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

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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 Rajasthan. The present report covers the study of six districts of state Maharashtra. These districts are Ahmednagar, Aurangabad, Pune, Sangli, Satara and Sholapur. The scientific teams of the Institute undertook visits to the state of Maharashtra and contacted the relevant state/central Govt. agencies for collecting the required data. The study includes various kinds of analysis of rainfall, groundwater level data for assessing drought impacts.

Based on the analysis, inferences, highlighting hydrological aspects of the recent droughts, have been drawn up. The study has been carried out by Shri Avinash Agarwal, Scientist 'C', Shri Sudhir Kumar Goyal, Scientist 'B', Shri R P Pandey, Scientist 'B' and scientific staff Shri Yatveer Singh, R.A. under the guidance of Dr. G C Mishra, Scientist 'F'. The manuscript has been typed by Mrs. Mahima Gupta.

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ABSTRACT

Drought is a frequent hazard in India, striking in some part or the other. In recent years droughts were experienced in succession in years, 1985-86, 1986-87 and 1987-88 in different parts of the country causing local as well as regional imbalances. Drought occurrence results in reduced stream flows, reservoir levels, ground water levels and soil moisture levels. The problem posed by droughts vary from area to area depending upon the amount of precipitation and its variability and on the demand of water for the specified user.

The present report describes the results of studies carried out for the year 1988-89 in six selected districts of Maharashtra namely; Ahmednagar, Aurangabad, Pune, Sangli, Satara, Sholapur. The report includes analysis of rainfall and groundwater data. The rainfall and groundwater data have been used for finding deficit of rainfall and trend of ground water table as a result of drought incidents. The Seasonal rainfall departure was observed of the order of 46-68 percent in the districts of Ahmednagar, Satara and Pune in the year 1988-89. Some districts like Pune and Satara recorded continuous seasonal rainfall deficiency in last 17 years. In case of monthly rainfall analysis, deficiency figures indicate that in most of the months monthly rainfall deficiency ranges from 11% to 100%. The frequency analysis shows that the probability of occurrence of 75% normal rainfall in all the districts are above 80 except Pune indicating that the districts selected for analysis are not drought prone based on this analysis as per IMD criteria. Herbst Analysis shows that Ahmednagar, Pune, Sholapur, Sangli & Aurangabad experienced drought during years 1984-89. The district Satara, however, did not record any drought spells during 1989 though drought spells were found in this districts from late 70's to early 80's. The maximum intensity of drought was recorded in the case of Satara district and the no. of drought spells varied from 4-12 in these districts during the period 1951-89. The district of Sangli experienced the largest spell of drought during 1983-84. The longest period of drought spell over the entire period was found in case of Ahmadnagar district during late 70's and early 80's.

An attempt has also been made to see the effects of scarce rainfall on groundwater regime by carrying out statistical analysis of groundwater level data. In all the six districts selected for the analysis, the seasonal rainfall for 1987-89 showed deficiency in the range of 9% to 60% except in case of Sholapur. The rate of decline in water table was found increasing in Pune, Satara and Sangli. However, Aurangabad, Pune, Sangli and Sholapur experienced an increase in watertable in year 1989 as compared to previous years. During 1987 the storages in the four selected reservoirs namely Jayakwadi, Khadakwasla, Koyana & Bhima were deficient as compared to previous 2-3 years and year 1989.

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 stand points (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. It has been further reported that these subdivision account for about 53% of the total food grains production in the country. A quick glance of foodgrains 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 foodgrain 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 hydrologic 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 scarce water resources.

The Institute has initiated studies to lay emphasis on Hydrological Aspects of Droughts starting year 1985 as these aspects were by and large neglected in past studies whatever carried out. Keeping in view the successive three drought years since 1985-86, in major parts of the drought prone area 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 chosen states have been completed and the study reports have been widely circulated.

Since the study for the year 1987-88 covered six districts each in six states, separate report for each of the six states have been prepared. The present report describes results of studies carried out for the year 1988-89 with six districts chosen in the state of Maharashtra. The report includes analysis of rainfall & groundwater level data for finding the impacts of deficit of rainfall and trend of groundwater tables. The status of storages in four selected reservoirs i.e. (i) Jayakwadi, (ii) Khadakwasla, (iii) Koyana and (iv) Bhima in the state has been compared with previous years.

The report is an attempt towards developing a comprehensive drought index for characterizing hydrologic drought situations. List of offices and places from where data and information have been collected in the state of Maharashtra are shown in Appendix-II.

2.0 DESCRIPTION OF STUDY AREA

2.1 General

There are 99 districts spread over 13 states, identified as drought prone districts in the country (Fig.2.1 - CWC, 1982). This report covers the study of six selected drought prone districts of Maharashtra viz., Ahmadnagar, Sholapur, Pune, Satara, Aurangabad and Sangli. The locations of the districts are shown on the state map (Fig.2.2).

Maharashtra is the third biggest state in the country both in respect of area and population. The state is situated entirely within the tropics, but because of the altitude, a major portion of the state does not have a tropical climate associated with low annual variation in temperature and humidity. A large part of the state suffers, every now and then, from crop failures, partial or even complete, due to the vagaries of monsoon. Rainfall is the principal factor affecting yields of unirrigated crops and in this respect, major portion of Maharashtra is at a considerable disadvantage, since the irrigation facilities in the state are very limited. Again, unlike the deep alluvial soils of North India and parts of Gujarat, the soils in Maharashtra have a substratum of homogeneous rock of greatdepth. This makes the striking of a dependable source of groundwater very much a matter of chance, apart from increased costs.

2.2 Area and Population

Maharashtra, with a total geographical area of 307.7 lakh hectares and covering 27 districts, forms about one tenth of the area of the country and occupies a major portion of the Peninsular India. It is located between 16° 04' to 22° 01'N latitudes and 72° 06' to 80° 10' E longitudes. The population of the State is over 5 crores and nearly 37% of the population is affected by droughts.

Administratively and meteorologically, the state has been divided into four regions. The four regions and the districts they comprise are as follows;

1. Konkan - Greater Bombay, Kolaba, Ratnagiri and Thane
2. Madhya Maharashtra - Dule, Jalgaon, Ahmednagar, Nasik, Pune, Kolhapur, Sangli, Satara, Sholapur
3. Marathwada - Aurangabad, Jalna, Bir, Nanded, Osmanabad and Pasbhani
4. Vidarbha - Akola, Amaravati, Bhandara, Buldana, Chandrapur, Nagpur, Wardha and Yevatmal.

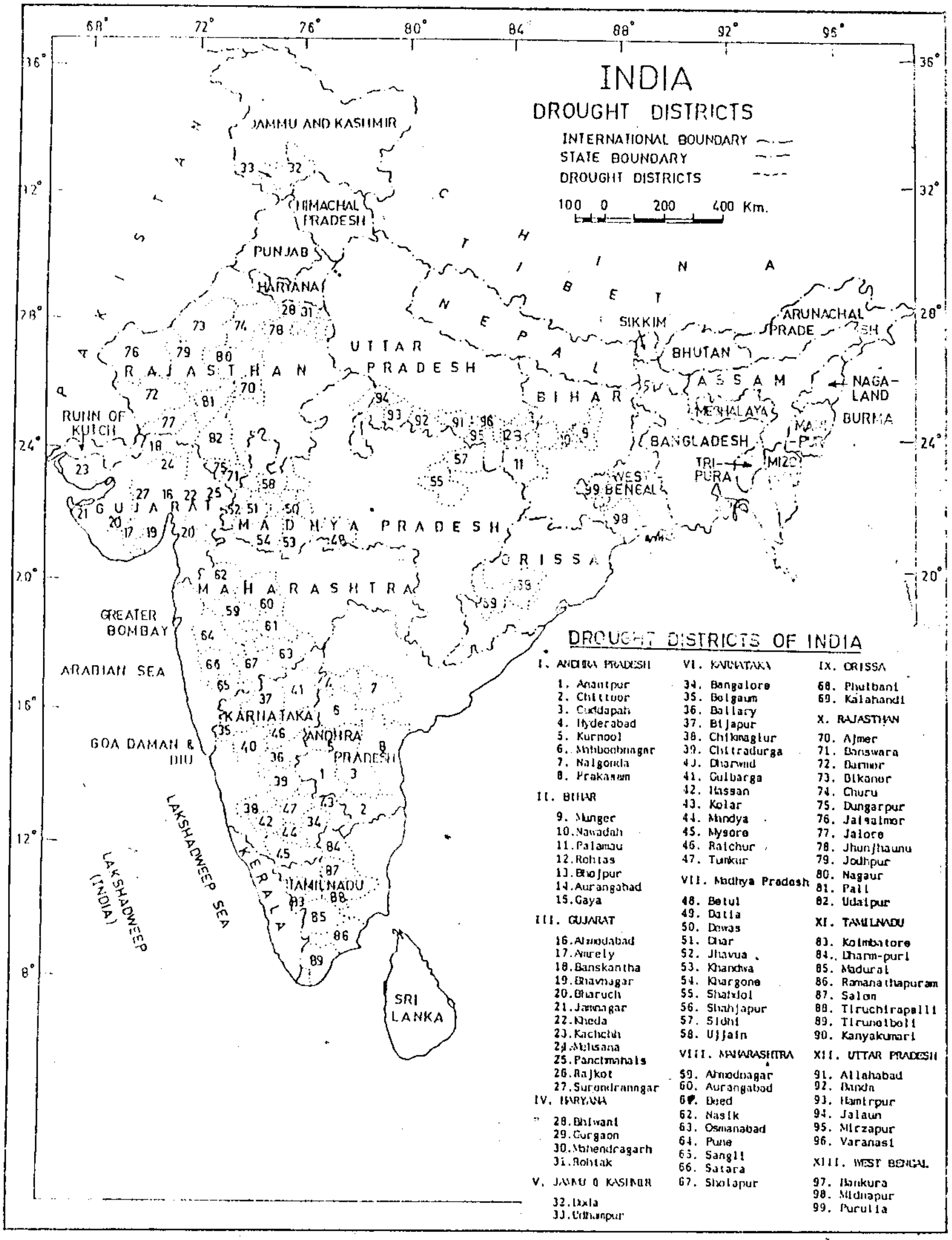


Fig. 2.1 DROUGHT PRONE DISTRICTS IN INDIA

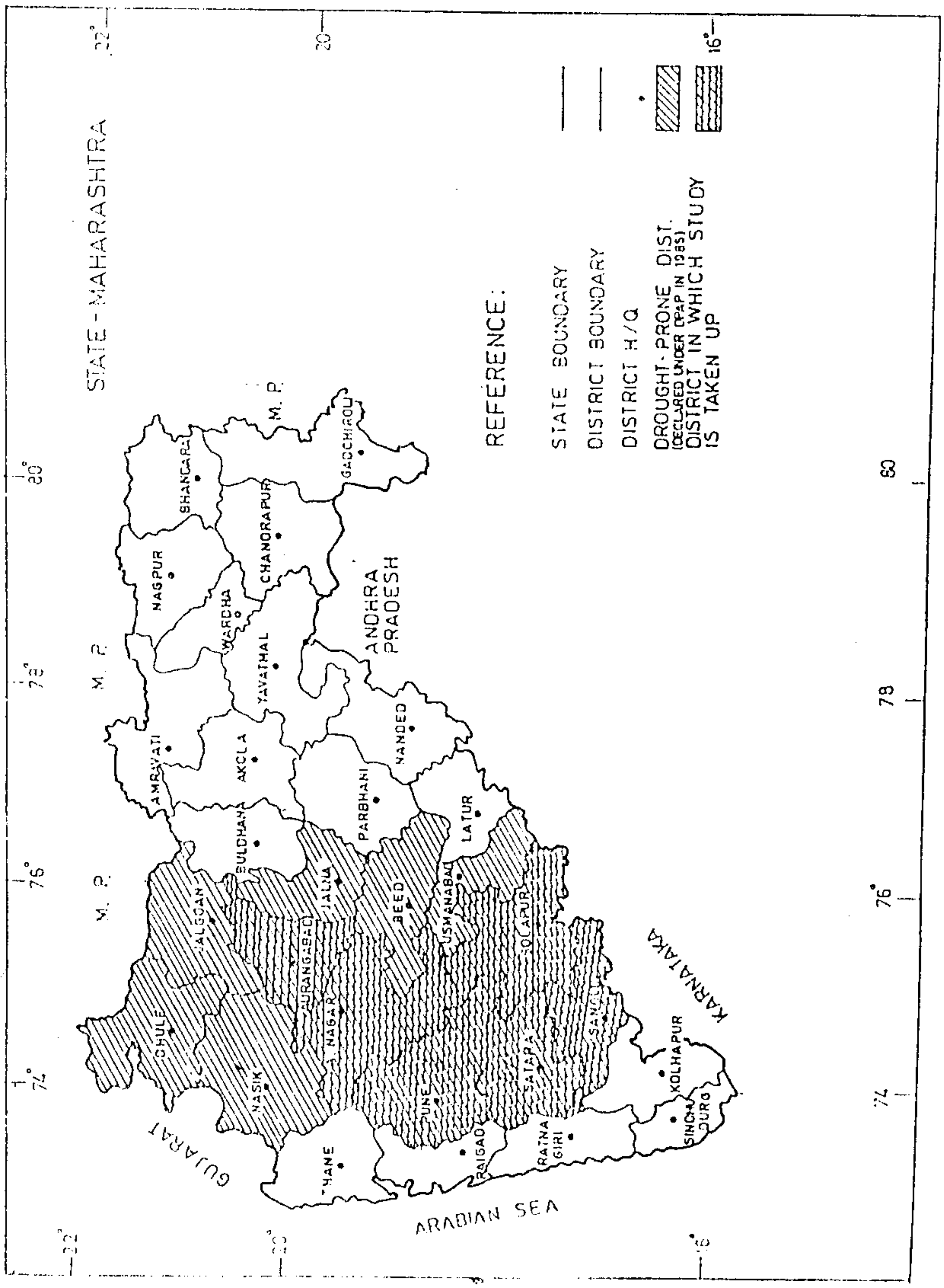


FIG. 2.2 : DROUGHT PRONE DISTTS. IN MAHARASHTRA

2.3 Physiography

The chief element in the lithological complex of the region is basaltic plateau which has been configurated by diastrophic movement of the past and later on by sub-aerial processes resulting in several microforms in the present terrain. Physiographically, the state could be divided as :

1. The coastal belt of Konkan which is about 25 meters above sea level.

2. The undulating Deccan Plateau to the east of SAYADRI range with åltitude ranging from 150 to 600 metres and

3. The Tapi trough running through the districts of Dhule, Jalgaon, Buldana and Akola flanked by Satpura and Satmala ranges on the north and south respectively.

2.4 Landuse and vegetal cover

The land utilization pattern of Maharashtra reveals that about 60% is under cultivation including about 8% under irrigation, 18% under forest and the remaining 22% is under miscellaneous land use. The land use pattern as per 1984 in the state is given in Table 2.1 and Fig.2.3.

Table 2.1 : Landuse details of state Maharashtra.

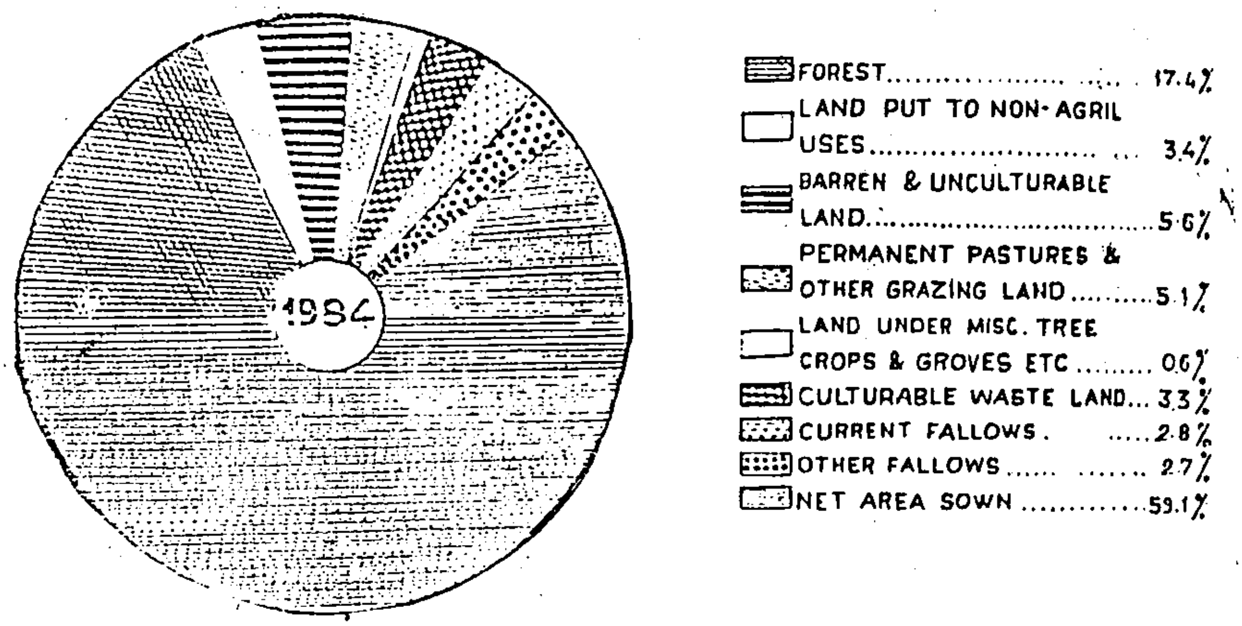
Present Land use	% coverage of the total area
Forest	17.4
Barren and uncultivated land	5.6
Land put to non-agricultural use	3.4
Cultivable waste	3.3
Permanent pasture and grazing land	5.1
Land under tree crops	0.61
Current fallows	2.8
Other fallows	2.7
Net sown area	59.1

Source: Epitome of Agriculture, Maharashtra 1987.

2.5 Soils

The soils of the Maharashtra can be classified into 9 categories:

i. Coarse shallow soils (High level)
ii. Medium Black Soils (Plains)
iii. Deep Black Soils (Valleys)
iv. Reddish Brown Soils of Hill Slopes (Trap)
v. Coastal Alluvium
vi. Yellowish Brown Soils (High level)
vii. Yellowish Brown Soils of Plains
viii Laterite and Lateritic Soils
ix. Coastal Soils



Source : Epitome of Agriculture in Maharashtra, 1987-88

Fig. 2.2 Landuse Details of State Maharashtra

The soils over a major part of the state to the East of the Western ghats and to the West of the Eastern Vidarbha is of the medium black variety interspersed by long patches of deep black soil. East of the coastal alluvium, the soil is laterite and reddish brown laterite and brown. Bhandara district in the state is having shallow black soils.

2.6 Surface Water Availability

The position of storages in respect of projects already completed, under completion and proposed projects is given in Table 2.2 (CWC, 1988).

Table 2.2 : Storages in the projects of Maharashtra.

Sl. No.	Type of Projects	Gross Storage in M.ha.m.	Live Storage in M.ha.m.
1.	Projects completed	2.2202	1.7343
2.	Projects under completion	1.6608	1.3805
3.	Total	3.881	3.1148
4.	Proposed Projects	1.671	1.511

Source: CWC report on Water Resources of India, 1988.

2.7 Groundwater Availability

The Groundwater Survey and Development Agency (GSDA) carried out assessment of groundwater potential on systematic basis in respect of small groups of elementary watersheds, each watershed having an area of about 200 to 300 sq.km. As per the fourth assessment carried out in the year 1985 the utilisable ground water resources are 31,03,874 ha. m. and annual draft is 6,84,749 hectare-metres through the existing 10.57 lakh irrigation wells. The balance of 24,19,125 hectare-metres is left over for further development through additional 16.2 lakh dug wells. Table 2.3 gives the districtwise details of total groundwater recharge, withdrawal, balance and number of existing and additional feasible wells. Table 2.4 gives districtwise static water levels in observation wells in 1983, 1984, 1985 and 1986 (GSDA, Maharashtra).

2.8 Water Use

The annual requirement of water in the state for domestic & livestock purposes during 1981 was of the order of 0.1656 M.ha.m. This has increased to a level of around 0.2537 M.ha.m. by the year 1991. Data of net area irrigated by different sources and gross area irrigated in Maharashtra from 1978-79 to 1985-86 are shown in Table 2.5. (Epitome of Agriculture, Maharashtra, 1987-88). Details of irrigated area under principal crops in Maharashtra from 1979-80 to 1985-86 are 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 2.3 : Districtwise groundwater assessment of Maharashtra (1985).

Sl. No.	District	Annual Ground-water Net recharge (Hect.M.)	Net Ground-water with-drawal (Hect.M.)	Balance of Ground water (Hect.M.)	Total No of Existing Wells	Additional No. of feasible Wells
1	2	3	4	5	6	7
1.	Pune	135565	46507	89105	78781	602[illegible]
2.	Solapur	1[illegible]59	48404	60477	82985	40863
3.	Satara	104257	32824	71443	53076	48273
4.	Sangli	80840	36484	44356	51494	29970
5.	Kolhapur	99957	27464	72691	31235	49055
6.	Thane	33066	3372	35694	7661	24118
7.	Raigad	52857	3578	50279	11568	33972
8.	Ratnagiri	42742	2345	40397	27725	13363
9.	Sindhudurg	27746	2686	25060	23048	16932
10.	Aurangabad	95646	33610	62035	46453	41916
11.	Jalna	126025	23636	102288	35007	69113
12.	Parbhani	146715	24162	122553	33105	82806
13.	Bhir	85131	17955	67176	31795	45389
14.	Nanded	117454	17030	100424	19686	67854
15.	Osmanabad	82715	23387	59328	33766	40086
16.	Latur	73880	15196	58684	19323	39651
17.	Nasik	128727	51633	77471	60321	52345
18.	Ahmednagar	213812	76093	138383	126599	93502
19.	Dhule	126761	37033	88928	47186	60086
20.	Jalgaon	111270	50033	58603	48552	39596
21.	Nagpur	135859	24158	112233	35129	75833
22.	Bhandara	123907	6888	117319	7631	79270
23.	Chandrapur	150312	3115	147198	5309	99458
24.	Gadchiroli	221272	1660	219612	3600	148386
25.	Wardha	60241	14959	45282	20461	30595
26.	Amravati	118493	25575	92139	30077	62256
27.	Akola	112041	12772	99269	23749	67074
28.	Buldhana	64908	13041	51867	47216	35045
29.	Yavatmal	117005	10149	106856	14842	72200
	Total	3103874	684749	2417060	10573[illegible]	1619213

Table 2.4: Statement showing districtwise details of static water levels of observation wells 1983-86 in Maharashtra.

Sl. No.	District	No. of observation wells fixed	Details of Water Levels in Open Wells, metres							
			1983		1984		1985		1986	
			Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
1	2	3	10	11	12	13	14	15	16	17
1.	Pune	69	7.57	4.12	6.84	4.80	7.00	5.17	7.50	5.31
2.	Solapur	67	8.26	3.73	7.84	5.29	8.01	6.04	9.05	6.33
3.	Satara	72	8.44	6.07	8.54	5.67	7.92	6.35	8.81	6.88
4.	Sangli	77	8.85	5.74	8.72	5.76	9.01	5.83	8.53	6.17
5.	Kolhapur	38	8.47	4.67	8.05	4.33	7.28	4.85	9.78	5.15
6.	Thane	36	5.27	3.30	4.47	3.17	4.09	3.51	-	3.70
7.	Raigad	37	4.86	2.31	5.04	2.99	4.62	2.88	4.73	2.95
8.	Ratnagiri	26	9.02	9.27	8.73	5.97	8.73	4.09	9.28	6.37
9.	Sindhudurg	37	6.85	4.14	6.20	4.33	6.14	4.37	5.77	6.15
10.	Aurangabad	52	10.16	5.18	8.97	8.97	10.96	7.22	9.58	7.83
11.	Jalna	42	9.31	3.59	8.62	6.33	9.47	7.19	10.73	8.20
12.	Parbhani	52	10.09	4.41	7.92	5.74	8.47	6.03	8.70	6.63
13.	Bhir	47	8.39	4.06	7.43	4.80	8.37	5.84	9.50	7.19
14.	Nanded	47	7.19	3.36	6.64	4.67	7.00	4.71	5.77	5.33
15.	Osmanabad	41	10.89	3.38	8.82	5.45	10.92	7.01	13.01	-
16.	Latur	43	12.79	4.10	10.27	6.10	11.17	6.65	12.09	10.24
17.	Nasik	138	7.67	4.65	7.16	4.61	6.71	4.94	6.26	5.70
18.	Ahmednagar	76	9.52	5.11	8.20	6.04	8.85	7.71	10.90	9.29
19.	Dhule	62	8.01	4.89	7.22	5.68	7.70	6.14	8.45	-
20.	Jalgaon	63	9.80	6.92	8.40	7.59	9.95	8.18	11.29	7.06
21.	Nagpur	59	9.02	4.05	7.84	4.80	7.74	4.83	7.65	6.67
22.	Bhandara	64	9.37	3.46	8.33	5.13	9.61	4.40	9.67	4.45
23.	Chandrapur	61	8.17	3.60	8.05	5.00	9.03	3.84	8.47	4.57
24.	Gadchiroli	47	8.16	3.96	7.87	5.33	8.42	4.77	8.63	4.84
25.	Wardha	40	8.53	4.20	6.96	5.60	7.99	5.70	7.88	6.10
26.	Amravati	94	7.60	4.60	6.87	5.07	-	5.68	8.94	6.71
27.	Akola	96	9.16	5.43	8.01	6.74	9.29	5.73	8.39	3.93
28.	Buldhana	55	9.49	4.57	7.82	3.25	9.00	6.61	9.07	6.83
29.	Yavatmal	78	7.38	3.56	6.23	5.99	6.64	4.58	6.57	4.44

Note: The Pre Monsoon/Post Monsoon water levels shown are the averages of all the observation wells fixed in the District.

Table 2.5: Net area irrigated by different sources and gross area irrigated in Maharashtra state from 1978-79 to 1985-86, (Figures in '00' ha.).

Particulars	78-79	79-80	80-81	81-82	82-83	83-84	84-85	85-86
Net area irrigaged by Different sources								
Surface irrigation	8299	8228	8410	8710	8268	9130	8190	8182
Well irrigation	10967	11408	11380	11540	10817	11620	10570	10627
Total net Area irrigated	19266	19636	19790	20250	19085	20750	18760	18809
Area irrigated more than once	4779	4679	5370	6610	6225	6580	6420	5810
Gross Irrigated Area	24045	24315	25160	26860	25310	27330	25180	24619

Note: Figures for the year 1980-81 to 1985-86 are provisional.

Table 2.6: Irrigated area under principal crops in Maharashtra state from 1979-80 to 1985-86, (Area in '00' hectares)

Crops	Irrigated Area, Years						
	79-80	80-81	81-82	82-83	83-84	84-85	85-86
Rice	3,974	4,123	4,085	3,891	3,715	3,793	3,967
Wheat	5,710	5,768	6,122	5,384	6,502	5,485	4,842
Kharif Jowar	836	384	387	251	330	311	258
Rabi Jowar	4,120	3,366	3,498	3,424	3,531	3,750	3,593
Bajra	526	523	571	424	495	490	469
Maize other	311	546	607	426	450	370	397
Cereals	211						
Total Cereals	15,498	14,710	15,270	13,800	15,023	14,199	13,526
Tur	28	50	-	-	-	-	-
Gram	745	850	1,042	967	1,131	1,186	1,235
Other Pulses	89	-	-	-	50	-	38
Total Pulses	862	900	1,042	967	1,181	1,186	1,273
Total Food-grains	16,360	15,610	16,312	14,767	16,204	15,385	14,799
Sugarcane	2,949	3,168	3,663	3,896	3,593	3,544	3,191
Cotton	1,040	1,523	1,411	1,187	1,038	1,003	1,094
Groundnut (kh.)	167	267	312	277	272	249	181
Turmeric	66						
Potato	112						
Chillies	629	4,592	5,162	5,183	6,226	4,999	5,354
Tobacco	17						
Other Crops	2,975						
Total Irrigated Area	24,315	25,160	26,810	25,310	27,333	25,180	24,619

Note: Figures for the years 1980-81 to 1985-86 are provisional.

Table 2.7: Water availability and water requirement for drought prone districts of state Maharashtra.

Sl. No.	District	Water Availability 50% Dependability	75% dependability	Total requirements
1.	Ahmednagar	3.47	3.03	3.81
2.	Aurangabad	3.99	3.39	1.75
3.	Bir	2.45	1.91	1.34
4.	Nasik	5.63	4.72	2.05
5.	Osmanabad	3.71	2.99	1.31
6.	Pune	4.97	4.33	2.95
7.	Sangli	1.86	1.66	2.49
8.	Satara	4.71	4.44	1.85
9.	Sholapur	3.05	2.59	3.66

Source: Central Water Commission, 1988.

2.9 Crops and Fodder

Based on the rainfall, type of soil, topography and cropping pattern, the state of Maharashtra is divided into nine agro-climatic zones.

1. Very high rainfall zone with lateritic soils.
2. Very high rainfall zone with non-lateritic soils.
3. Ghat zone.
4. Transition zone I with soils formed from basalt.
5. Transition zone II with soils formed from basalt.
6. Scarcity zone with soils formed from basalt.
7. Assured rainfall zone with soils formed from basalt.
8. Moderate rainfall zone with soils formed from basalt.
9. High rainfall with soils formed from mixed parent materials.

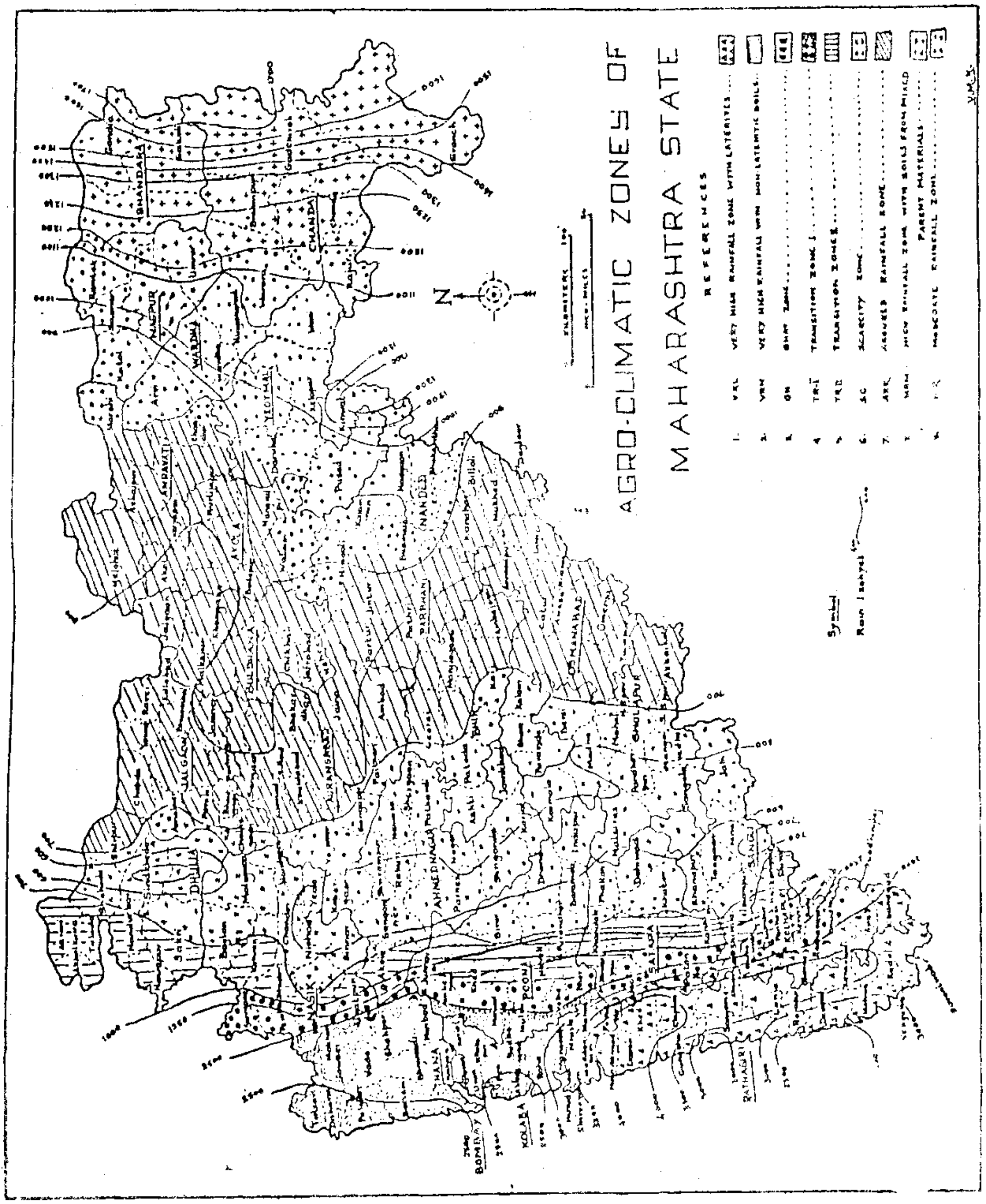
Fig. 2.4 shows the agroclimatic zones of state Maharashtra. (Agriculture Bulletin No.574 Dept. of Agriculture, Maharashtra), which are mostly drought prone, of the state where rainfall is small and its variability is high, agriculture is dependent to a large extent on the rainfall only and the yields are always uncertain. Dry farming is practiced in these areas by growing less water consuming crops like Jowar and Bajra. The dry farming area in the state accounts for nearly 70% of the geographical area of the state. Table 2.8 gives the details of crop wise area, production & yield of principal crops in Maharashtra state during the year 1985-86.

2.10 Districts Chosen for Study

The following section include description of individual districts taken up for study in the state.

2.10.1 Sholapur

Sholapur is one of the drought affected districts of Maharashtra state. The geographical location of the district is between 17° - 10' to 18° -32' North latitude and 74° - 12' to 76°



Source : Agriculture Bulletin No.574, Deptt. of Agriculture, Maharashtra State,

Fig. 2.4 : Agroclimatic Zones of State Maharashtra

-15' East longitude. The geographical area of the district is 15.021 sq.km. The district consists of eleven talukas all of which are generally vulnerable to drought. This district has 948 inhabited villages, 5 uninhabited villages and 10 towns. The population of the district is 2,607,172 & density of population is 174 person per sq.km. as per the census figure of 1981.

Table 2.8: Statement showing state level estimates of area, production and average yield principal crops in Maharashtra state during the year 1985-86, (Area in lakh ha; Production in lakh tonnes; Average yield in kg./ha).

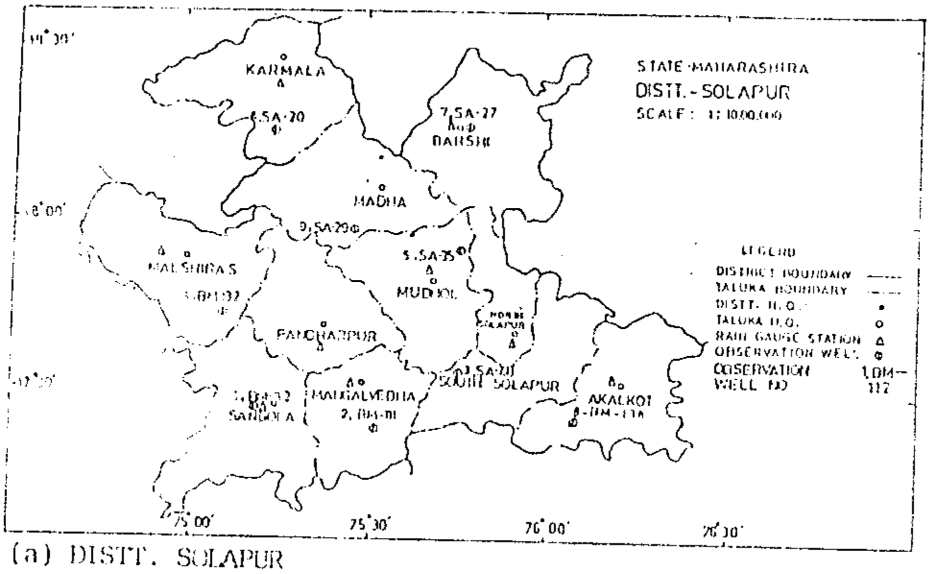
Crop.	Area	1985-86 Production	Av.Yield
1	2	3	4
Rice	15.15	21.32	1407
Kharif Jowar	28.80	26.52	921
Bajra	17.03	4.20	246
Rabi	2.22	2.61	1178
Other Kharif Cereals	2.21	1.48	670
Total Kharif Cereals	65.41	56.13	858
Tur	7.57	4.51	597
Other kharif pulses	13.83	4.86	351
Total kharif puises	21.40	9.37	438
Total Kharif foodgrains	86.81	65.50	755
Rabi jowar	37.45	12.71	339
Wheat	8.82	6.44	731
Other rabi cereals	0.38	0.37	995
Summer rice	0.25	0.50	1988
Total rabi cereals	46.90	20.02	427
Gram	5.34	1.76	329
Other rabi pulses	1.86	0.51	277
Total rabi pulses	7.20	2.27	315
Total rabi foodgrains	54.10	22.29	412
TOTAL FOODGRAINS	140.91	87.79	623
Total cereals	112.31	76.15	678
Total pulses	28.60	11.64	407
Cotton	27.53	19.90 (bales)	123 (lint)
Sugarcane	2.65 (H)	237.06	89.3

Contd.

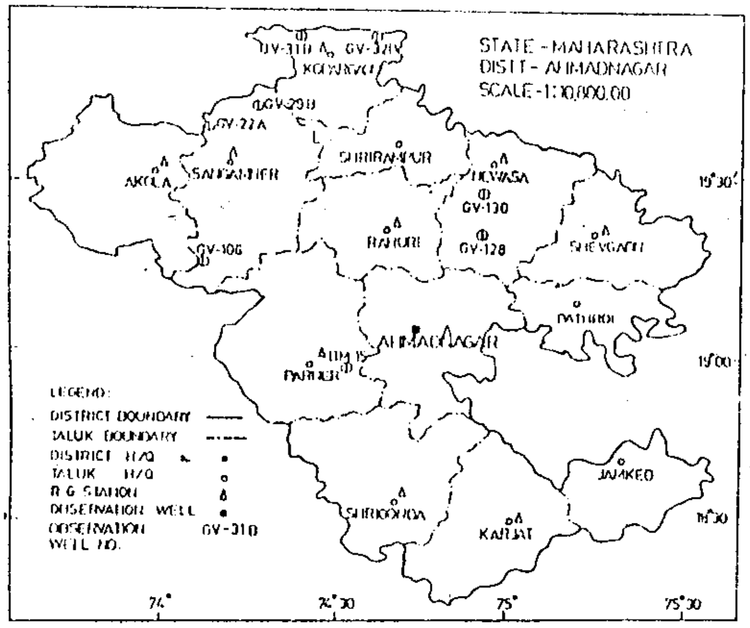
1	2	3	4
Groundnut	6.26	4.22	673
Sesamum	1.30	0.31	239
Sunflower	2.00	0.78	392
Nigerseed	0.96	0.21	212
Soyabean	0.56	0.18	318
Castorseed	0.04	0.02	357
Total Kharif oilseeds	11.12	5.72	514
Sunflower	6.19	2.49	402
Linseed	2.47	0.54	218
Sunflower	1.25	0.57	458
Sesamum	0.97	0.19	193
Rape & mustard seed	0.05	0.02	292
Summer groundnut	0.37	0.47	1272
Total rabi oilseeds	11.30	4.28	379
TOTAL OILSEEDS	22.42	10.00	446

The soils in the district are generally classified into three groups viz., light soils, medium black soils and black cotton soils. The land use description in the district as per data from 1970-71 to 1977-78 is forests 32,800 ha., land put to non-agricultural uses 3,300 ha., barren & unculturable land 68,900 ha., culturable area 1,334,100 ha. and culturable waste 43,100 ha. As per the data available from 1971-72 to 1977-78, the total irrigated area is 146,980 ha. in the district which has source wise distribution of 31,485 ha. by surface water and 115,495 ha. by ground water.

The Bhima is the main river flowing through the Solapur district. The catchment area of Bhima river within the district is 15,021 sq.km. As per CWC studies of 1982, the normal annual rainfall of the district is 616.70 mm and normally there are 37.4 rainy days in a year according to analysis of data from 1901 to 1978. There are 54 raingauge stations located in the district and the density of raingauge stations is 287.8 sq.km. per raingauge station. The maximum annual rainfall in the district was 1100.2 mm in year 1916. The south west monsoon gives about 74.0% of annual rainfall in the district. The coefficient of variation for annual rainfall has been reported as 24.7% for the district. As per CGWB data, the utilisable groundwater resources are of the order of 3103874 hact. m., while the draft is 684749 hact. m. As per CWC (1982) observations, the district faced 12 hydrological drought years during the period 1946 to 1978. A map of the district showing location of raingauges and observation wells which have been chosen for analysis is shown in Figure 2.5.



(a) DISTT. SOLAPUR



(b) DISTT. AHMADNAGAR

FIG. 2.5 : LOCATION OF RAINGAUGE STATION & OBSERVATION WELLS

2.10.2 Ahmadnagar

Ahmadnagar is the second largest district of the Maharashtra State and is among the drought prone districts. The district is situated in the heart of Maharashtra state between 18° - 22' and 20° - 00' north latitudes and between 72° - 32' and 75° -30' east longitudes. The geographical area of the district is 17,035 sq.km. as per the 1971 census. The district consists of 13 talukas and has 1,312 inhabited villages, 5 uninhabited villages and 6 towns. The population of Ahmadnagar district is 2,711,216 and the density of Population is 159 persons per sq.km., according to data available in 1981.

The soils in the district are mostly of three types namely, black soils, red and laterite soils. The details of land use in the district as per data from 1970-71 to 1977-78 indicate forests 184,500 ha., land put to non agricultural uses 5,300 ha., barren and unculturable land 157,900 ha. and culturable area 1,312,200 ha. As per data available from 1971-72 to 1977-78, the total irrigated area in the district is 212,073 ha., with the source wise distribution as 140,023 ha. by ground water and 72,050 ha. by surface water.

Godavari & Bhima are the two main rivers flowing through the district. The catchment area of Godavari river within district is 10,979.5 sq.km. and Bhima river has 6,055.5 sq.km. as its catchment within the district.

As per CWC studies of 1982, the normal rainfall of the district (1901 to 1978) is 556.3 mm and there are normally 35.6 rainy days in a year in the district. There are 115 raingauge stations located in the district and the density of raingauge stations is 145.80 sq.km. per rain-gauge station. The maximum annual rainfall of 921.7 mm was experienced in the district in year 1916. Rainfall generally depends on south west monsoon in the district. The south west monsoon gives about 77.0% of annual rainfall in the district. The coefficient of variation for annual rainfall has been reported as 26.1% for the district. As per CGWB data, the annual net recharge to ground water is 213812 hact. m. while the net draft is 176093 hact. m. As per CWC (1982) observations, the district faced 13 hydrological drought years during the period 1946 to 1978. The location of raingauges and observation wells is shown in the district map given in Fig.2.5.

2.10.3 Pune

Pune is the largest district of Maharashtra state. The geographical location of the district is 17° 52' to 19° 23' north latitudes and 73° 20' to 78° 10' east longitudes with the area of 15,640 sq.km. The district consists of fourteen talukas and has 1481 inhabited villages, 17 uninhabited villages and 22 towns. The population of the district is reported as 4,162,284, as per 1981 census.

The soil of the district are of three types namely - shallow light brown soils, medium black soils and deep black cotton soils. The details of land use of the district as per 1970-71 to 1977-78 data include forests 189,000 ha., land put to non-agricultural uses 37,300 ha., barren and the unculturable land 159,800 ha., and culturable area 1072,800 ha. The main rivers flowing through the district are Bhima & Nira. The catchment area within district of Bhima is 11,404 sq.km. and Nira has 4,236 sq.km. catchment in the district.

As per the CWC studies of 1982, the normal rainfall of the district (1901 to 1978) is 1080.3 mm and normally there are 51.3 rainy days in a year in the district. There are 163 raingauge stations located in the district and density of raingauge stations works out to 96.2 sq.km. per raingauge station. The maximum annual rainfall of 1877.1 mm was experienced in the district in year 1956. Rainfall in the district generally depends on southwest monsoon which gives about 85.4 percent of the normal annual rainfall. The coefficient of variation for annual rainfall has been reported as 23.9% for the district. As per CGWB data, the utilisable groundwater resources are of the order of 3103874 hact. m. and the draft is 684749 hact. m. resulting in surplus.

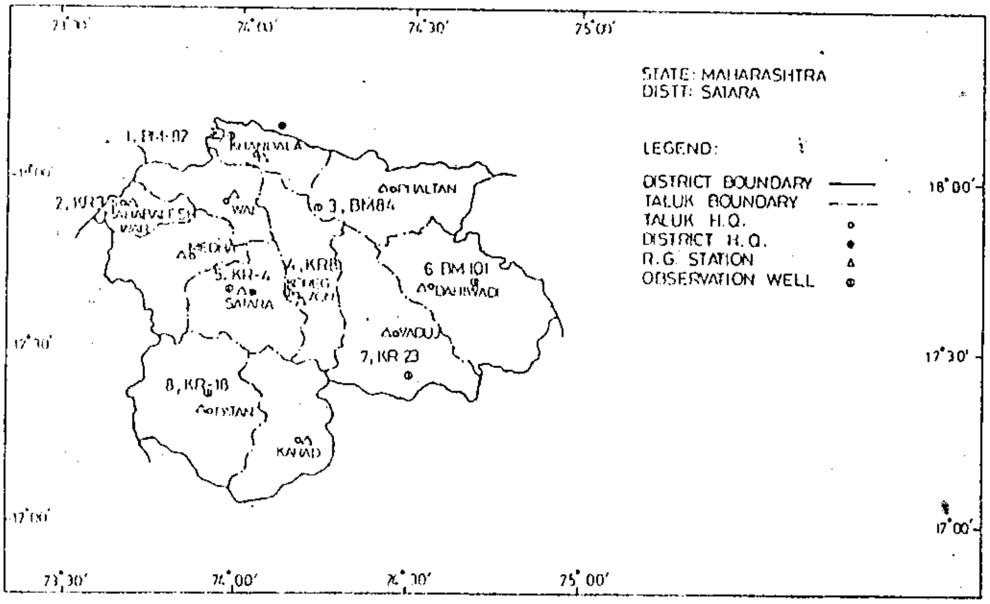
The studies of CWC (1982) indicate that the district experienced 4 hydrologic drought years during the period 1940-78. The location of raingauges and groundwater observation wells is shown in the district map (Figure 2.6).

2.10.4 Satara

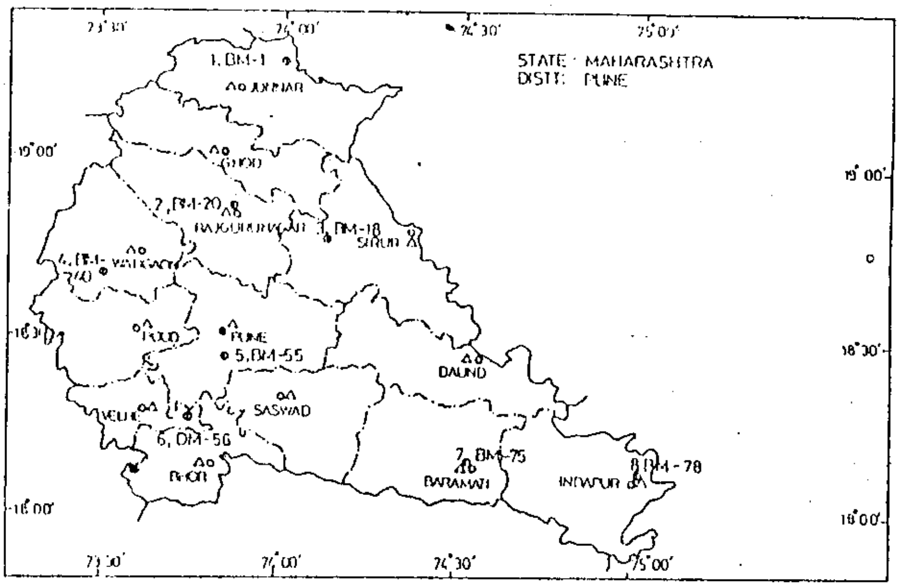
Satara is one of the drought prone districts in Maharashtra with the geographical located between 17° -05' and 18° -11' north latitudes and between 73° -33' and 74° -54' east longitudes. The geographical area of the district is 10,492 sq.km. The district consists of 11 talukas. The district population is 2,041,409 and density of population is 195 persons per sq.km., as per 1981 census. Soils in the district are mostly of three types namely; medium black or deep black soils, lighter soils of reddish brown colour and lateritic soils. The details of land use in the district as per data from 1970-71 to 1977-78 include: forests 148,600 ha., land put to non agriculture uses 25,500 ha., barren and unculturable land 115,300 ha., culturable area 676,300 ha., and the cultivable waste 52,400 ha.

As per the data available from 1971-72 to 1977-78, the total area of irrigation in the district is 103,997 ha. surface water sources such as canals, tanks etc. irrigate 47,992 ha., and sources such as ground water is 56,005 ha. Mainly two rivers flow in the districts and they are Krishna and Bhima. The catchment area of Krishna river within the district is 6917 sq.km. Bhima river has a catchment area of 3575 sq.km. within the district.

As per CWC studies of 1982, the normal rainfall of the district (1901 to 1978) is 1131.73 mm and normally there are 55.98 rainy days in the district. There are 84 raingauge



(a) DISTT. SATARA



(b) : DISTT. PUNE

FIG. 2.6 : LOCATION OF RAINGAUGE STATION & **OBSERVATION WELLS**

stations located in the district and density of raingauge stations works out to be 124.2 sq.km. per raingauge station. The maximum annual rainfall of 1673.36 mm was experienced in the district in the year 1978. The rainfall in the district generally depends on southwest monsoon which gives about 83.2 percent of the normal annual rainfall. The coefficient of variation for annual rainfall has been reported as 20.43% for the district. As per CGWB data the utilisable groundwater resources are 104267 hact. m. and the draft is 32824 hact. m., resulting in a balance of 71443 hact. m. As per CWC (1982) observations, the district faced 4 hydrological drought years during the period 1940-78. Figure 2.6 shows location of raingauges and observation wells which have been chosen for analysis

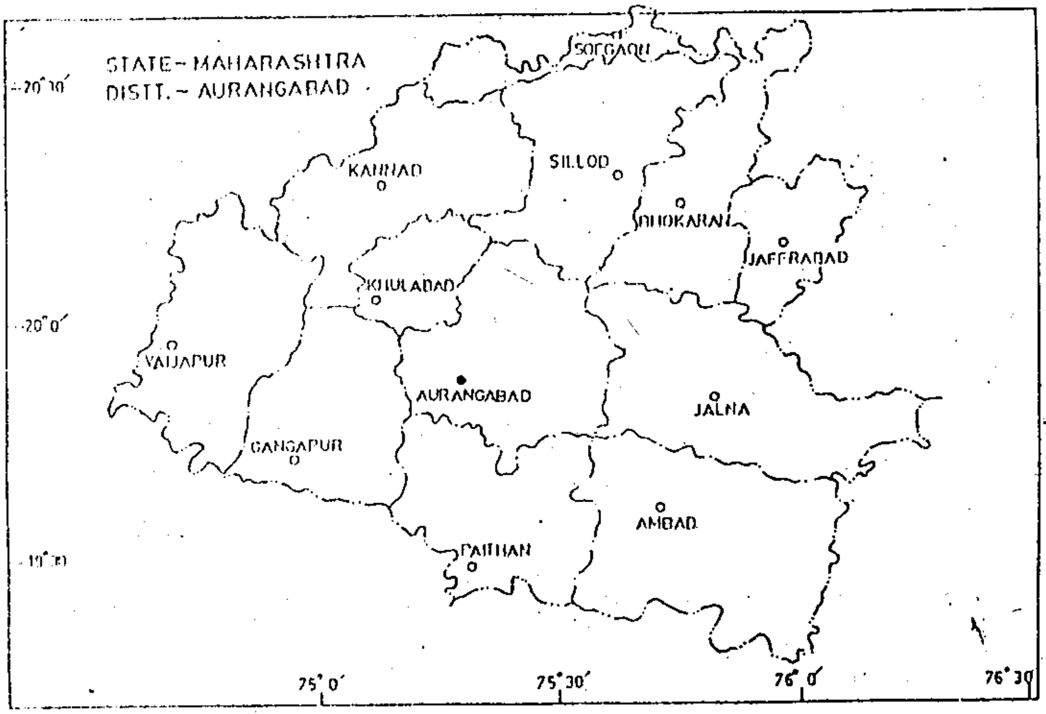
2.10.5 Aurangabad

Aurangabad is the third largest district of Maharashtra state and is among the drought prone districts. The geographical location of the district is between 19° 17' and 20° 40' north latitudes and between 74° 39' and 76° 40' east longitudes. The district has a geographical area of 16305 sq.km. and consists of 12 talukas. It has 1866 inhabited villages, 109 uninhabited villages and 10 towns. The population of the district is 24,32,010 and density of population is 149 persons per sq.km., as per 1981 census.

Soils in the district are generally of three types namely; coarse shallow soil, medium deep soil and deep black soils. The land use in the district as per data 1967-68 to 1977-78 include: forests 83845 ha., barren and unculturable land 25555 ha., land put to non agricultural uses 52,754 ha. and culturable area 1,389,428 ha. As per data available from 1967-68 to 1976-77, the total irrigated area in the district is 111,266 ha. and source wise distribution is : by surface water 9,340 ha., by ground water 82,972 ha. and 423 ha. by other sources.

The main river passing through the district is Godavari. The catchment area of Godavari in the district is 15,337 sq.km.

As per CWC report (1982), the normal annual rainfall of the district is 724.16 mm and normally there are 44.0 rainy days in a year according to the analysis of data from 1902 to 1980. There are 29 raingauge stations located in the district and the density of raingauge stations is 565 sq.km. per raingauge station. The maximum annual rainfall in the district of 1171.70 mm was experienced in year 1916. The rainfall of the district generally depends on south west monsoon, which accounts for 83 percent of the annual rainfall. The coefficient of variation of annual rainfall has been reported as 26.0% for the district. As per state GSDA data the annual recharge to ground water is 95646 hact. m., while the net draft is 33610 hact. m., resulting in surplus of 62035 hact. m. in one year as per CGWB census. The district is reported to have faced 8 hydrological drought years during the period 1951 to 1979 as per CWC (1982) observations. The location of raingauges and observation wells in the district are shown in Fig. 2.7.



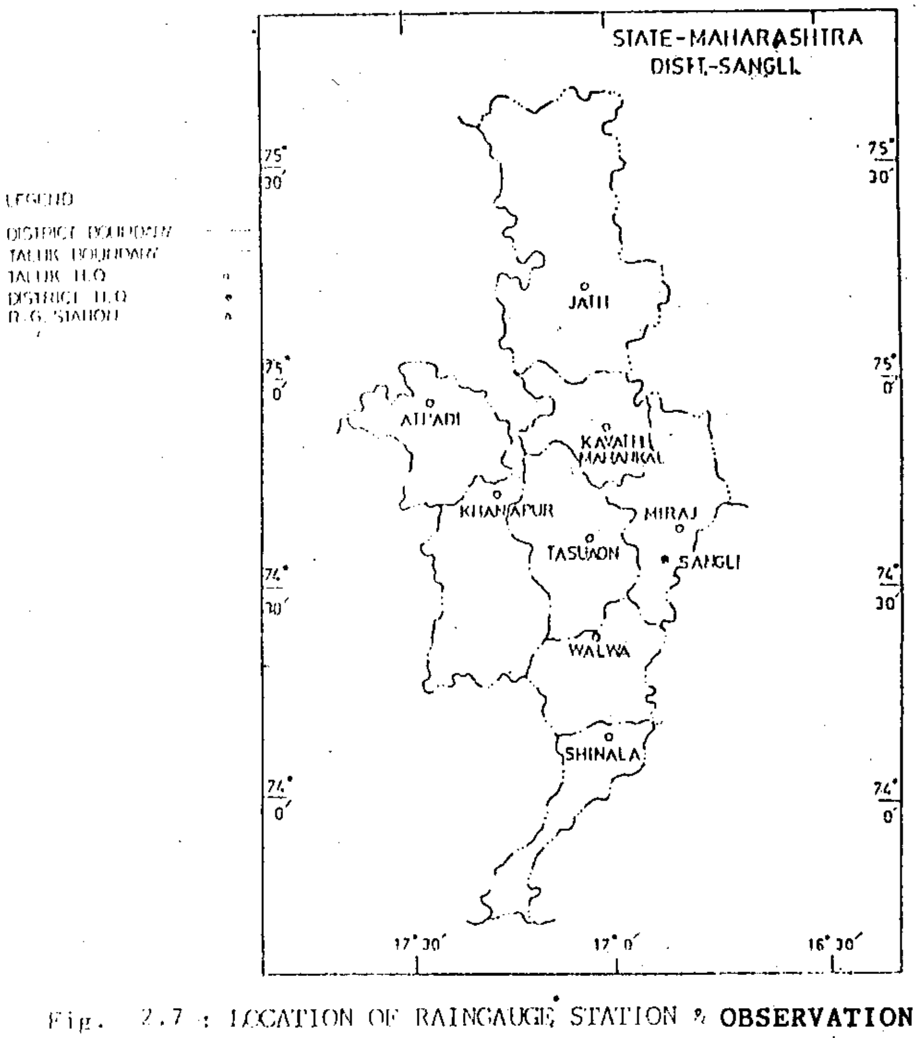


Fig. 2.7 : LOCATION OF RAINGAUGE STATION & OBSERVATION WELLS

2.10.6 Sangli

Sangli is one of drought prone districts in Maharashtra with the geographical location between 16° 43' and 17° 38' north latitudes and between 73° 41' and 75° 41' east longitudes. The geographical area of the district is 5610.25 sq.km. The district consists of the eight talukas and has 539 inhabited villages, 4 uninhabited villages and 7 towns. The population of the district is 18,26,186 and density of population is 212 persons per sq.km., as per the 1981 census.

The soils in the district are mostly of three types namely; black, red and laterite soils. The details of land use in the district as per data from 1970-71 to 1977-78 indicate: forests 47100 ha., land put to non-agricultural uses 26200 ha., barren and unculturable lands 41900 ha., culturable area 727500 ha. and cultivable waste 18300 ha.

As per the data available from 1970-71 to 1977-78, the total irrigated area in the district is 74500 ha. with the source wise distribution of 27967 ha. by surface water and 46533 ha. by groundwater. The Krishna is the main river flowing through the Sangli district. The catchment area of Krishna river within the district is 1812 sq.km.

As per CWC studies of 1982, the normal rainfall of the district (1901 to 1980) is 635.1 mm. and normally there are 45.98 rainy days in a year in the district. There are 22 raingauge stations located in the district and the density of raingauge stations works out to 255 sq.km. per raingauge station. The maximum annual rainfall of 957.33 mm was experienced in the district in year 1932. The south west monsoon gives about 66.70 percent of normal annual rainfall in the district. The coefficient of variation for annual rainfall has been reported as 31% for the district. As per CGWB data, the utlisable resources are of the order of 80840 hact. m., while the net draft is 36484 hact. m., resulting in net balance of 44356 hact. m. in one year. As per CWC (1982) observations, the district faced 13 hydrological drought years during the period 1951 to 1980. Fig. 2.7 shows location of raingauges and wells in the district.

3.0 RAINFALL ANALYSIS

3.1 General

As has already been described in chapter 2.0, Six districts, viz., Ahmednagar, Sholapur, Pune, Satara, Aurangabad and Sangli from the state of Maharashtra 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 the 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 1988 have been collected during visits of scientific teams to various central/state Govt. offices in Maharashtra.

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 1970-91 have been used for this analysis. Seasonal normals for the six chosen districts of Maharashtra have been calculated as the summation of normals for the months (June to September) as provided in the CWC reports. Only four months i.e. June, July, gust and September are taken in account while estimating seasonal normals as the Southwest monsoon is active for these four months in the state. The results of analysis are given in in Table 3.1. The graphical representation of seasonal deficiencies are shown in Fig.3.1. The major inferences that could be drawn from the seasonal analysis are :

The seasonal rainfall departure pattern in the state Maharashtra has been deficient in Ahmadnagar, Pune, Sangli and Satara in year 1990 and in Pune, Satara and Sholapur in year 1991. The districts Pune and Satara recorded continuous deficient seasonal rainfall since 1970 with the extremes lying in between 15 to 60 percent.

3.2.2 Monthly rainfall departure for the year 1990-91

In order to observe deficiency in monthly rainfall during the year 1990-91, monthly departures have been worked out for the six districts. This analysis has been done for all the taluks and the district as a whole. Monthly rainfall values from June '90 to May '91 along with monthly normals of representative raingauges of various taluks have been considered for the purpose. Monthly rainfall values for a district from June'90 to May'91 have been computed as weighted average rainfall of all the taluks considered for analysis

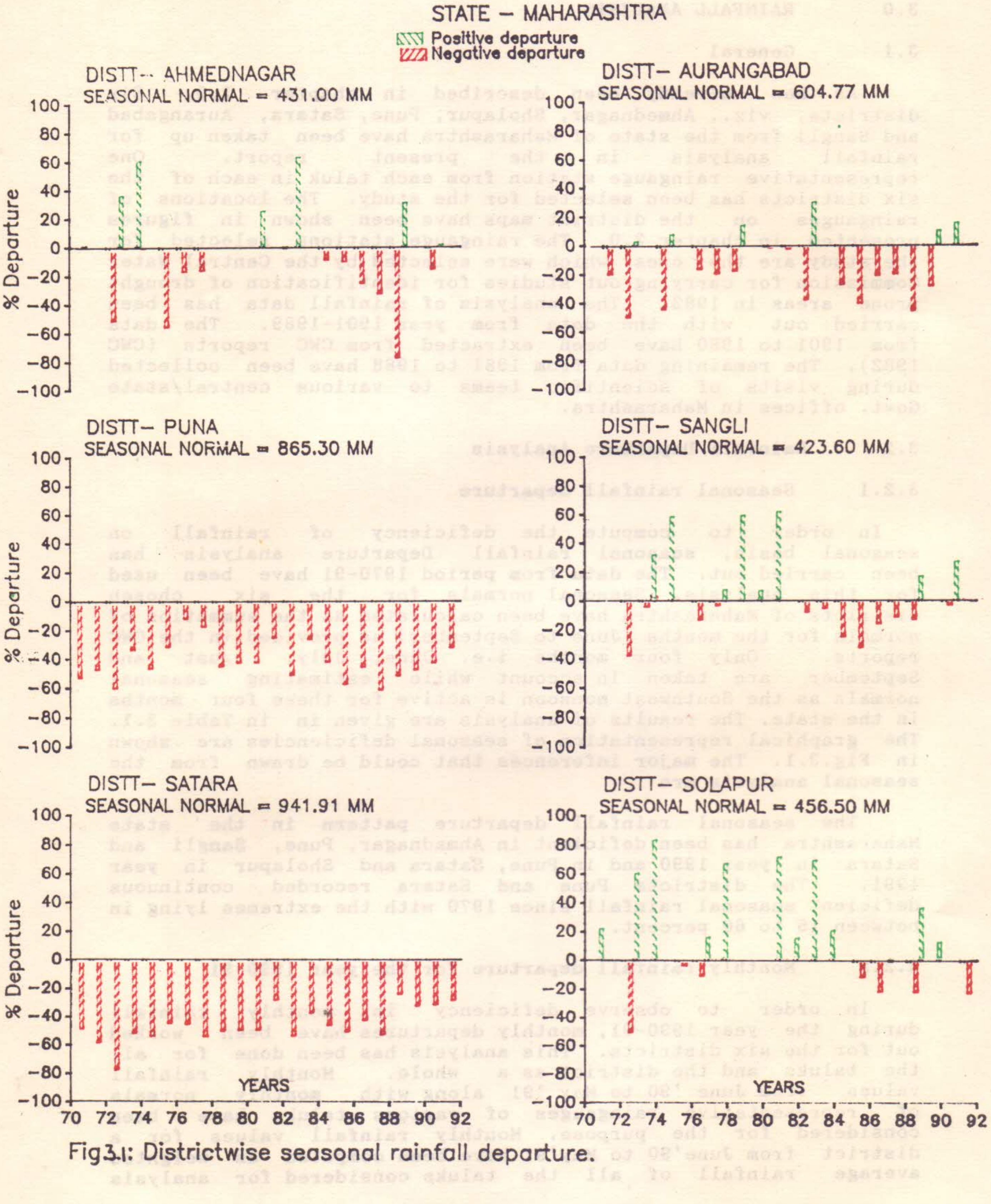


Fig3.1: Districtwise seasonal rainfall departure.

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 the districts of Maharashtra.

Year	Districts					
	Ahmed-nagar	Auranga-bad	Pune	Sangli	Satara	Sholapur
Seasonal normal, mm	431.00	609.77	865.30	5423.60	941.91	456.50
70	7.79	41.65	-51.55	1.28	-47.31	44.60
71	0.78	-19.16	-45.94	0.00	-57.11	21.38
72	-49.51	-49.13	-58.93	-37.38	-76.36	-50.07
73	36.38	2.75	-32.27	-3.49	-50.47	59.89
74	60.83	-43.75	-45.34	31.53	-52.78	83.08
75	-53.99	7.61	-30.00	58.30	-43.47	- 3.11
76	-15.24	-15.67	-10.59	-12.61	-44.22	-10.31
77	-14.75	-18.91	-16.06	-2.77	-52.94	15.46
78	0.0	-17.01	-43.81	7.30	-49.00	66.61
79	0.0	13.79	-41.33	59.02	-48.44	0.0
80	0.0	-1.09	-41.33	6.64	-48.44	0.0
81	25.49	-2.04	-24.04	61.81	-27.18	71.43
82	-0.34	-37.31	-50.10	-7.64	-52.52	15.04
83	63.37	30.02	-25.06	-5.09	-36.38	69.04
84	-7.63	-26.78	-41.04	-24.67	-45.21	20.17
85	-8.82	-40.19	-56.43	-32.10	-49.72	-11.58
86	-23.78	-20.69	-44.68	-15.78	-41.45	-21.56
87	-31.28	-19.79	-60.45	-11.22	-51.86	-0.27
88	-76.15	-45.45	-50.77	-13.05	-23.01	-21.82
89	31.16	-28.18	-46.57	16.29	-31.47	35.79
90	-14.17	9.89	-41.80	-3.06	-30.50	12.08
91	1.73	15.16	-31.09	26.67	-27.49	-22.69

The variations in rainfall, month wise (monthly rainfall and corresponding normals) have been plotted for all the six districts for water year June'88 to May'89 and are shown in Figure 3.2. The departure figures for one taluk of each of the six districts are shown in Figure 3.3. The results of the monthly departure analysis for the districts as a whole are presented in Table 3.2. Based on monthly departure values, two categories of monthly departure i.e. 20-50% and more than 50% have been made for deriving monthly deficiency inferences. Table 3.3 gives description of districts in the state which experienced rainfall deficit during months of June '88 to May '89 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 Maharashtra.

Year/month	Districts of Maharashtra, (Percent departure)					
	Ahmednagar	Aurangabad	Pune	Sangli	Satara	Sholapur
1990 June	-11.40	93.71	-14.27	94.93	-22.74	93.19
1990 July	-39.90	-17.81	-43.21	-10.91	-41.91	-53.29
1990 Aug.	83.21	31.25	-29.33	23.14	-21.73	111.52
1990 Sept.	-50.67	-46.39	-73.27	-76.88	-24.42	-52.77
1990 Oct.	305.75	305.21	109.66	35.30	21.87	146.84
1988 Nov.	-63.34	-48.49	-72.18	-45.34	-27.40	-52.08
1990 Dec.	-41.44	-60.44	-31.79	-100.00	-100.00	-100.00
1991 Jan.	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
1991 Feb.	-100.00	-100.00	-100.00	-100.00	-100.00	-88.81
1991 March	-100.00	-100.00	-100.00	-97.49	-100.00	-100.00
1991 April	2.20	-46.71	-35.96	44.66	10.76	55.31
1991 May	164.14	-58.39	-36.72	119.13	-69.22	31.68

Table 3.3 : Monthly rainfall deficits in districts as a whole during 1990-91.

Month/ year	Group Range of Deficiency in rainfall (expressed as percentage of normals)	
	20 to 50%	50% and above
June '90	Satara	NIL
July	Ahmadnagar, Pune Satara	Sholapur
August	Pune, Satara	NIL
September	Aurangabad, Satara	Ahmadnagar, Pune, Sangli, Sholapur
October	NIL	NIL
November	Aurangabad, Sangli, Satara	Ahmadnagar,Pune, Sholapur
December	Ahmadnagar, Pune	Aurangabad, Sangli, Satara, Sholapur
Jan. to March	NIL	All districts
April	Aurangabad, Pune	NIL
May	Pune	Aurangabad, Satara

In monsoon months of June, July, August & September '90 one or other district experienced deficiency in rainfall. In the month of October, the rainfall was too heavy and no deficiency was experienced. Again from September '90 to March '91, the deficiency was observed in one or the other districts of Maharashtra.

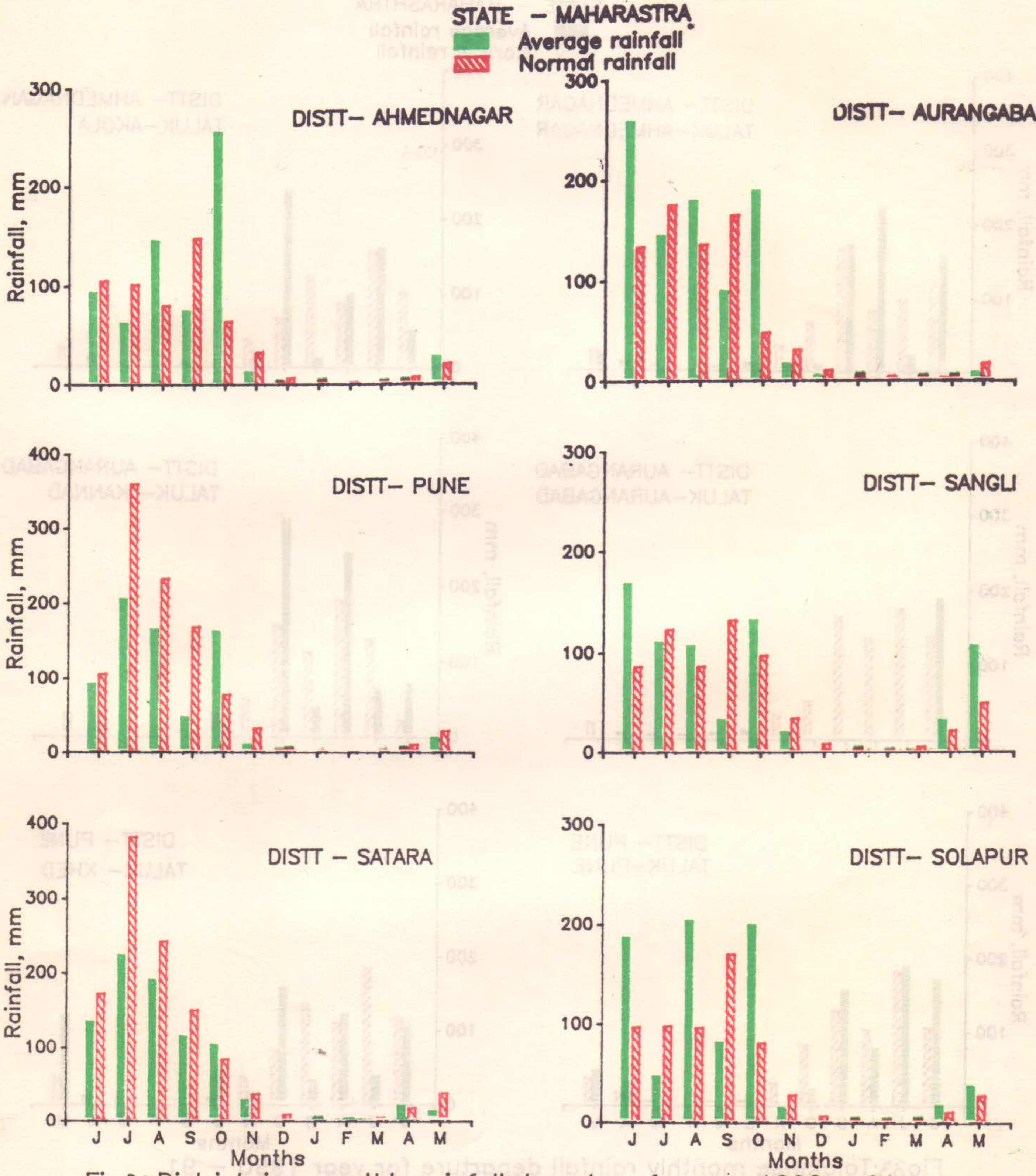


Fig.32:Districtwise monthly rainfall departure for year 1990 - 91.

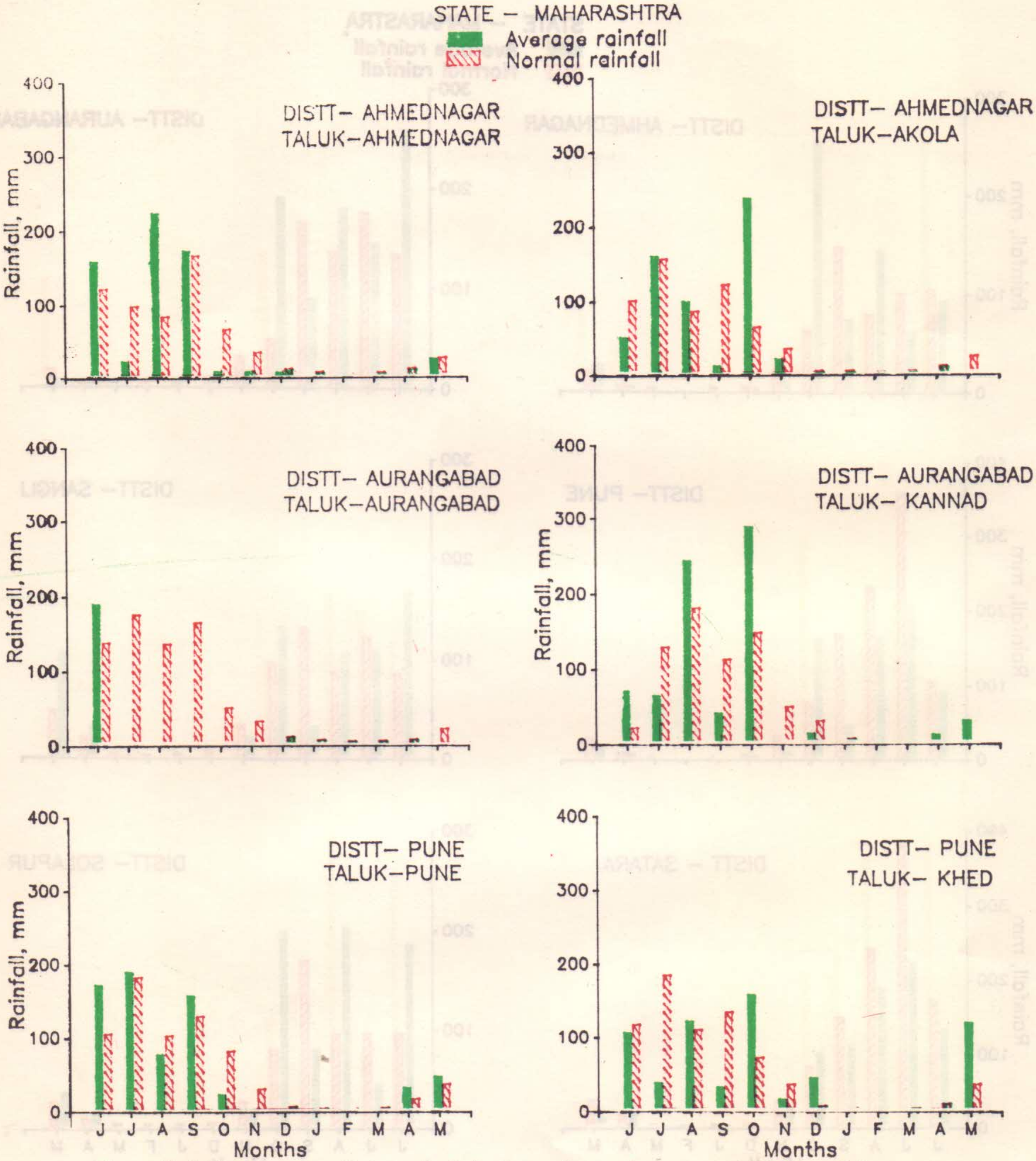


Fig33:Talukwise monthly rainfall departure for year 1990 – 91.

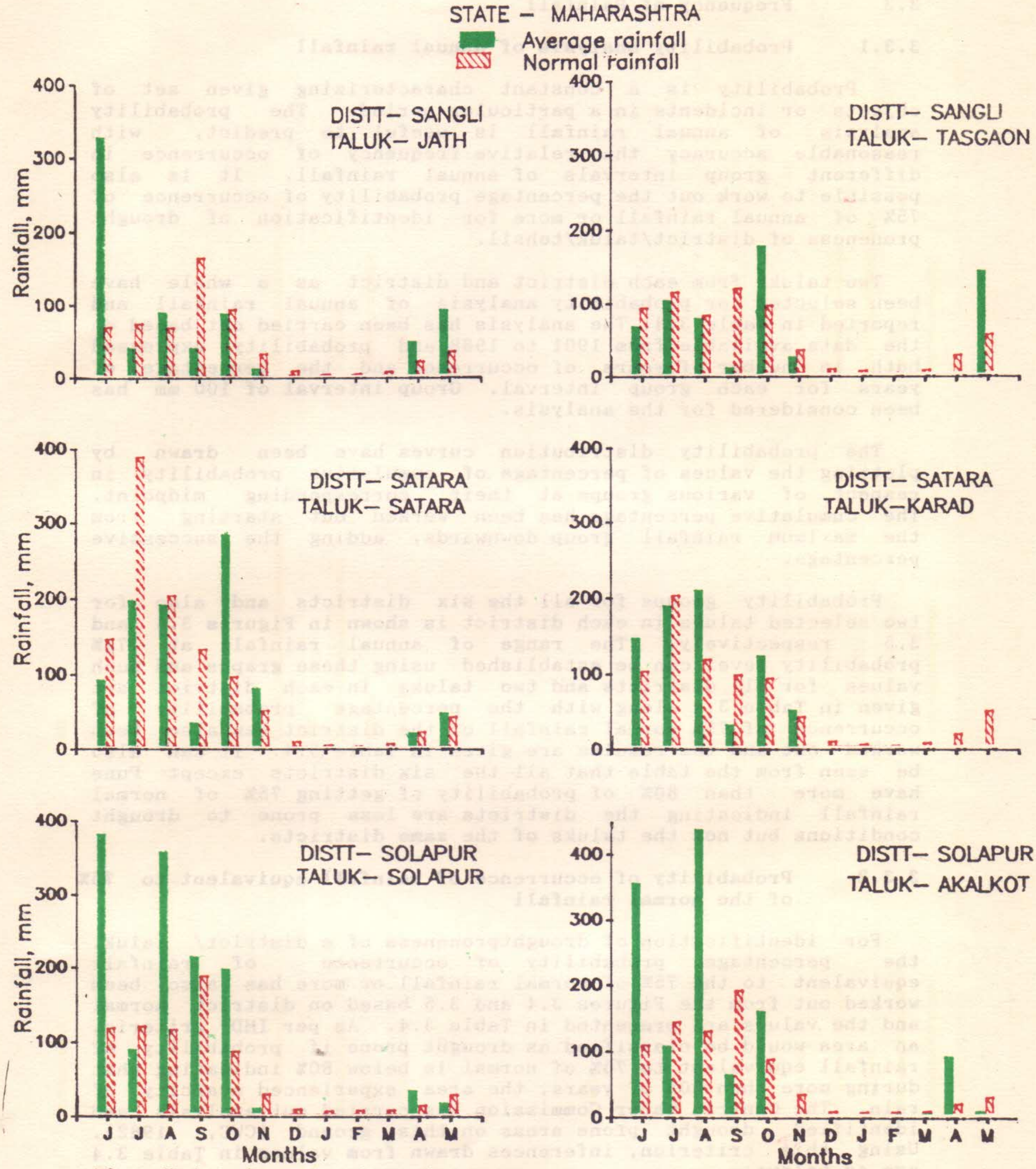


Fig.3.3:Talukwise monthly rainfall departure for year 1990 – 91.

3.3 Frequency of Rainfall

3.3.1 Probability analysis of annual rainfall

Probability is a constant characterizing given set of objects or incidents in a particular period. 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/taluk/tehsil.

Two taluks from each district and district as a whole have been selected for probability analysis of annual rainfall and reported in Table 3.4. 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 have been drawn by plotting the values of percentage of cumulative probability in respect of various groups at their corresponding midpoint. The cumulative percentage has been worked out starting from the maximum rainfall group downwards, adding the successive percentage.

Probability groups for all the six districts and also for two selected taluks in each district is 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 districts and two taluks in each district are given in Table 3.4 along with the percentage probability of occurrence of 75% normal rainfall of the district has also been worked out and the results are given in Table 3.4. It can also be seen from the table that all the six districts except Pune have more than 80% of probability of getting 75% of normal rainfall indicating the districts are less prone to drought conditions but not the taluks of the same districts.

3.3.2 Probability of occurrence of rainfall equivalent to 75% of the normal rainfall

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

Table 3.4: Probability distribution of annual rainfall of Maharashtra.

Sl.	District	Name of Taluks	75% probability & above (Range in mm)	75 % of normal rain fall, mm	Probability of occurrence of rainfall equivalent to 75% normal, %
1.	Ahmednagar	Ahmednagar	500-600		84
		Akola	200-300		65
		District as a whole	400-500	417.22	90
2.	Aurangabad	Aurangabad	600-700		84
		Kannad	400-500		75
		District as a whole	600-700	543.12	84
3.	Pune	Pune	500-600		35
		Khed	500-600		35
		District as a whole	800-900	810.22	79
4.	Sangli	Jath	400-500		79
		Tasgaon	500-600		82
		District as a whole	500-600	476.32	87
5.	Satara	Satara	900-1000		82
		Karad	600-700		40
		District as a whole	900-1000	848.79	84
6.	Sholapur	Sholapur	600-700		91
		Akalkot	300-400		73
		District as a whole	500-600	462.52	90

The probability values of occurrence of 75% normal rainfall in all the six districts namely Ahmednagar, Aurangabad, Pune, Sangli, Satara and Sholapur are 90, 84, 79, 87, 84 and 90 respectively. The value for Pune & Sholapur are below 80% indicating that this district can be classified as drought prone, based on this analysis as per IMD criteria. This can also be inferred that the district Pune experienced rainfall less than 75% of normal in 21 percent of years. The taluks of districts Aurangabad, Pune and Satara showed drought proneness.

3.4 Excess/Deficit Rainfall Using Herbst's Approach

3.4.1 Model description

Herbst et al (1966) evolved a new method of drought analysis using monthly rainfall data, whereby it is possible to

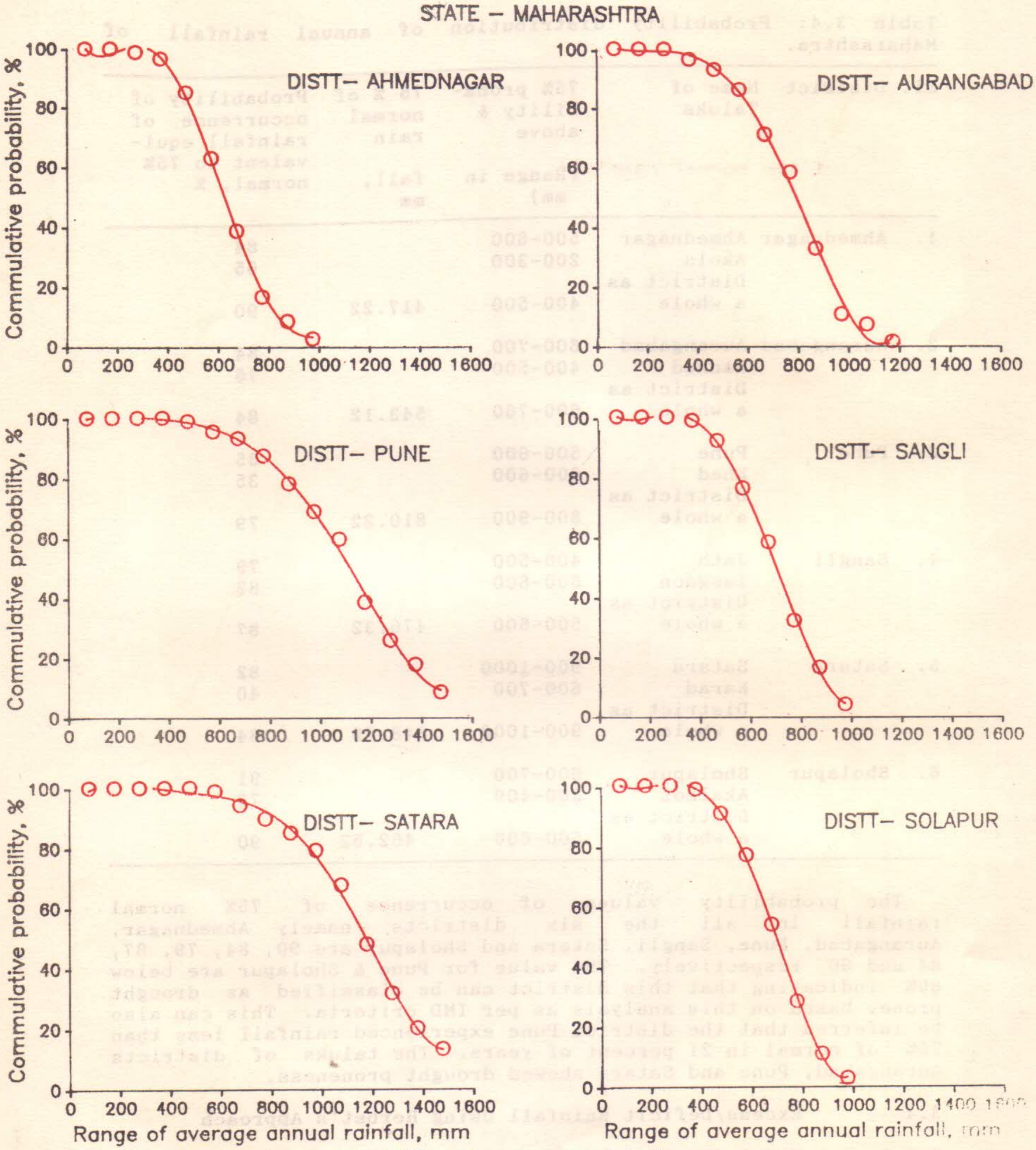


Fig.3.4:Districtwise probability of annual rainfall.

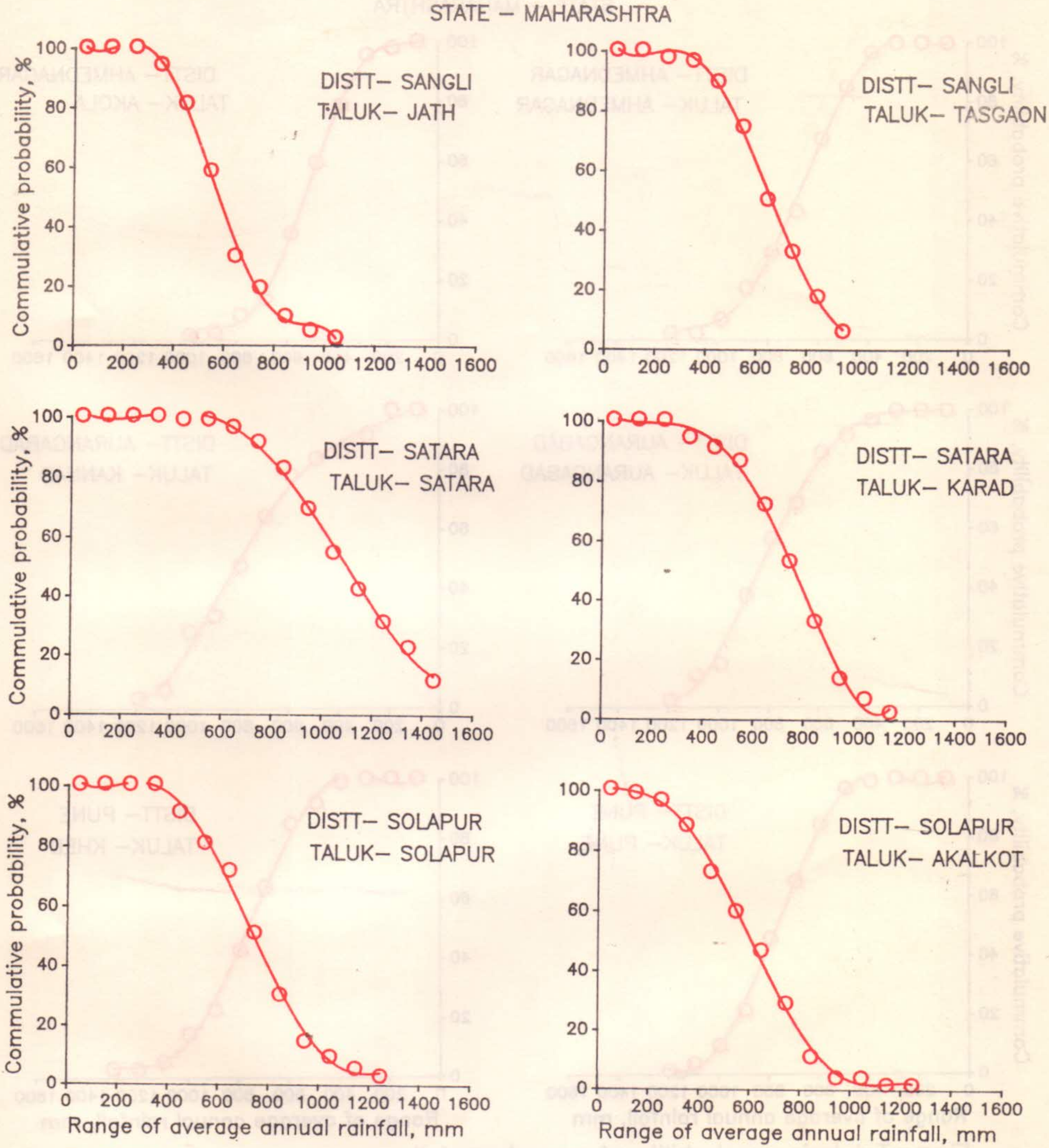


Fig.3.5:Talukwise probability of annual rainfall.

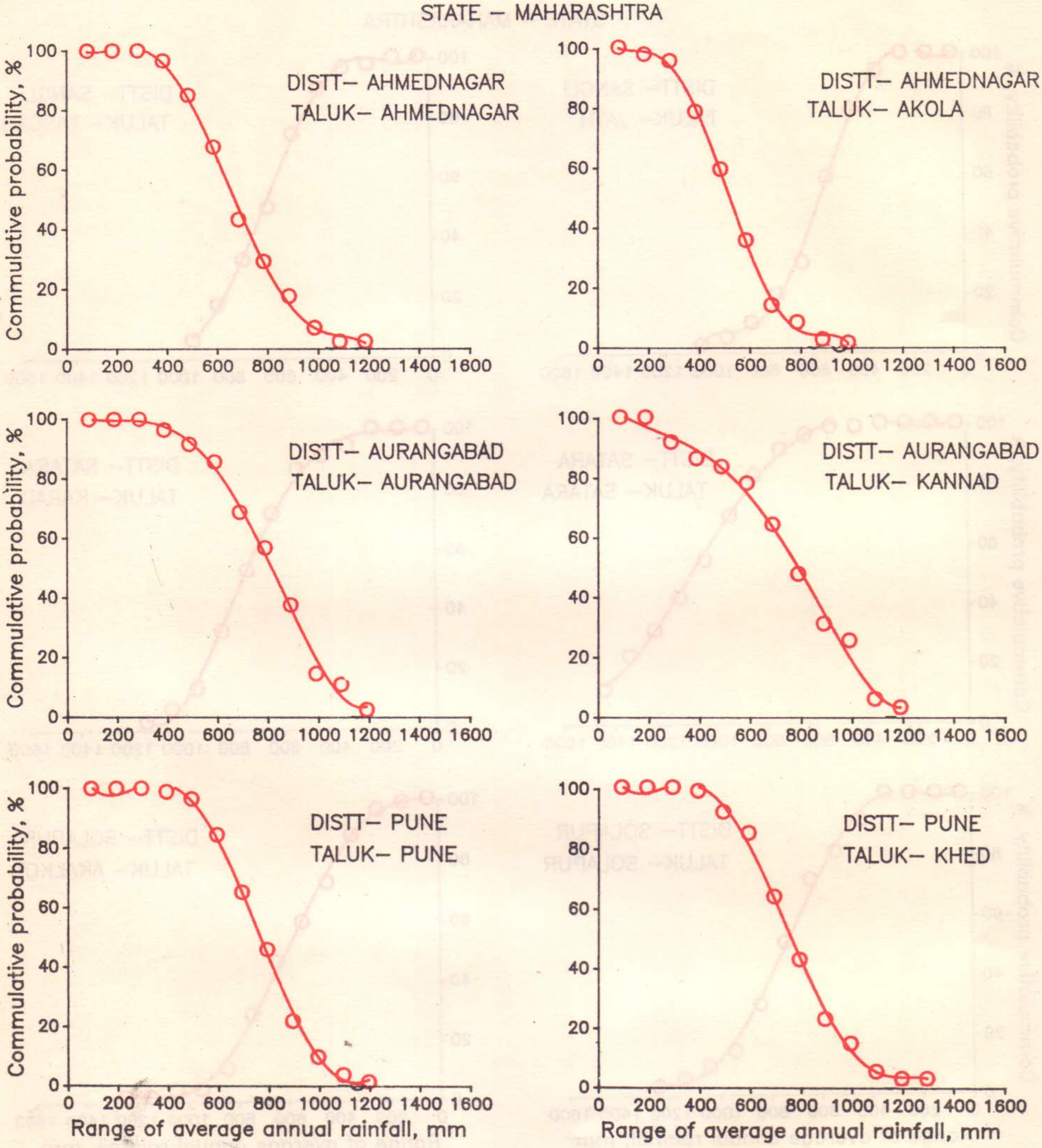


Fig.3.5:Talukwise probability of annual rainfall.

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**

In evolving 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 emperical formula as suggested by Herbst et al (1966).

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

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

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

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

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 is 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, are reported as zero. Thus the 'Mean Monthly Deficits (MMD)' were based not only on those months in which a negative difference occurred, but also on the differences (i.e., negative deficits) which are taken as zero and thus also included in the computation.

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

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

'Mean Monthly Deficit' for each month is calculated using:

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

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

$$MAD = \sum_{J}^{NMN} MMD(J) \quad ...(11)$$

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 upto 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 differences 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^{th} ,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 that 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 becomes positive, the drought is deemed to have terminated, otherwise the second test is carried out for testing of termination.

ii) The second test 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 months 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, upto a comparison of the sum 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 has occurred, testing for the start of the next drought begins in 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 numerator is less than 0.0 (i.e., negative), then numerator 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 six selected districts of Karnataka. Monthly rainfall data for period 1951-1991 of raingauge station located at five selected taluk headquarters of each district have been used for analysis. A computer programme using the above approach was used for the analysis. The analysis has yielded in the distinct spells of drought along with monthly and the 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 analysis by using the Herbst program for the period 1951 to 1991 of six selected drought prone districts namely; Ahmednagar, Aurangabad, Pune, Sangli, Satara, Sholapur and Aurangabad showed 5-12 drought spells indicating that the districts are drought prone. The analysis also showed the maximum drought duration of 68 months in Sangli and Ahmadnagaar during 1983 to 1989 and maximum drought intensity of 4.81 in Satara during 1978 to 1981. The districts of Sholapur, Sangli & Aurangabad had the drought spells in the range of 10-12, however, the districts Ahmednagar, Pune & Satara in the range of 5-7. This indicates the more droughtproneness of districts of Sholapur, Sangli & Aurangabad than others. All the six districts except Satara showed drought during 1985-88 indicating that due to successive droughts in these five districts the situation had been more disastrous. In year 1990-91, the districts Ahmadnagar, Aurangabad and Sangli showed the drought spell with maximum drought intensity in Ahmadnagar.

This approach is more relastic as compared to probability analysis, since in this approach, the results are based on the monthly rainfall data. On the other hand, the results of the probability analysis are based on yearly rainfall data. The approach has yielded comparable results of drought analysis and has further scope for improvement taking into account the revision of monthly weightage 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 (≥ 2 weeks) within monsoon season has importance specially for rainfed 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 six districts of Maharashtra.

The criterion for identification of a dry spell is that the daily rainfall should not have exceeded 5 mm on any day in a continious period of 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 districts of state Karnataka have been presented in Appendix II-(A). The number of dry spells have been counted, starting from the monsoon season of 1981 to

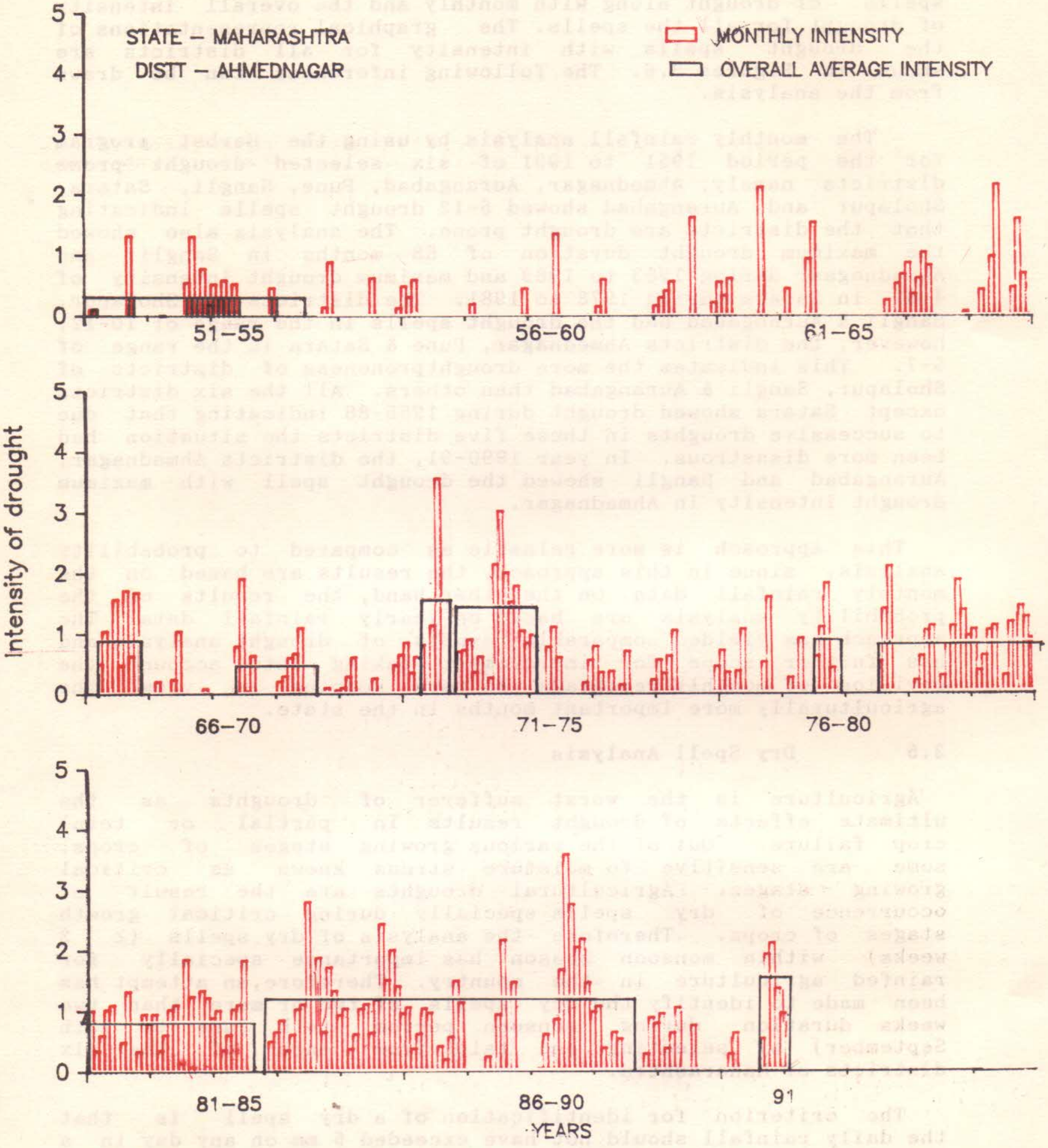


FIG:3.6.Overall average and monthly intensity of drought.

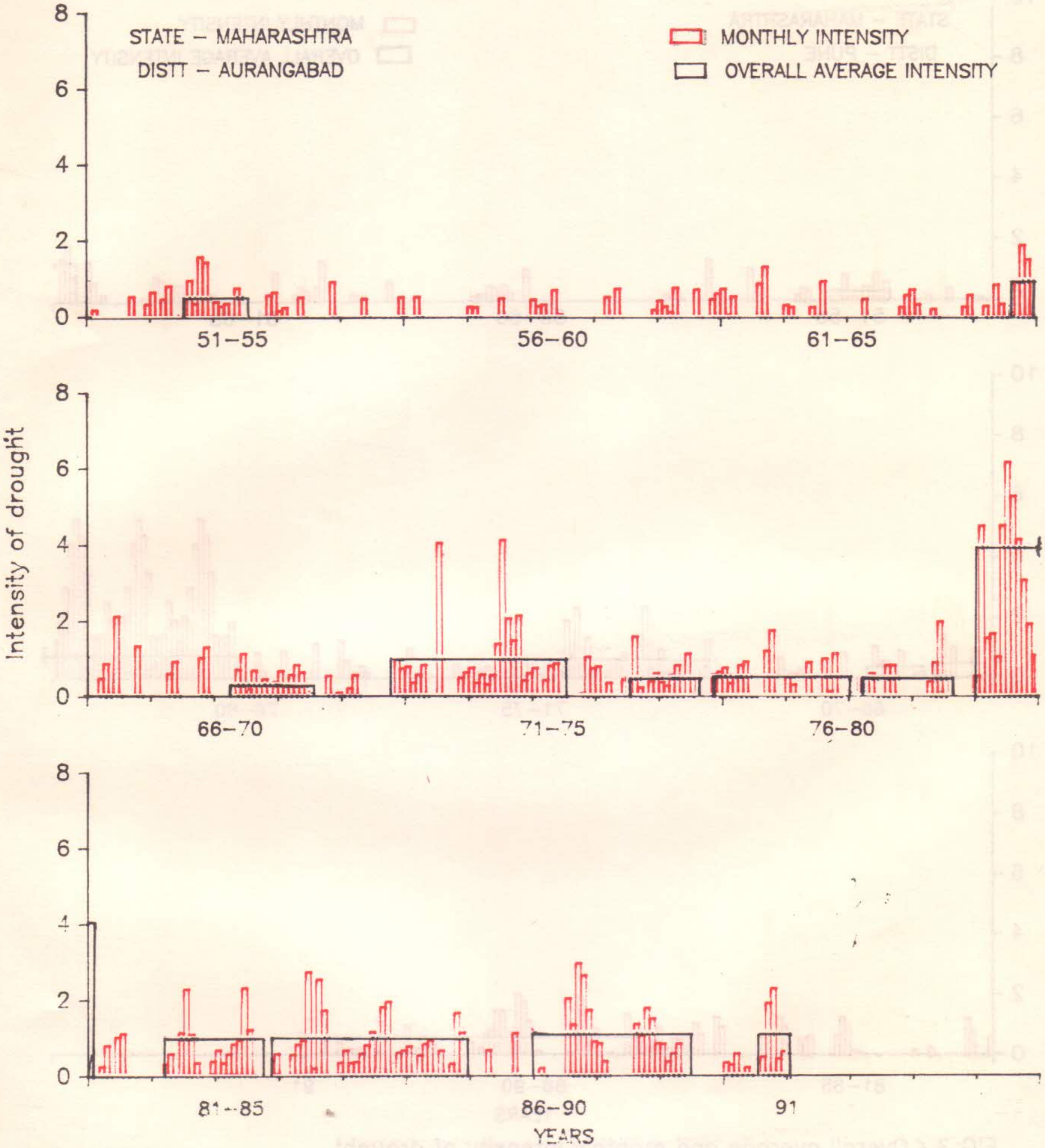


FIG:3.6.Overall average and monthly intensity of drought.

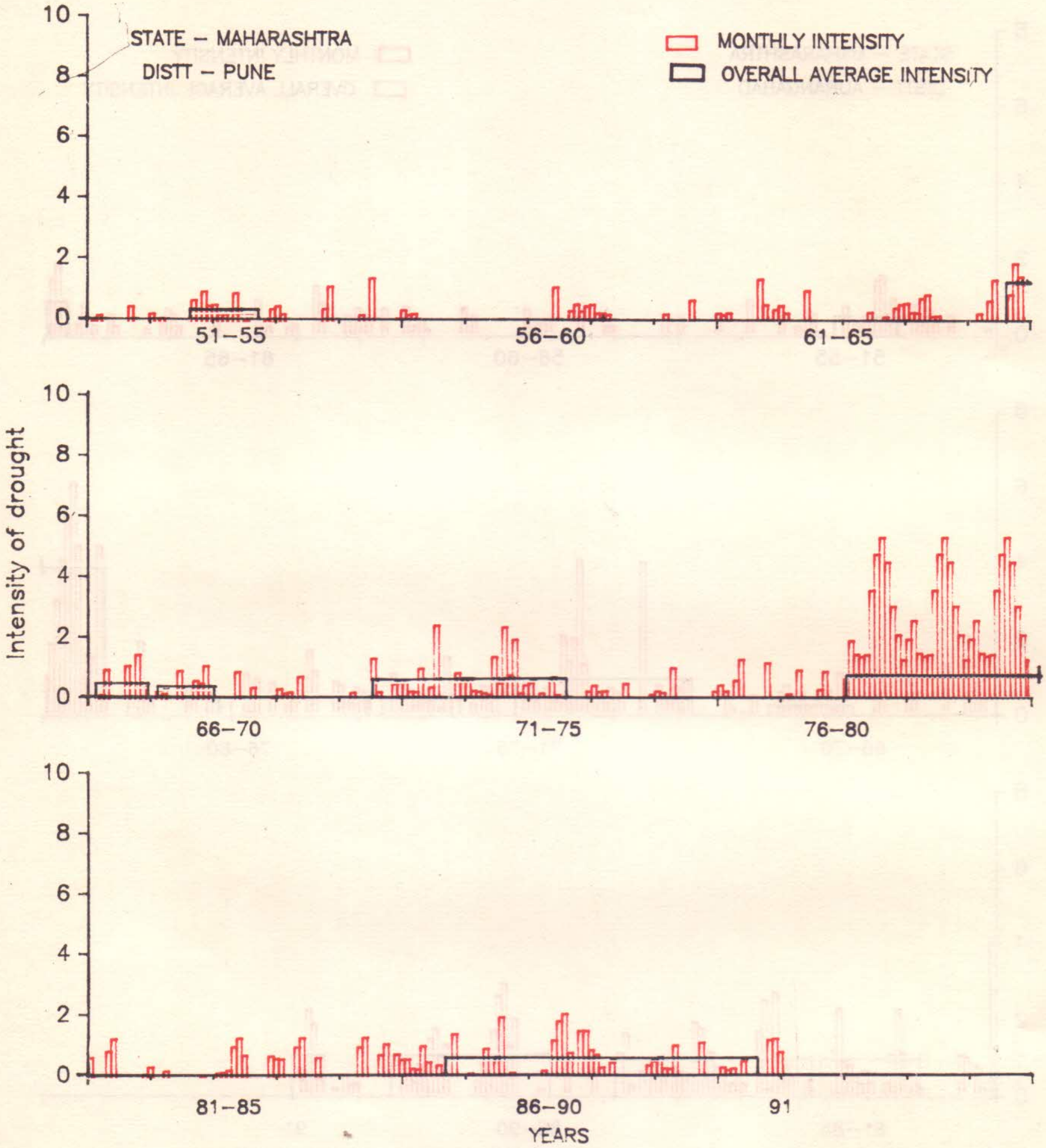


FIG: 3.6 Overall average and monthly intensity of drought.

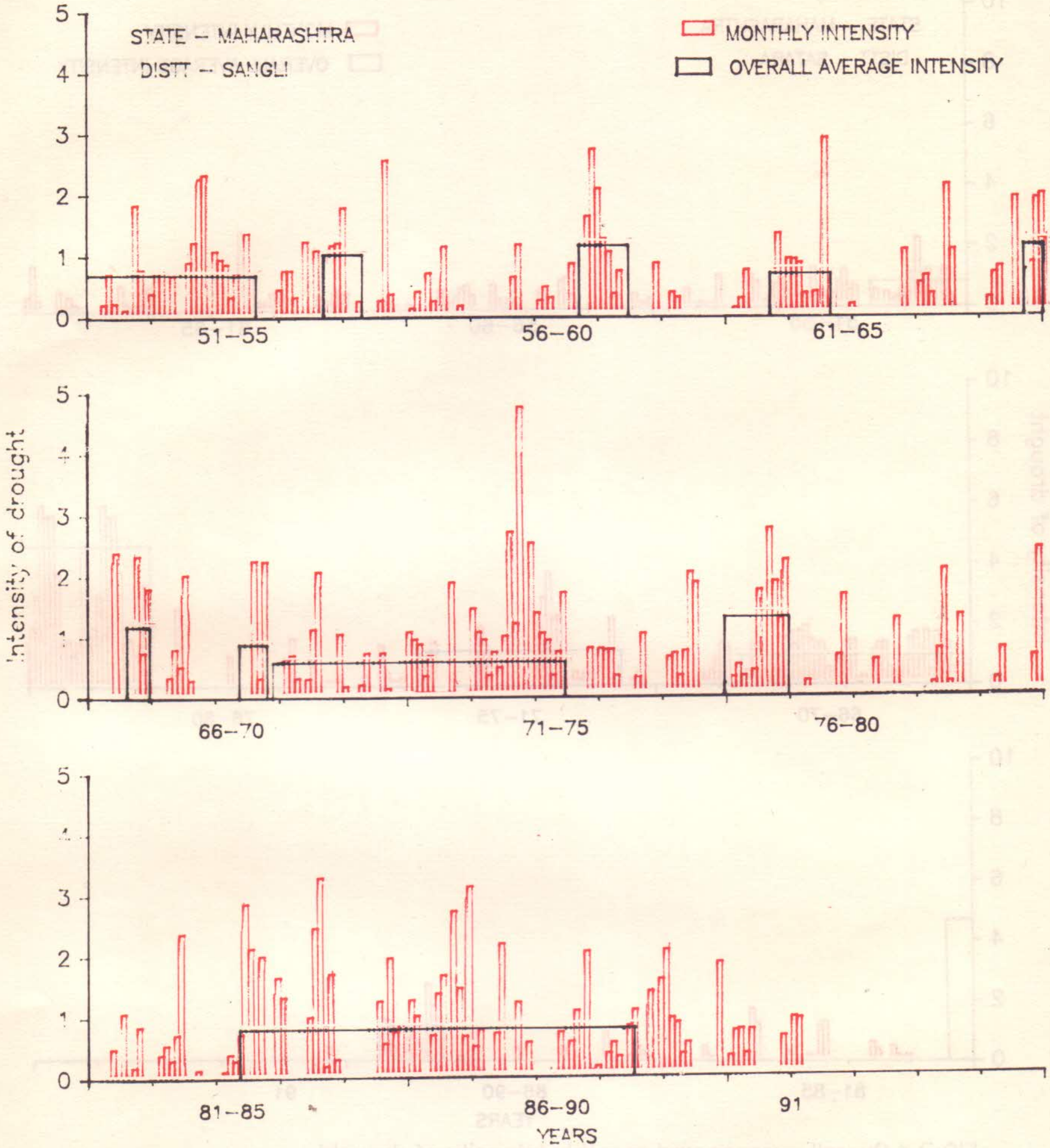


FIG:3.6.Overall average and monthly intensity of drought.

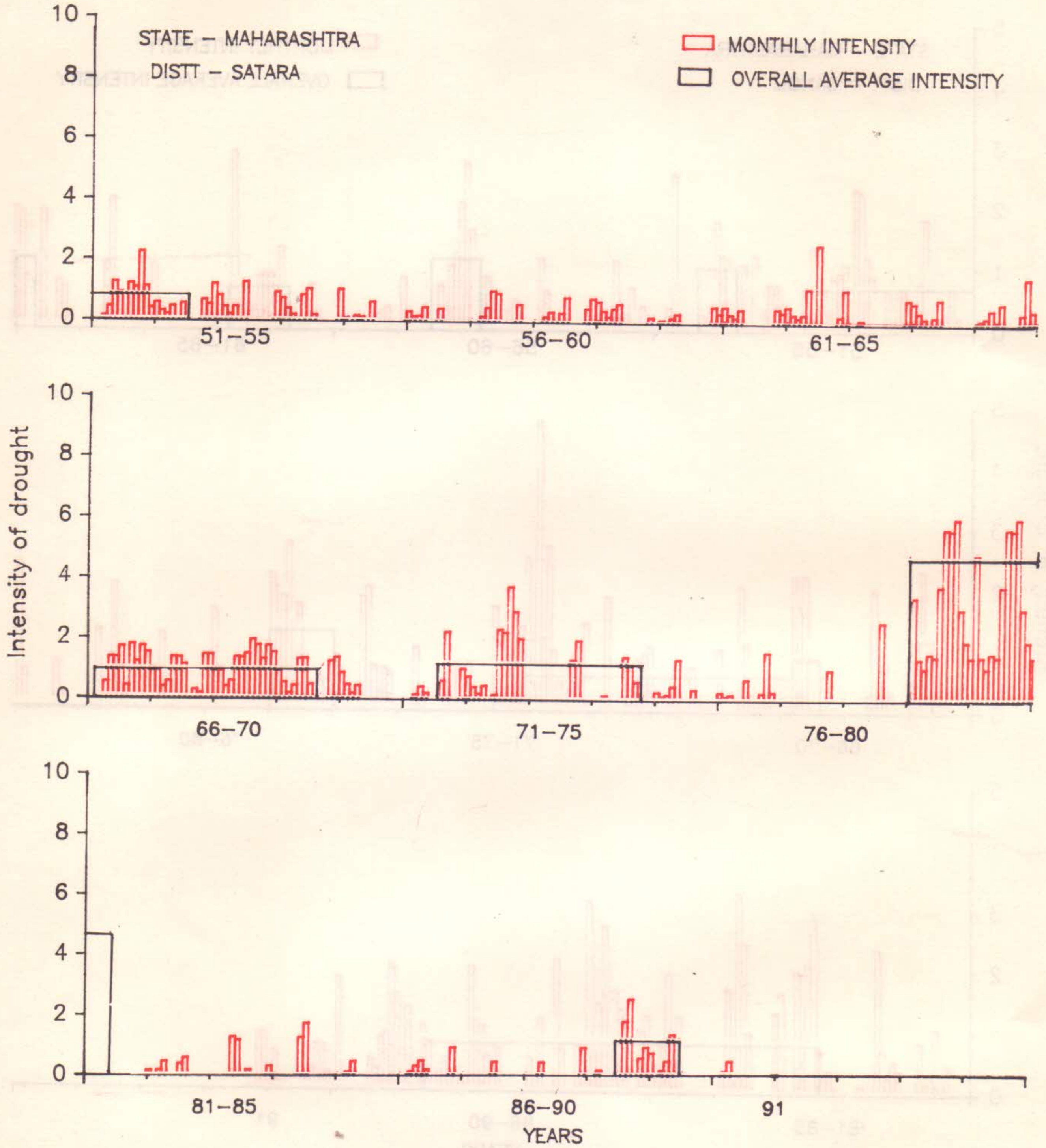


FIG:3.6.Overall average and monthly intensity of drought.

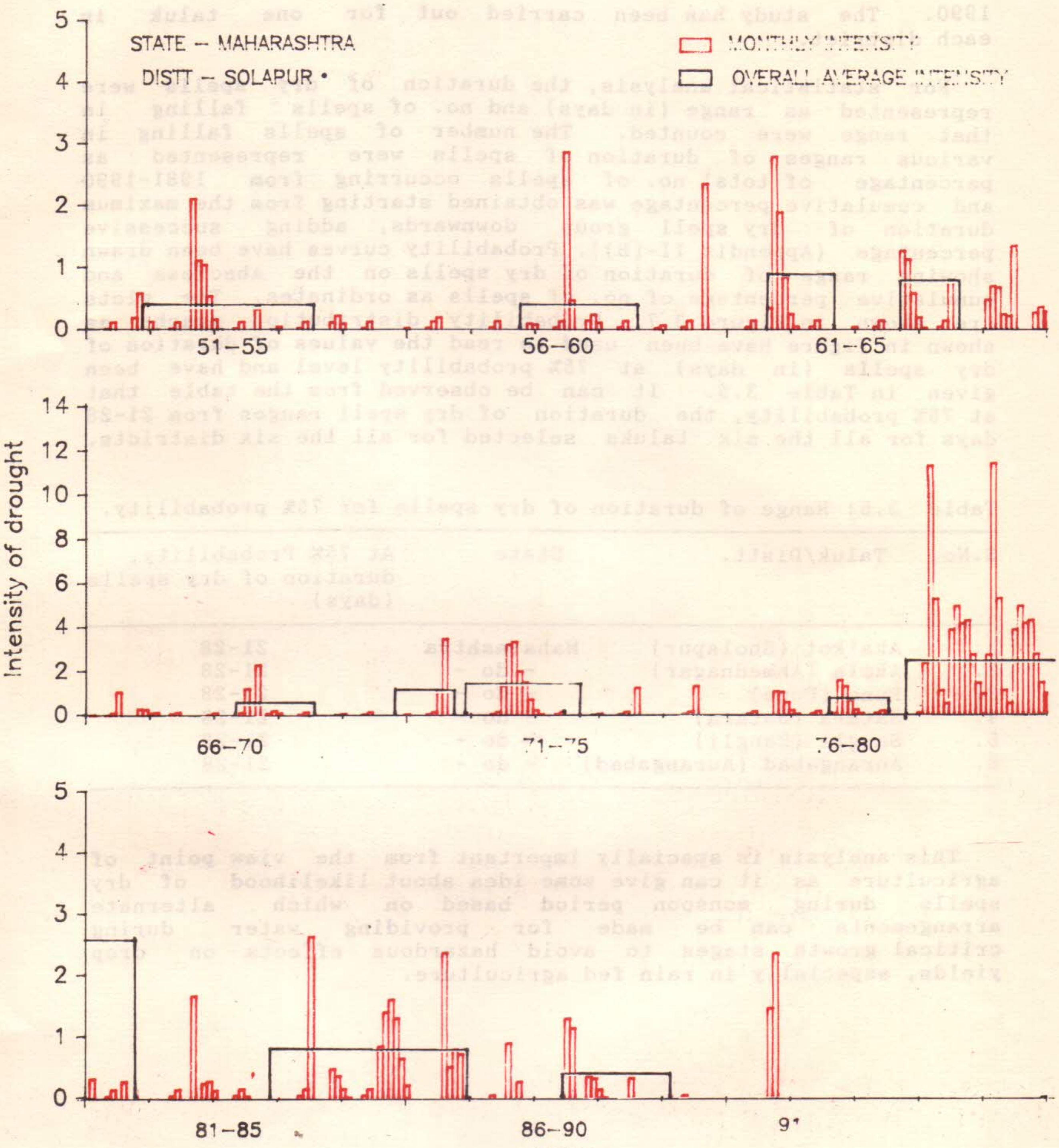


FIG:3.6.Overall average and monthly intensity of drought.

1990. 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 no. 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 no. of spells occurring from 1981-1990 and cumulative percentage was obtained starting from the maximum duration of dry spell group downwards, adding successive percentage (Appendix II-(B)). Probability curves have been drawn showing range of duration of dry spells on the abscissa and cumulative percentage of no. 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. It can be observed from the table that at 75% probability, the duration of dry spell ranges from 21-28 days for all the six taluks selected for all the six districts.

Table 3.5: Range of duration of dry spells for 75% probability.

S.No.	Taluk/Distt.	State	At 75% Probability, duration of dry spells (days)
1.	Akalkot (Sholapur)	Maharashtra	21-28
2.	Akola (Ahmednagar)	- do -	21-28
3.	Pune (Pune)	- do -	21-28
4.	Satara (Satara)	- do -	21-28
5.	Sangli (Sangli)	- do -	21-28
6.	Aurangabad (Aurangabad)	- do -	21-28

This 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.

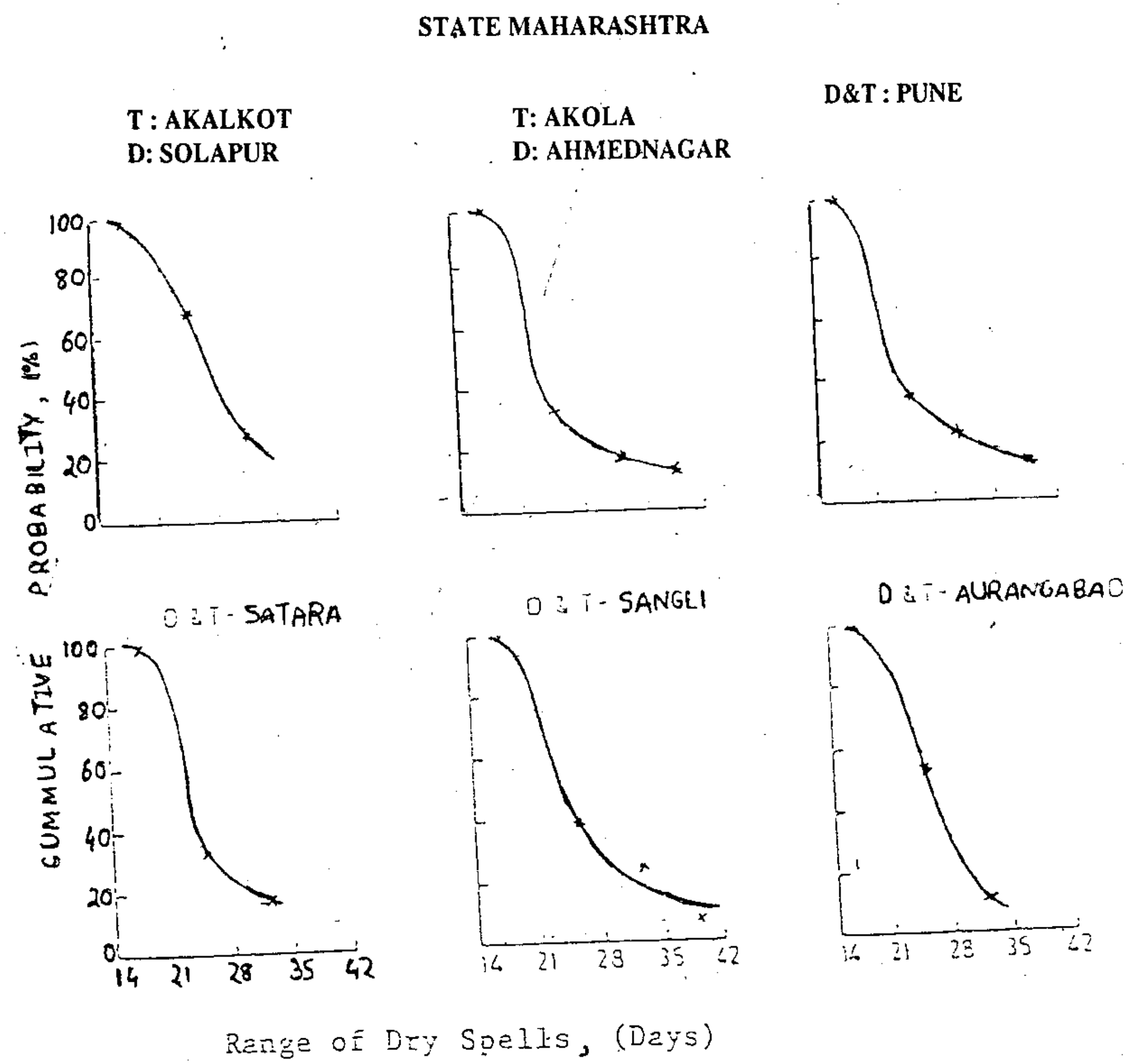


Fig. 3.7 : Probability Distribution of Dry Spells.

4.0 GROUND WATER DEFICIT

4.1 General

The main objective of groundwater management is to ensure that groundwater is be available at an appropriate time and in the required quantity and quality to meet the most important demands of society. The measurement of groundwater levels and their evaluation can play an important role in management of this underground resource. The fluctuations of watertable reflect the effects of infiltration, precipitation and discharge of groundwater 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 of rains, there is a greater dependence on ground water storage and steep decline in groundwater levels is experienced. Because of improper management of aquifers after development, numerous undesirable consequences such as the depletion of aquifers and groundwater 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 overexploited in certain pockets resulting in a fall in the watertable. 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 groundwater should be restricted to average annual recharge. This will conserve water from over exploitation during drought periods.

There is therefore, a long standing need for a better understand the relationship between precipitation and groundwater levels. The relationship can be developed by carrying out statistical analysis of precipitation data and well level observations. Besides, information regarding well abstractions should be available for evaluating effects on water table only due to reduced precipitation.

In order to see the effects of scarce rainfall as experienced during three successive drought and non drought years (1976-1989) on groundwater regime, statistical analysis of groundwater level data vis a vis precipitation has been carried out for all the 6 districts chosen in the state of Maharashtra. 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 groundwater level fluctuations were collected in respect of observation wells in all the six districts of Ahmednagar, Sholapur, Pune, Satara, Aurangabad & Sangli. 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 groundwater data of state Maharashtra.

Sl. No.	Districts	Period of data availability	No. of obse. wells	Source of data availability
1.	Ahmednagar	1976-91	8	G.W.Survey & Dev.Agency
2.	Pune	1976-91	8	- do -
3.	Satara	1976-91	8	- do -
4.	Sholapur	1976-91	9	- do -
5.	Aurangabad	1977-91	10	- do -
6.	Sangli	1976-91	10	- do -

As is evident from Table 4.1, about 8-10 wells were chosen in each district for evaluating impact of drought on groundwater regime. It was kept in mind that these wells are evenly distributed within the district. The locations of the wells on the district map have already been shown in the figures presented in chapter 2.

The groundwater level analysis was attempted with the help of seasonal pre and post monsoon data. Appendix III-I gives the details of various observation wells spread over 6 selected drought prone districts of Maharashtra state with their latitude and longitude. The analysis has been carried out for ground water level data from 1976-91.

The water levels in the wells have been reduced 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 groundwater level calculated with respect to mean sea level, multiplied by Thiessen weight, gave average ground water level for the district. Based on the values of water levels in wells, computed with respect to MSL, average ground water level for the district was obtained. 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.

4.3 Inferences

The rainfall trends for all the districts have shown declining trend over years except in case of Satara district. The water table analysis has indicated that the water table (post-monsoon) has been falling for the districts of Satara and Pune. However, the districts of Ahmednagar and Sholapur showed rather positive trends in pre and post monsoon water table positions, indicating a rise in water table levels over years. The water table in Sangli and Aurangabad are nearly stable. The pre and post monsoon water table, in year 1991 have shown declining trend for Sholapur only. The other districts showed an increase. The analysis of ground water levels based on the watertable fluctuation data of past 16 years has yielded in knowing the groundwater level trends (pre & post) as a result of seasonal rainfall departure. In most cases the water table has been recorded falling and the rate of recharge was found lesser. The

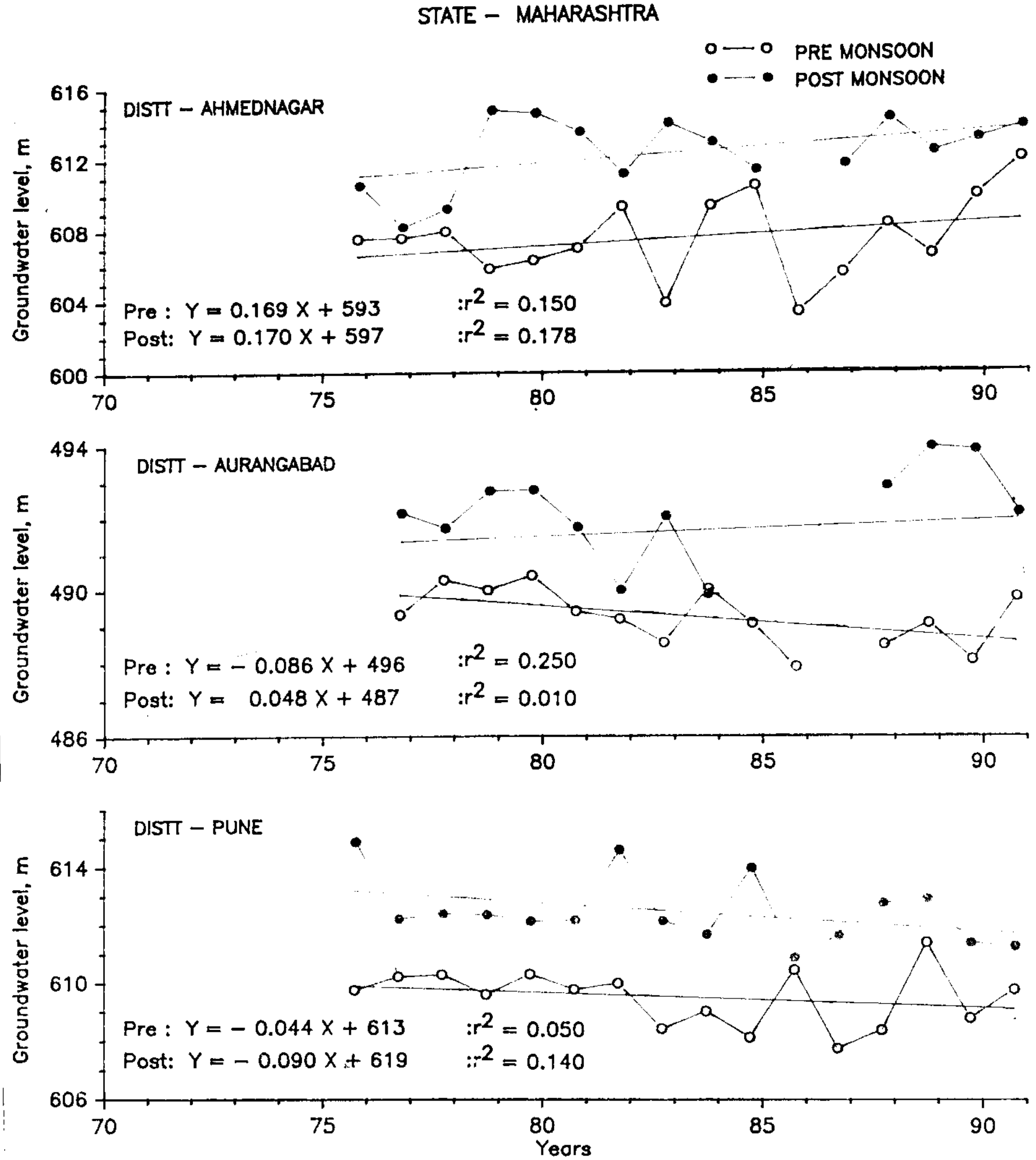


Fig.4.1: Groundwater level fluctuation for pre and post monsoon seasons

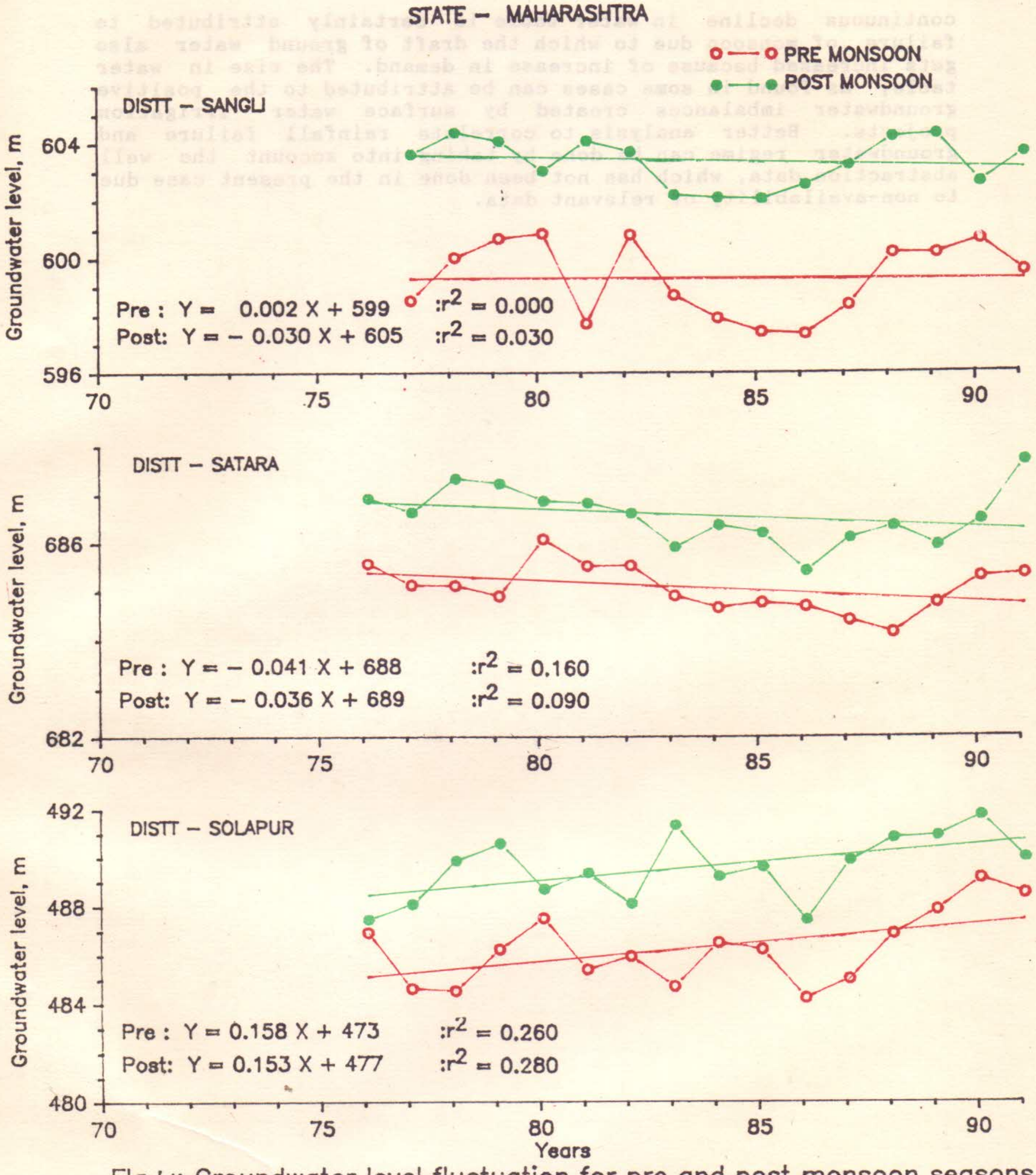


Fig.4.1: Groundwater level fluctuation for pre and post monsoon seasons

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 groundwater imbalances created by surface water irrigation projects. Better analysis to correlate rainfall failure and groundwater regime can be done by taking into account the well abstraction data, which has not been done in the present case due to non-availability of relevant data.

5.0 ANALYSIS OF RESERVOIR STORAGE

In order to illustrate the impact of failure of monsoon on storage reservoirs, an attempt has been made to compare the reservoir level only for four selected reservoirs (i) Jayakwadi, Godavari, (ii) Khadakwasla, Krishna (iii) Koyana, Krishna & (iv) Bhima, Krishna. For this purpose, the live storages & corresponding reservoir level in some selected months (May, August and October) have been plotted against time. The weekly reservoir level data as supplied by Central Water Commission (CWC) from 1985-1992 have been used for this analysis. As can be observed from Figures 5.1 that all the reservoirs showed more deficient storages during 1987 as compared to previous 2 to 3 years and 1988 to 1992. The Koyna reservoir showed worst impact of drought on storages as compared in year 1987. The situation of reservoir level has increased in all cases from year 1989 onwards. In 1991 non of the reservoir showed a significant decrease in storage. Only the Jayakwadi reservoir showed a decrease in storage in year 1992.

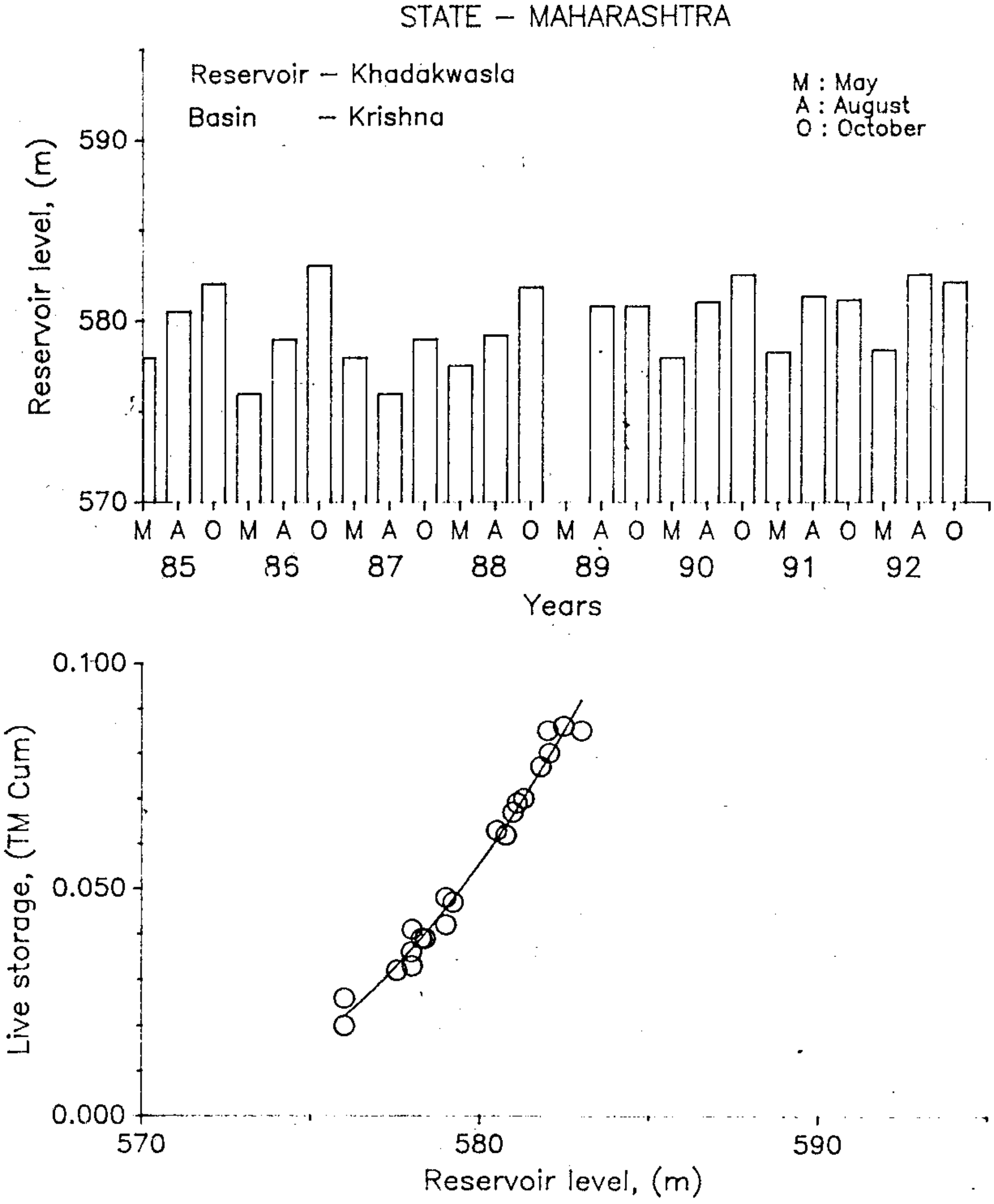


Fig.5·1: Reservoir level with time and the relationship between reservoir level and live storage.

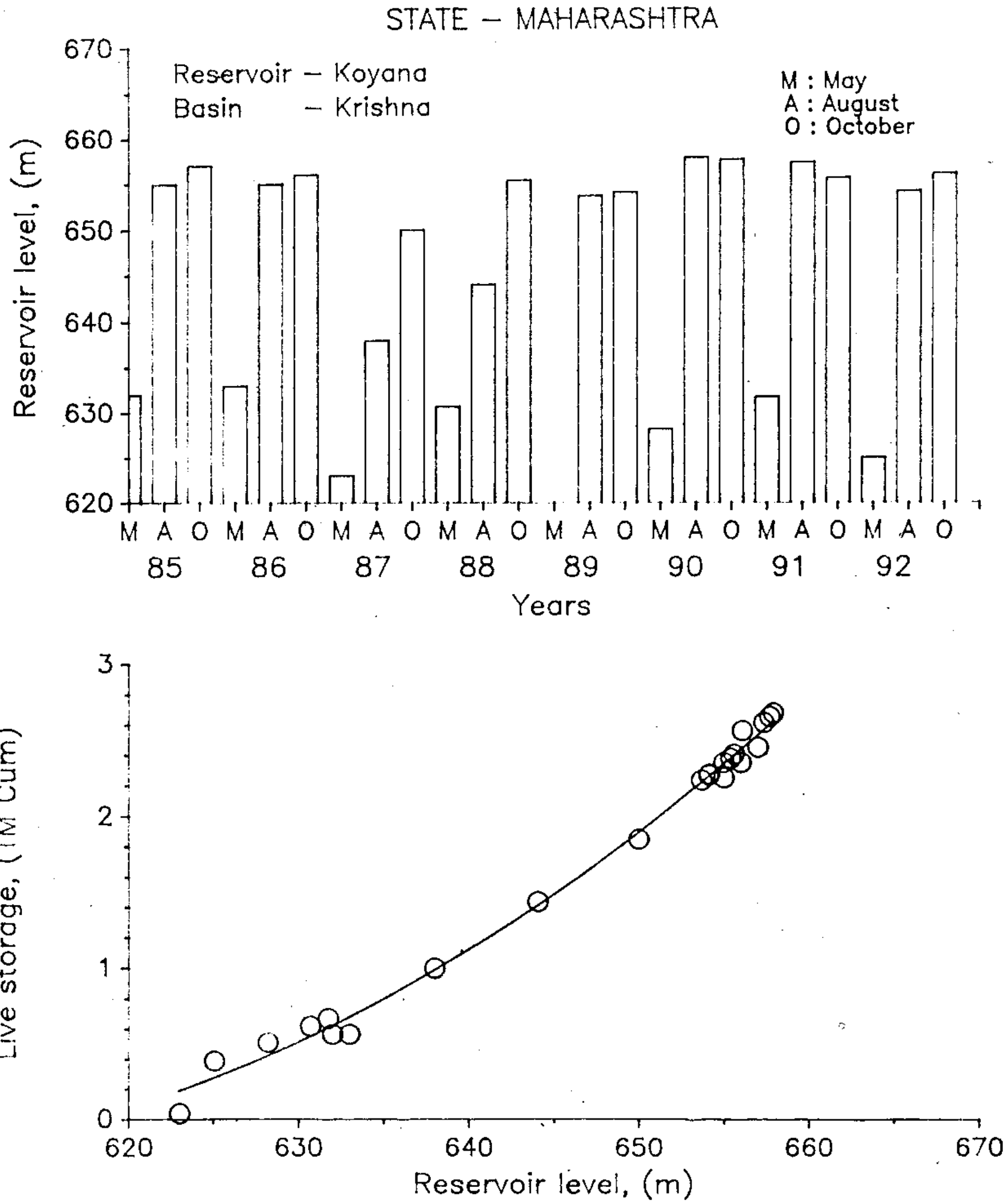


Fig.5.1: Reservoir level with time and the relationship between reservoir level and live storage.

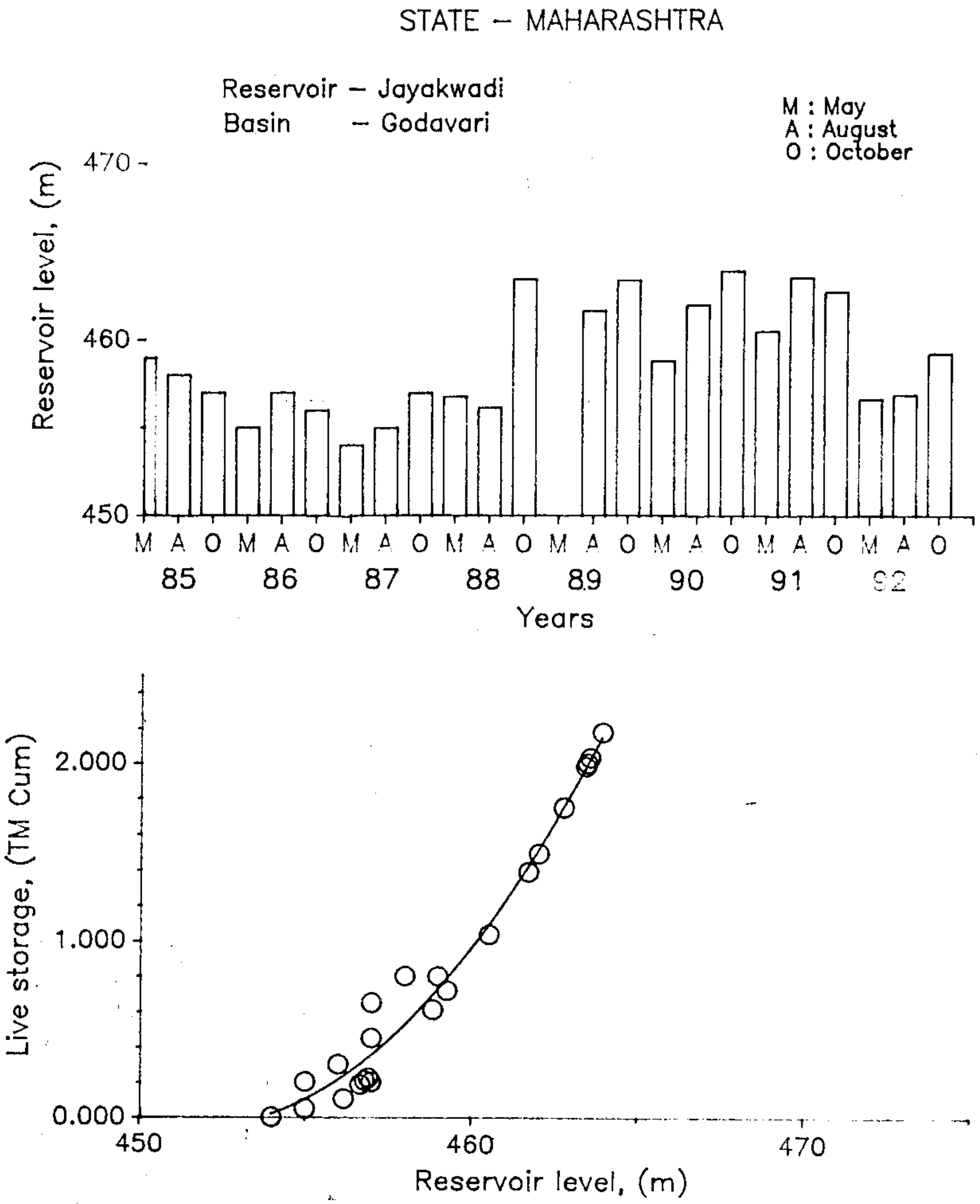


Fig.5-1: Reservoir level with time and the relationship between reservoir level and live storage.

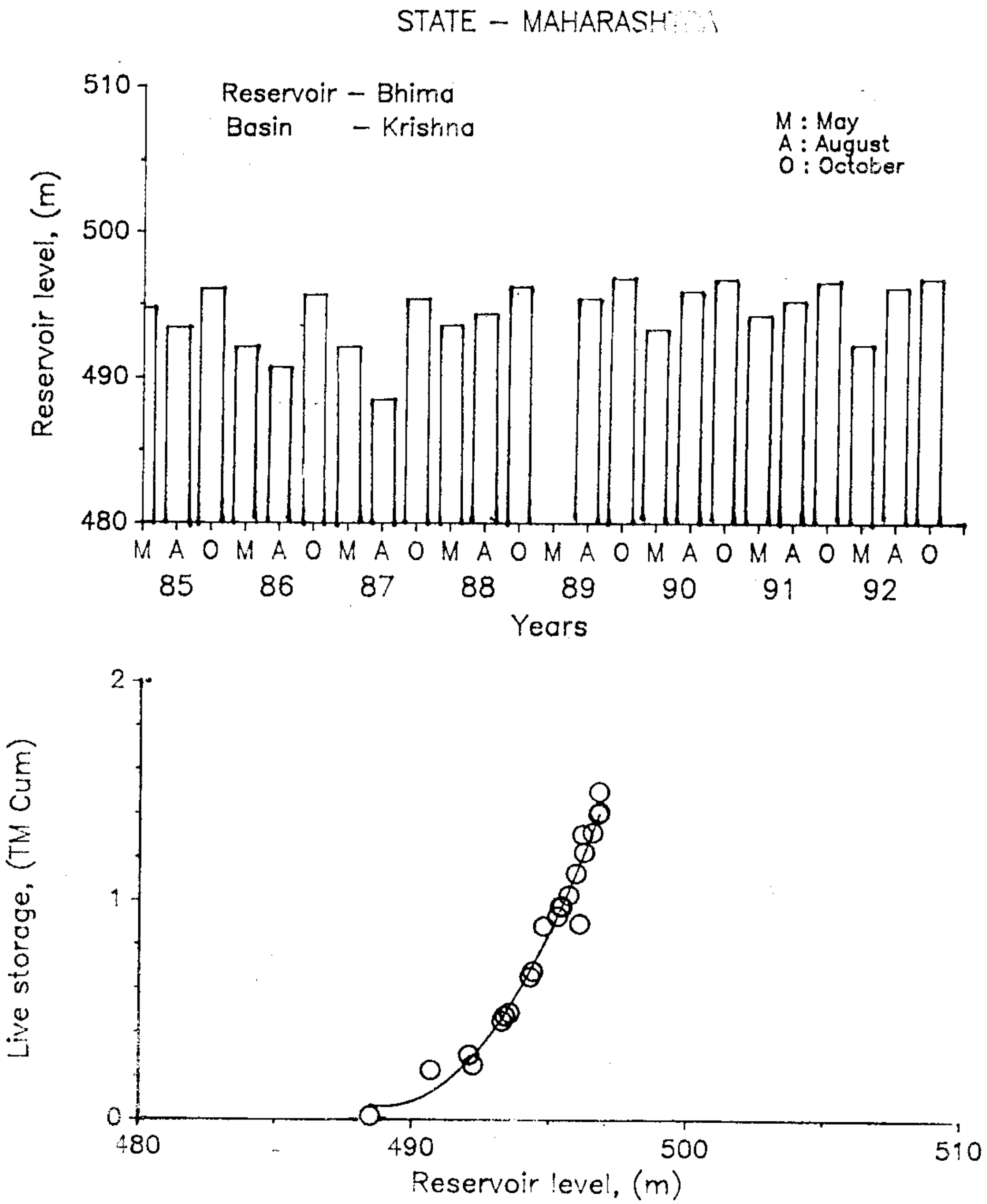


Fig.5.1: Reservoir level with time and the relationship between reservoir level and live storage.

6.0 CONCLUSIONS & RECOMMENDATIONS

1. The report presents analysis of rainfall & groundwater data for year 1990-91 on the hydrologic regime. For this purpose, six districts namely Sholapur, Satara, Pune, Aurangabad, Ahmednagar and Sangli were selected for the analysis. The analysis for drought has been done using field data which have been obtained by carrying out field trips and information extracted from the published reports by the state and Central Government organizations.

2. The seasonal rainfall departure analysis indicates that during 1990-91, districts Pune, Satara and Sholapur have recorded deficiency in seasonal rainfall. It has been further observed that in Pune and Satara districts, the seasonal rainfall has been observed with the deficiency since 1970.

3. Monthly rainfall departure analysis has been worked out for the water year 1990-91 for all the districts which have been chosen for analysis. The results indicated that in monsoon months i.e. June '90 to September '90, a deficiency was recorded in one or other district of State. In month of October no deficiency was recorded. The non monsoon months also recorded the deficiency in one or other districts.

4. Probability analysis of rainfall has been carried to work out the group range of annual rainfall at 75% level of the probability. For this purpose data from 1901-89 have been used. It has been found that most of the districts has a group range of 500-600 mm of rainfall at 75% probability level. However, districts of Pune and Satara have shown this range as 800-900 and 900-1000 mm using this analysis, the probability of occurrence of 75% of normal rainfall of various districts has also been worked out. The results indicate that the district Pune has the probability level below 80% indicated that in 20 years out of 100 years these districts have chances of getting less than 75% of the normal rainfall.

5. The monthly rainfall data have been used for using Herbst approach during the period of analysis and their duration. It has been found that all the districts recorded drought spells during the period 1951-91. However, the intensity of spells during the period of spells was found maximum in case of Satara as 4.81 during 1978 to 81 and in general 5-12 no. of drought spells were observed in various districts during the period of analysis. The district of Sangli and Ahmadnagar experienced the longest spell of 68 months drought during period of Analysis.

6. In order to work out the probability of getting a dry spell and its duration, dry spell analysis was carried out for the districts. A dry spell was assumed as a period in which daily rainfall should not exceeded 5 mm on any day in a continious period of 14 days or more. The analysis results have yielded duration of dry spells for various districts and it has been found that for most of the districts, the duration of dry spells at 75% of probability work out to be 21-28 days.

7. Analysis of ground water data as obtained from ground water wells has been carried out for assessing impacts on ground water regime. For this purpose, 8-10 wells were chosen in all the districts and average ground water level (pre and post monsoon) have been worked out. Based on the allocation of pre and post monsoon reports as recorded in the last 16 years, inferences have made on impacts of water regime. It was observed that post monsoon level were declining in Pune and Satara. However, the districts of Ahmednagar and Sholapur showed a trend in the monsoon indicating a rise in the post monsoon level. In year 1991 and decrease was observed in districts of Pune, and Sholapur. The other districts showed a little change in water table.

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APPENDIX - I

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

MAHARASHTRA

PLACE	
Bombay	Irrigation Department, Maharashtra
	Deptt. of Forest and Revenue
	Secretary, Rural Development Department of Agriculture
Pune	Asstt. Director, Ground Water Survey and Development Agency under Deptt. of Rural Development
	Met. Gr.I., Drought Research Unit, IMD
	Superintending Engineer, Poona
	Directorate of Agriculture
	C.E.(Irrigation), Zilla Parishad
	Pune Gauging Division, C.W.C.
Aurangabad	Chief Engineer, Aurangabad, Irrigation Circle
	Executive Engineer, Aurangabad Irrigation Circle
	Superintending Engineer Jayakwadi Project, Stage-I, Aurangabad Irrigation Circle Deptt.,
Sholapur	Krishi Vidhyapeeth, under All India Coordinated Dry Land Farming Project of ICAR, Sholapur
	Zilla Parishad
	DRDA
	Chief Geologists
	Agronomist & Agricultural Meteorologist N.A.P.P. Scarcity Zone, Mahatma Phule Krishi Vidhyapeeth
Beed	Senior Geologist, GSDA
	Collector's office

	Zilla Parishad
Parbhani	Agriculture Meteorology Deptt., Marathwada Agricultural University, Collector's office & Zilla Parishad
Ahmad Nagar	Zilla Parishad, Collector's Office
Satara	Collector's Office, GSDA, Zilla Parishad
Sangli	Collector's Office, Zilla Parishad.

APPENDIX -II-(A)

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

Akalkot (Sholapur)

First day of monsoon	Date of beginning of dry spell	Duration of dry spells (2 weeks in days)	Total no. of dry spells in a year
1	2	3	4
4.6.81	8.7.81	16	1
14.6.82	15.6.82	14	3
	16.7.82	14	
	24.8.82	24	
4.6.83	NIL	NIL	NIL
3.7.84	4.6.84	29	2
	10.8.84	31	
9.6.85	3.7.85	21	2
	17.8.85	23	
4.6.86	29.6.96	23	2
	14.8.86	22	
11.6.87	-	-	-
4.6.88	-	-	-
7.6.89	20.7.89	27	1
5.6.90	Nil	Nil	-
5.6.91	18.8.91	28	1
			12

Satara (Satara)

1	2	3	4
5.6.81	-	-	-
19.6.82	4.6.82	15	2
	26.8.82	21	
14.6.83	17.8.83	27	1
8.6.84	20.7.84	14	2
	28.8.84	15	
9.6.85	13.8.85	34	1
7.6.86	1.7.86	17	3
	23.7.87	14	
	14.8.86	33	
5.6.87	21.7.87	26	2
	27.8.87	18	
8.6.88	Nil	Nil	-
89	Nil	Nil	-
11.6.90	Nil	Nil	-
4.6.91	27.8.91	20	1
			12

Akola (Ahmednagar)

1	2	3	4
13.6.81	17.7.81	20	3
	7.8.81	16	
	24.8.81	14	
17.6.82	18.6.82	36	3
	26.7.82	17	
	26.8.82	21	
22.6.83	4.6.83	18	2
	17.8.83	22	
7.6.84	18.6.84	14	4
	20.7.84	15	
	8.8.84	21	
	28.8.84	14	
25.6.85	4.6.85	21	4
	26.6.85	21	
	18.7.85	20	
	8.8.85	39	
5.6.86	24.6.86	24	2
	19.7.86	59	
17.6.87	9.7.87	38	2
	27.8.87	20*	
3.6.88	15.6.88	26	2
	12.8.88	19	
89	-	-	-
10.6.90	26.8.90	21	1
5.6.91	17.8.91	30	1
			24

Aurangabad (Aurangabad)

1	2	3	4
9.6.81	Nil	-	-
25.6.82	4.6.82	21	2
	22.8.82	25	
14.6.83	18.8.83	14	1
1984	Date not available		
15.6.85	12.8.85	21	1
4.6.86	23.6.86	25	2
	13.8.86	34*	
6.6.87	27.8.87	15	1
4.6.88	Nil	Nil	-
6.6.89	Nil	Nil	-
90	-	-	-
7.6.91	23.8.91	24	1
			8

Pune(Pune)

1	2	3	4
5.6.81	9.8.81	20	1
19.6.82	4.6.82	15	3
	5.7.82	16	
	26.8.82	21	
16.6.83	24.6.83	17	1
8.6.84	20.7.84	15	2
	13.8.84	30	
8.6.85	10.6.85	18	3
	29.6.85	18	
	3.8.85	44*	
4.6.86	20.7.86	17	2
	13.8.86	34	
5.6.87	9.7.87	39	2
	27.8.87	20*	
8.6.88	17.6.88	25	2
	4.8.88	15	
89	-	-	
90	-	-	
6.6.91	1.9.91	15	1
			17

Sangli(Sangli)

1	2	3	4
6.6.81	8.7.81	16	3
	26.7.81	18	
	14.8.81	23	
18.6.82	4.6.82	14	4
	24.7.82	24	
	20.7.82	15	
	31.8.82	16	
14.6.83	21.7.83	19	1
1984	Date not available		
10.6.85	28.6.85	18	2
	11.8.85	36*	
4.6.86	28.6.86	20	3
	19.7.86	18	
	14.8.86	33	
17.6.87	9.7.87	27	2
	27.8.87	20	
5.7.88	4.6.88	32	1
23.6.89	4.6.89	19	
	28.7.89	19	3
9.6.90	16.8.89	31	
	Nil	-	-
			19

* Continuation of dry spell after 15th September.

APPENDIX II(B)

Probability Analysis of Dry Spells.

Taluk/Station (Distt.)	Class Interval (day)	No. of Spells	Percentage	Cumulative Probability
Akalkot (Sholapur)	14-21	4	33.3	100.0
	22-28	5	41.7	66.7
	29-35	3	25	25.0
	> 35	-	-	-
		12		
Akola (Ahmednagar)	14-21	16	66.6	100.0
	22-28	3	12.5	33.4
	29-35	1	4.2	20.9
	> 35	4	16.7	16.7
		24		
Pune (Pune)	14-21	12	70.6	100.0
	22-28	1	5.8	29.4
	29-35	2	11.8	23.6
	> 35	2	11.8	11.8
		17		
Satara (Satara)	14-21	8	66.6	100.0
	22-28	2	16.7	33.4
	29-35	2	16.7	16.7
	> 35	-	-	-
		12		
Sangli (Sangli)	14-21	12	63.1	100.0
	22-28	3	15.8	36.9
	29-35	3	15.8	21.1
	> 35	1	5.3	5.3
		19		
Aurangabad (Aurangabad)	14-21	4	50.0	100.0
	22-28	3	37.5	50.0
	29-35	1	12.5	12.5
	> 35	-	-	-
		8		

LIST OF OBSERVATION WELLS

STATE - MAHARASTRA
DISTT - AHMADNAGAR

SL NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	BH-15	SUPA	18 57 35	74 32 20	710.36	5958	0.3497
2.	GV-22A	SAIKHINDI	19 38 10	74 08 15	630.48	1291	0.0758
3.	GV-29B	TELEGAON	19 41 40	74 17 45	594.51	1071	0.0629
4.	GB-31B	TAKALI	19 55 00	74 23 00	509.14	355	0.0208
5.	GV-32B	APEGAON	19 55 15	74 37 20	521.64	489	0.0287
6.	GV-10C	BOTA	19 15 20	74 08 50	683.53	2122	0.1246
7.	GV-128	KUKANA	19 00 00	74 20 00	434.81	3991	0.1246
8.	GV-130	MALI-BABHULG	19 26 05	74 58 10	692.07	1758	0.1032

STATE - MAHARASTRA
DISTT - SOLAPUR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	BH-112	WADEGAON	17 26 00	75 14 15	486.28	1601.60	0.1066
2.	BH-111	DIKSAL	17 24 25	75 31 40	474.08	1508.45	0.1004
3.	SA-40	KANDALGAON	17 43 25	75 07 15	466.46	1186.81	0.0790
4.	BH-132	MUSTI	17 43 46	76 04 50	480.18	2311.29	0.1539
5.	SA-35	KALMAN	17 55 45	75 46 45	493.90	1239.32	0.0825
6.	SA-20	PENDE	18 14 30	75 14 00	542.68	2065.54	0.1375
7.	SA-27	KUSLAM	18 16 50	75 46 25	562.50	1505.10	0.1002
8.	BH-138	JEUR	17 28 38	76 06 30	440.54	1795.57	0.1195
9.	SA-29	UPLAI	17 58 00	75 29 30	493.90	1807.32	0.1203

STATE - MAHARASTRA
DISTT - PUNE

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	BM-1	OTTUR	19 16 00	73 59 08	681.40	1578	0.1009
2.	BM-20	KHED (RAJGURU-NAGAR)	18 51 10	73 52 50	609.76	1871	0.1196
3.	BM-18	DHAMARI	18 47 20	74 05 50	640.24	2351	0.1503
4.	BM-40	BAMBOLI	18 40 09	73 30 11	591.46	1972	0.1261
5.	BM-55	KATRAJ	18 26 30	73 51 30	667.68	1838	0.1175
6.	BM-56	MARGASANI	18 17 00	73 44 30	673.78	1916	0.1225
7.	BM-75	PANDARE	18 08 45	74 27 55	550.30	2987	0.1910
8.	BM-78	INDAPUR	18 07 00	75 01 40	515.24	1128	0.0721

STATE - MAHARASTRA
DISTT - SATARA

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	BM-82	NAIGON	18 06 30	73 58 00	626.52	728	0.0694
2.	KR-3	MAHABALE-SHWAR	17 55 30	73 39 40	1356.71	728	0.0694
3.	BM-84	ADARKI-II	17 55 44	74 13 02	640 22	1455	0.1387
4.	KR-8	KOREGAON	17 41 45	74 09 45	653.96	1152	0.1098
5.	KR-4	SATARA	17 41 00	73 59 30	712.50	1273	0.1214
6.	BM-101	PALSHI	17 40 20	74 41 00	626.52	1819	0.1734
7.	KR-23	CHATIALA	17 25 02	74 30 00	657.01	1152	0.1098
8.	KR-18	YERAPHAL	17 22 30	73 56 30	608.23	2183	0.2081

STATE - MAHARASTRA
DISTT - AURANGABAD

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	GP-10	NIPANI	19 43 30	75 27 14	553.96		0.1404
2.	GV-43	KANJRI	19 43 05	74 57 03	501.52		0.0731
3.	GV-40	PALASWADI	20 03 30	75 03 05	522.31		0.1011
4.	GV-44	KANNAD	20 15 20	75 08 30	620.42		0.1011
5.	GV-52	AKATAADE	19 30 17	75 26 30	452.13		0.0562
6.	TR-13B	AMKHEDA	20 35 35	75 36 45	376.52		0.0506
7.	GP-5	SILLOD	20 18 00	75 39 06	618.90		0.1011
8.	GV-33B	VAIJAPUR	19 55 42	74 43 30	533.53		0.0731
9.	GP-18B	MANDI	20 38 45	75 52 45	318.59		0.1348
10.	GV-53	THERGOAN	19 33 08	75 34 31	472.56		0.1685

STATE - MAHARASTRA
DISTT - SANGLI

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	KR-32	PALUG	17 05 15	74 27 25	588.41		0.1122
2.	KR-34	ALTE	17 09 59	74 32 50	608.84		0.1225
3.	KR-37	KUCHI	17 03 40	74 51 50	663.10		0.1020
4.	KR-37	RANJANI	16 58 10	74 56 35	609.75		0.1055
5.	KR-43	SHIRALA	16 59 03	74 07 40	603.65		0.1020
6.	KR-48	TANDULWADI	16 55 35	74 17 20	556.40		0.0476
7.	BM-103	UMBARGAON	17 32 30	74 57 48	571.64		0.0544
8.	BM-113	RHARSUNDI	17 20 35	74 46 40	707.31		0.1225
9.	BM-108	ANTRAI	17 10 10	75 13 00	603.65		0.1225
10.	BM-121	UTAGI	17 11 58	75 30 10	516.76		0.1088

STATE - MAHARASTRA
DISTT - AURANGABAD

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	GP-10	NIPANI	19 49 30	75 27 14	553.96		0.1404
2.	GV-43	MANJRI	19 43 05	74 57 03	501.52		0.0731
3.	GV-40	PALASWADI	20 03 30	75 03 05	522.31		0.1011
4.	GV-44	KANNAD	20 15 20	75 08 30	620.42		0.1011
5.	GV-52	AKATAADE	19 30 17	75 26 30	452.13		0.0562
6.	TE-13B	AMKHEDA	20 35 35	75 36 45	376.52		0.0506
7.	GP-5	SILLOD	20 18 00	75 39 06	618.90		0.1041
8.	GV-33B	VAIJAPUR	19 55 42	74 43 30	533.53		0.0731
9.	GP-18B	MANDI	20 38 45	75 52 45	318.59		0.1348
10.	GV-53	THERGOAN	19 33 08	75 34 31	472.56		0.1685

STATE - MAHARASTRA
DISTT - SANGLI

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	KR-32	PALUG	17 05 15	74 27 25	588.41		0.1122
2.	KR-34	ALTE	17 09 53	74 32 50	608.84		0.1225
3.	KR-37	KUCHI	17 03 40	74 51 50	663.10		0.1020
4.	KR-37	RANJANI	16 58 10	74 56 35	609.75		0.1055
5.	KR-43	SHIRALA	16 59 03	74 07 40	603.65		0.1020
6.	KR-48	TANDULWADI	16 55 35	74 17 20	556.40		0.0476
7.	BM-103	UMBARGAON	17 32 30	74 57 48	571.64		0.0544
8.	BM-113	RHARSUNDI	17 20 35	74 46 40	707.31		0.1225
9.	BM-108	ANTRAI	17 10 10	75 13 00	603.65		0.1225
10.	BM-121	UTAGI	17 11 58	75 30 10	516.76		0.1088

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