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

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PREFACE

A most important factor in understanding hydrological droughts 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 Gujarat. The present report covers the study of six districts of Gujarat state. These districts are Rajkot, Jamnagar, Ahmedabad, Surendranagar, Amreli & Bhavnagar.

The study includes various kinds of analysis of rainfall data, stream flow data and ground water 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 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

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ABSTRACT

In the recent past droughts of exceptional severity have caused major hardship in many areas of the country. The problem of droughts in the country has wider dimensions and is recurrent in nature. In recent years drought were experienced in the country for three successive years viz. 1985-86, 86-87 and 87-88. The recurring incidents of droughts lead to reduction in streamflow, 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.

The present report describes the results of studies carried out for the year 1988-89 in six districts namely, Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar of Gujarat.

These districts lie in Saurashtra region which has mostly black soils which is poor in fertility causing the area prone to drought. These drought affected districts lie in cotton dry wheat zone and ground nut zone. The Saurashtra region are under rocks hence no tubewells are there for groundwater development.

The report includes analysis of rainfall and groundwater level data for finding effects of deficit of rainfall and trend of groundwater table as a result of drought incidents. The rainfall data have been analysed using various techniques for classification of drought. The report also includes description of land use, population pattern, soils, geology water resources statistics etc. of the state.

The groundwater level analysis carried out for all the six districts showed a declining trend as a result of reduced rainfall. The water table trend lines for pre and post monsoon periods in 1987-88 showed greater effects on water table as a result of monsoon failure as compared to previous years. In year 88-89, the pre and post monsoon water level has indicated a rise in almost all districts.

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 affecting (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 (Upadhya & 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, Gujarat, Rajasthan 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 1988-89 have 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 report, presents the results of studies carried out in six selected districts of State Gujarat for the year 1988-89. It has been reported that the state has experienced 10 drought years since 1960. The districts included for studies are Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar. The report is an attempt towards developing comprehensive hydrological drought index for characterizing drought situations. List of offices and places from where data and information were collected in the state of Gujarat are shown 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 Gujarat namely; Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar . The locations of the districts are shown in the state map shown in Fig. 2.2. The Gujarat state lies between the North latitude 20° 30' N and 24° 30' N latitudes and 68° 5' E to 73° 20' E longitudes and in the western most state of the country covering the area about 1,96,024 sq.km.

The Gujarat, the average annual precipitation over different parts of the State varies widely from 300 mm in the Western half of Kutch to 1500 mm in the Southern parts of the Valsad Districts and Dengs. The monsoon usually commences by the middle of June and withdraws by the end of September.

2.2 Population-Man & Cattle

The state of Gujarat has the population 4,11,74,000 as per census of 1991. The various details of population in Gujarat is shown in Table 2.1. During the year 1987-88 , nearly 8 lakhs cattle heads have been maintained in 1015 cattle camps specially opened by voluntary agencies for maintenance of cattle. Apart from cattle camps, gaushalas and Pangirapoles were also maintained for taking care of 2.22 lakhs cattle heads. On the whole nearly 10 lakhs cattle heads were brought under the umbrella of voluntary agencies in the year 1987-88 (Govt. of Gujarat, 1988-89) .

Table 2.1 : Population details in Gujarat State.

Sl.No.	Item	Unit	Population
POPULATION			
1.1 a.	Rural Population-1991	'000	27010
b.	Percentage to Total Population	%	65.60
1.2 a.	Urban Population-1991	'000	14164
b.	Percentage to Total Population	%	34.40
1.3	Total Population-1991	'000	41174
a.	Males	"	21271
b.	Females	"	19903

2.3 Land Use and Vegetal Cover

Budget publication no.28 of directorate of economics and statistics 1991-92 has compiled information on land use and vegetal cover statistics in the state. Accordingly, the areas under different land uses and their percentages to the reported

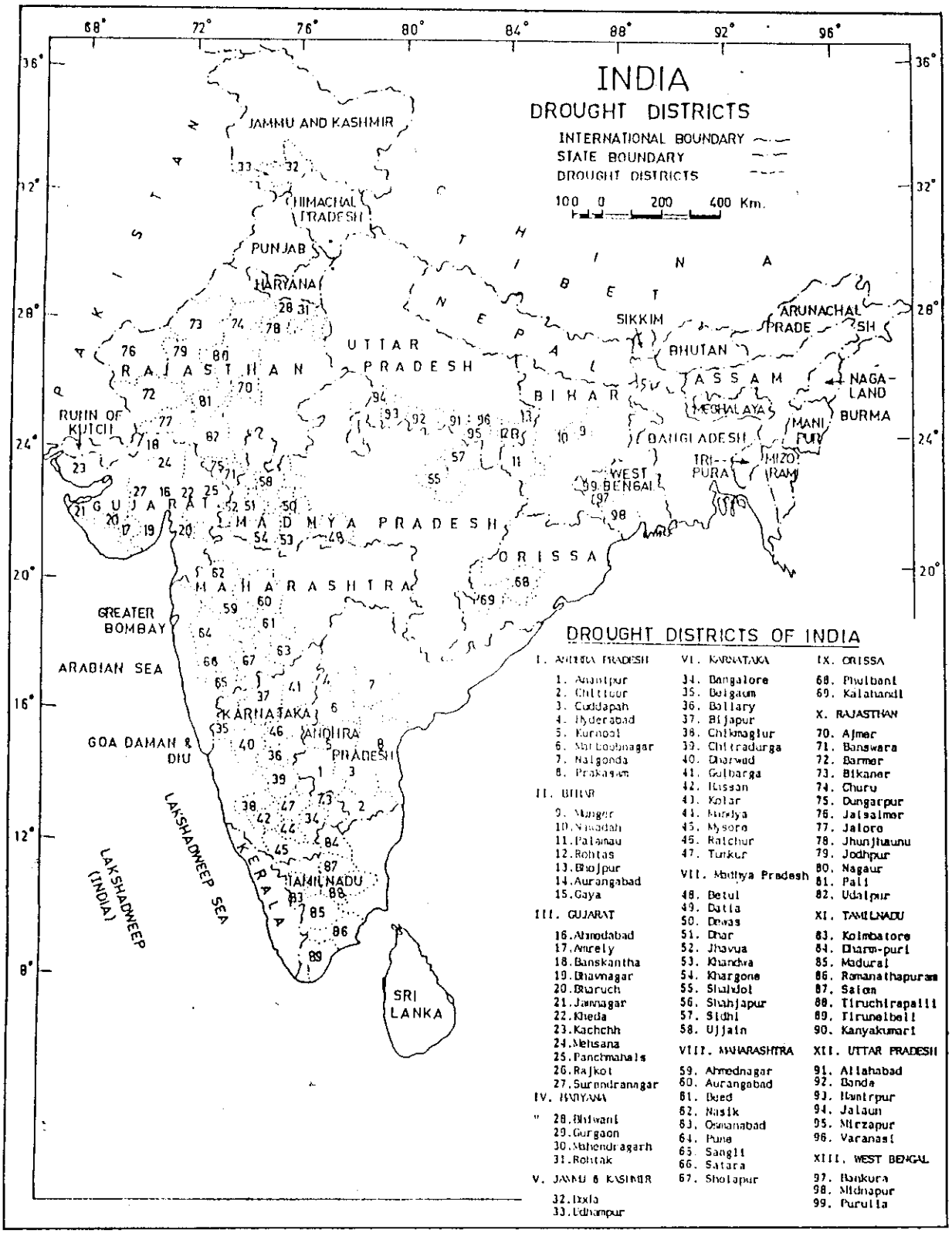


Fig. 2.1 DROUGHT PRONE DISTRICTS IN INDIA

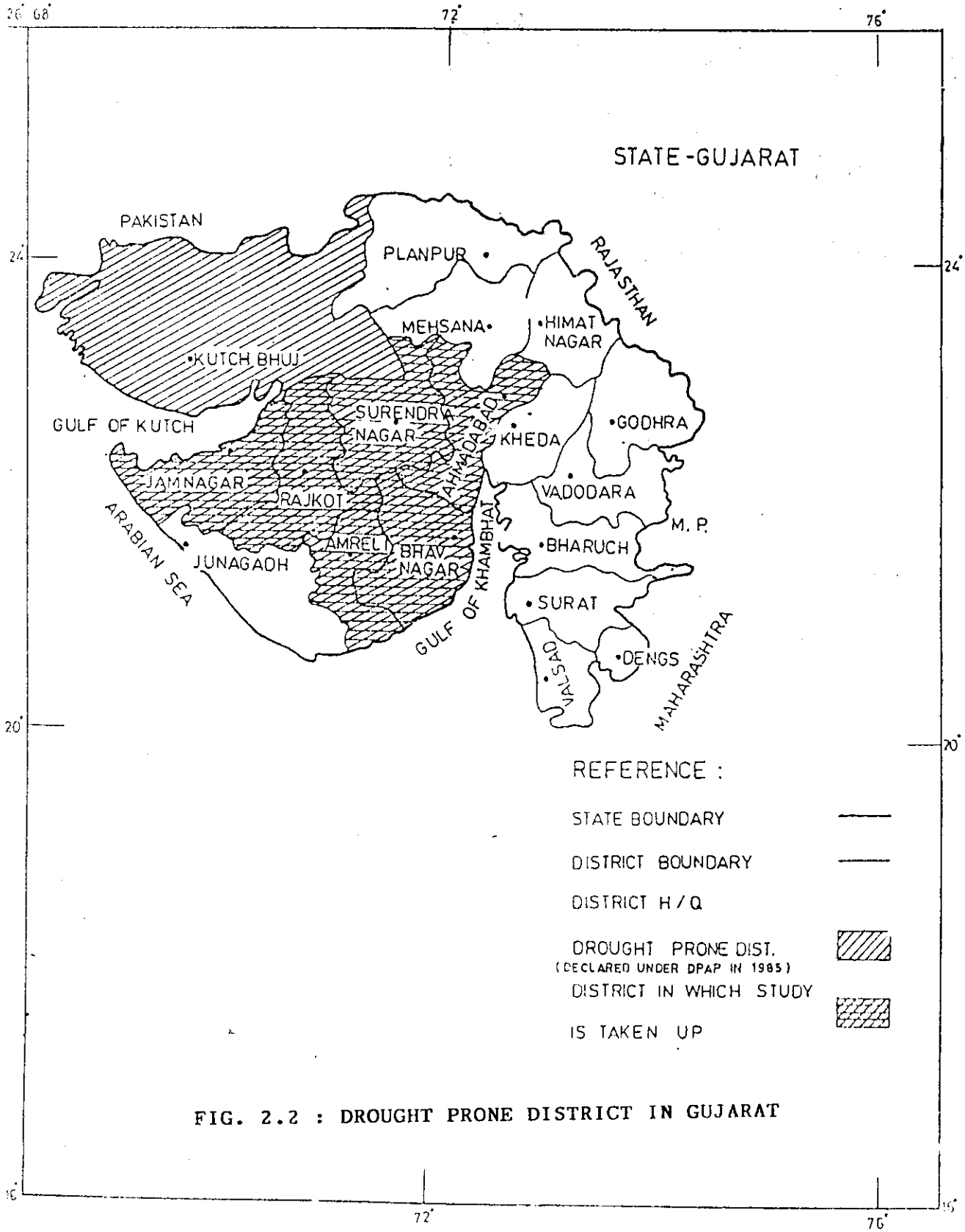


FIG. 2.2 : DROUGHT PRONE DISTRICT IN GUJARAT

geographical area for the year 1980-81 and 1986-87 are Table 2.2.

Table 2.2 : Average Land Use Particulars in the State of Gujarat (Unit : Lakhs).

Sl. No.	Type of Land	Area in Lakh ha.		Percentage with regard to reported geographical area of the state	
		1980-81	1986-87	1980-81	1986-87
1.	Forest	19.65	18.934	10.44	10.00
2.	Barren and Unculti-vable Land	25.03	26.77	13.3	14.22
3.	Land put to non-agricultural use	10.67	10.97	5.66	5.83
4.	Culturable waste land	19.85	19.31	10.55	10.26
5.	Permanent pasture & grazing land	8.48	8.45	4.5	4.49
6.	Land Under Misc. trees, crops & groves	0.04	0.04	0.02	0.02
7.	Current fallows	5.40	12.76	2.8	6.78
8.	Other fallows	3.32	0.43	1.76	0.23
9.	Net Area Sown	95.76	90.62	50.87	48.15
10.	Total Reporting Area	188.32	188.21		

Source: Budget Purification No.28, Directorate Economic and statistics, Govt. of Gujarat.

From Table 2.2 it is evident that percentage of forest cover has reduced from 1980-81 to 1986-87. The percentage of the land put to non agricultural use has increased to 5.83 in 1986-87 from 5.66 in 1980-81. However, it may be noted that there has been decrease in culturable waste land during the period of record. Even the net area available for cultivation also got increased to 20.05% in 86-87 which was reported as 18.96% in 80-81

2.4 Soils

The soils of Gujarat can be broadly classified into nine groups. These are black soils, mixed red and black soils, residual sand soils, alluvial soils, saline/alkali soils, lateritic soils, hilly soils, desert soils and forest soils. The soil map of the state is shown in Fig.2.3. As can be seen from the soil map, the Saurashtra region has mostly black soils which are poor in fertility causing this area prone to drought. The district of Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar which are taken up for study in this report have mostly black soils which are poor in fertility.

2.5 Surface Water Availability

In the State of Gujarat the ultimate and utilisable surface water availability in minor, medium and major irrigation schemes

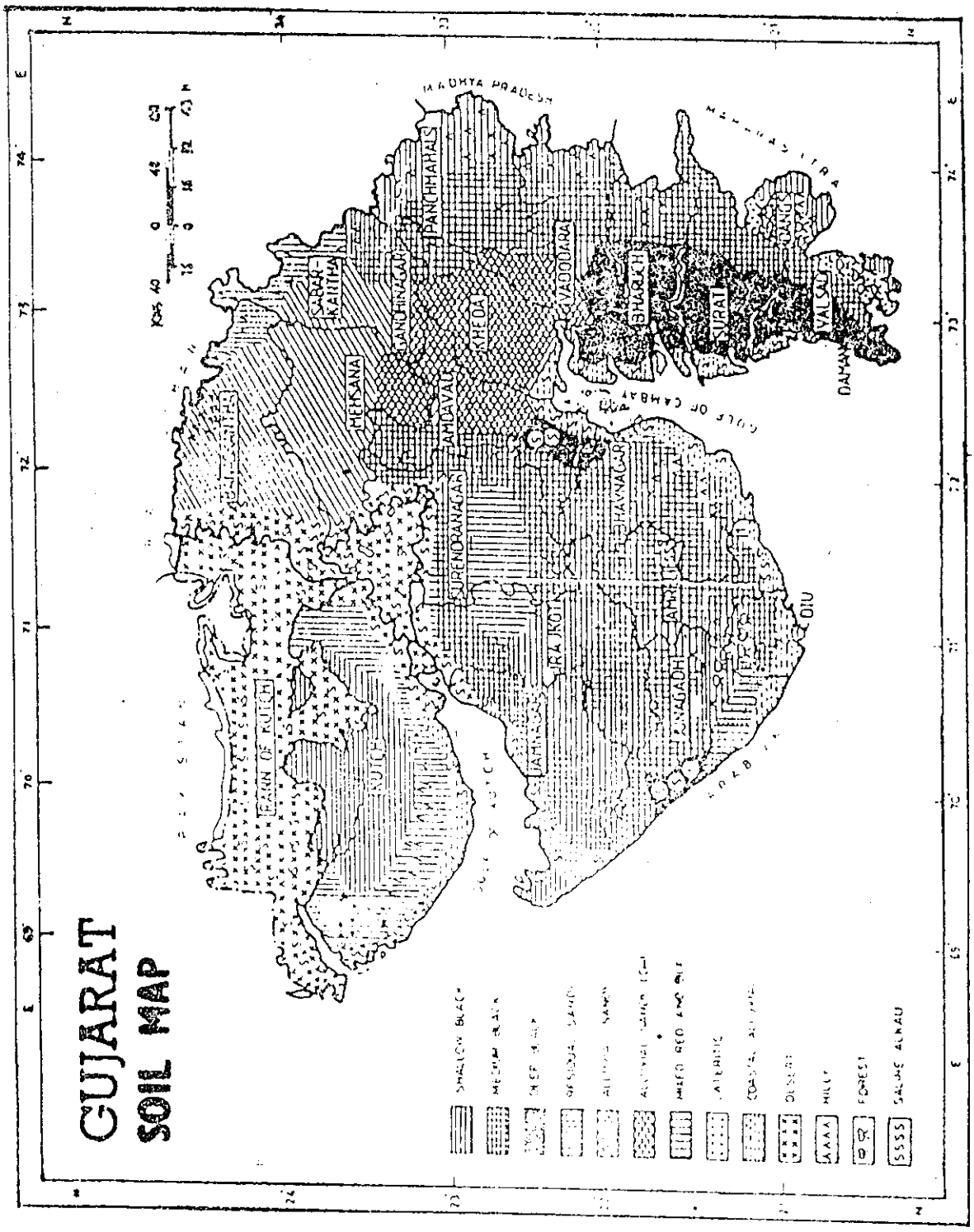


FIG.2.3: SOIL MAP OF STATE GUJARAT

of is the order of 2.95 M. ha. m and for Sardar Sarovar project alone it is 2.03 M.ha.m (Mistry and Goswami, 1988). The position of storages in the state for already completed, under completion and proposed projects are given in Table 2.3 (CWC, 1988).

Table 2.3: Storages in the projects of state Gujarat.

Sl.No.	Type of Projects	Gross storage in m.ha.m.	Live Storage in m.ha.m.
1.	Projects completed	1.498	1.275
2.	Projects under construction	1.353	0.931
3.	Total	2.851	2.206
4.	Proposed Projects	0.253	0.223

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

2.6 Ground Water Availability

It has been estimated that the total available ground water resources of the state are of the order of 1.73 M.ha.m. There are 16,935 tube wells spread over the state as per figure for the year 1982-83 given in Technical bulletin No.111 of Directorate of Agriculture, Gujarat. However, there are no tubewells in the Saurashtra region of Gujarat as most of the area is under rocks.

The recurreal occurrences of droughts in the state have had impacts on the ground water resources. Studies conducted by the Central Ground Water Board reveal that the continued drought conditions have brought progressive reduction in recharge component which against the continued ground water withdrawals resulted in the emergence of a lowering trend of ground water levels. Since the pattern of rainfall recharge, ground water withdrawals and hydrogeological set up were different in different regions of the state, the magnitudes of ground water level decline have also been different. Results of studies on estimation of ground water recharge, draft and average decline in water levels as conducted in three distinct regions of the state, namely; Saurashtra, kachchh and North Gujarat are presented in Table 2.4 (Mistry & Goswami, 1988). It can be observed that highest decline in water levels were observed in Kachchh followed by North Gujarat and Saurashtra in year 1987.

2.7 Water Use

The annual requirement of water in the state for domestic and live stock purposes during 1981 was of the order of 0.085 m.ha.m. which has been estimated to increase to a level of 0.1332 m.ha.m. by 1991 (C.W.C., 1988). Important major irrigation projects include Ukai, Kadana, Kakrapar, Mahi Right Bank Canal Project-I, Shatruni (Paliatana), Dantiwada, Hathmati, Meshwa and Bhadar. Besides, reservoirs have been constructed on Ganga, Karjan, Sukhi and Watrak projects are in full swing and works on Sardar Sarovar (Narmada) Project are in progress. Sourcewise area irrigated from 1983-84 to 1986-87 is given in Table 2.5. Area of different crops under irrigation in the year 1983-84 to 1986-87 is given in Table 2.6. The water availability and water requirement figures for drought prone districts of the

state are given in Table 2.7.

Table 2.4 : Impact on Ground Water Resource During Drought Years.

Year	Rainfall in mm.	Ground Water Recharge in MCM	Ground water Draft in MCM	Average decline (May) in water levels in m (Since May, 1984)
			SAURASHTRA	
	(Average annual rainfall : 550 mm; Area : 64,339 sq.km.)			
1984	506	6426	3737	-
1985	291	3400	3830 (Overdraft)	1.30
1986	398	4650	3925	2.50
1987	140	1635	2757 (Overdraft)	2.50
			KACHCH	
	(Average annual rainfall : 350 mm; Area : 54,652 sq.km.)			
1984	335	803	282	1.3
1985	222	509	289	1.3
1986	164	422	296	2.5
1987	Nil	Nil	148 (Overdraft)	5.7
			NORTH GUJARAT	
1984	706	4535	2292	-
1985	331	2764	2063	1.5
1986	299	2169	1856	3.3
1987	175	1269	1763 (Overdraft)	4.5

Source: Mistry and Goswami (1988).

Table 2.5 : Sourcewise Irrigated Area in Gujarat, (1,00 Hectares).

Sr. No.	Source	Year			
		1983-84	1984-85	1985-86	1986-87
1.	Government Canals *	4889	4340	3586	3309
2.	Wells $	17370	18570	16532	16099
3.	Tanks	407	280	253	190
4.	Other Sources	43	46	24	16
5.	Total Net Area Irrigated	22709	23236	20395	19614
6.	Gross Area Irrigated	27974	27103	23812	23006

*: Including Panchayat canals
$: Including Tubewells.
Source: Directorate of Agriculture, Gujarat State.

Table 2.6 : Irrigated area of Different Crops in Gujarat, (100 Hectares).

Sr. No.	Crops	Year			
		1983-84	1984-85	1985-86	1986-87
1.	Rice	2666	2760	2488	2393
2.	Wheat	5956	5085	3530	3081
3.	Jowar	302	307	353	473
4.	Bajra	1382	1370	1398	1510
5.	All Food Crops	15512	14767	12169	11922
6.	Cotton	4175	4390	5129	4710
7.	Groundnut	2690	1760	934	832
8.	Tabocco	792	847	859	825
9.	All Non-food Crops	12462	12336	11643	11084
10.	Gross Area Irrigated	27974	27103	23812	23006

Source: Directorate of Agriculture, Gujarat State.

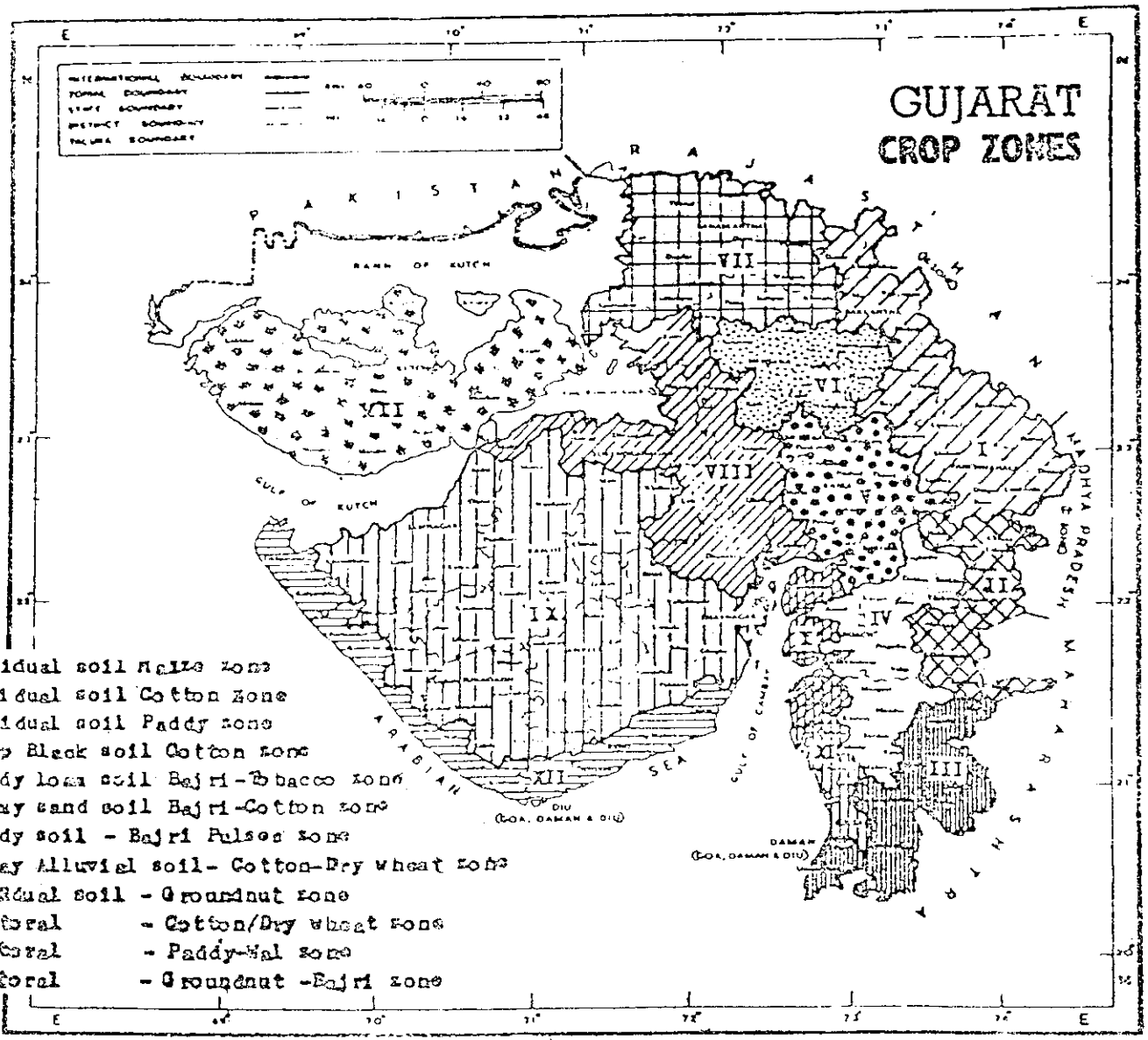
Table 2.7: Water availability and water requirement for drought prone districts (Unit : Cubic Km.)

Sl.No.	District	Water Availability		Total water Requirement
		50% Dependability	75% Dependability	
1.	Ahmedabad	4.57	3.88	2.71
2.	Amreli	0.39	0.34	3.32
3.	Banaskantha	3.37	2.61	2.40
4.	Bhavnagar	0.68	0.68	0.72
5.	Bharauch	3.03	2.11	2.53
6.	Jamnagar	0.45	0.41	0.51
7.	Kheda	4.53	3.92	3.45
8.	Kachch	1.29	0.90	0.90
9.	Mehsana	1.62	1.45	1.94
10.	Panchmahal	2.93	1.80	1.61
11.	Rajkot	2.21	1.28	1.24
12.	Surendranagar	2.48	2.48	2.39

Source: CWC 1988.

2.8 Crops and Fodder

On the whole the state has been divided in to 12 crop zones, (Fig.2.4). Most of the drought affected districts lie in crop zone Nos. VIII & IX which are cotton-dry wheat zone and ground nut zone, respectively. Table 2.8 shows important crops grown in each district seasonwise. Table 2.9 gives the figures of area production and yield per hectare of principal crops in the state for the year 1981-82 to 1990-91 (Directorate of Agriculture, Gujarat state).



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Zone-I Residual soil Maize zone
Zone-II Residual soil Cotton Zone
Zone-III Residual soil Paddy zone
Zone-IV Deep Black soil Cotton zone
Zone-V Sandy loam soil Bajri-Tobacco zone
Zone-VI Loamy sand soil Bajri-Cotton zone
Zone-VII Sandy soil - Bajri Pulses zone
Zone-VIII-Clay Alluvial soil- Cotton-Dry wheat zone
Zone-IX Residual soil - Groundnut zone
Zone-X Littoral - Cotton/Dry wheat zone
Zone-XI Littoral - Paddy-Val zone
Zone-XII Littoral - Groundnut -Bajri zone

Source: Technical Bulletin No.III, Govt. of Gujarat,1987.

Fig. 2.4: Crop zones of state Gujarat.

Table 2.8 : List of important crops grown in each district (seasonwise).

Sr. No.	District	Kharif crops	Rabi crops	Hot-weather crops
1	2	3	4	5
1.	Ahmedabad	Paddy, Bajri, G'nut Jowar, Hy.Castor Cotton deshi & Hy.	Wheat (Dry), Wheat (Irri.) Gram, Mustard, Cumin	Bajra
2.	Banaskantha	Bajri, Jowar, Pulse Guwar, Castor Cotton, Maize/ Fennel	Wheat,Mustard, Cumin,Isabgul, Gram,Potato	Bajri,Mug
3.	Baroda	Cotton,Paddy,Jowar Bajri, Tobacco,G'nut Pulse,Vegetable Pegionpea (Tur) Soyabean	Rabi Jowar, Wheat,Gram Maize,Mustard Vegetable	Bajri,G'nut (Erract) Maize Vegetables Mug
4.	Bharuch	Cotton,Jowar,Paddy Pegion Pea (Tur) Bajri Soyabean	Wheat (Dry), Wheat (Irri.) Jowar, Gram, Sunflower Vegetables/ Pulse	
5.	Bulsar	Paddy,Sugarcane Maize, Kharsani	Limabean; Sugarcane Wheat, Vegetables Jowar, Pegion Pea (Tur)	Sugarcane Paddy, Cowpea, Mug
6.	Dangs	Paddy, Nagli,Wari	Gram,Wheat	
7.	Gandhinagar	Bajri, Paddy,Castor Pulse,Vegetables Cotton	Wheat,Mustard, Gram,Vegeta- bles, Grass	Bajri,Pulse Vegetables
8.	Kheda	Paddy, Bajri, Tobacco, Cotton, Maize, Pegion pea (Tur) Ginger Turmeric, Jowar, Fennel	Wheat,Mustard, Potato,Tobacoo (Calcutti) Vegetable Sunflower, Chilly,Onion Grass	Mug,Cowpea Grass, H.W. G'nut (Erract) Hy.Bajri

Contd.

1	2	3	4	5
9.	Mehsana	Hy.Bajri,Hy.Castor Cotton,Jowar,Pulse, Sesamum,Vegetable Chilly/Fennel	Wheat,Cumin, Mustard, Isabgul,F. grick,Tobacco Lucern,Cow-pea	Hy.Bajri G'nut,Pulse Mug
10.	Panchmahal	Maize,Paddy,G'nut Hy.Bajri,Cotton, Jowar	Wheat,Mustard, Gram, Cumin, Maize	Bajri,Maize G'nut(Errect) Pulse,Mug, Cow-pea
11.	Sabarkantha	Cotton,Maize,Bajri, G'nut,Paddy,Pegion pea (Tur), Pulse Sesamum,Castor	Wheat,Mustard, Gram, Cumin, Maize,Isabgul	Bajri,Maize G'nut (Errect) Pulse, Mug Cow-pea
12.	Surat	Sugarcane, Paddy Hy.Cotton,Jowar, G'nut, Pegion pea Pulse, Banana	Wheat, Gram, Pulse, Jowar, Limabean	G'nut,Paddy Mug,Cow-pea
13.	Amreli	G'nut, Bajri, Jowar, Cotton Sesamum	Wheat,Mustard Cumin	G'nut,Pulse
14.	Bhavnagar	G'nut,Bajri,Cotton, Sesamum, Jowar Soyabean	Wheat,Cumin, Onion	G'nut
15.	Jamnagar	G'nut,Bajri,Cotton, (Dry & Irri.),Chilly Pulse,Sesamum, Castor,Sugarcane Sunflower,Soyabean	Potato,Wheat, Garlic,Onion, Gram,Mustard, Cumin, Isabgul	G'nut,Bajri
16.	Junagadh	G'nut,Hy.Bajri, Cotton, Jowar, Pulse,Sunflower	Wheat,Mustard, Cumin, Gram, Sugarcane,Jowar Vegetable Garlic/Onion	G'nut,Bajri
17.	Kutch	G'nut,Bajri,Pulse, Cotton,(Dry & Irri.) Jowar,Castor,Sesamum	Wheat,Mustard	G'nut,Bajri
18.	Rajkot	G'nut,Cotton,Bajri, Jowar,Sunflower,	Wheat,Mustard, Cumin,Sugarcane,	G'nut,Bajri Garlic
19.	Surendra-nagar	Cotton,Bajri,Jowar, Sesamum,G'nut, Vegetable	Wheat,Mustard, Gram,Vegetable Maize,Cumin	G'nut,Bajri Jowar,Maize

Source: Technical Bulletin No.111, 1987, Govt. of Gujarat.

Table 2.9: Statement showing area, production and yield of important food and nonfood crops in Gujarat State.
(Area in 000 Hectares, Production in 000 Tonnes, Yield in Kg)

Sl. No.	Crops	APY	Year 1984-85	1985-86$	1986-87$	1987-88*	1988-89*	1989-90*	1990-91*
1	2		3	4	5	6	7	8	9
1.	Rice	A	627	585	556	347	536	601	531
		P	940	550	534	279	870	817	791
		Y	1499	940	960	804	1623	1360	1490
2.	Wheat	A	672	507	377	192	649	619	717
		P	1393	887	722	351	1512	1102	1444
		Y	2073	1750	1912	526	781	1179	2014
3.	Jowar	A	1083	1134	1127	526	781	873	853
		P	606	420	309	125	425	433	379
		Y	560	370	275	238	544	497	444
4.	Bajra	A	1509	1506	1493	786	1489	1332	1152
		P	1666	713	1162	346	1488	1325	1925
		Y	1104	473	778	440	999	995	889
5.	Maize	A	328	309	339	275	337	323	369
		P	397	110	476	93	456	480	530
		Y	1210	356	1404	338	1353	1486	1436
6.	Total Cereals	A	4416	4213	4049	2214	3832	3842	3690
		P	5166	2762	3271	1219	4835	4220	4217
		Y	1170	656	808	551	1230	1098	1143
7.	Tur	A	404	360	369	325	337	382	402
		P	304	264	146	111	251	319	352
		Y	752	733	396	342	744	834	877
8.	Gram	A	121	87	57	20	107	110	170
		P	105	45	32	11	66	66	116
		Y	868	511	569	550	609	606	681
9.	Total Pulse	A	975	870	827	483	771	891	932
		P	690	385	270	143	491	567	627
		Y	708	443	327	296	637	637	673
10.	Total Food-grains	A	5391	5083	4875	2697	4703	4733	4622
		P	5856	3147	3541	1361	5326	4788	4843
		Y	1086	619	726	505	1132	1012	1048
11.	Cotton **	A	1334	1451	1322	719	1091	1187	921
		P	2159	2122	1157	295	1470	1756	1323
		Y	275	249	149	70	229	251	244
12.	Groundnut	A	2091	1868	1827	1051	1823	2072	1702
		P	1596	473	1328	140	2875	1694	1053
		Y	763	253	727	133	1577	818	619
13.	Tobacoo	A	131	129	117	82	90	113	110
		P	202	204	202	122	151	183	193
		Y	1542	1581	1736	1488	1678	1624	1760

$ Revised
* Based on final forecast
** In '000 bales of 170 kgs. each
A = Area, P = Production, y = Yield per hectare
Source: Directorate of Agriculture, Gujarat State.

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 as follows:

2.9.1 Jamnagar

The district of Jamnagar forms part of Saurashtra region and the Irrigation Commission (1972) and other agencies have identified it as drought prone. The district has an area of 10143 sq.km. and a population of 1390125 according to the census figures of 1981. The district comprises of nine taluks i.e. Bhanwan, Dhroi, Jamjodhpur, Jamnagar, Jodia, Kalwad, Kalyanpur, Khambhalia Lalpur and Okhamandal.

The normal rainfall of all the taluks is generally less than 750 mm. The district gets about 93 percent of the total rainfall from south-west monsoon. The district is mainly drained by 14 rivers. The soils of the district are broadly classified as Alluvial black, alluvial light brown and alkaline soil. The evaporation and evapotranspiration losses in the district vary between 245.4 mm to 94.4 mm from summer to winter months. Most of the villages of the district depend for their domestic water requirements on wells. In summer months many wells go dry due to the lowering of water table. In drought years particularly, this problem gets very much aggravated and severe. There are two cropping seasons i.e. Kharif from June to October and Rabi from October to April. More than 91 percent of crops are fed by monsoon rains in Kharif season. The rest of the 9 percent of cropped area comes under Rabi cultivation. The main crop of the district are Jowar, Paddy, Bajra, Cotton, Groundnut and Wheat. The map of district showing location of raingauges and groundwater observation wells which have been chosen for analysis is shown in Figure 2.5.

2.9.2 Rajkot

The district of Rajkot forms a part of Saurashtra region & the Irrigation Commission (1972) and other agencies have identified it as drought prone. The district has an area of 11152.3 sq.km. and a population of 2058136 according to the provisional census figures of 1981. The district comprises of 13 taluks viz. Dhoraji, Gondal, Jamkandorna, Jasdan, Jetpur, Kotda-Sangani, Lodhika, Morvi, Malia, Paddhari, Rajkot, Uplete and Wankaner. The normal rainfall of all the taluks is generally less than 750 mm except Paddhari taluk. The district gets about 93 percent of the total rainfall from South-West monsoon. The district is mainly drained by the river Bhoalan, Machhu & Aji. The soil of the district are broadly classified as medium black, Alluvial black (Salty) and mixed red soil. The evaporation and evapotranspiration losses in the district vary between 302.4 mm to district, the domestic water requirements is mostly met by wells which go dry due to the lowering of water table in summer. The main crops of the district are Jowar, Paddy, Bajra, Cotton, Groundnut and Wheat. The location of raingauges and groundwater

observation wells is shown in the district map given as Fig.2.5.

2.9.3 Ahmedabad

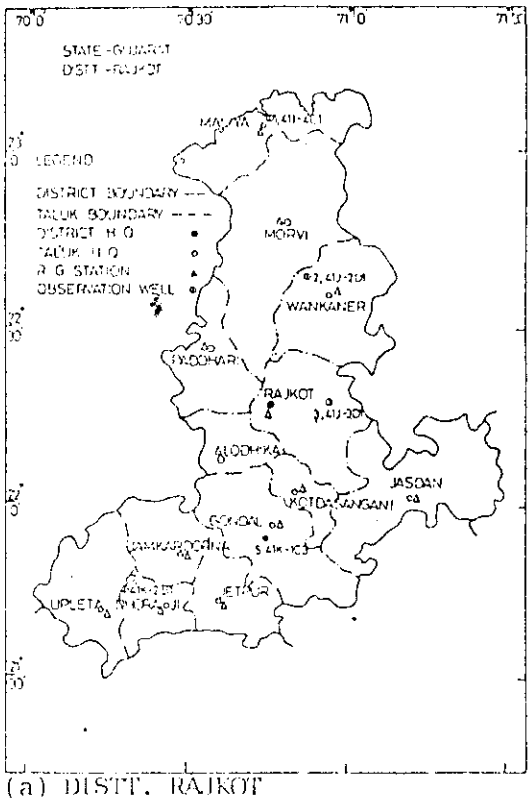
The district of Ahmedabad forms a part of North Gujarat & the irrigation Commission (1972) and other agencies have identified it as drought prone. The district has an area of 87707 sq. kms. and a population of 38,40,472 according to census figures of 1981. The district comprises of seven taluks viz. Dehgam, Ahmedabad city, Daskroi Dholka, Dhandhuka, Sanand and Viramgam talukas. The normal annual rainfall of all the talukas is generally less than 750 mm except Ahmadabad city and Daskroi taluks in which it is marginally more than 750 mm. The district gets 675.1 mm rainfall (i.e. 95.9 percent of the annual rainfall) from South-West monsoon. The district is mainly drained by the river Sabarmati along with its tributaries Khari, Vatrau, Meshwo and Bhogawo. The soils of the district are broadly classified into five types viz. i) Black soil ii) medium black soil iii) red clay or Goradu soil iv) red sand or Kyari soil and v) rocky soil or mixed saline evaporation and evapotranspiration losses in the district vary between 234.8 mm to 73.9 mm from Summer to winter months, respectively. Most of the villages of the district depend for their domestic water requirements on 25,658 number of wells. The main crops of the district are Jowar, Paddy, Pulses, Wheat, Groundnut, Bajra, Castors & Cotton etc. The location of raingauges and groundwater observation wells is shown in the district map as given in Figure 2.6.

2.9.4 Surendranagar

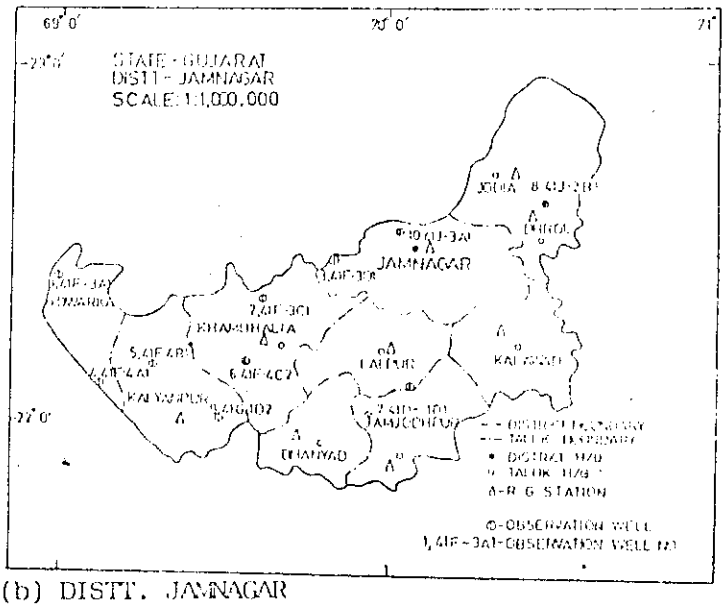
The district of Surendranagar forms a part of Saurashtra region and the Irrigation Commission (1972) and other agencies have identified it as drought-prone. The district has an area of 10443.8 sq.km. and a population of 1033423 according to the census figures of 1981. The district comprises of 9 taluka viz. Chotila, Dasada, Dharamgadhra Halvad, Lakhtar, Limbdi, Mali, Sayal aand Wadhwan. The normal rainfall of the taluks is generally less than 750 mm. The district gets about 94.55 percent of the total rainfall from South-West monsoon. The district is mainly drained by the river Kankavati, Limdi Bhogaro, Bhamini, Chandrabhaga & Falka. The soils of the district are broadly classified as Medium black, Light Sand soil, red soil, alluvial, and rocky soil. Evaporation and Evapotranspiration losses in the district varies between 120.7 mm to 302.4 mm from winter to Summer months. The source of drinking water in most of the villages is groundwater. The main crops of the district are Jopwar, Paddy, Bajra, Cotton, Groundnut and Wheat. Locations of raingauges and groundwater observation wells in the district map are shown in Figure 2.6.

2.9.5 Amreli

The district of Amreli forms a part of Saurashtra region and the Irrigation Commission (1972) and other agencies have identify it as drought prone. The district has an area of 6711.4 sq.km. and a population of 10,75,766 according to the census figures of 1981. The district comprises of 10 talukas viz. Amreli, Babra, Dhari, Zafrabad, Khambat, Kodinar, Kankaravat, Lathi, Lilia and Rajula. The normal rainfall of all the talukas is generally less

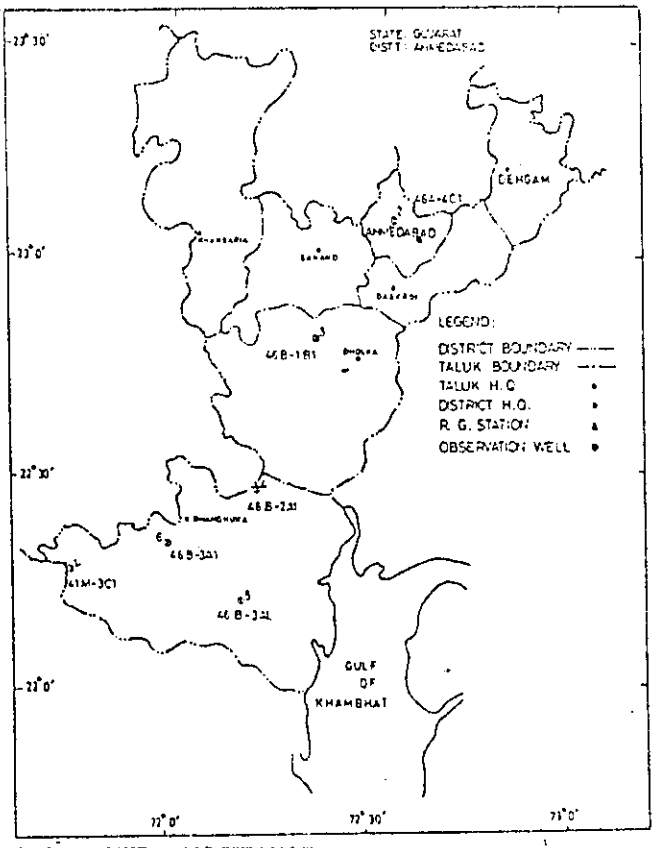


(a) DISTT. RAJKOT

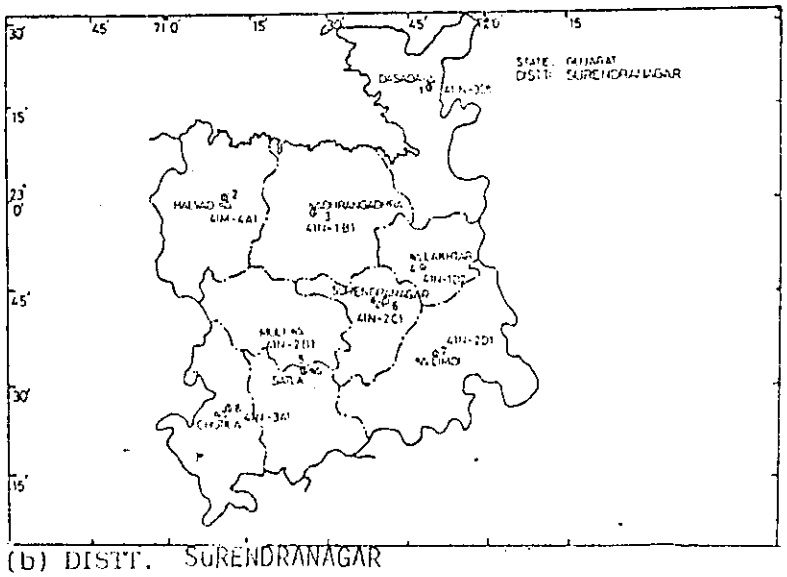


(b) DISTT. JAMNAGAR

DISTT. 2.5 LOCATION OF RAINGAUGE STATION AND GROUNDWATER WELL



(a) DISTT. AHMEDABAD



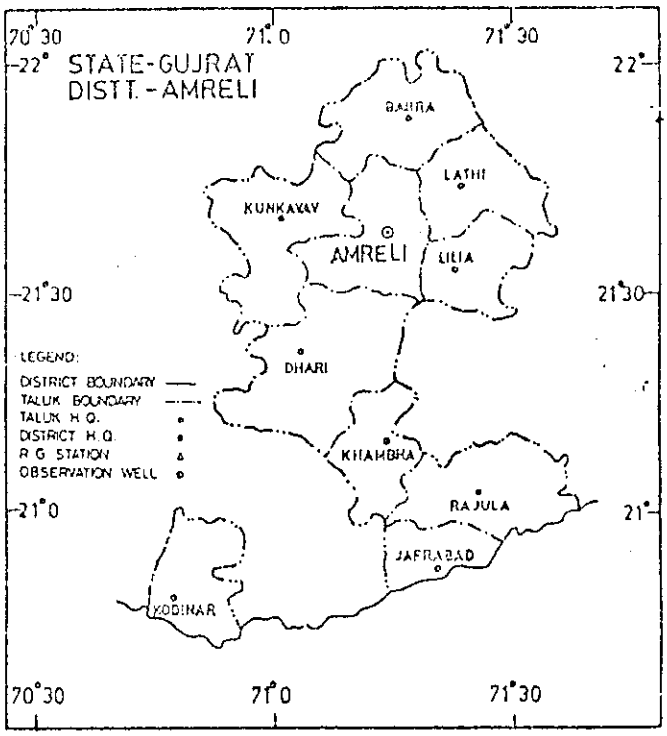
(b) DISTT. SURENDRANAGAR

FIG. 2.6: LOCATION OF RAINGAUGE STATION AND GROUND WATER WELL

than 750 mm. The district gets about 91.01 percent of total rainfall from South-West monsoon. The district is mainly drained by the river Shetrunji, Ghelo and Kalubhar. The soils of the district are broadly classified as medium blacks, coastal alluvial, and rocky soil. The evaporation and evapotranspiration losses in the district vary between 302 mm to 136.6 mm from summer to winter months. the domestic water supply in the villages,is by wells. The main crops of the district are Jowar, Paddy, Bajra, Cotton, Groundnut and Wheat. The Fig. 2.7 shows location of raingauges and groundwater observation wells which have been chosen for analysis.

2.9.6 Bhavnagar

The district of Bhavnagar forms a part of Saurashtgra region and the Irrigation Commission (1972) and other agencies have identified it drought prone. The district has an area of 9786.30 sq.km. and a population of 18,76,471 according to the census figures of 1981. The district comprises of twelve talukas viz. Bhavnagar, Botad, Gadhada, Gariadhar, Ghogha, Mahuva, Palitana, Savarkundla, Sihor, Talaja, Umral and Vallabhipur. The normal rainfall of the talukas is generally less than 750 mm. The district gets about 92.27 percent of the total rainfall from South-West monsoon. The district is drained by 11 rivers namely: Shetrunji, Ghelo, Kalubhar, Vagad, Kalbi, Padala, Keri, Goma, Dhatarwadi, Surajvadi, Malan, Bagad & Ranghola. Their soil of the district are broadly classified as medium black soil, coastal Sandy, alaluvial soil, light murrain soil, clayey lime soil and clay alluvial soil. The evaporation and evapotranspiration losses in the district have been recorded to vary between 245.4 mm to 94.4 mm from summer to winter. The ground water is the main source of domestic water supply in most of the villages of the district. The main crops of the district are Jowar, Paddy, Bajra, Cotton, Groundnut and Wheat. Figure 2.7 draws location of raingauges and groundwater wells in the district map.



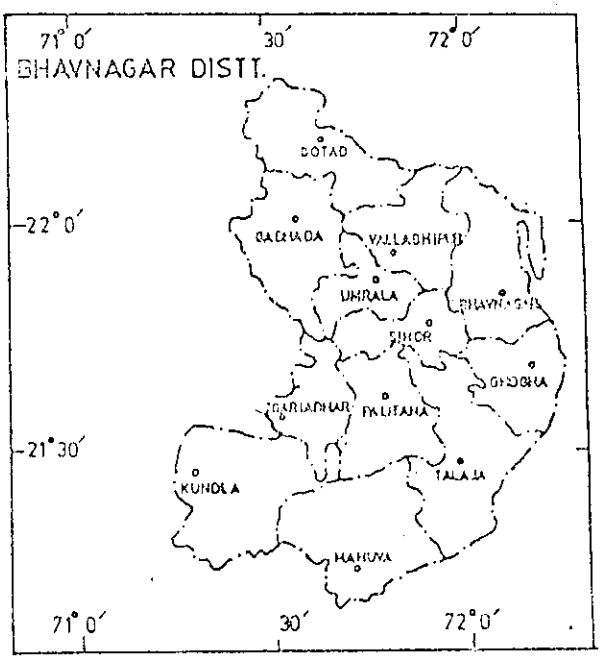


Fig.2.7 : LOCATION OF RAINGAUGE STATION AND GROUND WATER WELL

3.0 RAINFALL ANALYSIS

3.1 General

As has already been described in chapter 2.0, six district, namely Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar from the state of Gujarat have been taken up for rainfall analysis in the present report. One representative raingauge station from each taluk in each of the six district has been selected for the study. The locations of raingauges on the district maps have been shown in figures present 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 1980 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 Gujarat.

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 Gujarat 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 six districts namely Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar experienced positive departures in seasonal rainfall during year 1988-89. This indicates that the year 1988 experienced normal range conditions.

It was also observed that all the districts in the state have been experiencing seasonal rainfall deficits of more than 20% since water year 1984-89 indicating continued occurrence of water shortage in these districts affecting the economy of the region in these districts and also creating high water scarcity in the region during 1984-87.

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

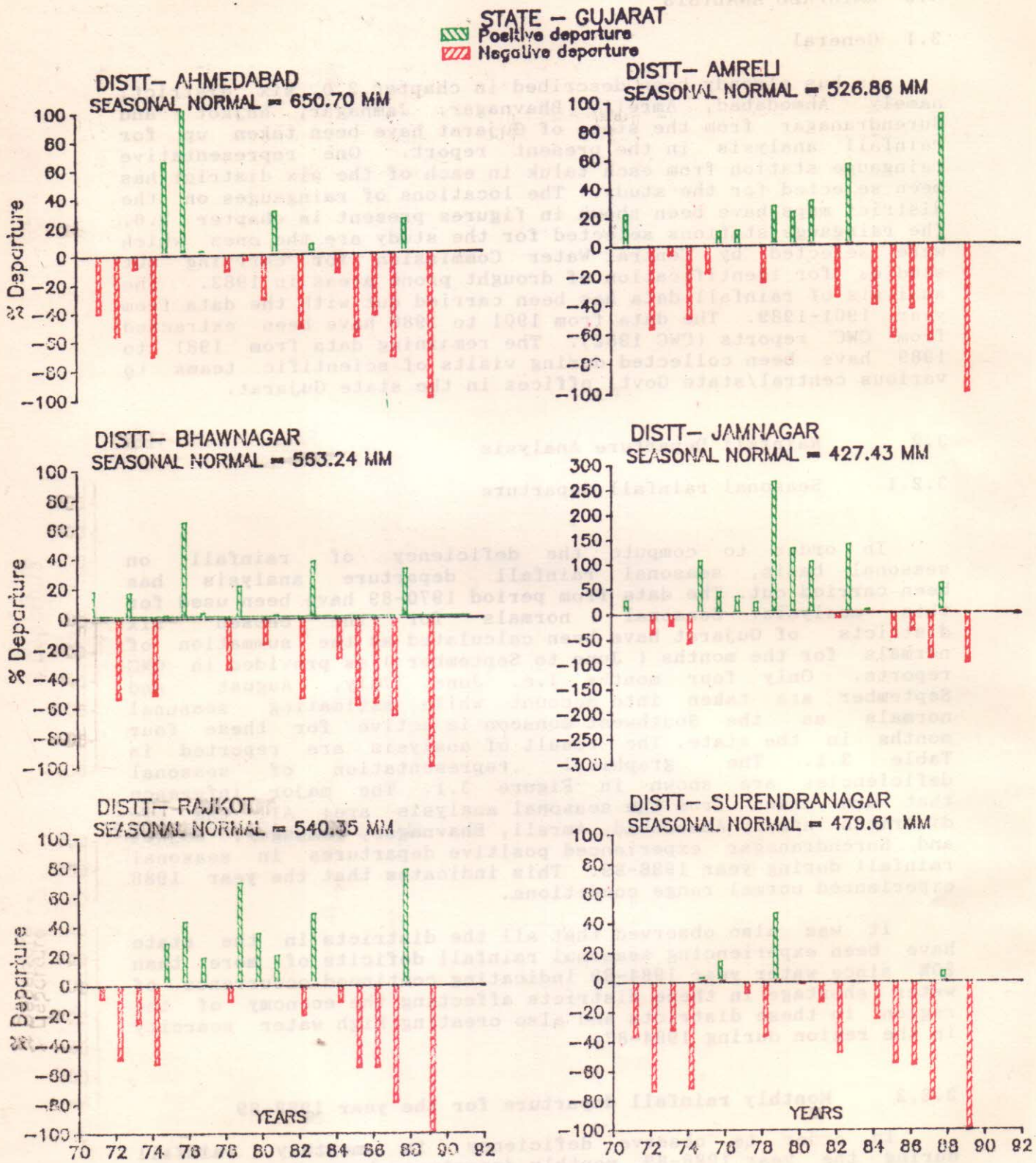


Fig. 7.1 Districtwise seasonal rainfall departure.

all the taluks and districts as a whole. Monthly rainfall values from June 1988 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.

Table 3.1 : Percent departure of seasonal rainfall for districts of Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar of State Gujarat.

Gujarat	Districts of Gujarat					
	Ahmedabad	Amreli	Bhavnagar	Jamnagar	Rajkot	Surendra-nagar
Seasonal Normal, mm	650.70	526.86	563.24	427.43	540.35	479.61
70	25.81	26.50	67.80	92.29	71.12	60.80
71	-40.04	21.36	16.61	24.34	- 9.20	-36.20
72	-55.76	-56.35	-53.92	-38.73	-50.20	-73.28
73	- 8.93	- 5.78	15.74	-22.75	-25.87	-32.05
74	-70.23	-49.29	-51.58	-57.40	-53.00	-71.58
75	64.24	-18.54	0.69	104.66	27.21	1.95
76	102.04	9.02	63.39	41.40	42.03	13.15
77	1.64	9.68	2.29	32.64	17.53	- 7.46
78	-10.92	-24.73	-34.17	20.96	-10.95	-36.45
79	- 3.33	26.11	20.28	263.57	68.36	45.77
80	-31.30	21.74	-17.09	128.96	34.28	- 1.26
81	28.60	29.22	0.83	102.06	19.18	-13.95
82	-51.71	-35.21	-53.94	- 9.14	-20.19	-47.55
83	5.42	54.28	36.86	136.67	47.49	0.11
84	-13.36	-40.45	-27.47	5.10	-11.47	-25.14
85	-57.99	-64.30	-59.01	-48.81	-55.23	-54.71
86	-43.04	-43.43	-57.48	-35.51	-55.26	-56.09
87	-72.11	-65.26	-65.86	-90.42	-79.20	-79.65
88	22.26	88.02	31.45	56.27	77.08	6.26

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 all the six districts have shown in Figs. 3.3.

The results of monthly departure analysis for the districts as a whole are presented in Table 3.2. Based on the Monthly departure values, two categories of monthly departures i.e. 20-50% and more than 50% have been made for driving monthly

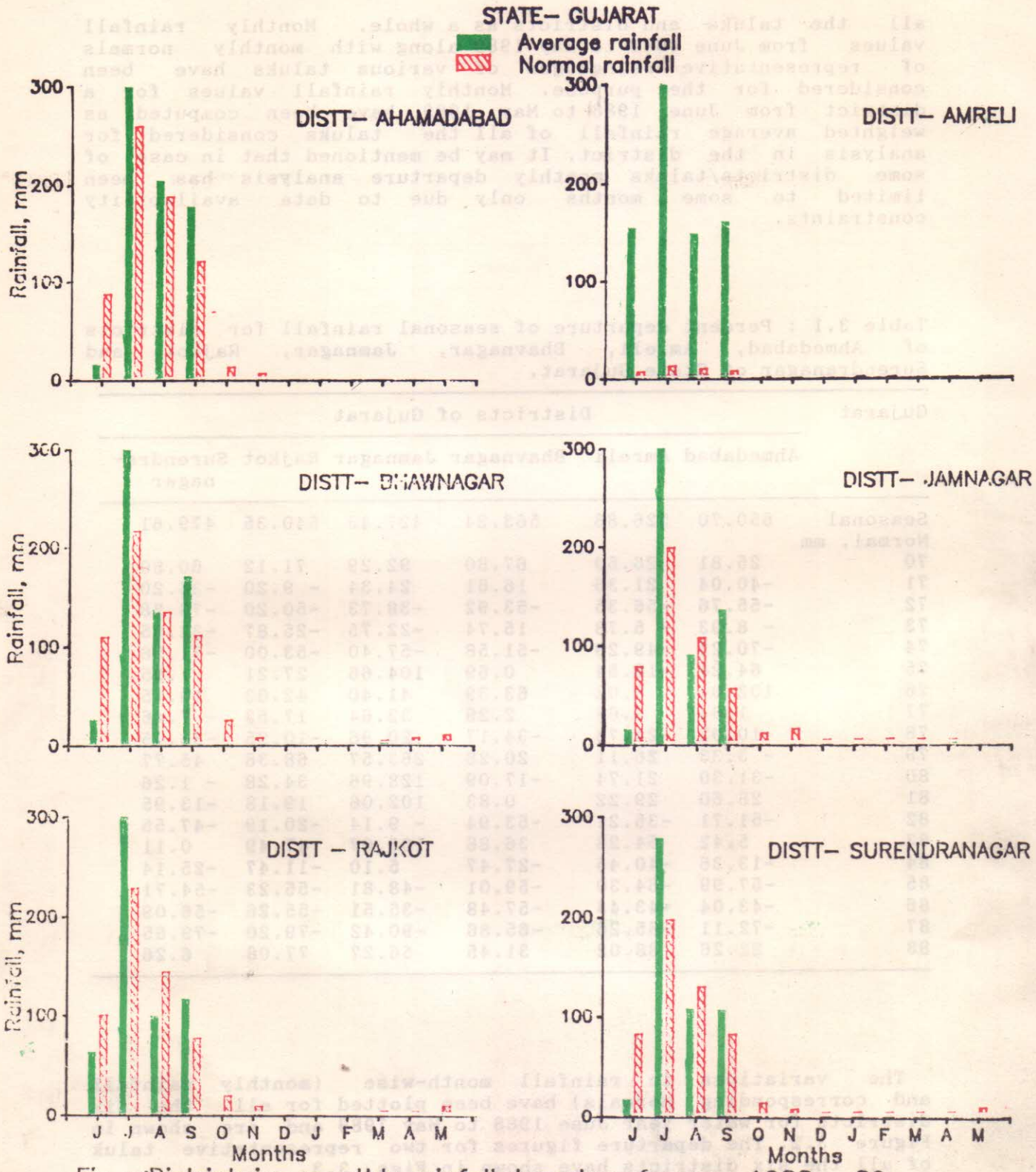


Fig. 3.2 Districtwise monthly rainfall departure for year 1988 – 89.

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, 3.3 and Table 3.3.

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

Year/Month	Districts of Gujarat, Percent departure					
	Ahmedabad	Amreli	Bhavnagar	Jamnagar	Rajkot	Surendra-nagar
1988 June	-81.43	36.69	-76.11	-79.34	-35.71	-78.37
1988 July	53.63	143.78	89.82	118.70	199.79	43.40
1988 Aug.	9.85	31.9	3.31	-13.39	-29.68	-14.99
1988 Sept.	48.31	87.77	56.90	156.00	55.67	34.23
1988 Oct.	-93.47	-99.68	-93.40	-97.51	-96.53	-41.87
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.	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
1989 Feb.	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
1989 March	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
1989 April	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
1989 May	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00

Table 3.3: Monthly Rainfall Deficits in District as a whole during 1988-89.

State	Months	Group of range of deficiency in rainfall (expressed in percentage of normals)	
		20 to 50%	50% and above
Gujarat	June'89	Rajkot	Jamnagar, Ahmedabad, Surendranagar, Bhavnagar
	July	Nil	Nil
	August	Rajkot, Jamnagar, Surendranagar	Nil
	September	Nil	Nil
	October		Amreli, Bhavnagar, Rajkot Jamnagar, Surendranagar, Ahmedabad
	November 89 to May 90		Jamnagar, Surendranagar, Amreli, Ahmedabad, Rajkot, Bhavnagar

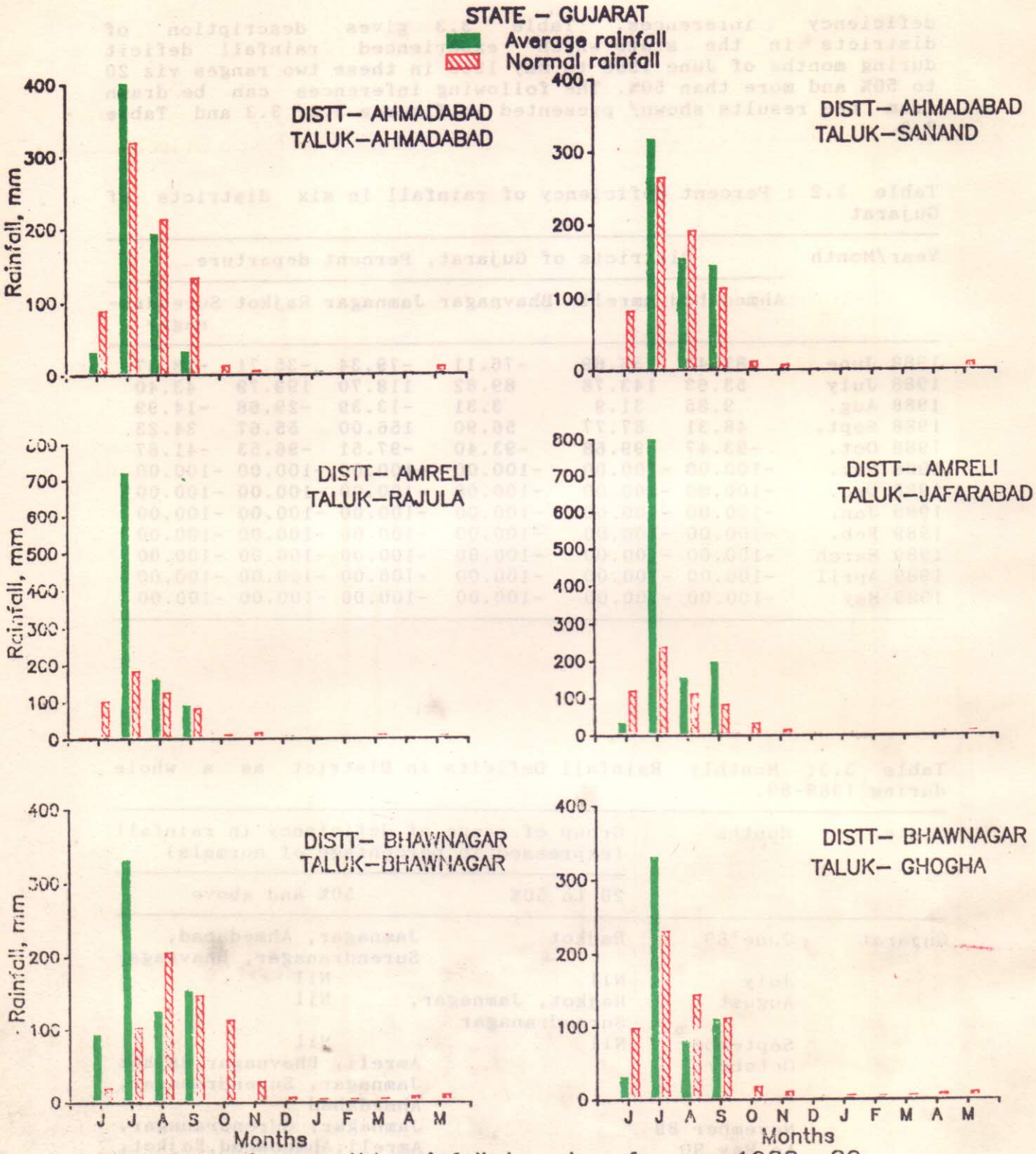


Fig.33:Talukwise monthly rainfall departure for year 1988– 89.

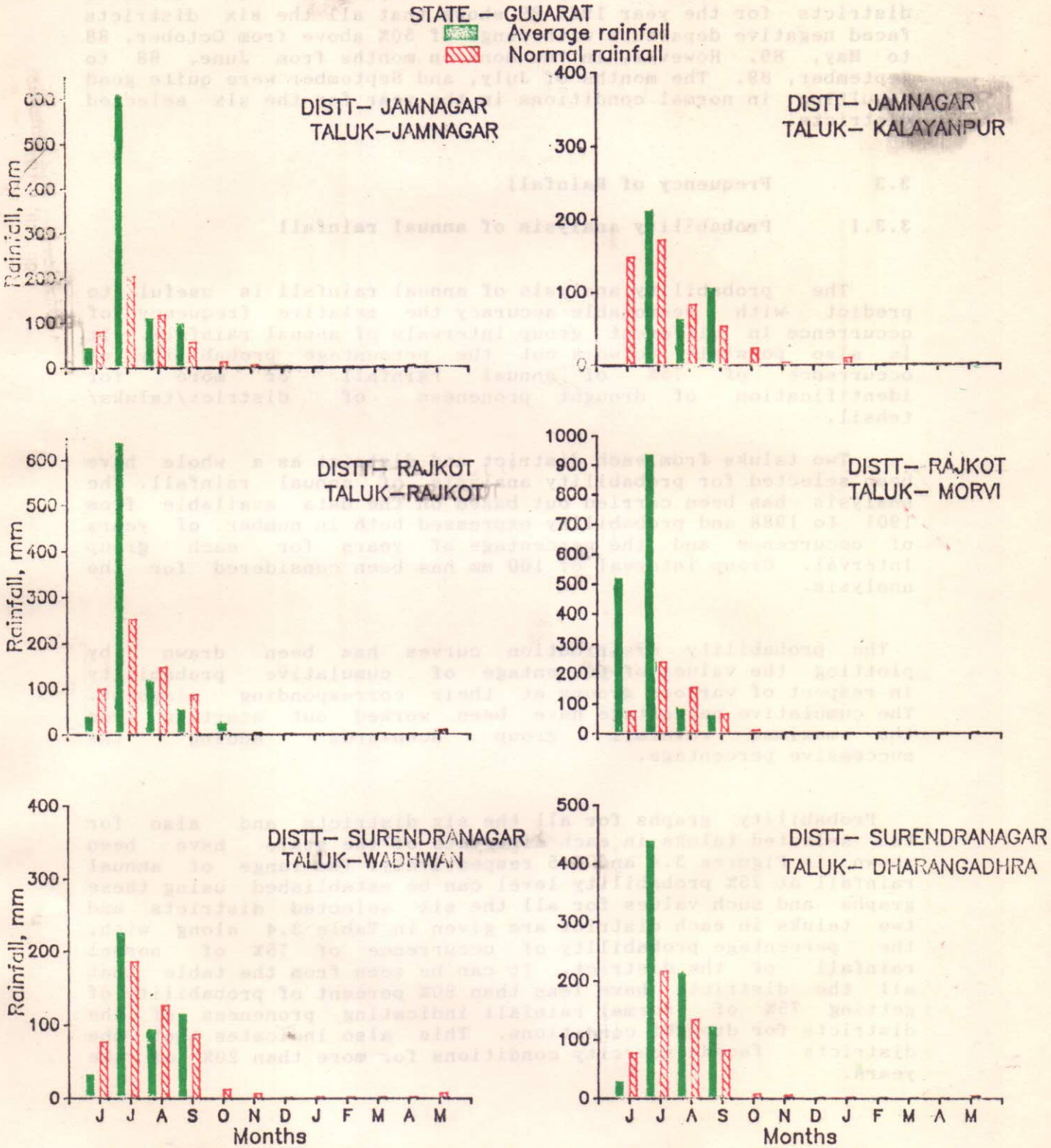


Fig.3.3 Talukwise monthly rainfall departure for year 1988– 89.

Monthly rainfall departure analysis of six selected districts for the year 1988-89 shows that all the six districts faced negative departure with range of 50% above from October, 88 to May, 89. However, in the monsoon months from June, 88 to September, 89. The months of July, and September were quite good resulting in normal conditions in the year for the six selected districts.

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 3.4 along with, the percentage probability of occurrence of 75% of normal rainfall of the district. It can be seen from the table that all the districts have less than 80% percent of probability of getting 75% of normal rainfall indicating proneness of the districts for drought conditions. This also indicates that the districts faced scarcity conditions for more than 20% of the years.

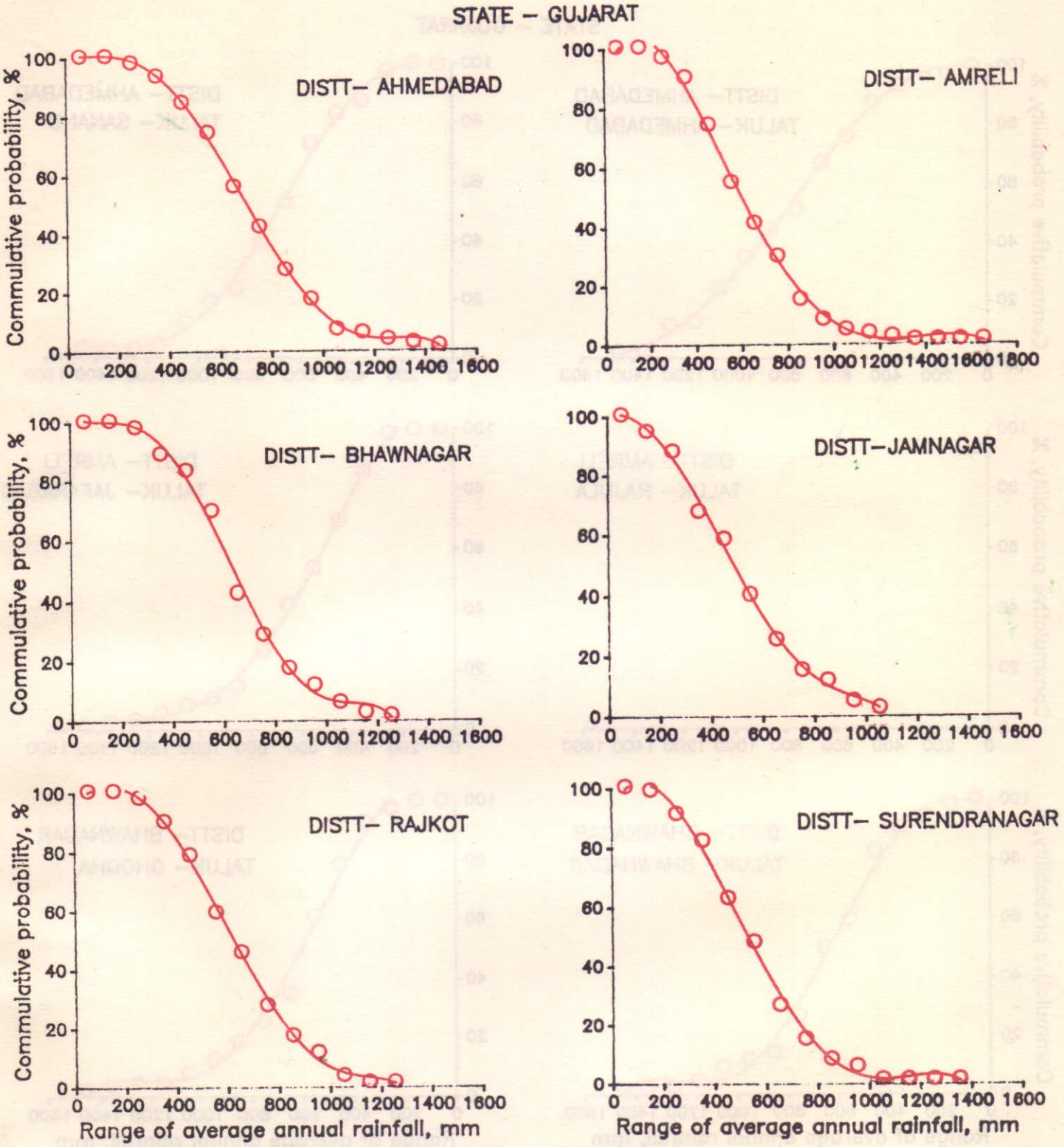


Fig.3.4:Districtwise probability of annual rainfall.

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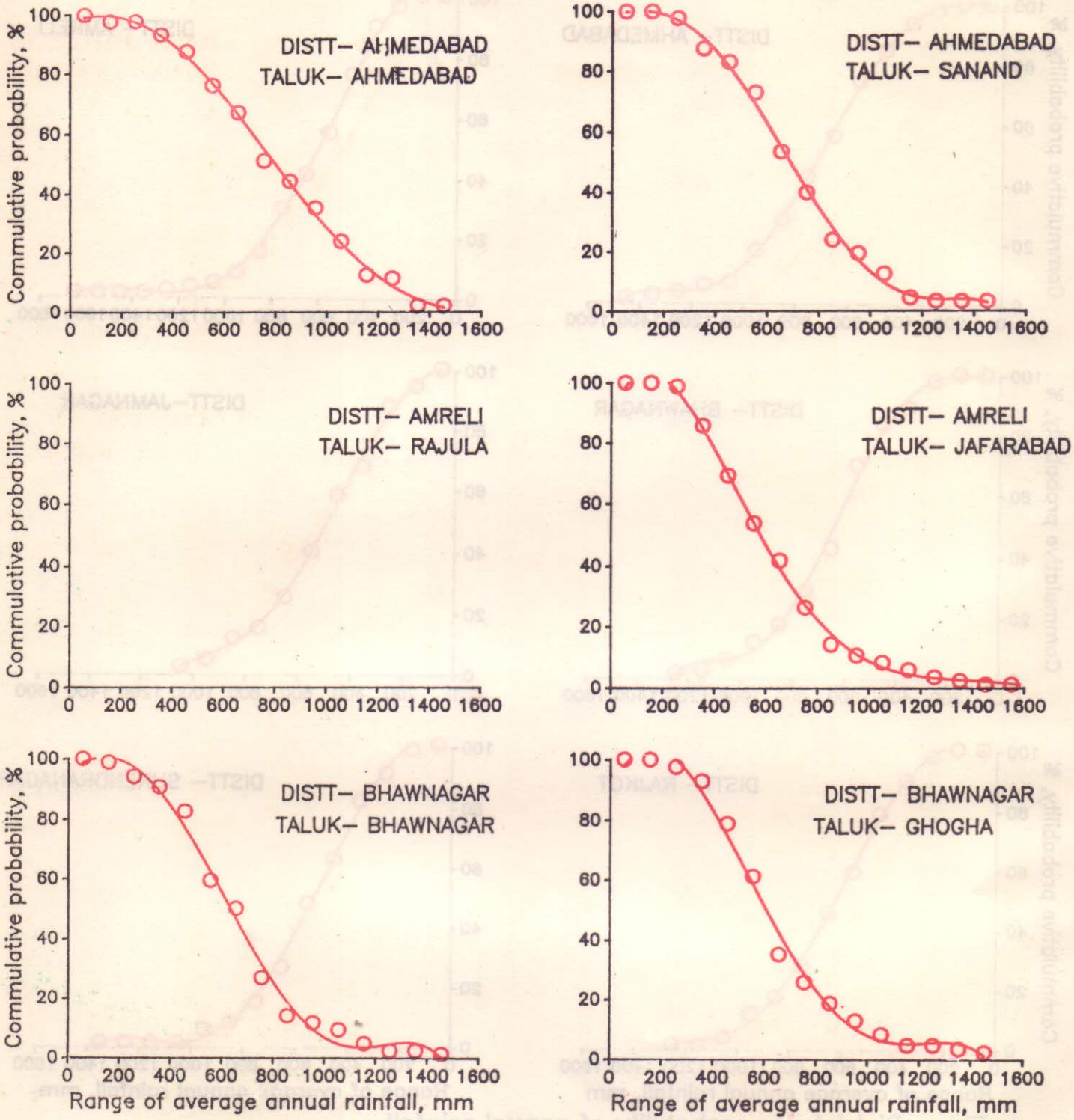

Fig.3.5;Talukwise probability of annual rainfall.

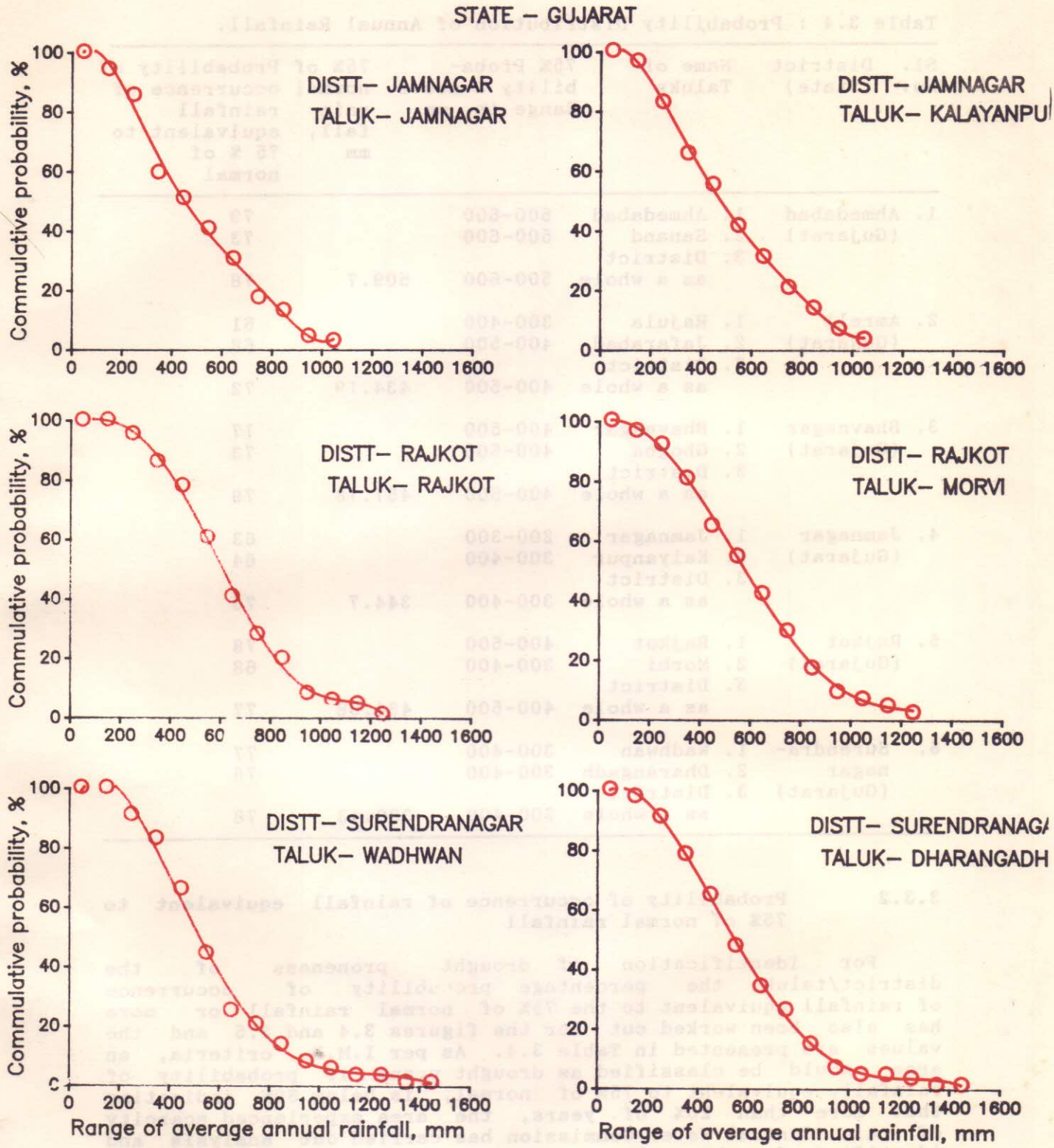

Fig.3.5 Talukwise probability of annual rainfall.

Table 3.4 : Probability Distribution of Annual Rainfall.

Sl. No.	District (State)	Name of Taluks	75% Probability & above Range in, mm	75% of normal rain fall, mm	Probability of occurrence of rainfall equivalent to 75 % of normal
1.	Ahmedabad (Gujarat)	1. Ahmedabad	500-600		79
		2. Sanand	500-600		73
		3. District as a whole	500-600	509.7	78
2.	Amreli (Gujarat)	1. Rajula	300-400		61
		2. Jafarabad	400-500		68
		3. District as a whole	400-500	434.19	72
3.	Bhavnagar (Gujarat)	1. Bhavnagar	400-500		77
		2. Ghogha	400-500		73
		3. District as a whole	400-500	457.78	79
4.	Jamnagar (Gujarat)	1. Jamnagar	200-300		63
		2. Kalyanpur	300-400		64
		3. District as a whole	300-400	344.7	73
5.	Rajkot (Gujarat)	1. Rajkot	400-500		78
		2. Morbi	300-400		68
		3. District as a whole	400-500	434.08	77
6.	Surendra-nagar (Gujarat)	1. Wadhwan	300-400		77
		2. Dharangadh	300-400		76
		3. District as a whole	300-400	380.43	78

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 and the values are presented in Table 3.4. As per I.M.D. criteria, an area would be classified as drought prone if probability of 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 the six districts namely Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar are 73, 77, 78, 78, 72 and 79 respectively which are all below 80% indicating that the districts are drought prone based on this analysis as per I.M.D. criteria. This infers that the districts of Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar experienced rainfall less than 75% of normal 27, 23, 22, 22, 28 and 21 percent of years, respectively. The taluks of all the six districts showed similar results indicating that these taluks as well as a whole are drought affected as per IMD 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).

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

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

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

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

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,

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

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'.

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

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.

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

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

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

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

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 exceeds (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 a period of a year is tested sequentially against the twelve 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

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

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 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 drought prone districts namely Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar shows that all the six districts experienced 10 drought spells of the intensity ranging from 0.27 to 1.82 during the period. This shows that the districts are drought prone. Over the entire period of analysis the highest drought duration of 109 months and severity index of 1.9 was observed during 1951 to 1960 in Jamnagar district. All the six districts faced successive drought years in continuation from 1985-1987 leading to disastrous drought conditions. In these 1988 all the six districts except Jamnagar & Rajkot faced drought conditions.

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 Gujarat.

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 Gujarat have been presented in Appendix-III-A. The number of dry spells have been counted starting

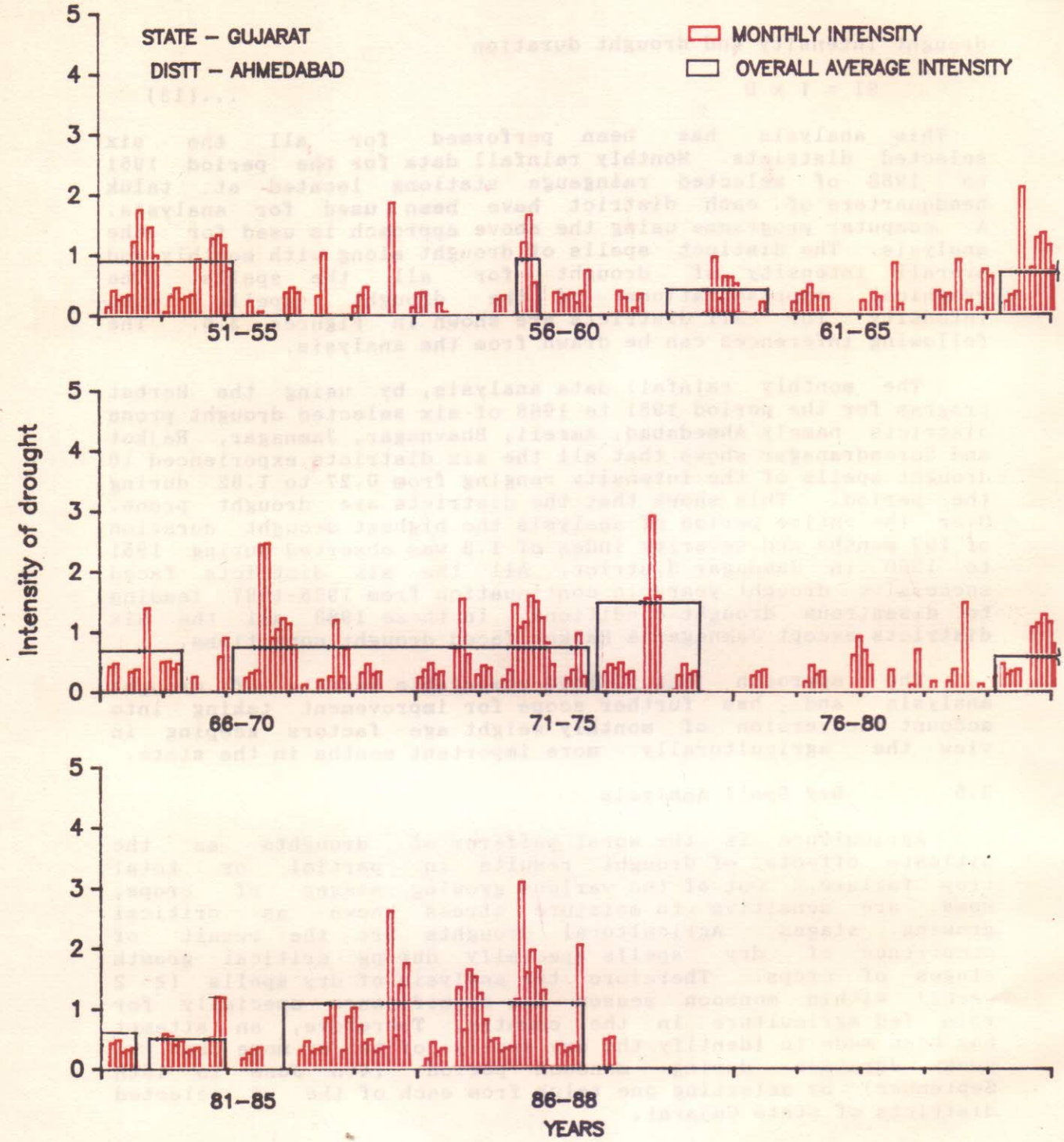

FIG:3.6: Overall average and monthly intensity of drought.

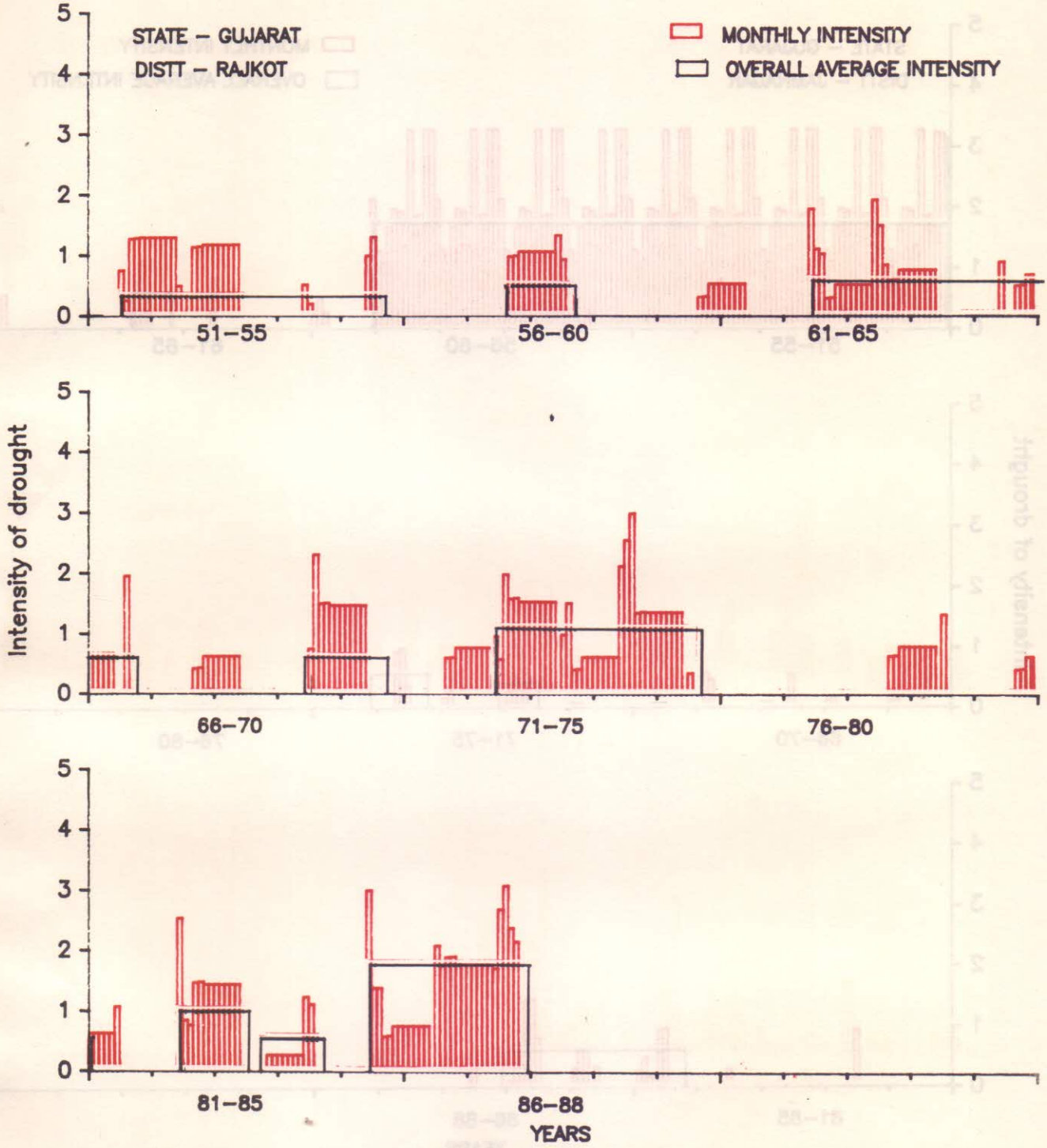

FIG:3.6:Overall average and monthly intensity of drought.

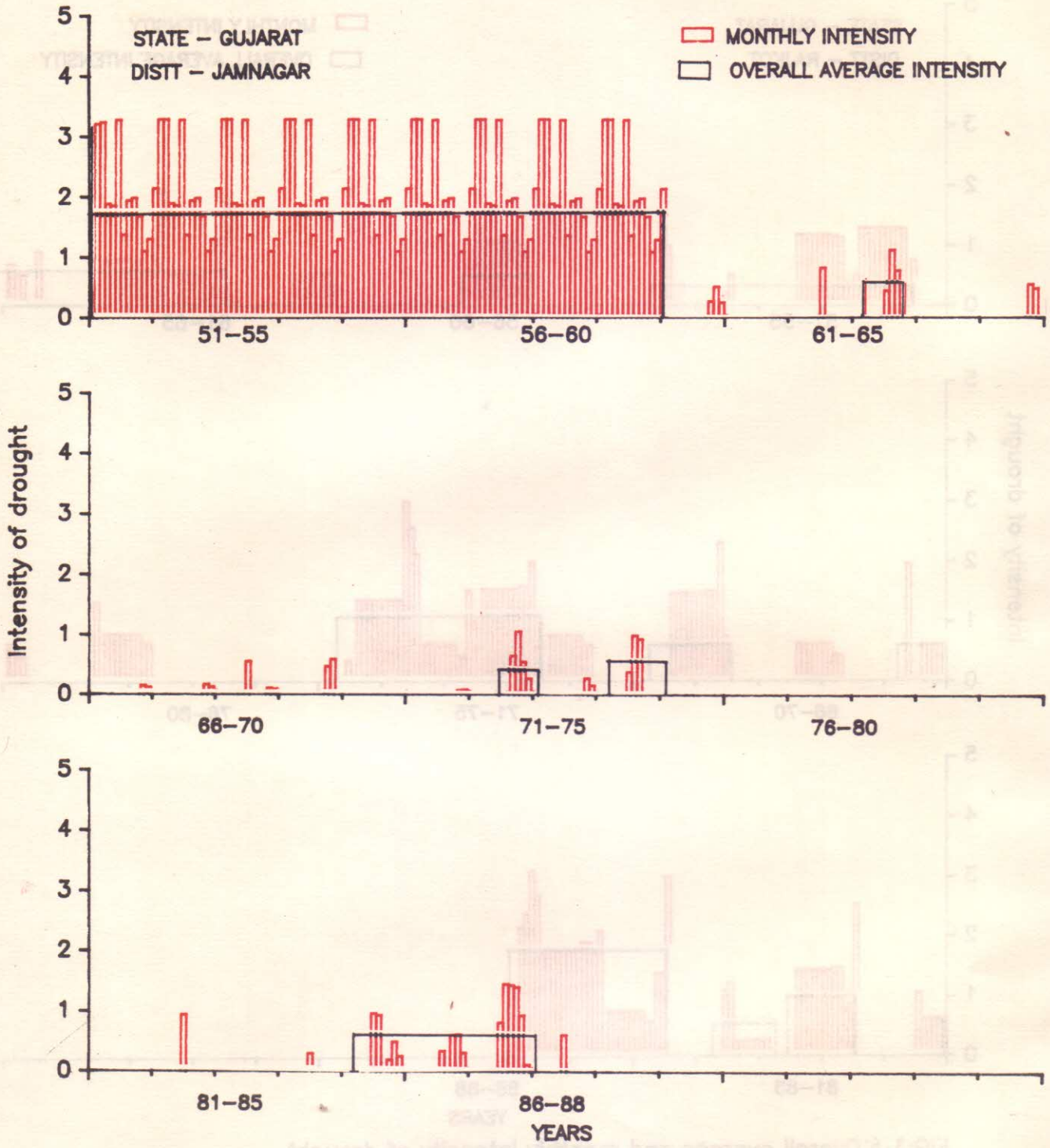

FIG:3.6:Overall average and monthly intensity of drought.

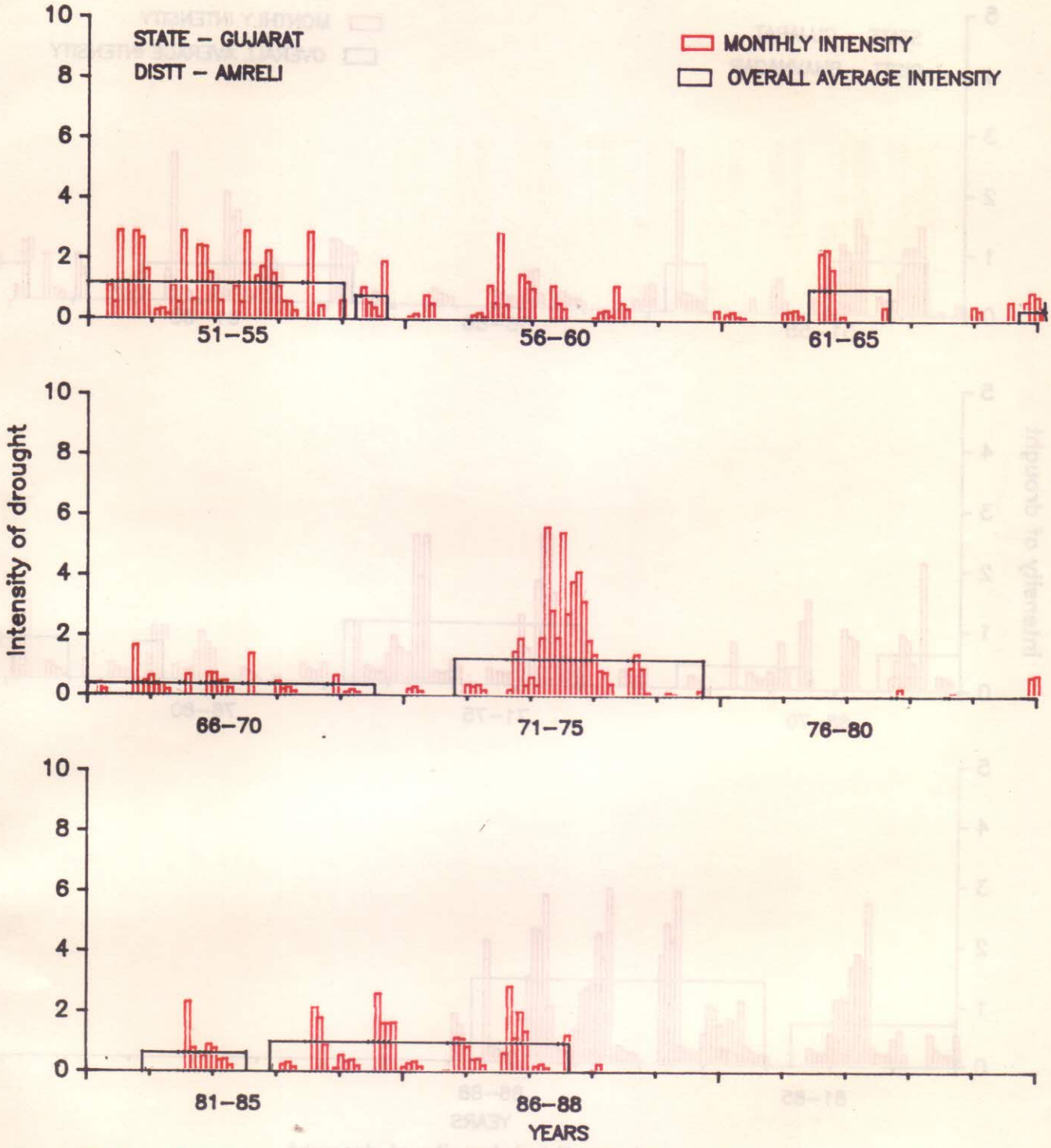

FIG: 3.6: Overall average and monthly intensity of drought.

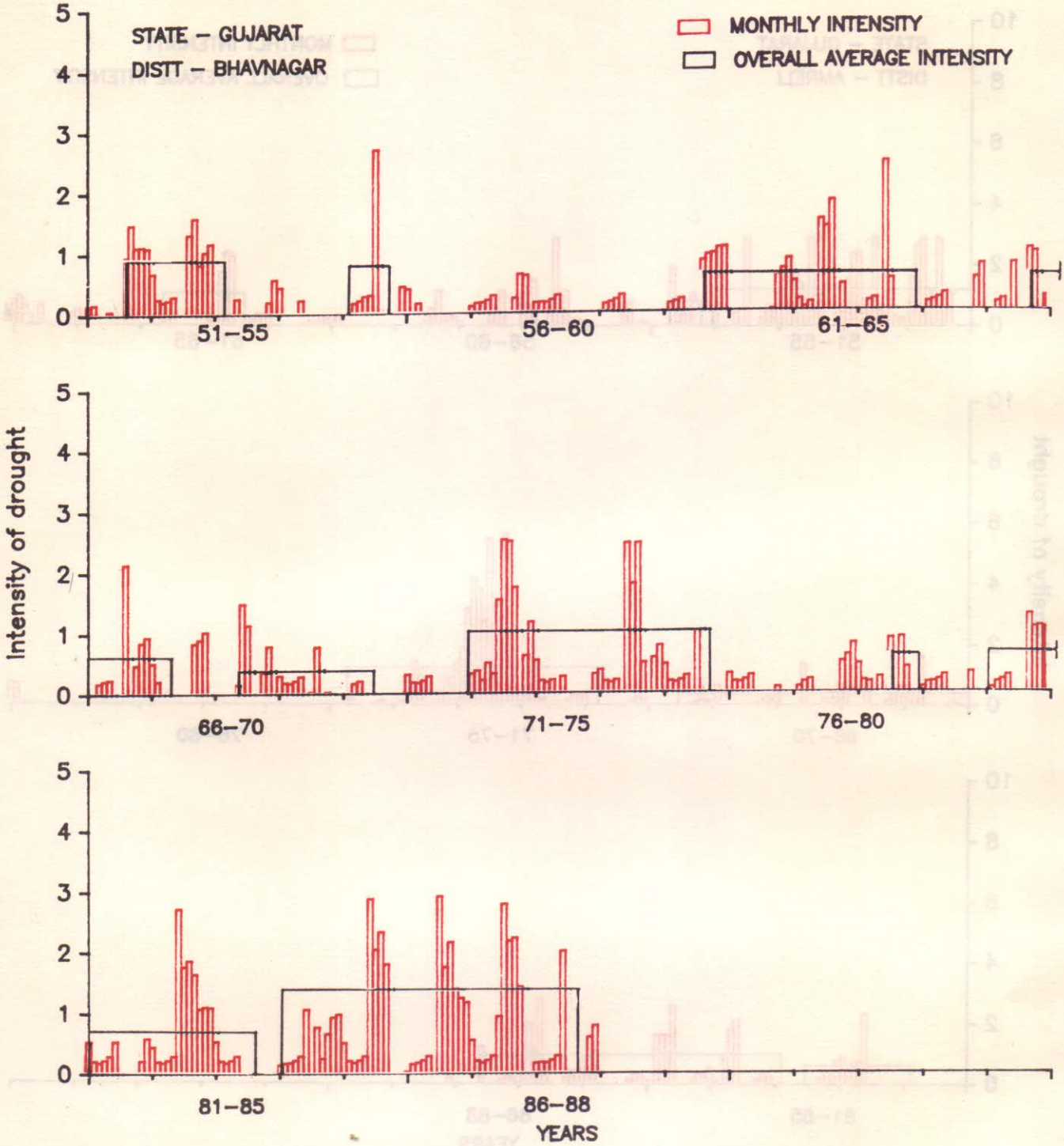

FIG:3.6:Overall average and monthly intensity of drought.

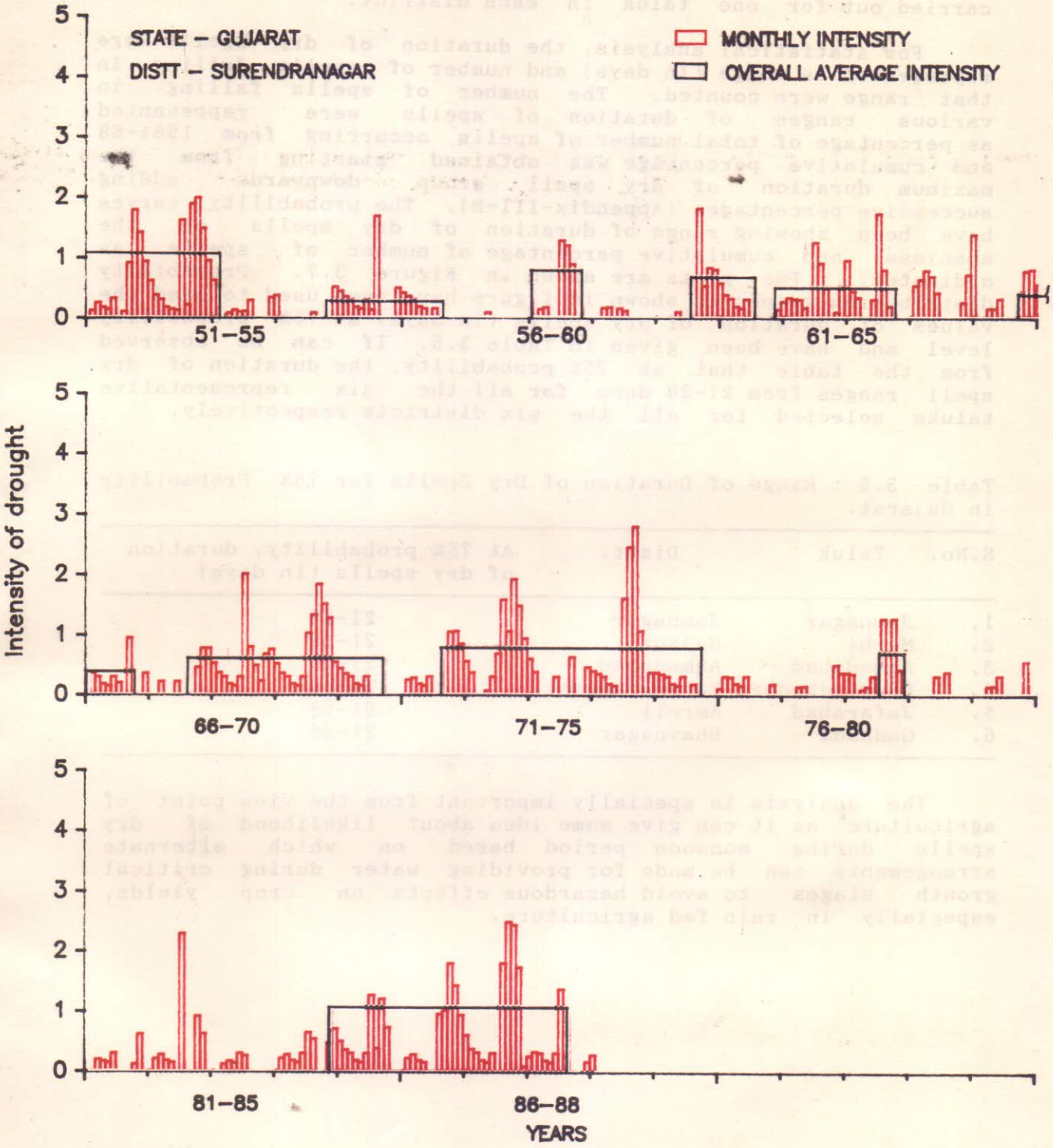

FIG3.6: Overall average and monthly intensity of drought.

from the monsoon season of 1981 to 1988. The study has been carried out for one taluk in each district.

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.

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

S.No.	Taluk	Distt.	At 75% probability, duration of dry spells (in days)
1.	Jamnagar	Jamnagar	21-28
2.	Morbi	Rajkot	21-28
3.	Ahmedabad	Ahmedabad	21-28
4.	Dharanghadhra	Surendranagar	21-28
5.	Jafarabad	Amreli	21-28
6.	Gadhada	Bhavnagar	21-28

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.

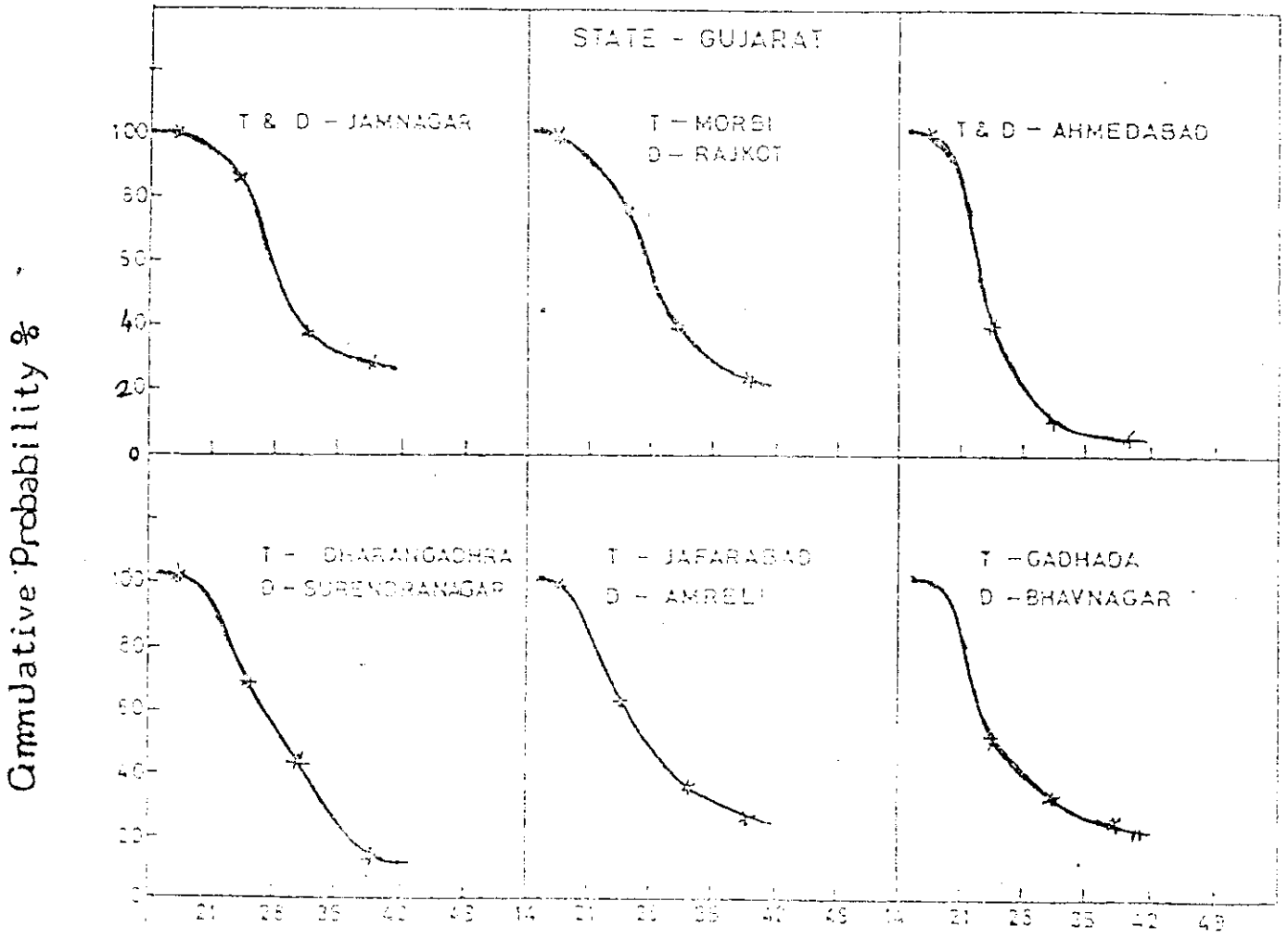

FIG. 3.7: Range of dry Spells (Days)

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 (1985-1987) on ground water regime, statistical analysis of ground water level data vis a vis precipitation has been carried out for all the 6 districts chosen in the state of Gujarat. However, 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 six districts namely Ahmdabad, Amreli, Bhavnagar, Jamnagar, Surandranagar of state Gujarat. The information regarding period of data used, no. of observation wells and the source of data is given in Table 4.1.

e 4.1: Status of Ground Water Data of State Gujarat.

S.No.	Name of District	Data available (four time in a year)	No. of Wells taken	Source of data availability
1.	Ahmedabad	1978-89	6	C.G.W.B.
2.	Jamnagar	1978-89	10	-do-
3.	Rajkot	1978-89	5	-do-
4.	Surendranagar	1978-89	8	-do-
5.	Amreli	1978-89	6	-do-
5.	Bhavnagar	1978-89	8	-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. Appendix IV-1 gives the details of various observation wells spread over 5 selected drought prone district of Gujarat state with their latitude and longitude. The analysis has been carried out for ground water level data up to 1989.

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 Polygon 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 districts. The values so obtained were plotted against each year to derive trend in ground water fluctuation. The trend was established for two periods namely, pre-monsoon and post monsoon.

In the present analysis of state Gujarat, pre and post monsoon levels have been analysed for six districts of Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar Fig.4.1. It can be observed from figures that during the year 1987 - 88, the ground water table recorded a falling trend in all the districts. The trend lines of pre and post monsoon for year 1987-88 have shown greater effects on water table as a result of monsoon failure as compared to previous years. The district of Jamnagar followed by Rajkot and Amreli showed highest rate of decline in post monsoon groundwater levels for 1987-88. The pre monsoon level was observed falling at highest rate in the district of Surenderanagar followed by Jamnagar. The district of Ahmedabad recorded lowest rate of decline in pre and post water table levels. The results of 1988-89 showed a rising trend as compared to 1987-88.

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) are a

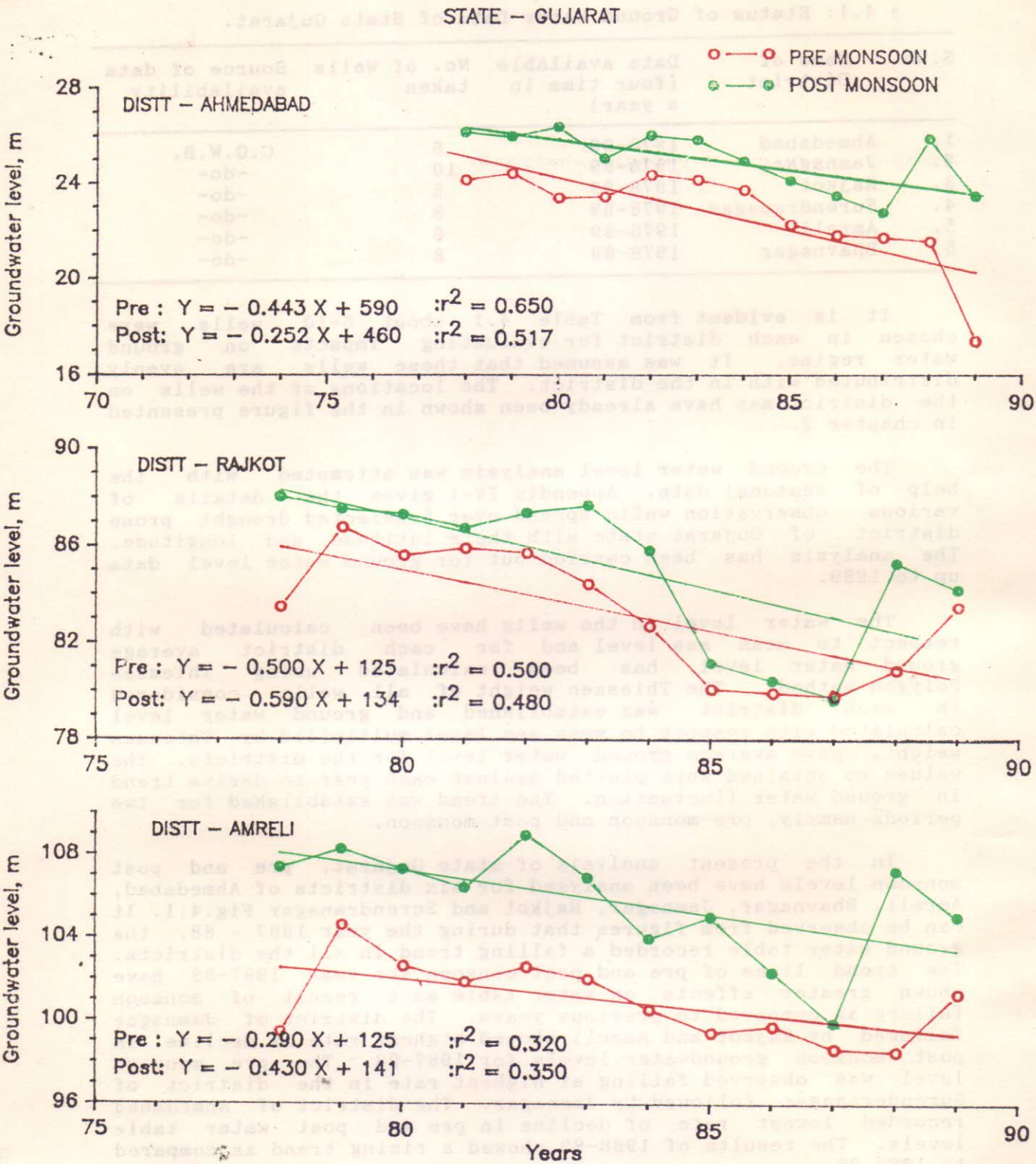

Fig. 4.1 :Groundwater level fluctuation for pre and post monsoon seasons.

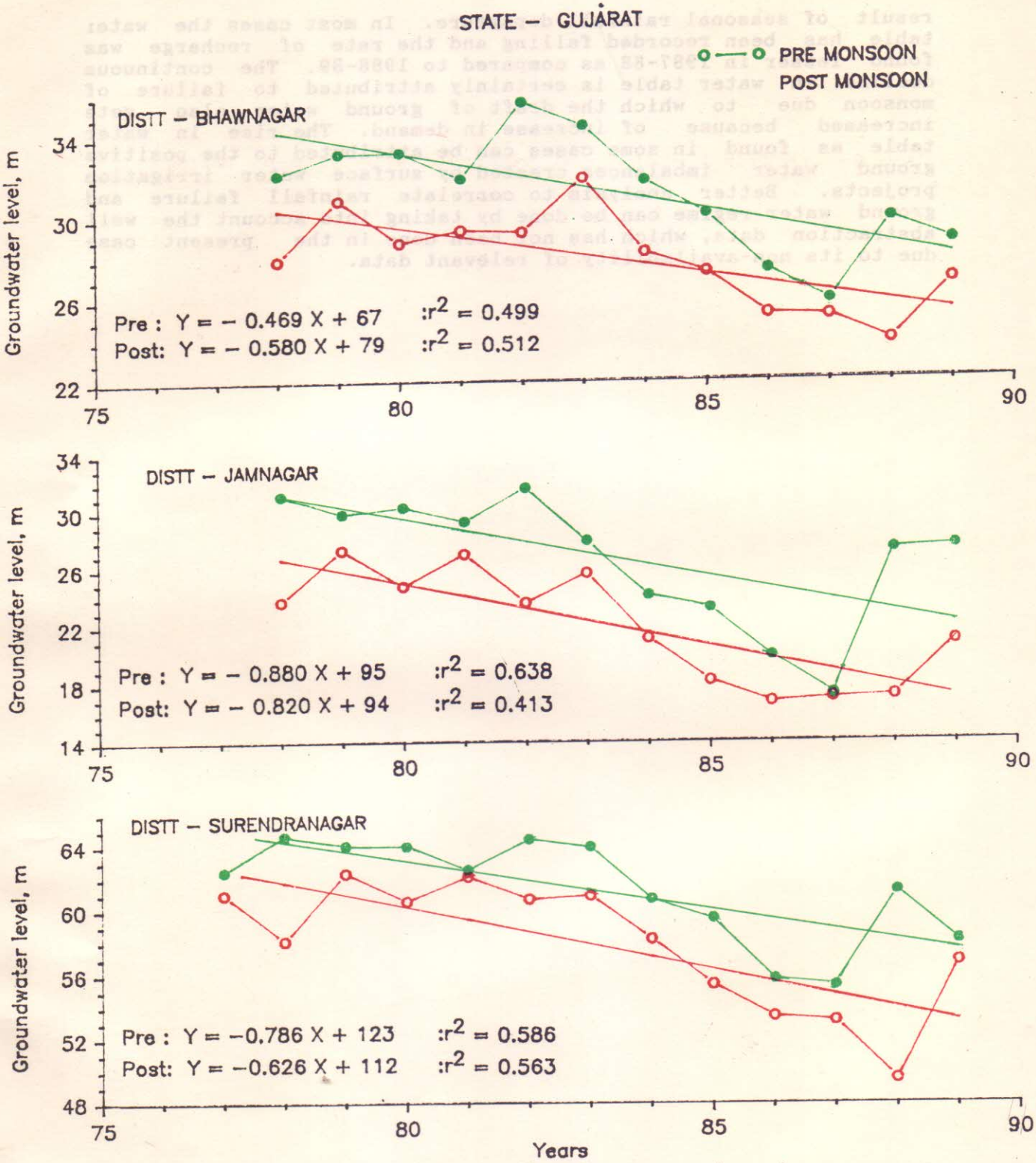

Fig.4.1:Groundwater level fluctuation for pre and post monsoon seasons.

result of seasonal rainfall departure. In most cases the water table has been recorded falling and the rate of recharge was found lesser in 1987-88 as compared to 1988-89. 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 rise in water table as found in some cases 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 of relevant data.

5.0 ANALYSIS OF RESERVOIR STORAGES

In order to illustrate the impact of failure of monsoon on storages of reservoirs, an attempt has been made to compare the reservoir level only for one selected Kadana Reservoir on Mahi river. . For this purpose, the live storages and corresponding reservoir levels in some selected months (May, August and October) have been plotted against time and the relationship between reservoir level and line storage. The weekly reservoir level data supplied by Central Water Commission from 1985 till 1989 have been used for the present analysis. Figure 5.1 shows the position of reservoir level during 1985 to 1989 in the Kadona Reservoir.

The inferences that can be drawn from the Fig.5.1 are as: The reservoir level and the relationship shows the storage position as in the Fig.5.1, shows that impact of rainfall failure had been more or less same on reservoir storages during the years 1986, 1987, 1988 and 1989 except the months of May and August showing little difference. The live storage in the reservoir at August 1987 was lowest of compared to 1988. Based on these results, it can be inferred that drought impact on reservoir storages were more pronounced during the year 1987 as compared to 1988. However in 1989, their was no indication of drought.

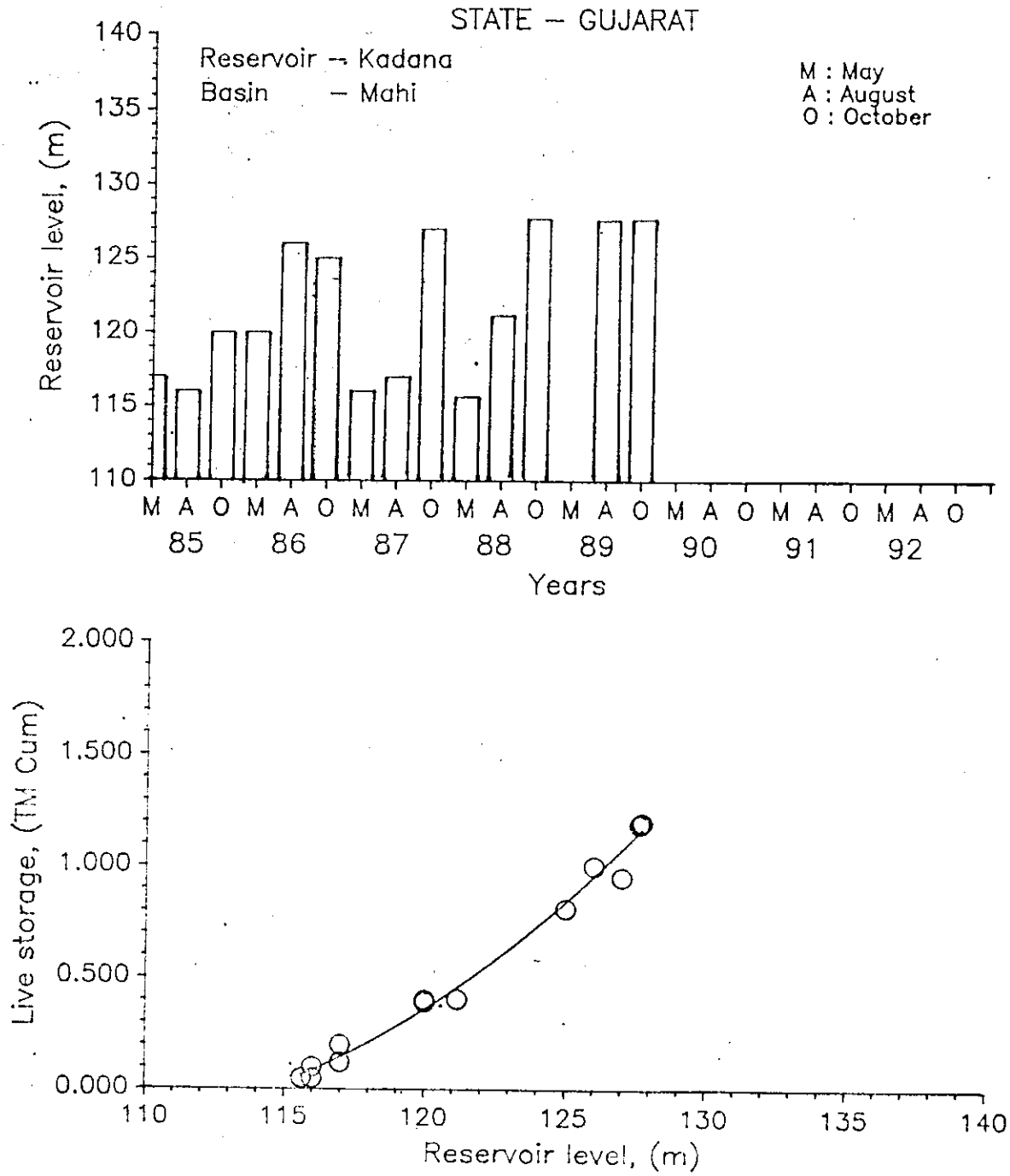

Fig.5.1: Reservoir level with time and the relationship between reservoir level and live storage.

6.0 CONCLUSIONS

1. The analysis of daily, monthly and annual rainfall data has been presented in the present report in a bid to classify the drought situation in the state of Gujarat. The data have been either collected by undertaking field visits to the study area or taken from the published reports by the state and central government organizations.

2. The seasonal rainfall departure analysis of year 1989 indicates that all selected districts, namely, Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar experienced positive seasonal rainfall during year 1988-89.

3. The values of monthly departures during year 88-89 showed that deficiencies ranged from 13.4-100%. During the monsoon months. Most of the districts had more than 50% deficiency on monthly basis. July and Sept. experienced positive departure in all districts. The month Oct. 1988 to May 1989 experienced 100 % negative departure.

4. The probability analysis of rainfall for two taluks in each district and district as a whole has been carried out. The group range of annual rainfall at 75% probability level has been found from 400-500 mm in most of the cases. The probability of occurrence of 75% of normal rainfall in all the six districts namely, Ahmedabad, Amreli, Bhavnagar, Jamnagar, Rajkot and Surendranagar were found as 73, 77, 78, 78 72 and 79%, respectively which are all below 80%, further certifying the drought proneness of the districts.

5. The analysis of monthly rainfall data using Herbst's Approach indicate that all districts had drought during year 1984-87. The district of Rajkot showed highest intensity of drought during 1959-88. All districts experienced 6-9 drought spells during the period 1959-88. The monthly intensities of drought were found highest in year 1987 as compared with 1985, 1986 and 1988.

6. The dry spell analysis indicated that for all taluks the duration of the dry spell ranged from 21-28 days at 75% level probability. A dry spell was assumed as a period during which daily rainfall does not exceed 5 mm for at least 2 weeks.

7. The ground water level analysis carried out for all the six districts showed a declining trend as a result of reduced rainfall in year 1986, 1987 in year 1988 the pre monsoon water level has increased in all districts but the post monsoon ground water level has not increased indicted a high abstraction during this year 1988. In year 1989 both pre and post monsoon level has shown an increasing trend except Ahmedabad. However on an average all districts showed an decreasing ground water level.

8. The positions of live storage in Kadana reservoir were compared during years 1985-89. The post and pre monsoon storages were found least during 1985 as compared with other years. In year 1987 and 1988 the storage position was improved.

9. The analysis needs to be extended to a basin to facilitate in deriving interrelationships between monsoon failure and its impacts on groundwater and streamflow regimes.

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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 IN THE STATE OF GUJARAT

PLACE	
Gandhinagar	Secretary and Commissioner (RD) Govt. of Gujarat
	Chief Engineer (Panchayat), Gujarat
	Secretary Irrigation, Gujarat
	Superintending Engineer, Gandhinagar Panchayat, Irrigation Circle
	Chief Engineer, Gujarat Irrigation Dept.
	Director, Gujarat Water Resources Development Corpn.
	Secretary, Gujarat Revenue Dept.
	Secretary, CADA, Gujarat Gujarat Water Supply & Sewerage Board
Rajkot	Zilla Panchayat Raj, Rajkot
	Deputy Director, Agriculture
	Superintending Engineer, Minor Irrigation Rajkot Circle
	Soil Officer, Soil Survey Deptt.
	Superintending Engineer, P.H.E.D.
	Irrigation Department
Ahmedabad	W.R.I. Bhadra Fort
	Director, Agriculture Gujarat State
	Eatern Gauging Division, Central Water Commission
	Geohydrologist, Ground Water Division
	Flood Control Cell
	Additional Director of Agricultural Sciences
	Deputy Director, Central Flood Forecasting Division, Central Water Commission.

Appendix - III-A

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

MORVI (RAJKOT)

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
21.6.81	4.6.81	20	2
	18.8.81	16	
4.6.82	5.6.82	36	2
	14.8.82	33	
18.6.83	4.6.83	14	2
	21.8.83	26*	
15.6.84	17.6.84	15	3
	5.7.84	14	
	24.8.84	20	
13.7.85	4.6.85	39	2
	15.8.85	35	
18.6.86	29.6.86	30	2
	11.8.86	36*	
12.6.87	13.6.87	33	3
	17.7.87	31	
	18.8.87	28*	
26.6.88	2.6.88	22	2
	6.8.88	29	
			18

JAMNAGAR (JAMNAGAR)

1	2	3	4
27.6.81	4.6.81	23	3
	26.7.81	16	
	25.8.81	22	
1.7.82	4.6.82	27	2
	22.8.82	17	
19.6.83	4.6.83	15	2
	12.8.83	35	
15.6.84	14.8.84	31	1
17.7.85	4.6.85	43	2
	20.8.85	27*	
18.6.86	24.6.86	44	2
	8.8.86	26	
16.7.87	4.6.87	42	2
	24.7.87	54*	
30.6.88	4.6.88	26	3
	12.8.88	23	
			16

DHARANGADHRA (SURENDRANAGAR)

1	2	3	4
26.6.81	4.6.81	22	2
	26.8.81	21*	
21.7.82	4.6.82	47	3
	26.7.82	18	
	23.8.82	24*	
13.6.83	19.8.83	19	1
3.7.84	4.6.84	29	3
	19.7.84	16	
	12.8.84	33	
17.7.85	4.6.85	43	2
	6.8.85	41	
9.6.86	26.6.86	34	2
	17.8.86	30	
12.6.87	13.6.87	15	3
	15.7.87	26	
	17.8.87	30*	
13.6.88	14.6.88	29	3
	6.8.88	15	
	24.8.88*	23*	
			19

AHMEDABAD (AHMEDABAD)

1	2	3	4
26.6.81	4.6.81	22	2
	26.8.81	22	
13.6.82	14.6.82	17	2
	23.8.82	24*	
21.6.83	4.6.83	17	1
1984 data not available			
14.7.85	4.6.85	40	3
	4.8.85	17	
	2.9.85		
17.6.86	27.6.86	20	2
	18.8.86	20*	
28.6.87	4.6.87	24	3
	18.7.87	20	
	28.8.87	19*	
16.6.88	17.8.88	14	2
	28.8.88	14	
			15

AMRELI (JAFARABAD)

1	2	3	4
7.6.81	6.7.81	19	3
	7.8.81	15	
	23.8.81	24	
10.6.82	11.6.82	36	3
	26.7.82	39	
	20.8.82	36*	
19.6.83	4.6.83	15	3
	20.6.83	19	
	15.8.83	32	
2.7.84	4.6.84	28	2
	28.8.84	24	
17.7.85	4.6.85	43	2
	14.8.85	33*	
19.6.86	4.6.86	15	3
	27.6.86	20	
	10.8.86	37*	
6.6.87	15.6.87	21	3
	15.7.87	26	
	20.8.87	27*	
15.6.88	19.7.88	19	1
			20

GANDHADA (BHAVNAGAR)

1	2	3	4
26.6.81	4.6.81	22	3
	25.7.81	14	
	21.8.81	24	
11.7.82	4.6.82	37	3
	23.7.82	18	
	15.8.82	15	
19.7.83	4.6.83	15	2
	18.8.83	21	
4.7.84	4.6.84	30	3
	21.7.84	14	
	13.8.84	30	
19.5.85	4.6.85	44	2
	5.8.85	36	
19.6.86	27.6.86	40	3
	9.8.86	20	
	31.8.86	16*	
18.6.87	4.6.87	14	3
	29.6.87	47	
	21.8.87	22	
13.6.88	14.6.88	15	1
			20

* - 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
Jamnagar (Jamnagar)	14-21	3	18.7	100.0
	22-28	7	43.8	81.3
	29-35	2	12.5	37.5
	> 35	4	25.0	25.0
		16		
Morbi (Rajkot)	14-21	5	27.8	100.0
	22-28	4	22.2	72.2
	29-35	5	27.8	50.0
	>35	4	22.2	22.2
		18		
Ahmedabad (Ahmedabad)	14-21	9	60.0	100.0
	22-28	4	26.8	40.0
	29-35	1	6.6	13.2
	>35	1	6.6	6.6
		15		
Dharangedhra (Surendranagar)	14-21	6	31.6	100.0
	22-28	4	21.0	68.4
	29-35	6	31.6	47.4
	>35	3	15.8	15.8
		19		
Jagarabad (Amreli)	14-21	8	40.0	100.0
	22-28	5	25.0	60.0
	29-35	2	10.0	35.0
	>35	5	25.0	25.0
		20		
Gadhada (Bhavnagar)	14-21	10	50.0	100.0
	22-28	3	15.0	50.0
	29-35	2	10.0	35.0
	>35	5	25.0	25.0
		20		

APPENDIX IV-1

LIST OF OBSERVATION WELLS

STATE - GUJARAT
DISTT - JAMNAGAR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	41F-3A1	SARMESOR	22 22 00	69 06 00	8.905	391	0.0385
2.	41F-3C1	SALAYA	22 18 00	69 37 00	3.491	557	0.0549
3.	41F-3D1	BED	22 25 30	69 48 45	12.260	598	0.0589
4.	41F-4A1	OKHAMADIN	22 05 00	69 07 00	4.323	317	0.0312
5.	41F-4B1	BHATIYA	22 05 00	69 17 00	27.095	720	0.0710
6.	41F-4C2	BHADTHOR	22 05 00	69 35 00	35.169	667	0.0660
7.	41D-1D1	AMBARDI	21 54 00	69 52 00	74.620	2589	0.2552
8.	41J-2B1	DHROL	22 34 00	70 30 00	25.010	2474	0.2439
9.	41G-1B2	RAWAL	21 55 40	69 29 30	0.999	720	0.0710
10.	41J-3A1	JAMNAGAR	22 27 30	70 04 45	11.905	1110	0.1094

STATE - GUJARAT
DISTT - RAJKOT

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	41I-4C1	MALIYA	23 05 30	70 45 30	10.20	1348	0.1209
2.	41J-2D1	WANKENER	22 37 00	70 52 00	90.08	2055	0.1843
3.	41J-3D1	RAJKOT	22 18 00	70 48 00	128.96	3618	0.3244
4.	41K-2B1	UPLETA	21 44 20	70 17 13	41.84	1869	0.1676
5.	41K-1CB	GUNDAL	21 14 36	70 44 30	126.90	2262	0.2028

STATE - GUJARAT
DISTT - AHMEDABAD

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	41N-3C1	RANPUR	22 16 00	71 43 00	66.355	435	0.0500
2.	46A-4C1	GHATLODIA	23 05 00	72 32 30	52.215	2721	0.3125
3.	46B-1B1	BAOLA	22 49 00	72 22 00	26.970	2448	0.2812
4.	46B-2A1	BAGODRA	22 28 30	72 12 00	14.083	1306	0.1500
5.	46B-3A2	BHARIYAD	22 17 38	72 10 00	7.395	1197	0.1375
6.	46B-3A1	ADWAL	22 21 32	72 00 00	14.530	599	0.0688

STATE - GUJARAT
DISTT - SURENDRA NAGAR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	41N-3D1	DASADA	23 19 30	71 49 30	28.170	1201	0.1150
2.	41N-4A1	HALVAD	23 01 00	71 11 00	44.750	1389	0.1330
3.	41N-1B1	DHAGANDHRA	22 59 35	71 27 45	50.955	1399	0.1340
4.	41N-1D2	LAKHTAR	22 21 30	71 47 30	43.125	1253	0.1200
5.	41N-2B1	SALAYA	22 38 00	71 29 00	60.500	1567	0.1500
6.	41N-2C1	SURENDRA -NAGAR	22 42 50	71 38 00	66.966	762	0.0730
7.	41N-2D1	LIMDI	22 34 00	71 49 00	43.685	1420	0.1360
8.	41N-3A1	CHOTILA	22 25 30	71 11 45	205.270	1452	0.1390

STATE - GUJARAT
DISTT - AMRELI

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	410-3B1				159.75		0.1175
2.	410-2A1				135.75		0.2200
3.	410-2A1				121.87		0.1412
4.	410-3A1				127.57		0.2529
5.	41B-102				12.25		0.0274
6.	41P-1B1				10.55		0.8069

STATE - GUJARAT
DISTT - BHAVANAGAR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	410-1B1				18.6		0.3045
2.	410-2B1				42.7		0.0585
3.	410-2B2				24.3		0.1604
4.	410-3B2				123.1		0.1123
5.	410-4B1				26.1		0.1125
6.	460-1A1				15.6		0.1125
7.	460-2B1				34.7		0.0585
8.	460-3A2				11.7		0.1177

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