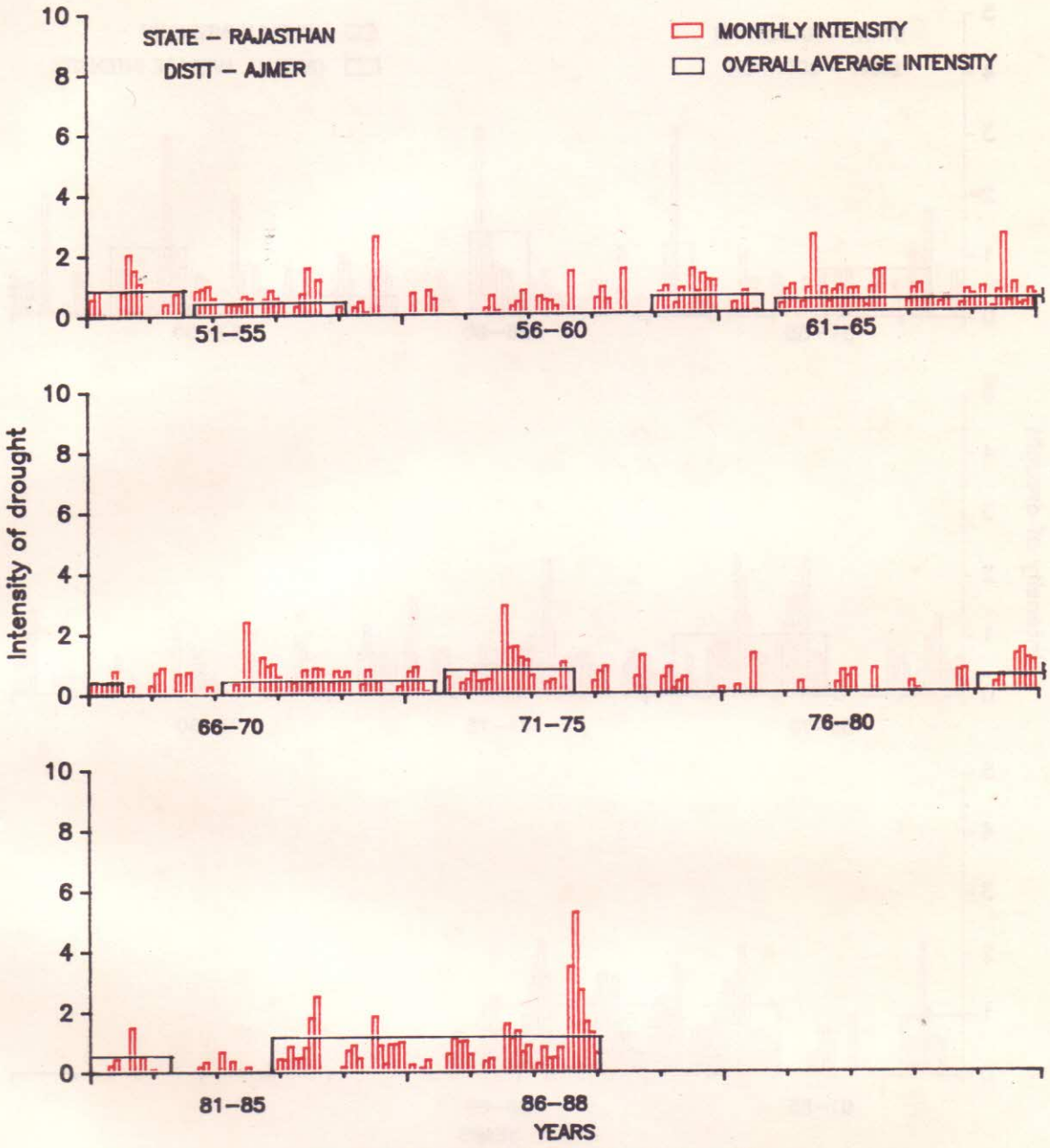


FIG.3.6: Overall average and monthly intensity of drought.

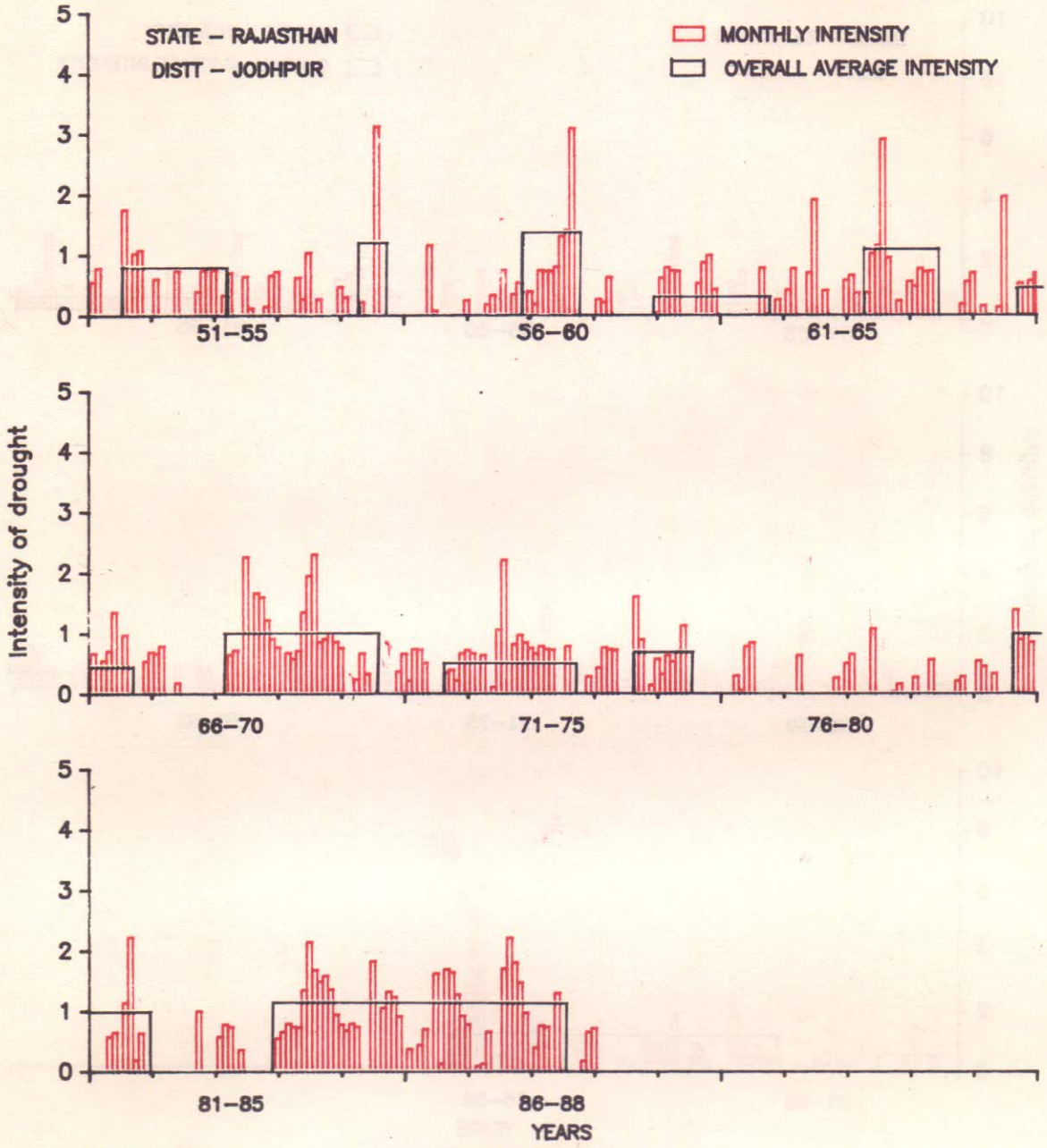


FIG.3.6: Overall average and monthly intensity of drought.

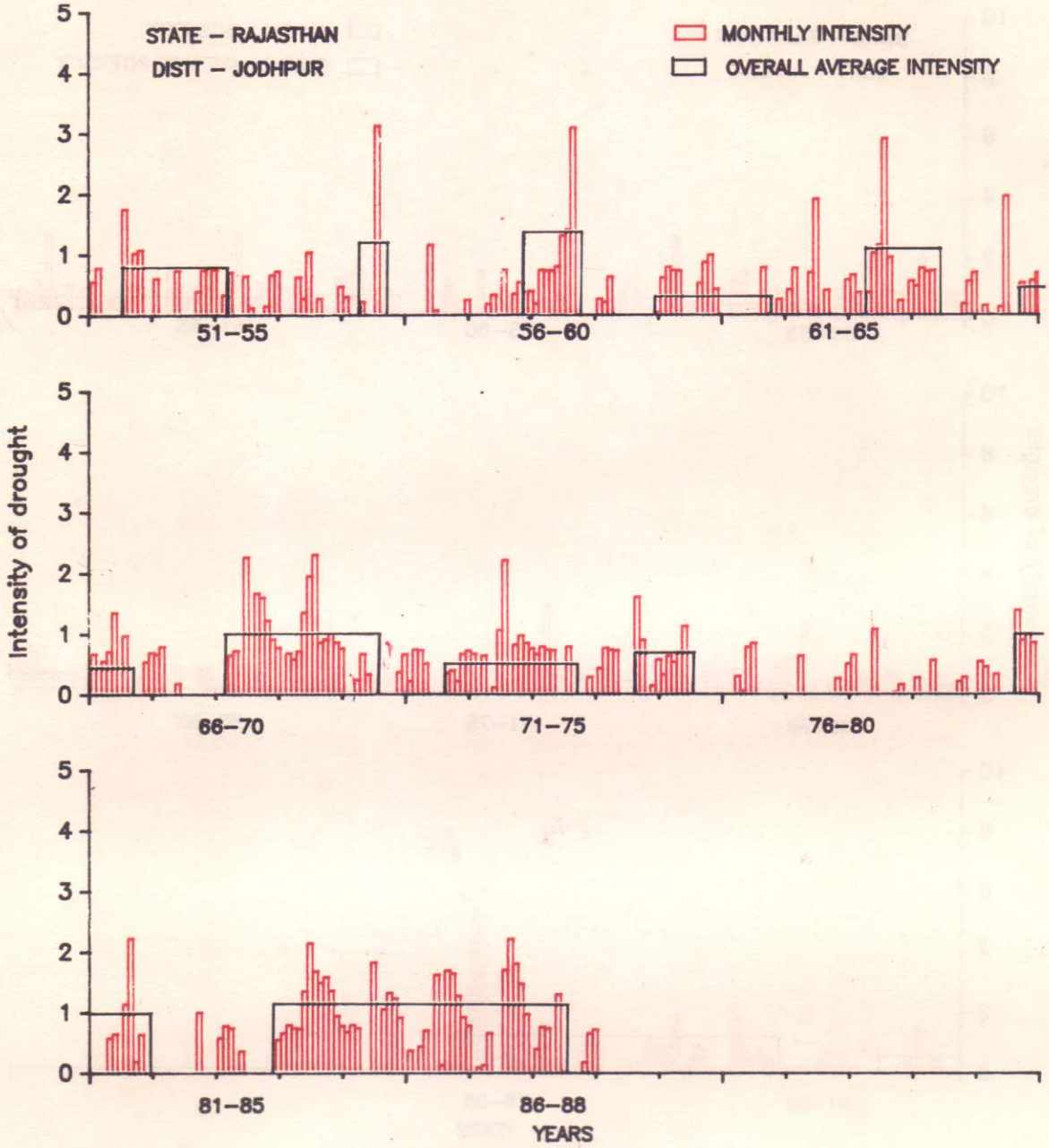


FIG.3.6: Overall average and monthly intensity of drought.

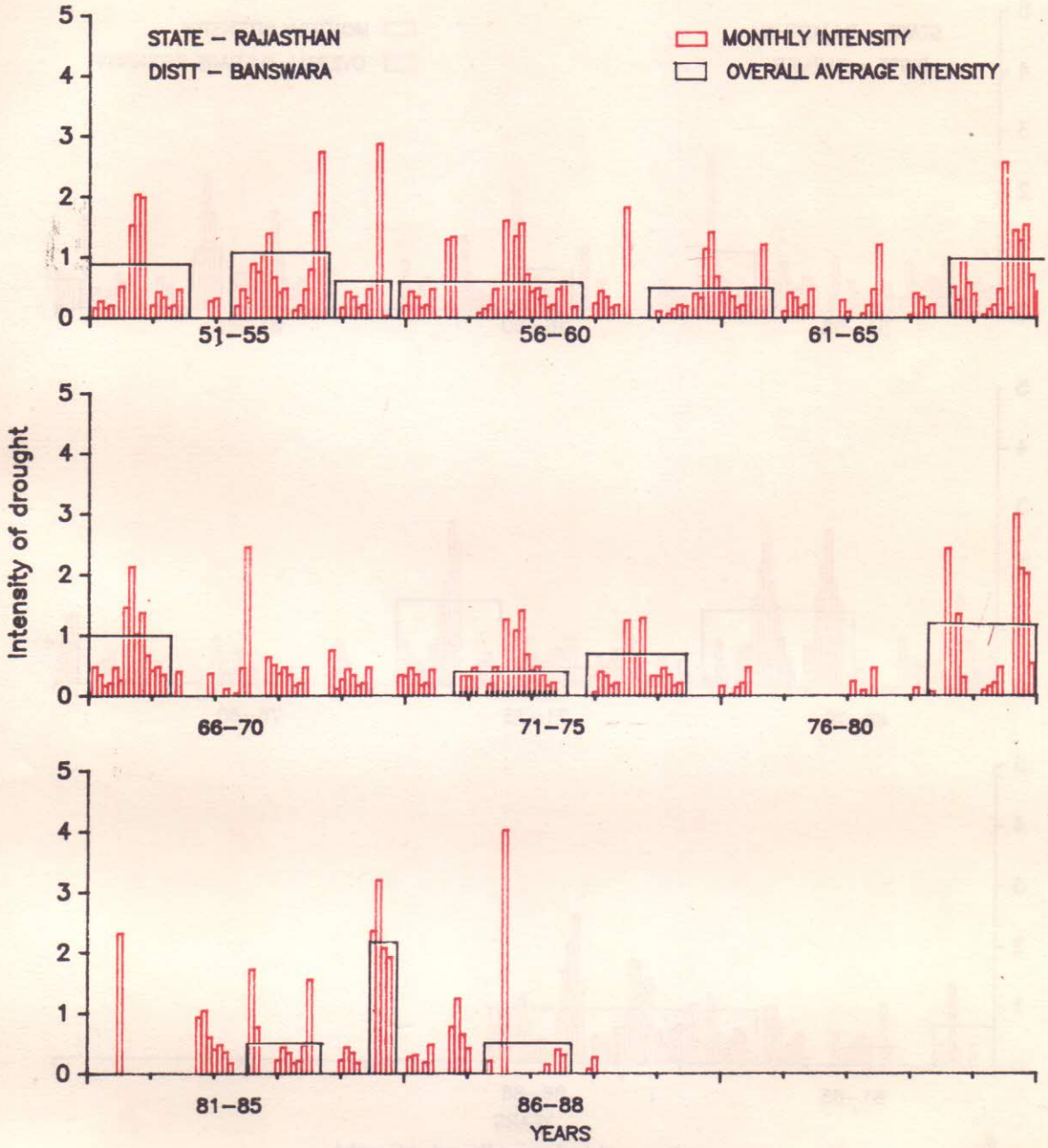


FIG.3.6:Overall average and monthly intensity of drought.

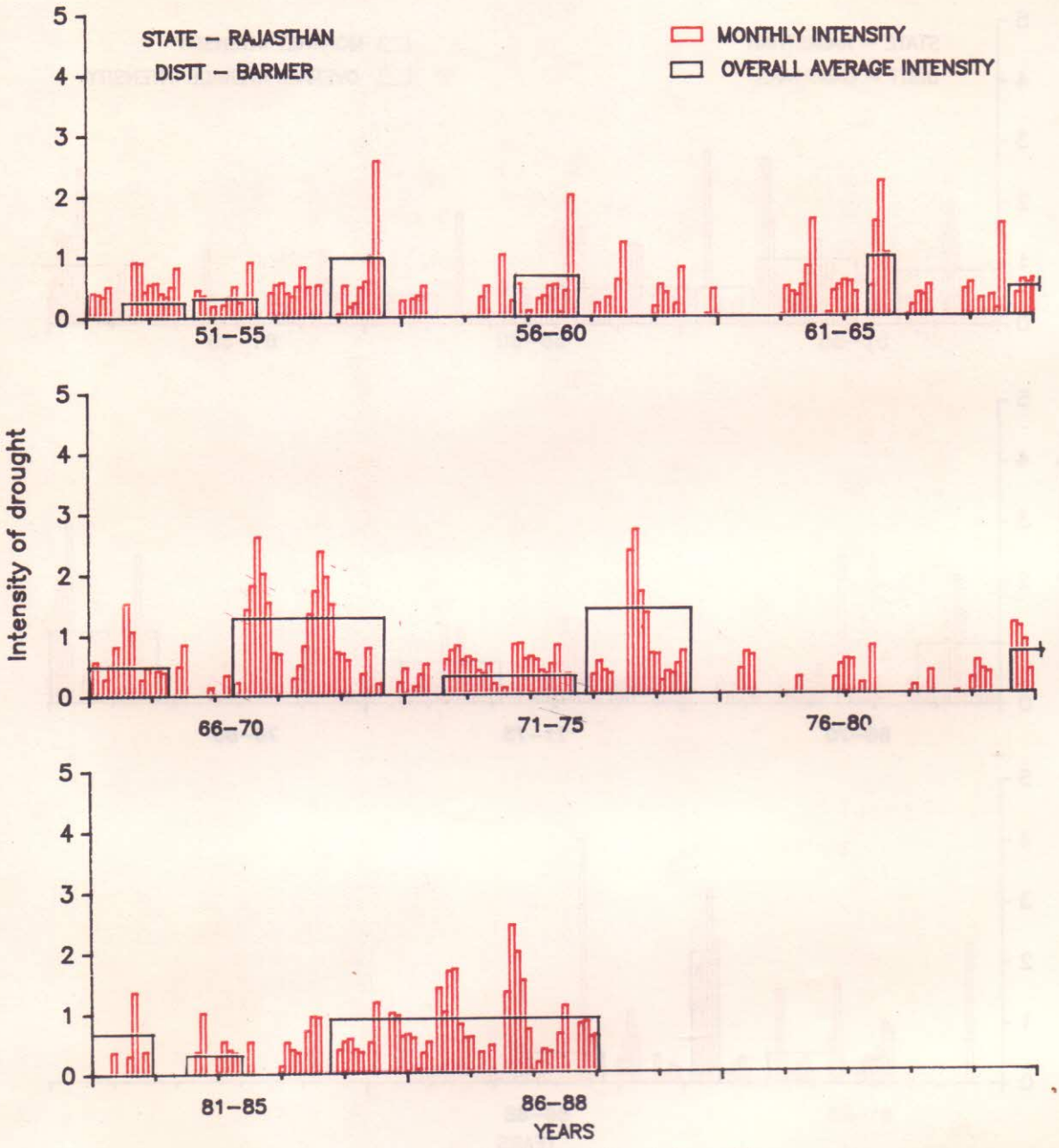


FIG. 3.6: Overall average and monthly intensity of drought.

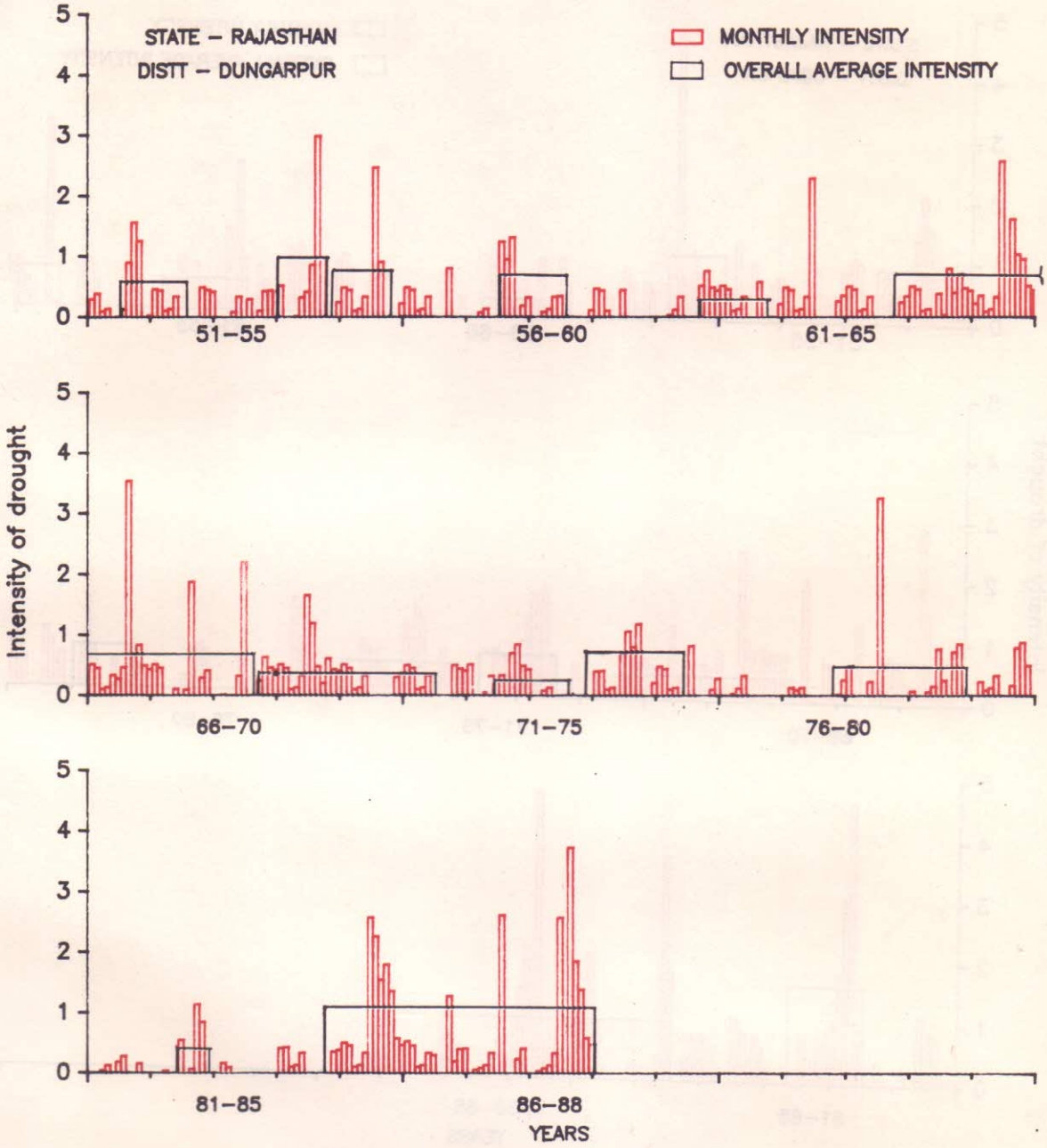


FIG.3.6: Overall average and monthly intensity of drought.

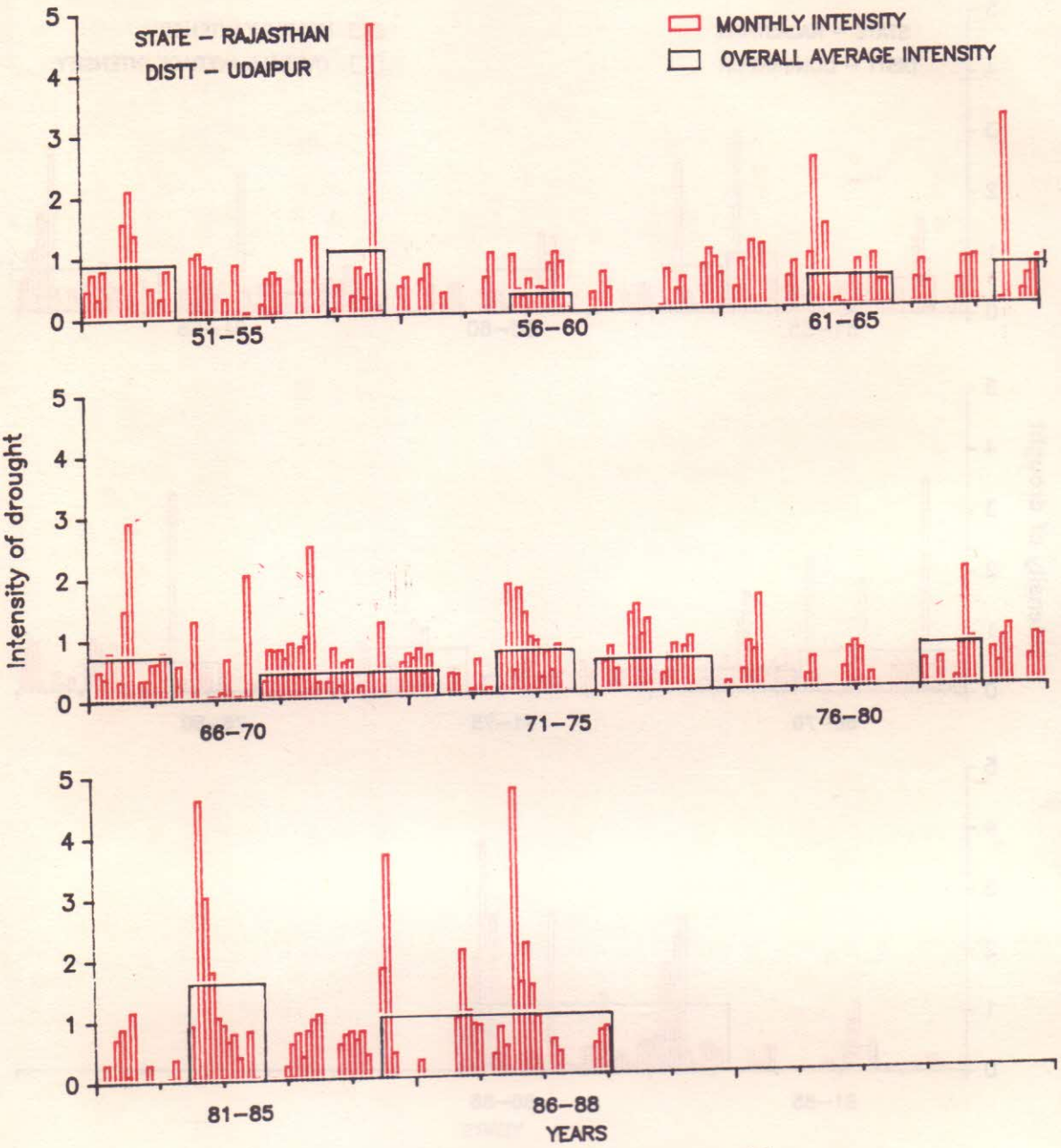


FIG.3.6: Overall average and monthly intensity of drought.

For statistical analysis, the duration of dry spells were represented as range (in days) and number of spells falling in that range were counted. The number of spells falling in various ranges of duration of spells were represented as percentage of total number of spells occurring from 1981-88 and cumulative percentage was obtained starting from the maximum duration of dry spell group downwards adding successive percentages (Appendix-III-B). The probability curves have been showing range of duration of dry spells on the abscissa and cumulative percentage of number of spells as ordinates. The plots are shown in Figure 3.7. Probability distribution graphs as shown in figure have been used to read the values of duration of dry spells (in days) at 75% probability level and have been given in Table 3.5. If can be observed from the table that at 75% probability, the duration of dry spell ranges from 21-28 days for all the six representative taluks selected for all the six districts respectively.

The analysis is specially important from the view point of agriculture as it can give some idea about likelihood of dry spells during monsoon period based on which alternate arrangements can be made for providing water during critical growth stages to avoid hazardous effects on crop yields, especially in rain fed agriculture.

Table 3.5 : Range of Duration of Dry Spells for 75% Probability in Rajasthan.

S.No.	Taluk	Distt.	At 75% probability, duration of dry spells (in days)
1.	Ajmer	Ajmer	21-28
2.	Jodhpur	Jodhpur	21-28
3.	Banswara	Banswara	21-28
4.	Barmer	Barmer	21-28
5.	Durgapur	Durgapur	21-28
6.	Girwa	Udaipur	21-28

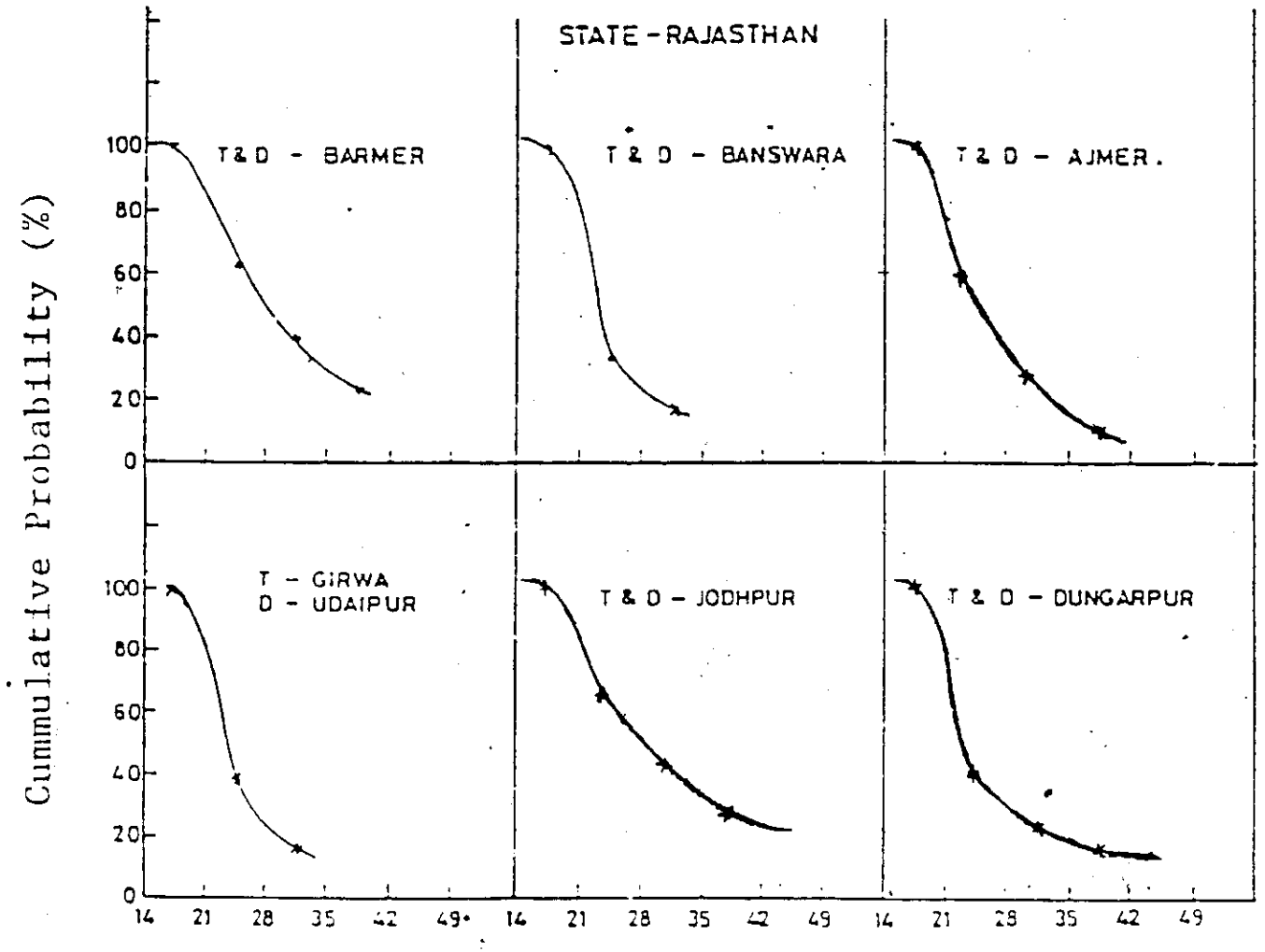


Fig.3.7 : Probability distribution of dry spells

4.0 GROUND WATER DEFICIT

4.1 General

The main objective of ground water management is to ensure that ground water will be available at an appropriate time and in an appropriate quantity and quality to meet the most important demand of the society. The measurement of ground water levels and their evaluation can play an important role in management of this underground resource of water. The fluctuations of water table reflect the effect of infiltration, of precipitation and of discharge of ground water to streams and lakes or withdrawal of water from wells. Usually the change in ground water storage is a seasonal phenomenon. However, during the period of scarcity and droughts, more dependence comes on ground water storages and steep decline in ground water levels are experienced. Because of improper management of ground water aquifers after development, numerous undesirable consequences such as the depletion of aquifers and ground water mining emerge, especially during drought years. Statistics recently compiled on the use of ground water and surface water show that in a number of states ground water is being over exploited in certain pockets resulting in a fall in the water table. During droughts, due to deficiency of rainfall and higher rate of evapotranspiration, the demand for irrigation gets enhanced, thereby the water level goes down. This results in increased use of energy for pumping water from greater depths involving higher expenditure. As a policy, the withdrawal of ground water should be restricted to average annual recharge. This will conserve water for over exploitation during drought periods.

Therefore, there is a long standing need to better understand the relationship between precipitation and ground water levels. The relationship can be developed by carrying out statistical analysis of precipitation data & well level measurements. Beside, information regarding well,abstractions should be available for evaluating effects on water table on, only due to reduced precipitation.

In order to see the effects of scarce rainfall as experienced during three successive drought years (1985-1989) on ground water regime, statistical analysis of ground water level data vis a vis precipitation has been carried out.

In the present analysis of state Rajasthan, five districts namely Ajmer, Udaipur, Jodhpur Barmer, and Banswara were chosen for the study of pre-monsoon and post-monsoon ground water levels and seasonal rainfall fluctuations. Due to non-availability of groundwater level data of district Dungarpur the study is restricted to five districts only. Due to non-availability of abstraction data, the effects of withdrawal could not be introduced in the analysis.

4.2 Ground Water Level Analysis

The data concerning ground water level fluctuations were collected in respect of observation wells in all the five districts namely Ajmer, Jodhpur, Banswara, Barmer, Dungarpur and

Udaipur of state Rajasthan. The information regarding period of data used, no. of observation wells and the source of data is given in Table 4.1.

Table 4.1: Status of Ground Water Data of State Rajasthan.

S.No.	Name of District	Data available (four time in a year)	No. of Wells taken	Source of data availability
1.	Ajmer	1975-89	5	C.G.W.B.
2.	Jodhpur	1979-89	5	-do-
3.	Banswara	1979-89	7	-do-
4.	Barmer	1979-89	10	-do-
5.	Udaipur	1981-89	7	-do-

It is evident from Table 4.1 about 5-10 wells were chosen in each district for evaluating impacts on ground water regime. It was assumed that these wells are evenly distributed with in the district. The locations of the wells on the district map have already been shown in the figure presented in chapter 2.

The ground water level analysis was attempted with the help of seasonal data depending upon the frequency of the data collected from central and state Govt. agencies of the state. Appendix IV-1 gives the details of various observation wells spread over 5 selected drought prone district of Rajasthan state with their latitude and longitude. The analysis has been carried out for ground water level data from 1975-89.

The water level in the wells have been calculated with respect to mean sea level and for each district average ground water level has been calculated using Thiessen method. The Thiessen weight of all wells considered in each district was established and ground water level calculated with respect to mean sea level multiplied by Thiessen weight gave average ground water level for the district.

4.3 Inference

The ground water level analysis was restricted to districts (Ajmer, Jodhpur, Banswara, Barmer and Udaipur) in the state of Rajasthan. The district of Dungarpur was not included in the study due to non-availability of data. The analysis of post monsoon levels have indicated that in case of Ajmer and Jodhpur districts higher rate of decline in pre and post monsoon levels were obtained. However, the district Barmer showed slightly positive trend in pre and post monsoon ground water table levels. The analysis of pre-monsoon water table levels have shown a general declining trend in all districts except Barmer. As compared to previous year the pre monsoon water table has shown an increasing trend in all districts except Jodhpur. The trends in water table levels and seasonal rainfall for all the chosen five districts are shown in Figures 4.1.

The analysis of ground water levels based on the water table fluctuation data of past 10-14 years has yielded in knowing the ground water level trends (pre and post) as a result of seasonal rainfall departure. Overall the water

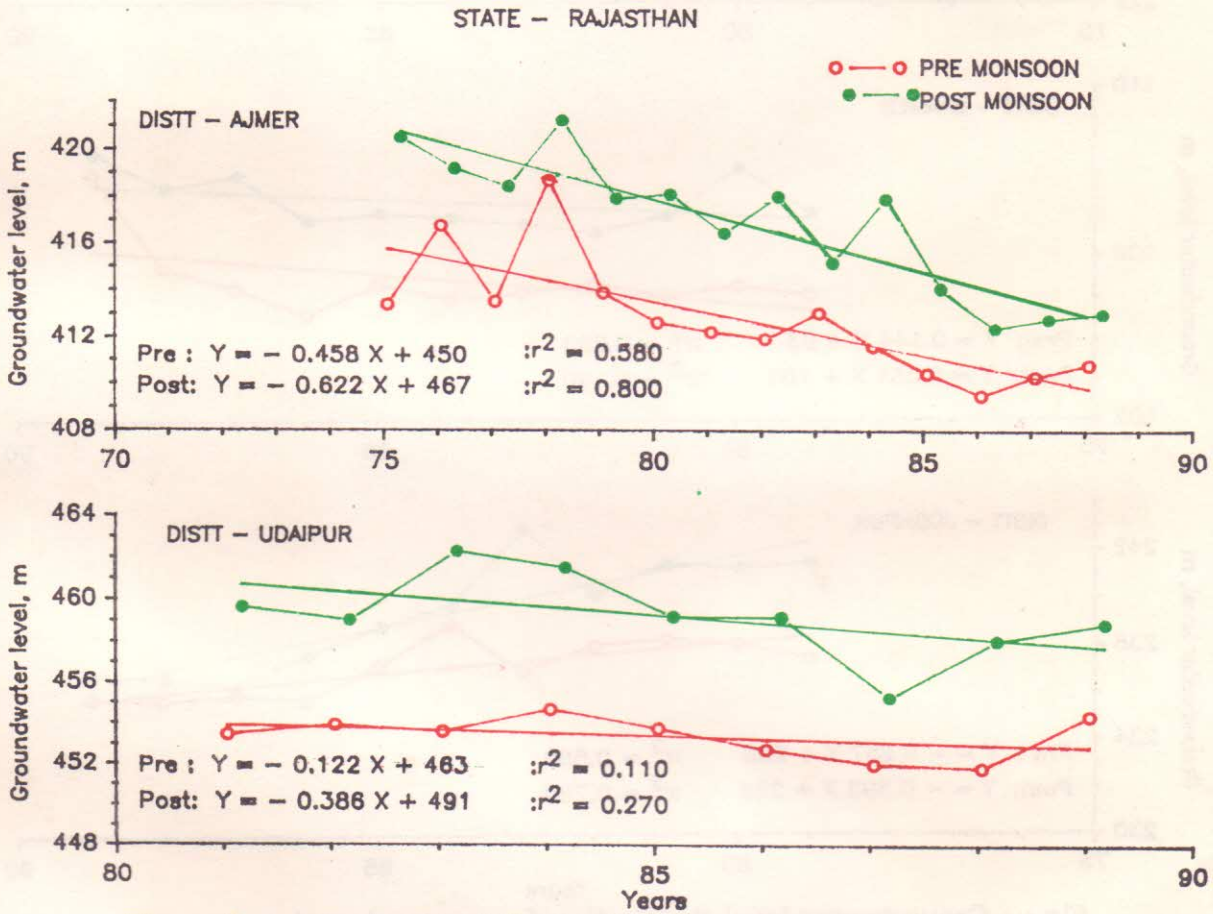


Fig 4.1: Groundwater level fluctuation for pre and post monsoon seasons.

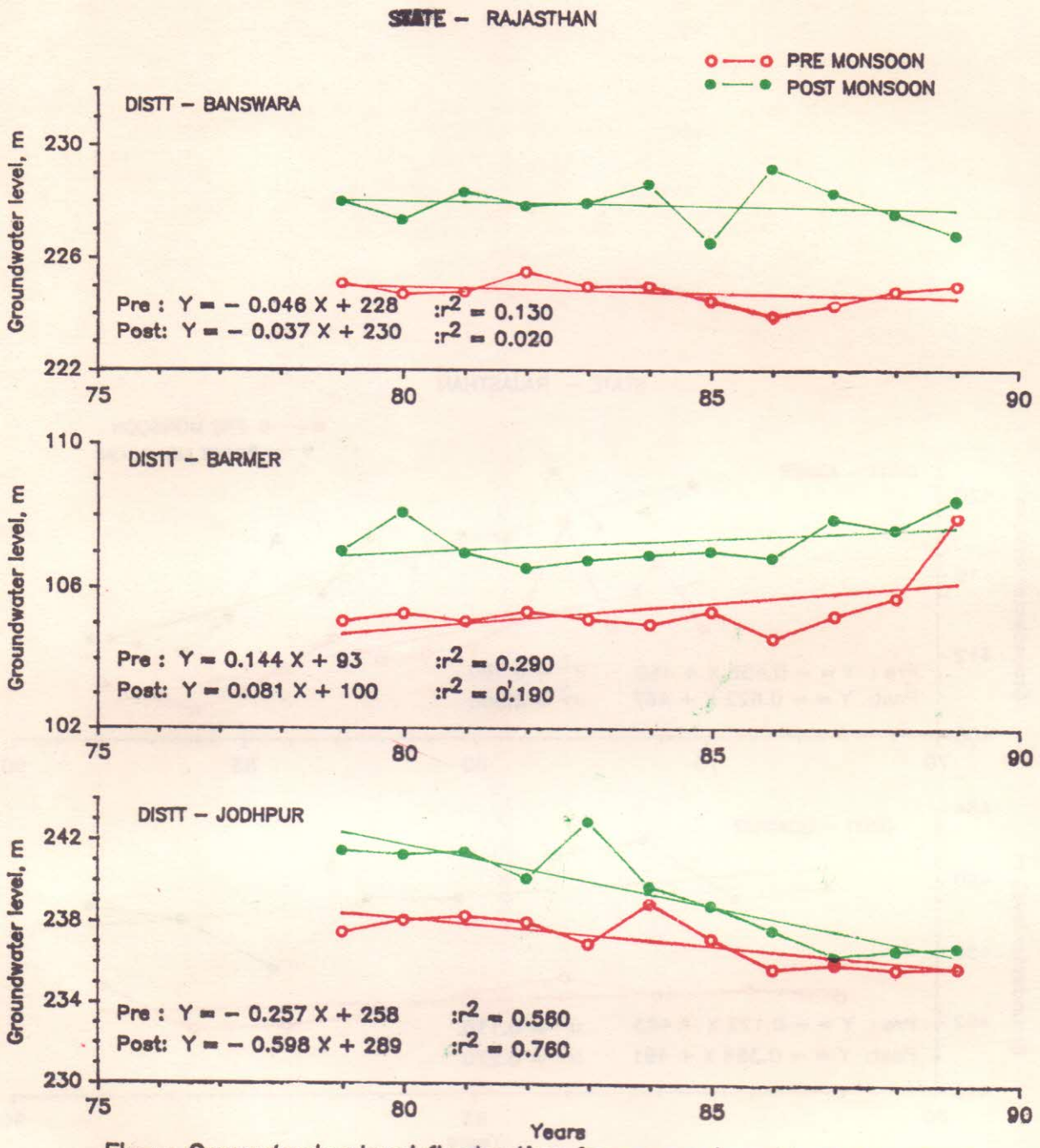


Fig.4.1:Groundwater level fluctuation for pre and post monsoon seasons.

table has been recorded falling in all districts except Barmer. The rate of recharge was found higher in 1988-89 as compared to previous year. In district Banswara it was almost same. The districts Ajmer, Udaipur and Jodhpur indicated a rise in water table as compared to previous years. The continuous decline in water table is certainly attributed to failure of monsoon due to which the draft of ground water also gets increased because of increase in demand. The continuous rise in water table as found in Barmer can be attributed to the positive ground water imbalances created by surface water irrigation projects. Better analysis to correlate rainfall failure and ground water regime can be done by taking into account the well abstraction data, which has not been done in the present case due to its non-availability.

5.0 ANALYSIS OF RESERVOIR STORAGES

In order to see, the impacts of failure of monsoon on storages of the reservoirs, an attempt has been made to compare the reservoir level in one selected reservoir of the state Rajasthan. For this purpose, reservoir levels in some selected months (May, August and October) have been plotted against time and the relationship between reservoir level and live storage. The weekly reservoir level data as supplied by Central Water Commission from 1985 till 1989 have been used for this analysis. Fig. 5.1 shows the position of storages during 1985 to 1989 in the Rana Pratap Sagar reservoir of Chambal basin. It can be seen from the figure that live storage during 1987 and 1988 is lower than the other years 1989. The Oct.'87 live storage was 31% to the previous year Oct.'s live storage which indicates reservoir storage was severely affected by the drought conditions during 1987 but not in 1989.

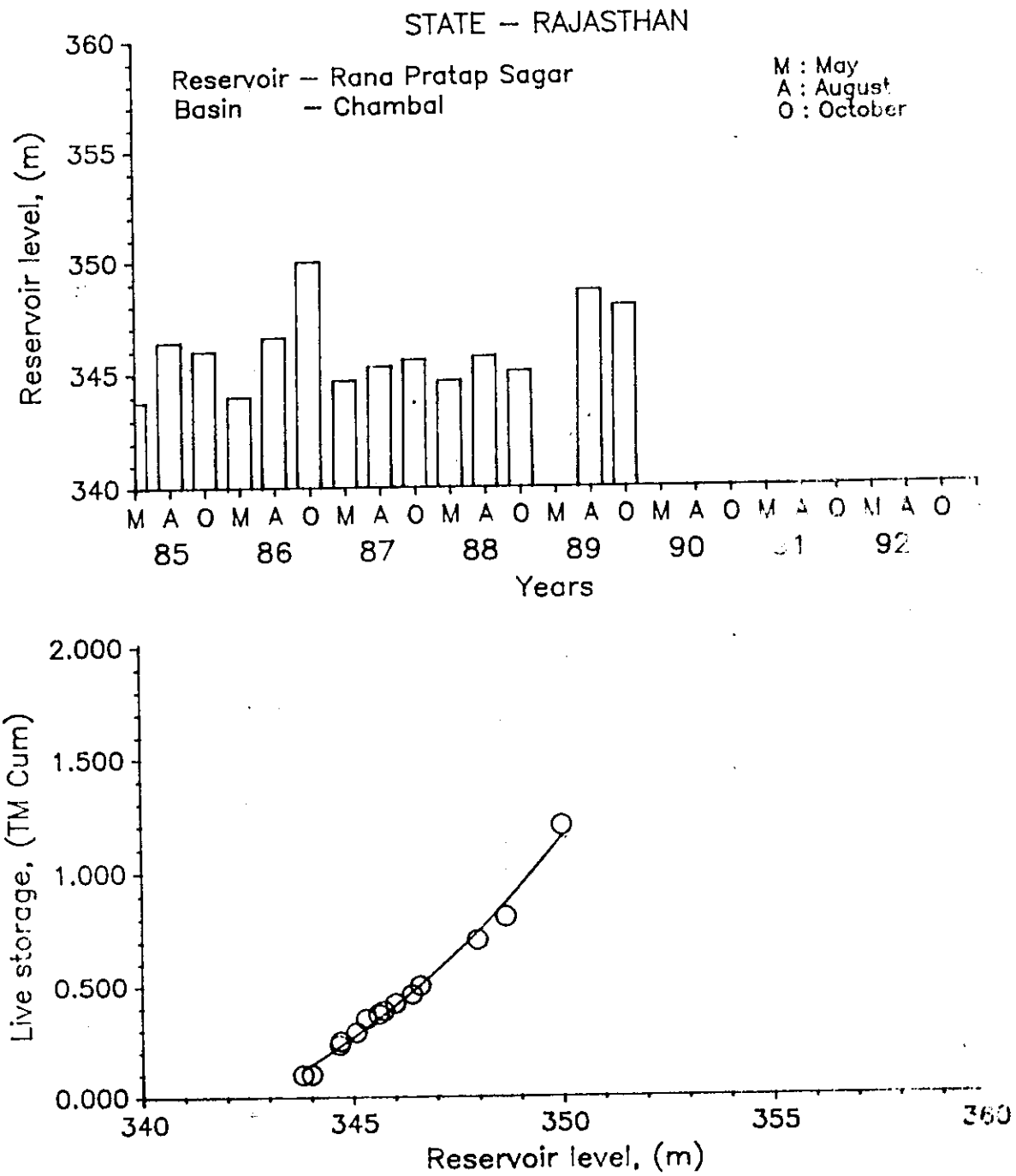


Fig.5.1: Reservoir level with time and the relationship between reservoir level and live storage.

6.0 CONCLUSIONS AND RECOMMENDATIONS

1. Studies were carried out in six districts of Rajasthan state to evaluate impacts of drought on hydrologic regime. For this purpose, analysis of rainfall data and ground water level data was carried out on water year basis.

2. The present report describes analysis of for year 1988-89 which is based on the collected data.

3. The rainfall analysis done on seasonal basis to evaluate the status of deficiency during the year in six districts indicated that there has been continuous seasonal deficiency of the order of 20-65% in all the districts except in Banswara (Fig.3.1).

4. The deficiency in rainfall on monthly basis indicated that departure from normal rainfall in various months of the year have been in the range of 2-100%. In case of Banswara some positive departure were noticed in month of July, 1988.

5. The probability analysis of rainfall for working out the range of rainfall at 75% probability level using annual rainfall data indicated that the rainfall works out to be 500-600 mm with the extreme of 200-300 mm and 700-800 mm. Using this analysis, the probability analysis of occurrence of 75% of the normal rainfall of the district was evaluated which was found as 82, 81, 90, 95, 81 and 81% for the districts of Ajmer, Jodhpur, Banswara, Barmer, Dungarpur and Udaipur respectively. This means all districts have chances of having more than 75% of normal rainfall in more than 20 years per 100 years.

6. Analysis of monthly data using Herbst Approach indicate that all districts experienced drought during year 1984-89. In fact most districts experienced continuous drought spells during 1985-89 except Banswara. Using this approach the no. of drought spells as experienced in these districts ranged from 12-24 during the period 1951-89. While Dungapur experienced seventeen nos. of drought spells, Ajmer recorded 12 numbers of drought spells as per analysis. The dry spell analysis was performed for working out duration of dry spells at each level of probability. It was observed that for all the districts, the dry spell duration worked out in the range of 21-28 days.

7. Ground water analysis was attempted for five districts for working out effects of drought on ground water levels. For this purpose, data as recorded in the observation wells in these districts were analyzed. The length of data used varied from district to district and about 10-12 years of data was used for the analysis. The analysis indicated that in case of Ajmer, Udaipur, Banswara and Jodhpur, a high rate of decline while the district of Barmer showed slightly positive trend. In most of the districts the levels were observed as following except Barmer. The continuous fall in ground water levels is certainly attributed to less recharge and increase demand during water scarce periods.

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The authors are also grateful to the Scientists and Scientific staff who have rendered their services in collecting necessary data from field agencies.

The authors also wish to express sincere thanks to all central and state government organization who have provided necessary data and extended all possible help for carrying out the study. Last but not the least, sincere thanks are due to all others who directly or indirectly helped to make this team effort successful.

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APPENDIX - II

LIST OF OFFICES AND PLACES FROM WHICH DATA AND INFORMATION WERE COLLECTED

RAJASTHAN

Jaipur	Chief Engineer, Irrigation Department
	Dy. Director (Hydrology), Rajasthan Irrigation Dept.
	Supdt. Engineer (Special Schemes), Rajasthan Irri. Dept.
	Director, Irrigation Research, Rajasthan, Irri. Dept.
	Agronomist (Irrigation) Rajasthan Irrigation Dept.
	Directorate of Agriculture, Rajasthan
	S.E. (Soil Conservation) Dept. of Agriculture, Rajasthan
	Secretary, Special Schemes Organization Rajasthan
	Secretary, Relief Rajasthan
	Dept. of Economics and Statistics, Rajasthan
	Directorate of Evaluation, Rajasthan
	Public Health Eng. Dept., Rajasthan
	Soil Survey Officer, Rajasthan
	Central Water Commission Field Officer
	Central Ground Water Board, Regional Office
Ajmer	Irrigation Department
Udaipur	Agriculture Department
Banswara	Soil Conservation
Dungarpur	District Rural Development Authority (DRDA)
Barmer	Land Record Office
Jodhpur	Ground Water Dept.
	Central Arid Zone Research Institute
	Chief Engineer, Rajasthan State Ground Water Department.

Appendix - III-A

Duration and Number of Dry Spells During Monsoon,(4th June to 15th September).

Banswara (Banswara)

First day of monsoon	Date of beginning of dry spell	Duration of dry spell (2 weeks in day)	Total no. of dry spell in a year
1	2	3	4
14.6.81	4.6.81	20	2
	24.8.81		
10.6.82	4.6.82	16	3
	23.6.82	17	
	26.8.82	16	
29.6.83	4.6.83	25	1
9.6.84	Nil	Nil	-
27.6.85	4.6.85	23	2
	26.8.85	21	
16.6.86	1.7.86	15	2
	17.8.86	30	
13.6.87	4.7.87	33	2
	2.9.87	14*	
6.6.88	Nil	Nil	-
			12

Barmer (Barmer)

1	2	3	4
26.6.81	4.6.81	22	3
	26.7.81	17	
	29.8.81	18	
20.6.82	4.6.82	16	4
	21.6.82	31	
	26.7.82	19	
	20.8.82	27*	
1.7.83	4.6.83	27	3
	2.7.83	20	
	19.8.83	11	
16.6.84	17.6.84	15	3
	9.7.84	27	
	6.8.84	41*	
16.7.85	4.6.85	42	3
	20.7.85	14	
	6.8.85	41*	
4.7.86	4.6.86	30	3
	5.7.86	24	
	10.8.86	37*	
15.7.87	4.6.87	41	2
	16.7.87	62*	
1.7.88	4.6.88	26	3
	2.7.88	14	
	8.8.88	38	
			24

Ajmer (Ajmer)

1	2	3	4
12.6.81	27.6.81	16	2
	19.8.81	28	
1982	Date not available		-
1983	Date not available		-
1.7.84	4.6.84	27	1
14.7.85	4.6.85	39	2
	20.8.85	27*	
21.6.86	4.6.86	17	2
	17.8.86	30*	
12.6.87	16.6.87	31	3
	21.7.87	17	
	29.8.87	19*	
1988	Data not available	-	-
			10

Udaipur (Girwa)

1	2	3	4
25.6.81	4.6.81	21	1
22.6.82	4.6.82	18	1
28.6.83	4.6.83	16	2
	28.8.83	18	
13.6.84	14.6.84	18	2
	20.8.84	17	
26.6.85	4.6.85	22	3
	27.6.85	16	
	18.8.85	29*	
17.6.86	24.6.86	23	2
	17.8.86	30*	
13.6.87	16.7.87	22	2
	1.9.87	15*	
29.6.88	4.6.88	25	2
	26.8.88	21	
			15

Jodhpur (Jodhpur)

1	2	3	4
10.7.81	4.6.81	36	2
	17.8.81	30	
14.7.82	4.6.82	40	3
	26.7.82	20	
	25.8.82	22*	
11.6.83	14.6.83	21	1
5.6.84	8.6.84	27	2
	21.7.84	57*	
14.7.85	4.6.85	40	3
	17.7.85	17	
	6.8.85	41	
15.7.86	4.6.86	41	3
	30.7.86	17	
	17.8.86	38*	
12.6.87	13.6.87	31	4
	17.7.87	22	
	9.8.87	17	
	28.8.87	19*	
29.6.88	4.6.88	25	2
	25.8.88	21	
			20

Dungarpur (Dungarpur)

1	2	3	4
25.6.81	4.6.81	21	2
	31.8.81	14	
22.6.82	4.6.82	19	2
	24.6.82	18	
22.6.83	4.6.83	23	2
	17.8.83	20	
8.6.84	15.6.84	17	3
	23.7.84	14	
	21.8.84	16	
16.6.85	4.6.85	42	2
	16.8.85	31*	
17.6.86	17.8.86	30	1
13.6.87	25.6.87	17	3
	14.7.87	23	
	31.8.87	16*	
4.7.88	4.6.88	30	2
	1.8.88	46	
			17

* - indicate the continuation of dry spell after 15th September

Appendix - III-B

Probability Analysis of Dry Spells

Taluk/Station (Distt.)	Class Interval (in day)	No. of Spells	Percentage	Cumulative Probability
1	2	3	4	5
Barmer (Barmer)	14-21	9	37.5	100.0
	22-28	6	25.8	62.5
	29-35	3	12.5	37.5
	> 35	6	25.0	25.0
		24		
Banswara (Banswara)	14-21	8	66.6	100.0
	22-28	2	16.6	33.2
	29-35	2	16.6	16.6
	>35	-	-	-
		12		
Ajmer (Ajmer)	14-21	4	40.0	100.0
	22-28	3	30.0	60.0
	29-35	2	20.0	30.0
	>35	1	10.0	10.0
		10		
Girwa (Udaipur)	14-21	9	60.0	100.0
	22-28	4	26.66	40.00
	29-35	2	13.33	13.33
	>35		-	-
		15		
Jodhpur (Jodhpur)	14-21	7	35.0	100.0
	22-28	4	20.0	65.0
	29-35	3	17.0	45.0
	>35	6	30.0	30.0
		20		
Dungarpur (Dungarpur)	14-21	10	58.8	100.0
	22-28	2	11.7	41.1
	29-35	2	17.64	29.4
	>35	2	11.76	11.76
		17		

APPENDIX IV-1

LIST OF OBSERVATION WELLS

STATE-RAJASTHAN

DISTT-AJMER

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq. km.)	AREA WEIGHT
1.	45J-2D1	KISHAN GARH	26 37 00	74 57 00	435.65	1837	0.2167
2.	45J-3C2	PUSHKAR	26 30 00	74 34 00	483.86	1307	0.1542
3.	45J-4C1	BANDANWARA	26 09 00	74 42 00	418.12	2261	0.2667
4.	45J-4B1	BEAWAR	26 06 00	74 20 00	447.93	1413	0.1666
5.	45C-4A1	KEKRI	25 50 00	75 10 00	356.60	1660	0.1958

STATE-RAJASTHAN

DISTT-JODHPUR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq. km.)	AREA WEIGHT
1.	45B-306	Narwa	26 24 05	72 56 45	255.60		0.2634
2.	45B-201	Osian	26 43 30	72 52 00	329.50		0.2055
3.	45A-451	Phalodi	27 07 10	72 22 00	230.90		0.2948
4.	45F-302	Raasisaon	26 22 00	73 45 10	306.08		0.1113
5.	45B 382	Shergarh	26 19 45	72 18 00	226.29		0.1250

STATE-RAJASTHAN

DISTT-BANSWARA

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq. Km.)	AREA WEIGHT
1.	46I-3A1	ARTHUNA	23 29 45	74 06 00	153.730	736.05	0.1461
2.	46I-2B1	BANSWARA	23 32 00	74 27 00	213.100	923.80	0.1834
3.	46I-2C2	BHUNGARA	23 41 00	74 31 00	240.825	747.59	0.1484
4.	46I-1B1	DUNGARIA	23 51 50	74 27 30	194.610	410.01	0.0814
5.	46I-1B2	GANORA	23 46 00	74 15 10	179.720	577.16	0.1146
6.	46I-2C1	HERIA BERI	23 31 00	74 39 00	337.275	383.03	0.0760
7.	46I-4B1	KUSHALGARH	23 12 00	74 27 00	292.725	1259.37	0.2500

STATE-RAJASTHAN

DISTT-BARMER

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq. Km.)	AREA WEIGHT
1.	40Q-2B	BARMER	25 44 10	71 23 50	213.410	2027.64	0.0714
2.	40O-4O1	GUDA	25 11 45	71 43 15	47.765	2179.77	0.0768
3.	40N-3B1	BISUKALAN	26 16 30	71 18 20	243.390	2558.28	0.0901
4.	40O-3A1	CHOHTAN	25 28 30	71 04 00	168.350	3494.21	0.1231
5.	40O-2A1	KALURI	25 42 43	72 03 30	101.900	6395.72	0.2253
6.	40O-2B2	NIMRI	25 29 00	71 17 00	187.560	2950.19	0.1030
7.	40P-1A1	SIHANIYA	24 55 55	71 09 30	49.680	1562.72	0.0551
8.	40J-4A1	SUNDRA	26 05 45	70 13 10	115.540	3211.85	0.1131
9.	40N-3B5	SARAN KA TALA	26 18 30	71 30 45	231.740	2112.84	0.0744
10.	40N-3O2	UNDU	26 20 30	71 44 55	230.040	1893.76	0.0667

STATE-RAJASTHAN

DISTT-UDAIPUR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq. Km.)	AREA WEIGHT
1.	45K-2A1	BHIM	25 44 00	74 05 00	524.42	869	0.0503
2.	45G-3D2	ANET	25 19 00	73 56 00		2220	0.1285
3.	45K-4A1	RAILMAGRA	25 02 00	74 07 00		966	0.0559
4.	45H-1D2	MAVLI	24 47 00	73 59 00	497.38	2124	0.1229
5.	45H-2C1	BHUWANA	24 37 00	73 43 00	482.68	5020	0.2905
6.	45H-4D2	SARADA	24 09 00	73 50 00		3572	0.2067
7.	45H-4C1	RIKHABDEV	24 05 00	73 41 00	336.85	2502	0.1452

DIRECTOR : SATISH CHANDRA

TECHNICAL COORDINATOR : G. C. MISHRA

STUDY GROUP

1.	AVINASH AGARWAL,	Scientist 'C'
2.	S. K. GOYAL,	Scientist 'B'
3.	R. P. PANDEY,	Scientist 'B'
4.	YATVEER SINGH,	R.A.