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HYDROLOGICAL ASPECTS OF DROUGHT UPTO 1988-89 - A CASE STUDY IN MADHYA PRADESH

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PREFACE

One of the most important factors in understanding hydrological droughts is the supply and demand phenomenon. To a hydrologist, drought means below average availability of flow in streams and below average storages in reservoirs, lakes, tanks, aquifers and moisture in soil profile. The various hydrological variables which can be used to study the hydrological aspects of drought include stream flow, 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 faced drought for three years in succession. Reliable estimates indicate that the drought of 1987 is ranked second in the century, the first one being that of 1918. It has been estimated by the Central Water Commission that about 1/3rd of the geographical area of the country (107 M. ha.) spread over 99 districts, is drought prone.

The National Institute of Hydrology initiated drought studies in the year 1986 duly laying emphasis on the hydrological aspects of drought and with the objective of developing suitable drought indices and 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 impact of drought. In this pursuit, the Institute has chosen six states viz., Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra and Gujarat. The present report covers the study of six districts of Madhya Pradesh. These districts Sidhi, Shahdol, Dhar, Jhabua, Khargone and Betul.

The study includes various kinds of analysis of rainfall data, stream flow data and ground water level data for assessing drought impact. Based on the analysis, inferences highlighting the hydrological aspects of the recent droughts have been drawn.

The study has been carried out by Shri. R. P. Pandey, Sc.'B', Shri. Avinash Agarwal, Sc.'C', and scientific staff Shri. Yatveer Singh, S.R.A.

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ABSTRACT

This report describes the results of studies carried out for the year 1988-89, for the six selected drought prone districts namely: Jhabua, Khargone, Dhar, Sidhi, Betul & Shahdol of state Madhya Pradesh, have been described. The report includes analysis of rainfall and groundwater level data for finding deficit of rainfall and trend of groundwater table as a result of drought incidents.

The seasonal rainfall departure analysis shows deficiency in all the six districts with the extremes lying between 30 percent to 65 percent except Sidhi and Shahdol. Monthly rainfall departure analysis shows that all the six districts recorded deficient rainfall ranging from 10% to 60% except Sidhi.

The frequency analysis of rainfall showed that the probability values of occurrence of 75% normal rainfall in all the six selected districts namely Jhabua, Khargone & Dhar of state Madhya Pradesh are 79, 79 & 78 respectively i.e. below 80, indicating drought proneness of districts based on this analysis as per IMD criteria. However, in case of district Sidhi, Betul & Shahdol the probability values of occurrence of 75% normal rainfall are 84, 87 & 89 indicating that out of 100 years, 16, 13 & 11 years will experience 75% of the normal rainfall and so less drought prone. Herbst analysis of monthly rainfall data of the districts has shown over two dry spells during 1984-89. The district of Sidhi showed maximum no. of drought spells and in general 4-5 spells were found in all districts since 1951. The maximum drought intensity was found in case of Khargone district while the longest spell of 94 days was observed in Betul district during 1978-86. The dry spell analysis, which has been done for one taluk in each of six districts, showed that at 75% probability level, the duration of dry spell ranges from 21-28 days, except the taluks of Dhar (Dhar) and Banas (Sidhi) were the duration of dry spell as expected at 75% probability ranges from 14-21 days.

The groundwater level analysis has been carried out in the districts of Jhabua, Khargone, Dhar, Shahdol & Betul. All the five districts experienced rainfall deficiency during 1988-89 ranging from 33-43%. As a result of declining trend of rainfall over the last three successive years, all the five districts except Shahdol have indicated a falling trend in pre and post monsoon water table levels and in most of the cases the rate of decline has been observed more than the previous year. This continuous decline can be attributed to continued deficient seasonal rainfall and over pumpage of ground water for various usages.

1.0 INTRODUCTION

1.1 General

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

In India, the problem of droughts is recurrent. Estimates indicate that about one-third of the geographical area of the country (107 m. ha.) spread over 99 districts are prone to drought. In recent times, the country faced three drought years in succession namely, 985, 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 sub-divisions out of 35 recorded deficient/scanty rains leading to drought conditions. It has been further reported that these sub-divisions account for about 53% of the total food grains production in the country. 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 showed 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 uses.

1.2 Objectives of the Study

In spite of the repeated occurrence of drought in the country, the hydrologic aspects of droughts have not been studied

to the desired extent. Such studies may provide direct incentives for planning judicious use of water resources.

The Institute had 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, 87 major parts of the drought prone area of the country, study areas were chosen in six various states namely: A. P., 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 in each of the six states, it was decided to bring out separate reports for each of the six states. The present report describes results of studies carried out for year 1988-89 with six districts chosen in the state of Madhya Pradesh. The report includes analysis of rainfall and ground water level data for finding the impacts of deficit of rainfall and trend of groundwater tables. The status of storages in Tawa and Gandhisagar reservoirs, located in the state during drought period has been included in the report. The report is an attempt towards developing a comprehensive drought index for characterising hydrologic drought situations.

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. There are 45 districts in the state of M.P. out of which 11 districts covering an area of about 87300 sq. km have been declared drought prone by Central Water Commission (1982). This report covers the study of six drought prone districts of state of Madhya Pradesh namely: Jhabua, Khargone, Dhar, Sidhi, Betul and Shahdol. The locations of districts are shown on the state map as shown in Fig.2.2. The state of M.P. lies between the latitude 74 degree 2 minutes East to 84 degree 2 minutes East and longitude 17 degree 48 minutes North to 26 degree 52 minutes North and is the central part of the country. It has 12 revenue divisions and 9 land record regions spread over an area of about 443750 sq. km. The state can be broadly classified into 6 distinct physical regions i.e. i) Northern low lying plains, ii) the Malwa and Vindyan Plateau, iii) Narmada valley, iv) Satpura stretch, v) Chhattisgarh plains and vi) Bastar Plateau. In the tabular form the topography of the state is given in Table 2.1.

2.2 Population Human and Cattle

The state of Madhya Pradesh has a total population of men and women 521.79 lakhs as per the 1981 census. Out of which there are 268.86 lakhs male and 252.93 lakhs female. Only 27.87 percent people are literate out of total population of the state M.P. However about 40 percent male and 15% female are literate as per 1981 census. The details of live stock are shown in Table 2.2.

Table 2.1: Topography of the State Madhya Pradesh

Region (1)	Topography (2)	District (3)	Rainfall range in mm (4)	Major crops (5)
North West M.P.	Lowlying plains (Chambal Ravines)	Gwalior, Morena, Bhind, Datia	750 to 850	Wheat and Jowar
North-Central MP	- do -	Chatarpur, Tikamgarh	750 to 850	- do -
North Malwa upland	Undulating plains with dotted hills	Guna, Shivpuri	750 to 850	- do -
Malwa plateau		Rajgarh, Mandsaur Dewas, Ratlam,	750 to 1250	Cotton and Jowar

Contd.

(1)	(2)	(3)	(4)	(5)
		Dhar, Jhabua, Indore, Ujjain, Shajapur		
Vindhyas	Hilly plateau	Vidisha, Raisen, Sehore, Bhopal, Saugar, Domoh,	1050 to 1350	Wheat
		Panna, Satna, Rewa	1050 to 1350	Wheat & Rice
Narmada valley	Narmada valley	Jabalpur, Narsimhpur, Hoshangabad	1250 to 1350	Wheat
Western Satpura	..	Khargone, Khandwa	1050 to 1350	Cotton & Jowar
Central Satpura	Satpura hilly Range	Seoni, Chhindwara, Betul	1350 to 1450	Seoni-Wheat Mandla-Rice
Eastern Satpura	..	Mandla, Balaghat	1600 to 1750	*
(*Balaghat - Rice; Chhindwara-Wheat & Jowar, Betul-Wheat and Jowar)				
Bundelkhand plateau	Plains plateau	Shahdol, Sidhi, Surguja	1050 to 1250	Paddy
Chhattisgarh	..	Durg, Rajnandgaon, Raipur, Bilaspur, Raigarh	1500 to 1800	Paddy
Danka Karanya	..	Bastar	1600 to 1800	Paddy

2.3 Land Use and Vegetal Cover

Report on Land Record Statistics, 1986-87 (M.P.) has compiled the details on land use and vegetal cover statistics in the state of M.P. The areas under different land uses and their percentages to the geographical area for the year 1986-87 are given in Table 2.3. According to the table there is about 31.4% forest and the net area sown is about 43.5 percent of the total geographical area. Fig.2.3 shows the details of land use as per

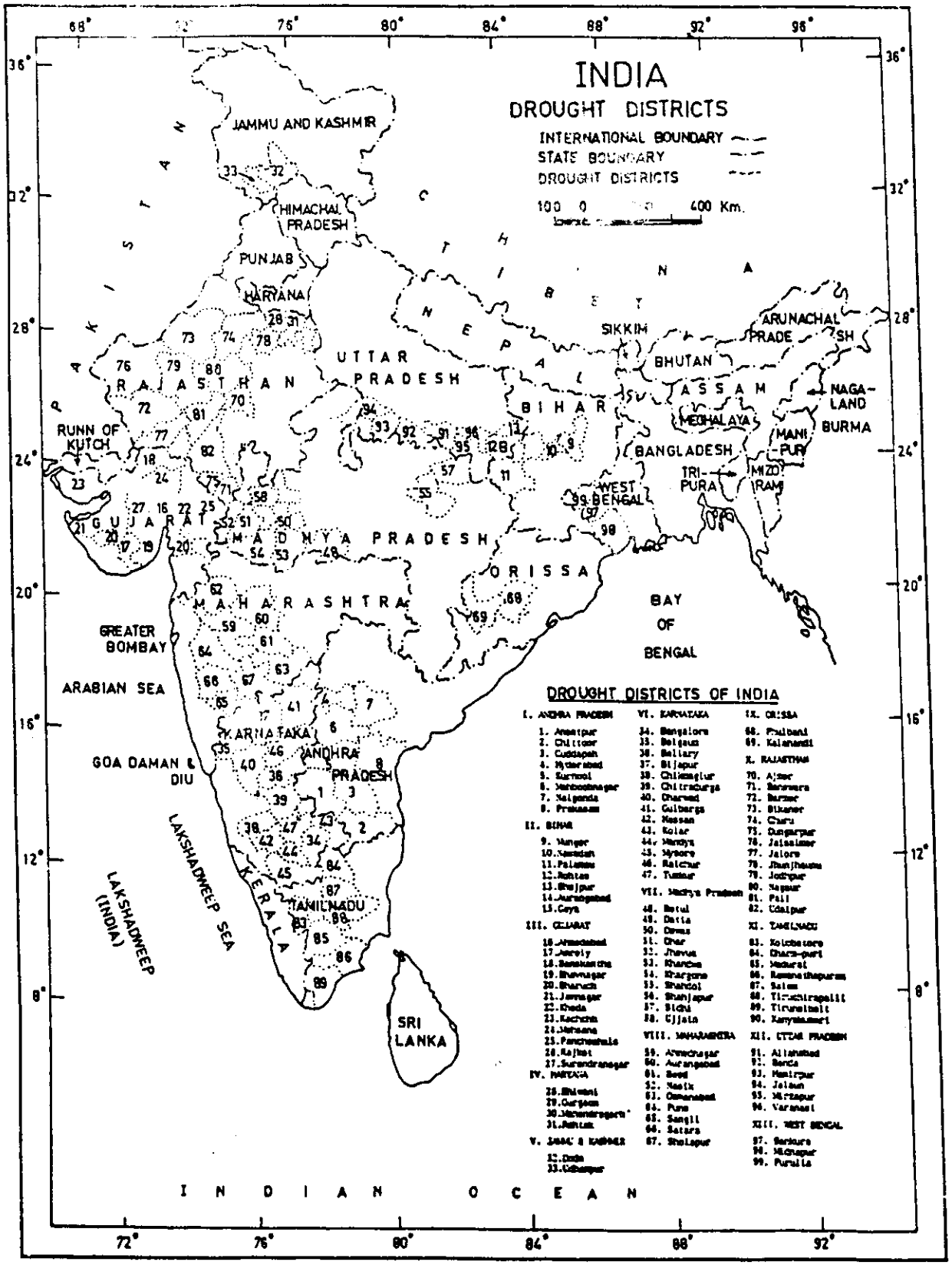


FIG. 2.1 : DROUGHT PRONE DISTRICTS IN INDIA

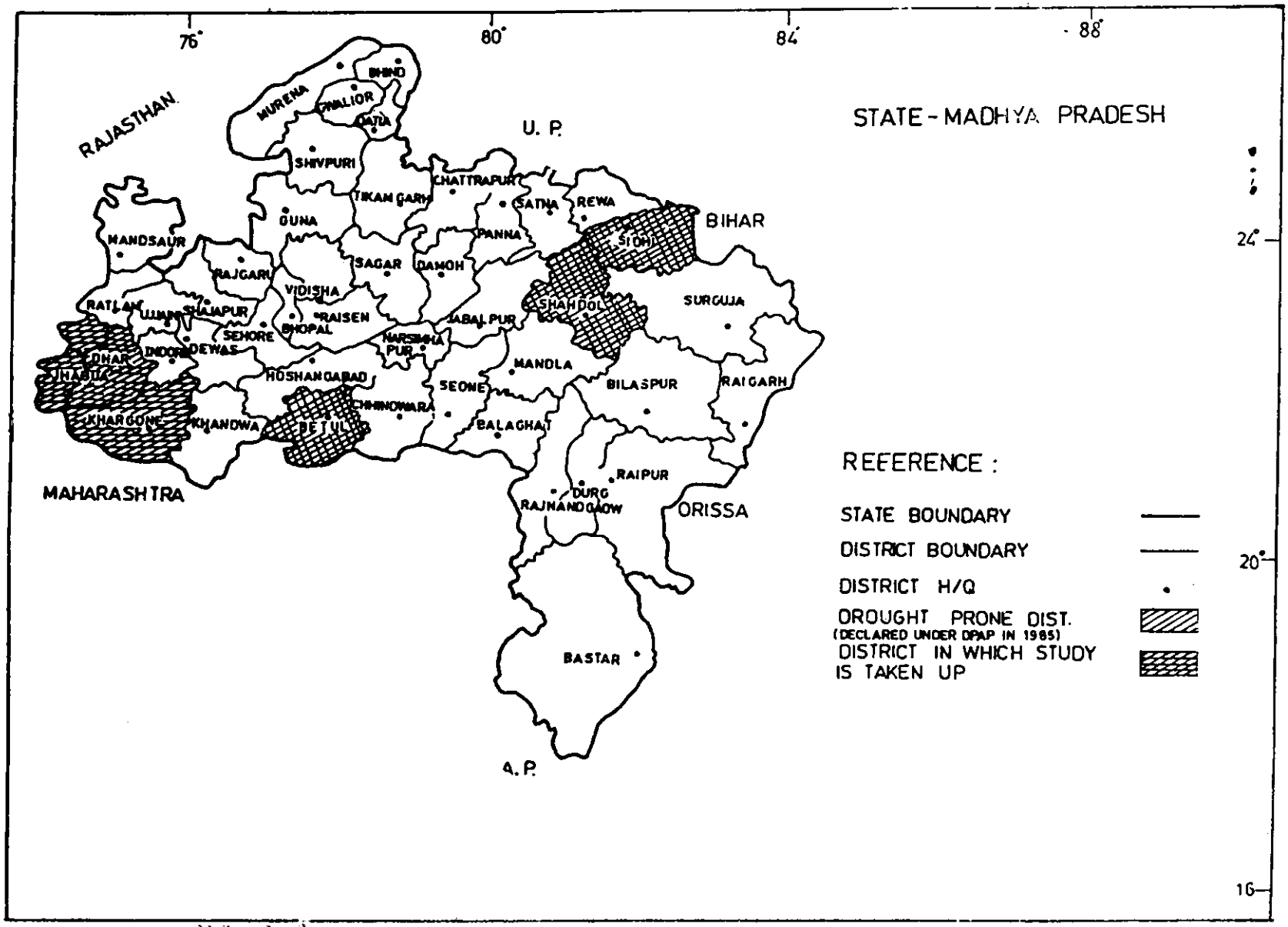
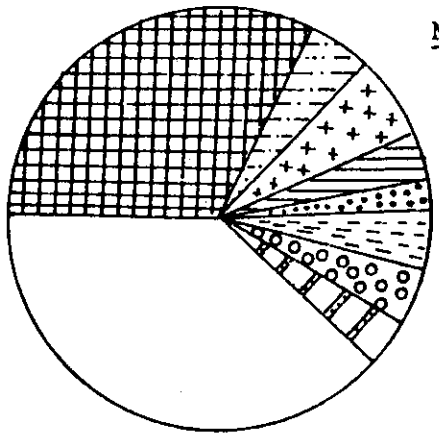


FIG. 2.2 : DROUGHT PRONE DISTT. IN MADHYA PRADESH



Madhya Pradesh Land Use 1986-87

Forest	31.4
Land under Non Agricultural Uses	5.2
Barren and unculturable land excluding fallow land	5.2
Permanent pastures & other grazing lands	6.0
Land under miscellaneous tree crops & groves not included net area sown	0.3
Culturable waste land	3.3
Current fallows	2.3
Old fallows	2.8
Net area sown	43.5

Fig. 2.3 : Land Use Statistics 1986-87 of State M.P.

the year 1986-87.

Table 2.2: Live Stock Details of Madhya Pradesh as per year 1986-87

Particulars		Number (in thousands)	Percentage
Cattle (Cow Bullocks)	Male over 3 yrs.	10243.5	24.1
	Female over 3 yrs.	7714.6	18.1
Cattle young stock		8336.7	19.6
	Total cattle	26294.8	61.8
Buffaloes	Male over 3 yrs.	1333.8	3.1
	Female over 3 yrs.	2652.3	6.2
Buffalo young stock		2847.0	6.7
	Total Buffalo	6833.1	16.0
Sheep		1121.0	2.6
Goats		7583.4	17.8
Horse and Ponies		109.0	0.3
Pigs		545.4	1.3
Camel		12.7	0.0
Other live stock		63.1	0.2
Total livestock		12562.5	100.0

Table 2.3: Land Use Statistics 1986-87

Details of land use	Area in lakh Hectares	Percentage
1. Forest	138.96	31.4
2. Land Under Non-agricultural uses	22.88	5.2
3. Barron and unculturable land excluding fallow	23.15	5.2
4. Permanent pastures & other grazing land	27.85	6.0
5. Land under miscellaneous tree crops & groves not included in net area sown	1.42	0.3
6. Culturable waste land	16.87	3.3
7. Current fallows	10.21	2.3
8. Old fallows	8.67	2.8
9. Net area sown	192.09	43.5
Total geographical area	442.10	100.0
Gist of Special Information		
i) Gross Area Sown	223.21	50.5
ii) Area Sown more than once	31.12	7.0
iii) Net Irrigated Area	33.46	17.4*
iv) Gross Irrigated Area	34.57	15.5**

* Percentage to net area sown
** Percentage to gross area sown
Source: Land Use Statistics, 1987, M.P. Govt.

2.4 Soils

The soils of state M.P. can be broadly classified into seven groups. These are i) Red and yellow soils ii) Gravelly soil, iii) Deep black soil, iv) Light black soil, v) Medium black soil, vi) Alluvial soil, vii) Mixed red and black soil. The soil map of the state is shown in Fig. 2.4. As can be seen from the soil map most of the drought prone district lies under black soil.

2.5 Surface Water Availability

The position of storages in the state of Madhya Pradesh already completed, under completion and proposed projects are given in Table 2.4 (CWC, 1988).

Table 2.4: Storages in the Projects of State Madhya Pradesh

S.No.	Type of Projects	Gross storage in M.ha.m.	Live storage in M.ha.m.
1.	Project completed	1.496	1.331
2.	Projects under construction	2.182	1.796
3.	Total	3.678	3.326
4.	Proposed Projects	0.326	0.275

Source: CWC Report on Water Resources of India 1988.

2.6 Ground Water Availability

The state ground water surveys, in the year 1978 have assessed that the annual ground water recharge in Madhya Pradesh (by Rainfall Infiltration Index Method) is of the order of 35 MAF (Million Acre Feet), of which about 17.5 MAF was considered as utilisable ground water recharge on a conservative and adhoc basis of 50 percent of the available recharge. This estimate was based on an infiltration idea of 9 percent for hard rock areas and 15 percent for alluvial areas. The evaluation of groundwater resources done for Madhya Pradesh on different occasions is described in the Table 2.5. (Irrigation Department, MP, 1990).

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 0.1132 M.ha.m. which has been estimated to increase to level of 0.2041 M.ha.m. by the year 1991 (CWC, 1988). Table 2.6 gives the details of source-wise number and net irrigated area in M.P. in 1986-87.

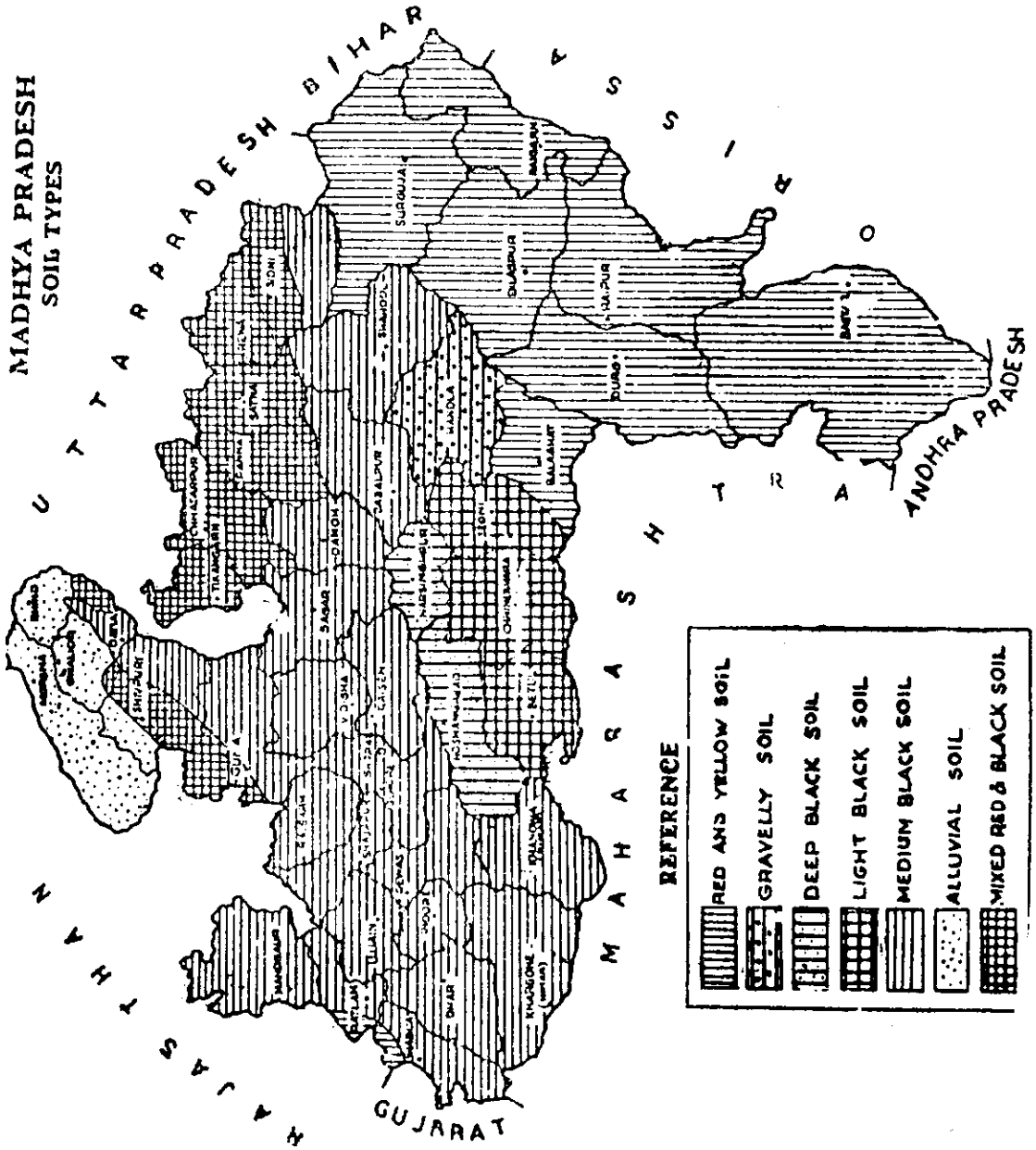


Fig.2.4 : Soil types in Madhya Pradesh

Table 2.5: Evaluation of Ground Water Resources

Name of Agency	Amount of contribution of rainfall to G.W. recharge	Possible recharge due to canal infiltration	Total recharge	Losses due to evapotranspiration, sub-surface out flow	MAF Net G.W.	Annual draft	Balance
1	2	3	4	5	6	7	8
Dr. K V Raghavarao et.al (1969)	43.1	1.4	44.5	17.8 (40%)	26.7	4.22 (67-68)	22.5
Irrig.Commission Report (1972)	43.1	1.4	44.5	17.8	26.7	4.22	22.5
Narmada Tribunal (1975)	43.1	1.4	44.5	17.8	26.7	4.22	22.5
Sagar University (1979)	-	-	58.7	11.70	47.0	-	-
G.W. Surveys for World Bank as per ARDC II Norms (1978)	40.74	0.55*	41.30	6.1	35.2	4.70	31.5
G.W. Surveys as per ARDC III Norms (1980)	66.45	1.49*	67.94	20.25	47.69	4.86	43.7

Source: Report on Ground Water in M.P. 1980 Irrigation Department, MP.

* Not due to canal infiltration but from infiltration due to Irrigation by ground water - Figure was under estimated as 0.55 MAF for earlier Ground Water Survey estimate.

Table 2.6: Sourcewise Number & Net Irrigated Area in Madhya Pradesh as per 1986-87

S.No.	Name of Source	Number	Area (lakh hectares)
1.	Canals - Govt.	2762	13.92
	Private	99	0.02
2.	Tanks - Govt.	31544	1.82
	Private	16308	0.16
3.	Wells - Govt.	42725	0.61
	Private	1050497	12.47
4.	Tube-wells - Govt.	1635	0.18
	Private	18087	1.01
5.	Other sources	-	3.21
	Total		33.40

The details of water availability and water requirement for drought prone districts of state Madhya Pradesh are given in Table 2.7.

Table 2.7: Water Availability and Water Requirement for drought prone Districts

S.No.	District	Water Availability		Total requirement
		50% dependability	75% dependability	
1.	Betul	2.94	2.47	0.39
2.	Datia	0.88	0.64	0.46
3.	Dewas	1.63	0.91	0.27
4.	Dhar	0.93	0.50	0.67
5.	Jhabua	2.94	2.10	0.37
6.	Khandwa	3.76	2.65	0.28
7.	Khargone	4.50	3.56	1.56
8.	Shahdol	4.06	2.45	0.39
9.	Shajapur	1.85	1.05	0.27
10.	Sidhi	3.33	3.20	0.55
11.	Ujjain	0.77	0.09	0.28

Source: CWC, 1988

2.8 Crops and Fodder

The state of Madhya Pradesh can be sub-divided broadly into five crop zone i) Rice zone, ii) Wheat zone, iii) Wheat Rice zone, iv) Wheat Jowar zone, v) Cotton-Jowar zone. The map showing principal crop zones is shown in Fig.2.5. There are twelve agroclimatic zones in the state of M.P. These agroclimatic zones are shown in the Fig.2.6. Table 2.8 gives the figures of area and production of principal crops in the state for the year 1986-87 (Land Record Statistics, 1987). Table 2.9 shows the division-wise information of area under fodder production in the year 1984-85.

Table 2.8: Area & Production of Principal Crops, 1986-87

Crops	In lakh hectares		In lakh Metric tonnes	
	Area	Percentage	Production	Percentage
1 2	3	4	5	6
1. Rice	50.41	22.6	41.78	26.4
2. Jowar	19.12	8.6	13.01	8.2
3. Bajra	1.66	0.7	1.24	0.8
4. Maize	8.50	3.8	7.61	4.8

Contd.

1	2	3	4	5	6
5.	Koden-Kutki	10.74	4.8	1.92	1.2
6.	Tur	4.37	2.0	4.13	2.6
7.	Wheat	35.02	15.7	42.64	27.0
8.	Barley	1.36	0.6	1.48	0.9
9.	Gram	22.18	9.9	14.8	9.4
10.	Other food-grain	23.79	10.7	6.6	4.2
Total food grain		177.15	79.4	135.21	85.5
11.	Other food crops	4.13	1.8	9.95	6.3
Total food crops		181.28	81.2	145.16	91.8
12.	Ground Nut	2.44	1.1	1.89	1.2
13.	Sesamum	2.09	1.0	0.20	0.1
14.	Rape and Mustard	3.31	1.5	2.08	1.3
15.	Linseed	4.69	2.1	1.25	0.8
16.	Soyabean	12.10	5.4	6.77	4.3
17.	Other Oil seeds	2.83	1.3	0.33	0.2
Total Oil seeds		27.46	12.4	12.52	7.9
18.	Cotton	5.23	2.3	0.41	0.3
19.	Other Fibres	0.23	0.1	0.06	-
20.	Tobacco	0.01	-	-	-
21.	Other Non-food crops	9.00	4.0	-	-
Total Non-food crops		41.93	18.8	12.99	8.2
Total all crops		223.21	100.0	158.15	100.0

The production of other non-food crops is not available
Source: Land Record Statistics, 1987, M. P. Govt.

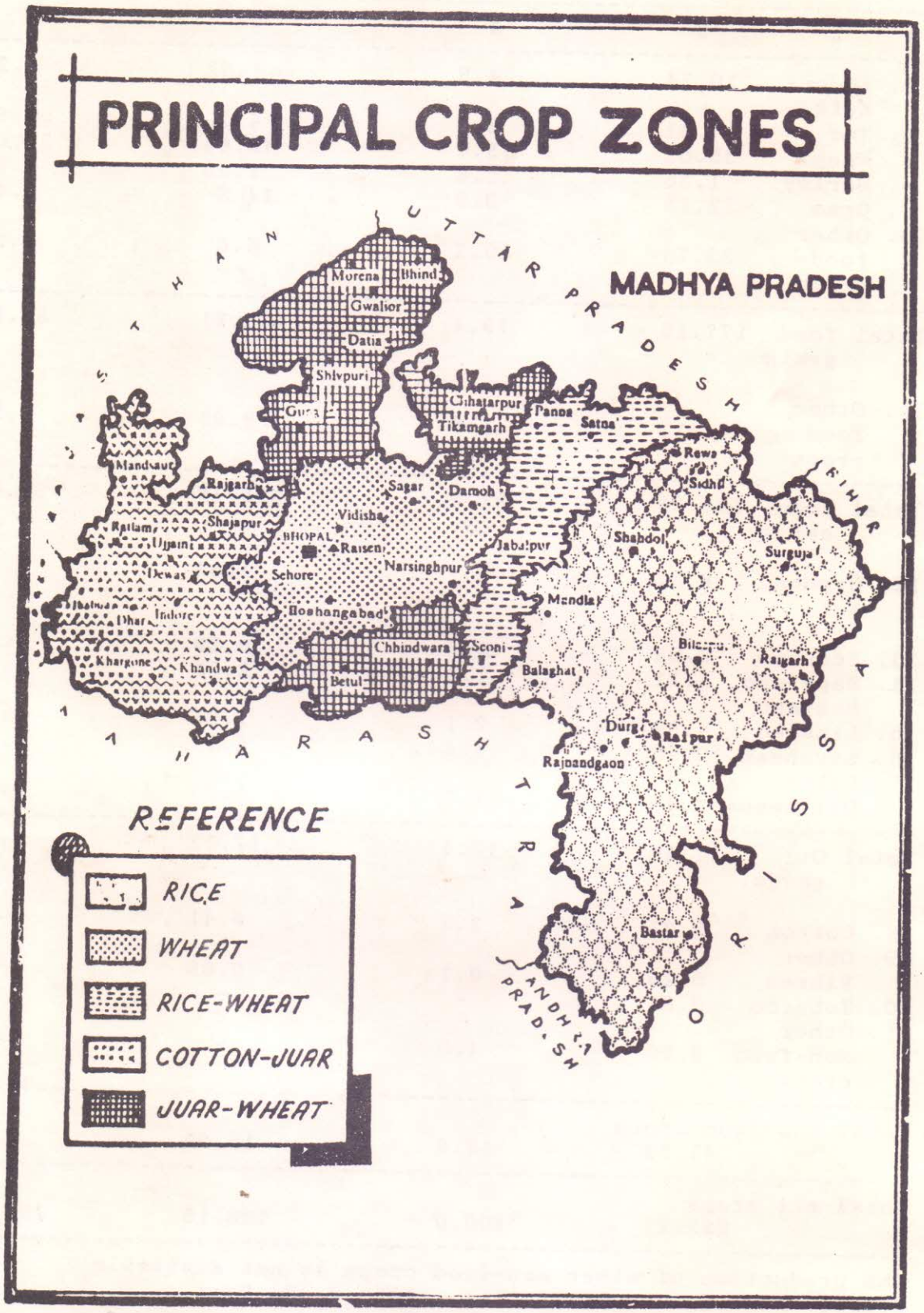


Fig.2.5 : Principal Crop Zones of State Madhya Pradesh

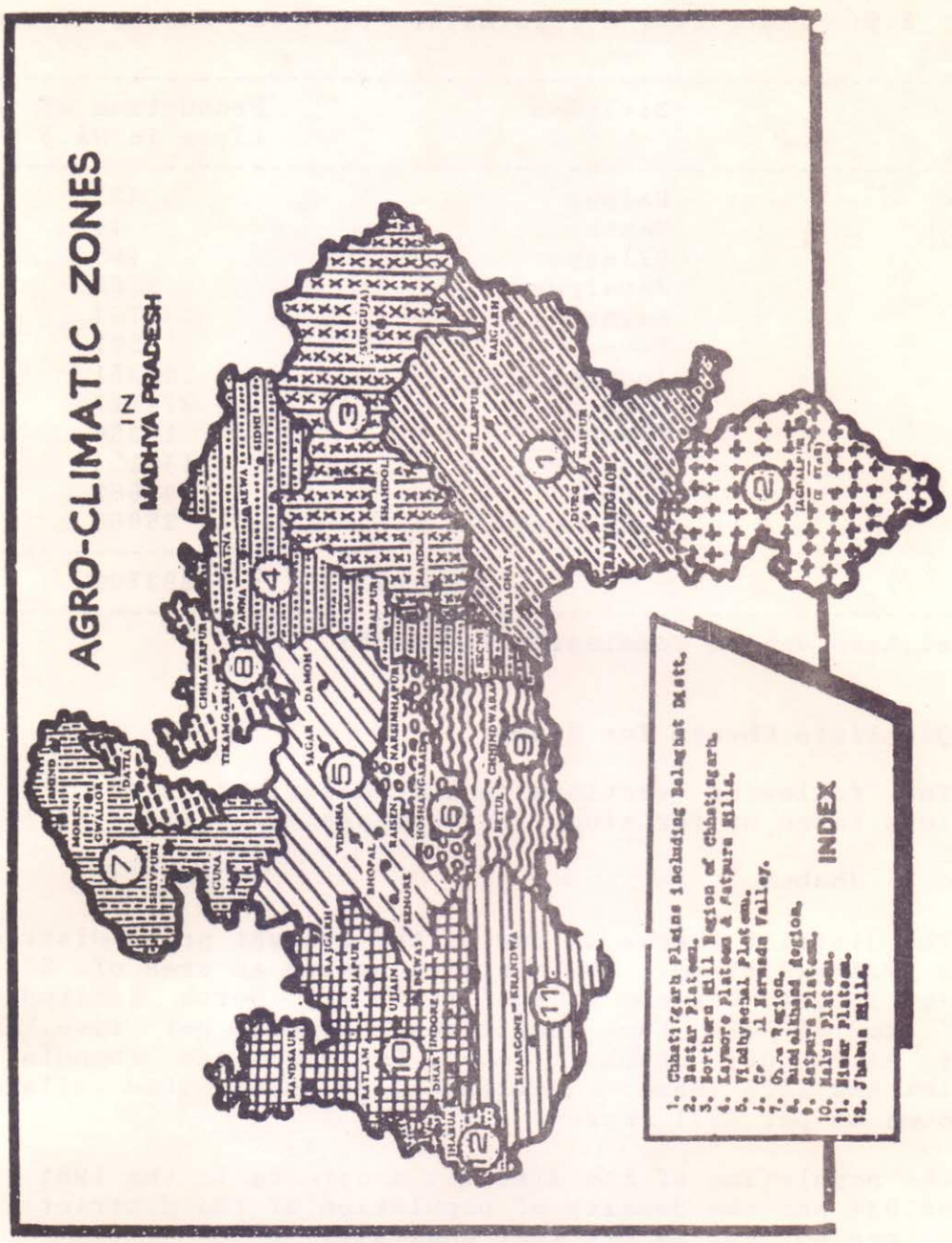


Fig.2.6 : Agroclimatic zones in Madhya Pradesh

Table 2.9: Districtwise Information of Area Fodder Production 1984-85

S.No.	Division	Production of fodder (Area in Ha.)
1.	Raipur	431
2.	Bastar	44
3.	Bilaspur	195
4.	Jabalpur	9163
5.	Sagar	139744
6.	Rewa	591
7.	Indore	100351
8.	Ujjain	274117
9.	Chambal	12356
10.	Gwalior	130133
11.	Bhopal	190682
12.	Hoshangabad	25965
	Total	883792

Source: Land Record Commission (1984-85)

2.9 Districts Chosen for Study

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

2.9.1 Jhabua

The district Jhabua is one of the drought prone districts of Madhya Pradesh state. The district having an area of 6781 sq. km. is, located between 22°-oo' to 23°-15' North latitudes and 74°-2' to 75°-01' East longitudes. It has got five tehsils namely Alirajpur, Jhabua, Jobat, Petlawad and Thandla. The district has 1326 inhabited villages, 39 uninhabited villages and six towns as per 1971 census.

The population of the district according to the 1981 census is 795,834 and the density of population of the district is 117 persons per sq. km. as per 1981 analysis.

It has been reported that generally three types of soils are found in the district namely, skeletal red and yellow, skeletal mixed red and yellow and skeletal black. As per data from 1970-71 to 1977-78 the land use in the district include forests 113,838 ha., barren and uncultivable lands 104,673 ha. and land put to non-agricultural uses 36,795 ha. and 396,160 ha. with culturable area.

The total irrigated area of the district is 12,842 ha. and the sources wise distribution of irrigated areas are 2381 ha. by surface water, 7,413 ha. by ground water and 2520 ha. other sources. The two main rivers Narmada and Mahi are flowing through the district. The catchment area within the district of Narmada is 3119 sq. km. and of Mahi is 3674 sq. km.

As per CWC analysis of 1982, the normal annual rain fall of the district is 827.31 mm, and there are normally 43.04 rainy days in a year. Twenty two number of raingauge stations are located in the district and the density of raingauge stations are 308.76 sq. km. per raingauge station as per data from 1901 to 1978. The south west monsoon gives about 93.59% of the annual rainfall and the coefficient of variation for annual rainfall is 30.17 percent.

As per CGWB data the groundwater potential data estimate recharge to ground water of the order of 10.0 m. cum. and the draft 2.0 m. cum. and the surplus is 8.0 m. cum. As per CWC (1982) study the district faced 5 years of hydrological drought during the period 1940 to 1980. The map of the district showing location of raingauges and groundwater observation wells which have been chosen for analysis is shown in Fig.2.7.

2.9.2 Khargone

The district Khargone is one of the drought prone districts of Madhya Pradesh state The district having an area of 1.35 m. ha., is located between 21° 22' to 22° 35' north latitudes and 74°25' to 76°14' east longitudes. It consists of eight tehsils namely Barwani, Barwah, Bhikangaon, Kasarawad, Maheshwar, Rajpur, Sendhwa and Khargone. The district has 1766 inhabited villages, 324 uninhabited villages and thirteen towns as per 1971 census.

The population of the district according to the 1981 census is 16,30,682 and the density of population of the district is 121 persons per sq. km. as per 1981 census.

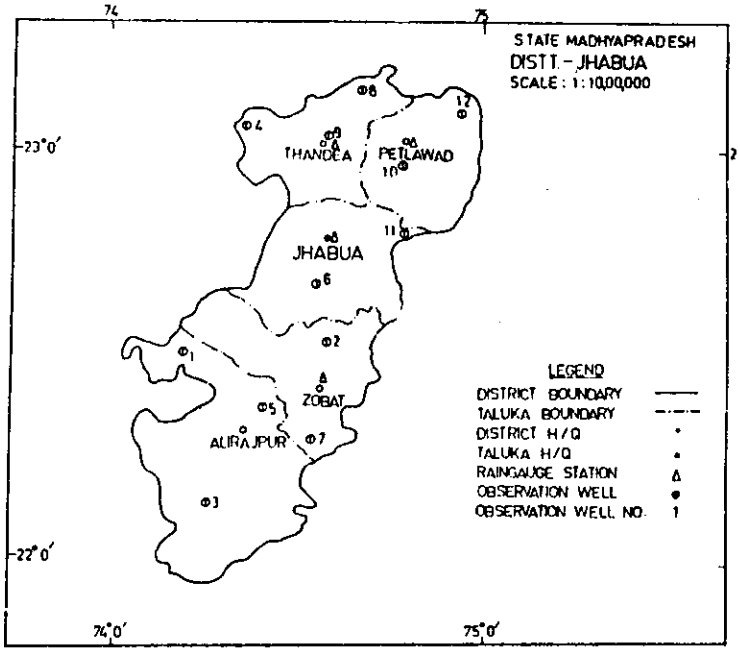
It has been found that generally there are five types of soils in the district namely Kali-I, Kali-II, Kali-III, Halki Khadri and Bardi. As per data from 1970-71 to 1979-80, the land use in the district include forests 4,73,166 ha., barren and uncultivable lands 53,132 ha. and land put to non-agricultural uses 47,890 ha.

The total irrigated areas of the district is 90,633 ha and the source wise distribution of irrigated areas are 10,554 ha. by surface water, 71,813 ha. by ground water and 8, 266 ha. by other sources.

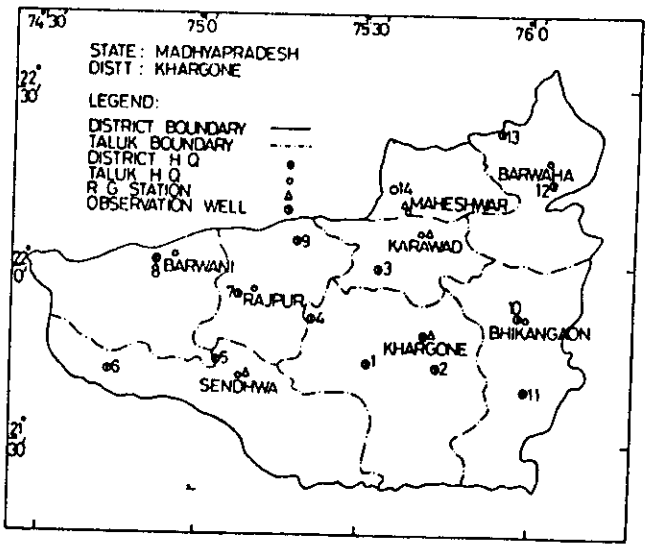
The two main rivers Narmada and Tapi are flowing through the district. The catchment area with in the district of Narmada is 11,810 sq. km. and of Tapi is 11,680 sq. km.

As per CWC analysis of 1982, the normal annual rainfall of the district is 804.2 mm. and there are normally 41.6 rainy days in one year. There are thirty eight number of raingauge stations in the district and the density of raingauge stations are 257 sq. km. per raingauge station as per data from 1901-1980. The south west monsoon gives about 91.2% of the annual rainfall and the coefficient of variation for annual rainfall is 21.3%.

As per SGWB data, the groundwater potential is that annual recharge to ground water of the order of 874 m. cum. and the draft 168 m. cum. and the surplus is 706 m. cum. As per CWC (1982) study, the district faced 12 years of hydrological drought



(a) DISTT. JHABUA



(b) DISTT. KHARGONE

FIG. 2.7 : LOCATION OF RAINGAUGE STATION & GROUNDWATER WELL

during the period 1957 to 1980. The location of raingauges and ground water observation wells is shown in district map given as in fig. 2.7.

2.9.3 Dhar

The district Dhar is one of the drought affected districts of Madhya Pradesh State. The district having an area of 8195.41 sq. km., is located between 22°-01 and 23°- 10 North latitudes and 74°- 28 and 75° 42 east longitude. It has got five taluks namely Badnawar, Dhar, Kukshi, Manawar, and Sardarpur. The district has 1484 inhabited villages and 87 uninhabited villages. This district consists of a 6 towns and cities. The population of the district according to the 1981 census is 1055826. The rural population is 89.83% of the total population of the district. The density of population of the district is 129 persons per sq. km. as per 1982 census.

The soils of the district are generally medium to heavy black cotton soil with good water retaining capacity. The land use details of the district include forests 74981 ha., land put to non agricultural uses 39710 ha. and barren and unculturable land 112088 ha. The total irrigated area of the district is 47947 ha. by groundwater (wells) and 4697 ha., by surface water and 5011 ha. by other sources.

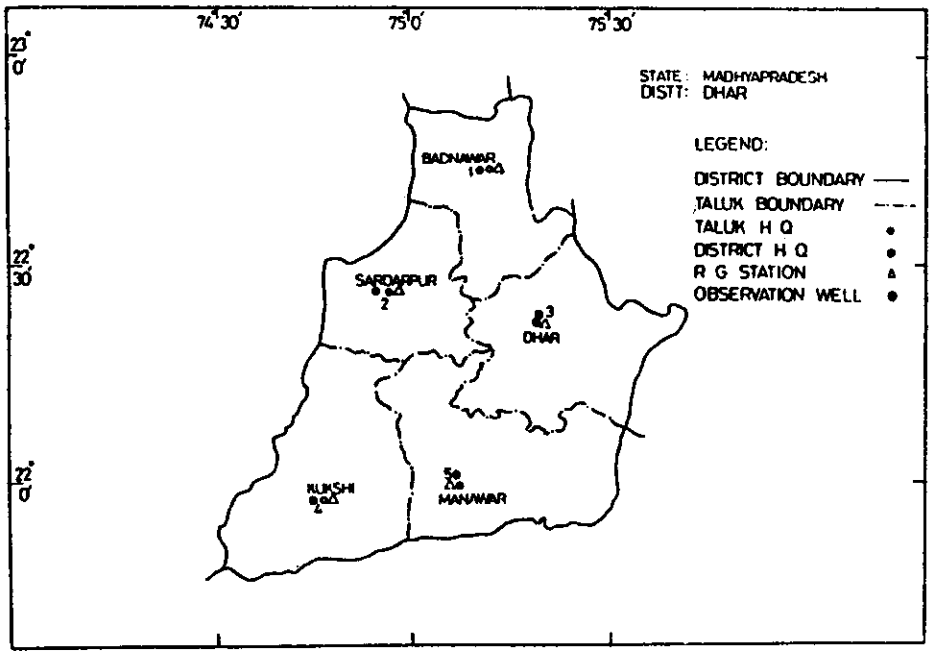
The three main rivers namely Narmada, Mahi, Chambal are flowing through the district. The catchment areas in the district of Narmada is 5030 sq. km. Mahi 1697 sq. km. and Chambal 1422 sq. km.

As per CWC study of 1982, the normal annual rainfall of the district is 837.8 mm. and there are normally 43.11 rainy day in one year. Eleven no. of rain gauge stations are located in the district and the density of raingauge stations is one station per 795.04 sq. km. The south west monsoon gives about 92.3% of the annual rainfall as per data analysis from 1901 to 1980.

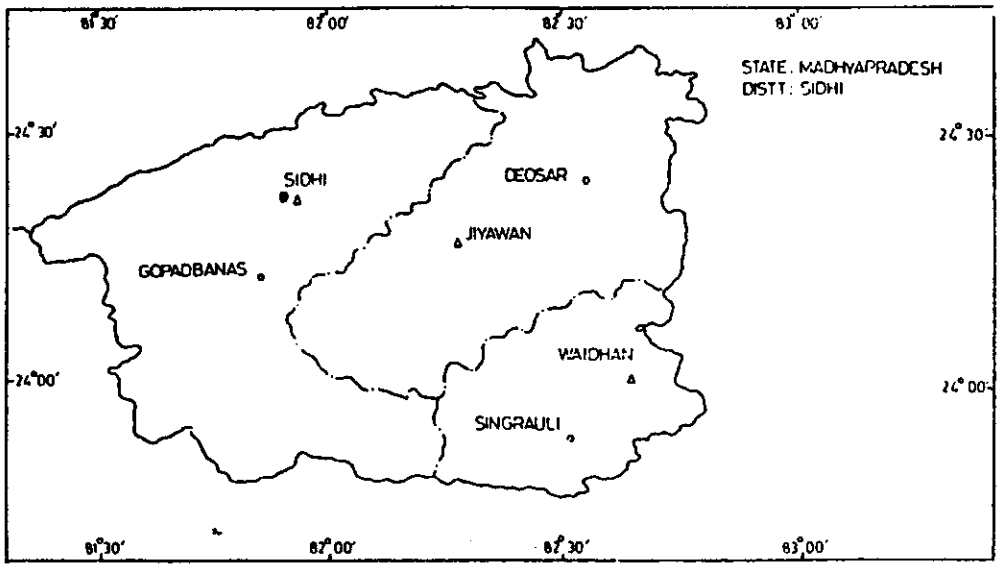
As per SGWB data, the groundwater potential in one year is that the annual recharge to ground water is of the order of 141.15 m. cum. while the draft 54.45 m. cum., and the surplus is 86.7 m. cum. As per CWC (1982) study the district faced 42 years of hydrological drought during the period 1901 to 1980. The location of raingauges and groundwater observation wells is shown in the district map as given in fig. 2.8.

2.9.4 Sidhi

The sidhi district is located on the north eastern edge of Madhya Pradesh state. This is one of the drought affected districts of the state as well as backward district. The district is situated between longitudes 81°- 18' to 82°-49' east and latitudes 23°- 47' to 24°- 42' north. The geographical area of the district is 10390.75 sq. km. The district is divided into three talukas namely, Deosar, Gopadbanas and Singauli. According to 1971 census there are 1791 inhabited villages, 119 uninhabited villages and only one town in Sidhi district. The total population of the district is 988929 as per 1981 observation and the average density of population per sq. km. in 1981 was 95 persons.



(a) DISTT. DHAR



(b) DISTT. SIDHI

FIG. 2.8 LOCATION OF RAINGAUGE STATION & GROUNDWATER WELL

As per the information available, the soils in the district may be classified as sandy to sand-loam with patches of clay loam in between. The land use details of the district as per data 1973-74 to 1977-78 includes the forests 424296 ha., land put to non agricultural uses 49083 ha., barren and uncultivable land 125124 ha and culturable areas is 440608. As per 1974-75 to 1976-77 data the total irrigated area was 4341 ha. in the district. The sources wise distribution includes 1956 ha. by ground water and 1440 ha. by surface water and 845 ha. by other sources.

The Sone and Tons are the main rivers that flow though the district. The catchment area of the Sone river in the district is of the order of 2241.6 sq. km.

As per CWC study of 1982 the district receives rainfall mainly from South-west monsoon. The normal annual rainfall in the district is 1245.82 mm. There are normally 54.46 rainy days in one year according to analysis from 1901 to 1980. About 89.57% of the annual rainfall is received during the south-west monsoon. Only three raingauge stations are located in the district and the density of raingauge stations is 1 station per 3510.67 sq. km. A maximum rainfall of 2081.5 mm was recorded in 1911 in the district and the coefficient of annual rainfall is 27.39% during the period 1901 to 1980.

As per state groundwater organisation data, the groundwater potential in one year is that the recharge to groundwater is of the order of 1394 m. cum. while the draft is 73.00 cecum. and the surplus 1321 m. cum. According to 1982 study of CWC the Sidhi district faced 10 years of hydrological drought during the period 951 to 1980. The location of raingauges and groundwater observation wells is shown in the district map as given in figure. 2.8.

2.9.5 Betul

Betul district is one of the southern districts of Madhya Pradesh. The district has been identified as drought prone district and is a small district of Madhya Pradesh. The geogrpahical location of Betul district which has an area of 10061 sq. km., is located between 21°- 22'N to 22°- 24'N latitudes and 77°- 04'E to 78°- 33'E longitudes. The district consists of three tehsils namely Betul, Bhainsdenni and Multai. The district has 1326 inhabited villages, 64 uninhabited villages and 5 towns. As per (1981) census the district had population of 924215 of which the rural population constituted 84.66%. The density of population is 91.86 persons per sq. km. in the district as per 1981 census.

It has been reported that generally superior black soil is found in the district. As per data from 1970 - 71 to 1976- 77 the land use in the district include forests 415624 ha., barren and uncultivable land 26140 ha., land put to non-agricultural uses 41766 ha. and cultivable land 502070 ha. It has been reported that the total irrigated area of the district is 32179 ha. as per data 1960-61 to 1977-78. The sourcewise distribution of irrigated area is 27433 ha. by groundwater and 4746 ha. by surface water.

Through Betul district the main river which flow include the Narmada, Tapi and Godavari. The catchment areas of these river basins in the district are 3765 sq. km. for Narmada,. 4077 sq. km. for Tapi and 2279 sq. km. for Godavari.

Accordingly to CWC study of 1982 the normal annual rainfall of the district is 1022.19 mm which is below the average annual rainfall of the state. The district gets 86.13 % of the annual rainfall from the south west monsoon. Normally there are 54.80 rainy days in a year as per analysis of data from 1901-1980. The district has 15 raingauge stations and the density of raingauge station is 670.73 sq. km. per raingauge as per data of the coefficient of variation for annual rainfall has been reported as 25.76% for the district.

As per SGWB data for the groundwater potential is that annual recharge to groundwater is 861 m. cum., draft 189 m. cum. and balance 672 m. cum. in one year. The 1982 observations of CWC indicate that during 1951 to 1980 the district faced 11 hydrological drought years. The location of raingauges and groundwater observation wells is shown in the district map as given in figure. 2.9.

2.9.6 Shahdol

The district Shahdol is one of the drought prone districts of Madhya Pradesh state. The district having a geographical area of 14028 sq. km. is located between 22°- 38' to 24°- 20' North latitude and 80°- 28' to 82°- 12' East longitude. It consists of four tehsils namely Bandogarh, Beohari, Pushparajgarh and Sohagpur. The district has 1981 inhabited villages, 169 uninhabited villages and ten towns as per 1971 census.

The population of the district according to the 1981 census is estimated to be 1,3,43,917 and the density of population of the district is 97 persons per sq. km. as per 1981 data. It has been reported that generally two types of soils are found in the district namely red and yellow soil, medium black soil and their sub-varieties. As per data from 1973-74 to 1977-78, the land use in the district include forests 405,581 ha. barren and uncultivable lands 69,791 ha, and land put to non-agricultural uses, 79,925 ha and 652, 116 ha with culturable area.

The total irrigated area of the district is 5463 ha and the source-wise distribution of irrigated areas are 2755 ha by surface water, 1478 ha by groundwater and 1230 ha by other sources. The main rivers flowing through the district are Sone and Johilla. The catchment area within the district of Sone is 8142 sq. km. and that of Johilla is 2513 sq. km.

As per CWC Analysis of 1982, the normal annual rainfall of the district is 1232.28 mm and there are normally 63.65 rainy days in one year. Four number of raingauge stations are located in the district and the density of rainguage station are 3507 sq. km. per raingauge stations as per data based from 1901 to 1980. The south-west monsoon gives about 87.22% of the annual rainfall and the coefficient of variation for annual rainfall is 21.67%.

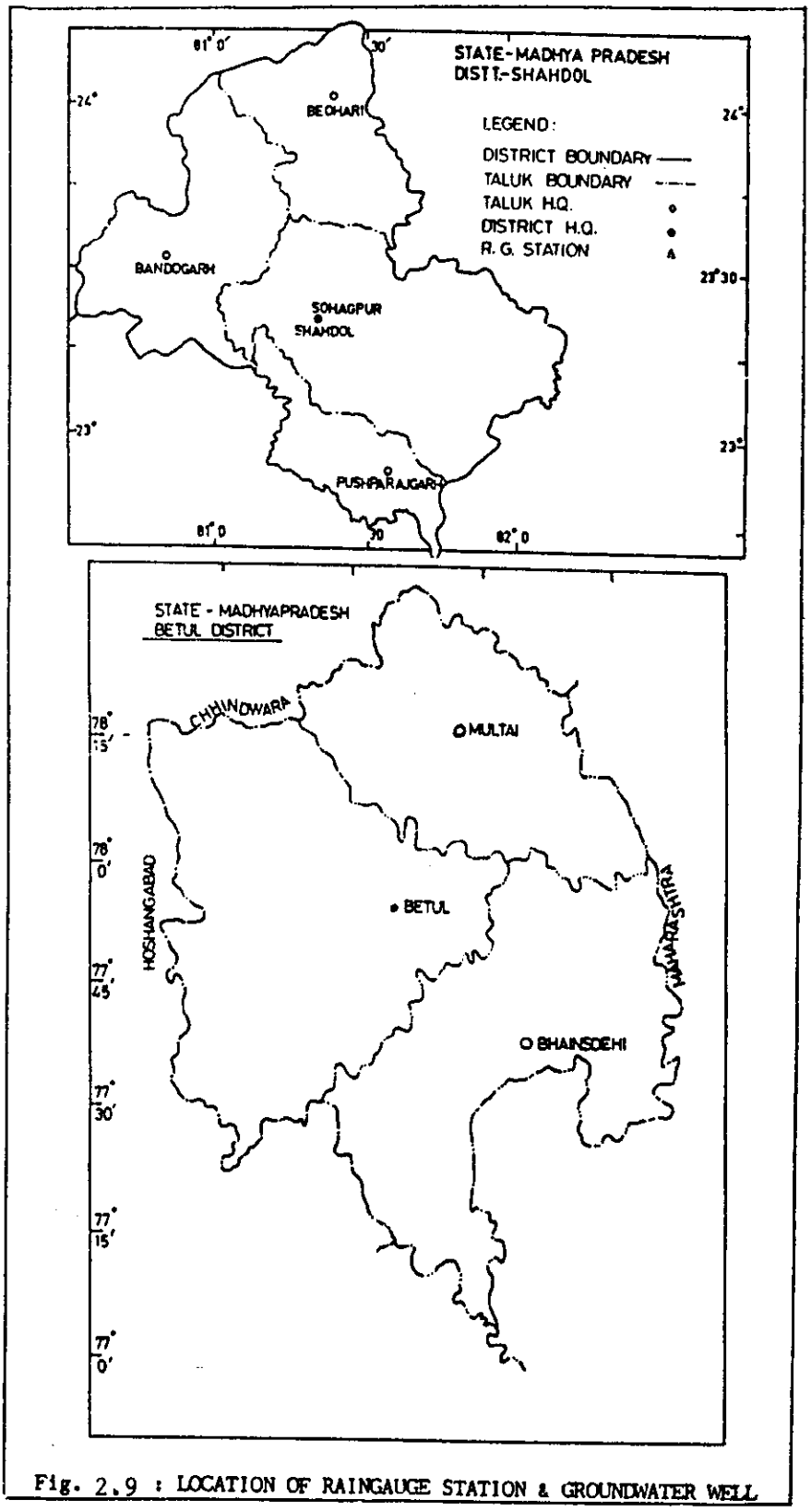


Fig. 2.9 : LOCATION OF RAINGAUGE STATION & GROUNDWATER WELL

As per CGWB data, the groundwater potential data estimate recharge to groundwater of the order of 1426 m. cum. and the draft is 32.00 m. cum. and the surplus is 8.0 m. cum. As per CWC (1982) study the district faced 5 hydrological drought years during the period 1941 to 1980. The location of raingauges and groundwater observation wells is shown in the district map as given in Figure 2.9.

3.0 RAINFALL ANALYSIS

3.1 General

As described in the previous chapter six districts namely, Jhabua, Khargone, Dhar,Sidhi, Betul and Shahdol have been taken up for rainfall analysis in this report. One representative raingauge station from each taluk in each of six districts has been selected for the study. The location of raingauges in various taluks on the district map has been shown in figures presented in chapter 2.0. The raingauge stations selected for the study are the ones which were selected by Central Water Commission for carrying out studies for identification of drought prone areas in 1982. The rainfall analysis has been carried out with the data from year 1901-89. The data from 1901-1980 have been taken from CWC reports (CWC 1982). The rainfall data from 1981 to 1989 have been collected during visits of scientific teams to various central/state Govt. offices of state of MP, as has been mentioned in chapter 2.0

3.2 Rainfall Departure Analysis

3.2.1 Seasonal Rainfall Departure

In order to see 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 above mentioned six districts of MP have been calculated as the summation of normals for the months (June to September) provided in CWC reports. Only four months i.e. June, July, August, and September are taken into account while estimating seasonal normals for the six selected districts, as the South-West monsoon is active for four months in the state of Madhya Pradesh. Analysis of seasonal rainfall departure to all the six districts i.e. Jhabua, Khargone, Dhar, Sidhi, Betul and Shahdol are given in Table 3.1. The graphical presentation of results have been shown in Fig. 3.1.

The major inferences that could be drawn from seasonal analysis are below:

From the Figures 3.1 and Tables 3.1 it is evident that all the six districts except Jhabua and Betul experienced deficit seasonal rainfall in the year 1988-89 in the range of 5 to 35%. The districts of Shahdol, Dhar and Khargone faced continuous negative departures since 1985. The analysis shows that district Betul received extremely deficit seasonal rain during 1989. As per the rainfall records supplied by irrigation department Govt. of M.P. the deficit was more than 80%.

3.2.2 Monthly Rainfall Departure for the year 1988-89

In order to find deficiency in monthly rainfall during the year 1988-89, monthly departures have been worked out for 6 districts selected in the state Madhya Pradesh. The departure analysis has been done for all the taluks and district as a whole, but to reduce the bulk of report only results of one taluk

Table 3.1: Seasonal rainfall departure (%) from seasonal normals for Madhya Pradesh.

Years	BETUL	DHAR	JHABUA	KHARGO	SHAHDOL	SIDHI
Seasonal Normal (mm)	880.53	773.60	790.70	733.27	1074.83	1115.82
70	20.92	43.00	42.07	54.41	- 5.08	-12.29
71	-16.45	11.82	23.51	- 4.80	10.47	31.36
72	-20.03	-27.21	-33.16	-37.69	- 3.15	-16.45
73	52.28	56.20	-	61.65	-51.45	-28.81
74	-18.68	-38.47	-22.14	-19.92	-22.71	-36.30
75	34.48	-34.82	-23.08	9.26	32.36	3.02
76	-37.21	31.97	69.11	23.75	-63.41	-24.94
77	-20.20	4.27	48.69	- 7.34	11.23	6.55
78	-33.95	3.51	30.76	7.77	15.41	6.23
79	-18.31	-24.54	- 7.47	- 1.00	-45.90	-44.48
80	-22.46	-12.63	- 1.77	-16.85	32.46	17.71
81	- 5.40	32.52	28.63	33.10	-26.98	3.23
82	- 5.40	-39.26	- 7.47	-27.63	-11.03	16.20
83	12.22	2.16	30.85	11.64	10.37	- 3.24
84	- 5.40	- 1.45	- 3.49	-23.42	7.35	-18.46
85	-20.83	-41.65	-46.39	-39.93	- 2.05	14.06
86	11.23	-21.46	-26.31	-16.64	- 5.64	-31.14
87	-46.05	-30.27	-33.43	-40.56	- 4.81	8.88
88	26.44	- 3.02	8.17	- 8.79	-14.50	-39.03
89	-100.00	-27.08	-37.70	-33.27	-26.62	-35.25

and district as a whole are included in the report. Monthly rainfall values from June 1988 to May 1989 along with monthly normals of various representative raingauges of various taluks have been considered for the analysis. Monthly rainfall values for a district from June 1988 to May 1989 have been taken as weighted average rainfall of all the taluks considered for analysis in the district.

The variability of rainfall monthwise (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 fig. 3.2. The departure figures for one selected taluk in each district are shown in fig. 3.3. Based on the monthly departure values, two categories of monthly departures i.e. 20-50% and more than 50% have been established for deriving monthly deficiency inferences. The results of analysis indicate that in the year 1988 the rainfall during the months of July, August and September was more or less good enough over Betul, Dhar, Shahdol and Jhabua whereas in sidhi district it was less than the normals during all the months of the year. Rainfall in the month of June was less than normal in all the district except Betul. This indicate threshold the detailed on set of monsoon in the year 1988. As the months from Dec. 88 to May 89 lies in non-monsoon period and a low normal rainfall, these do not much. The district wise monthly rainfall departure for year 1988 - 89 makes clear that monsoon in this year was better than that of previous year.

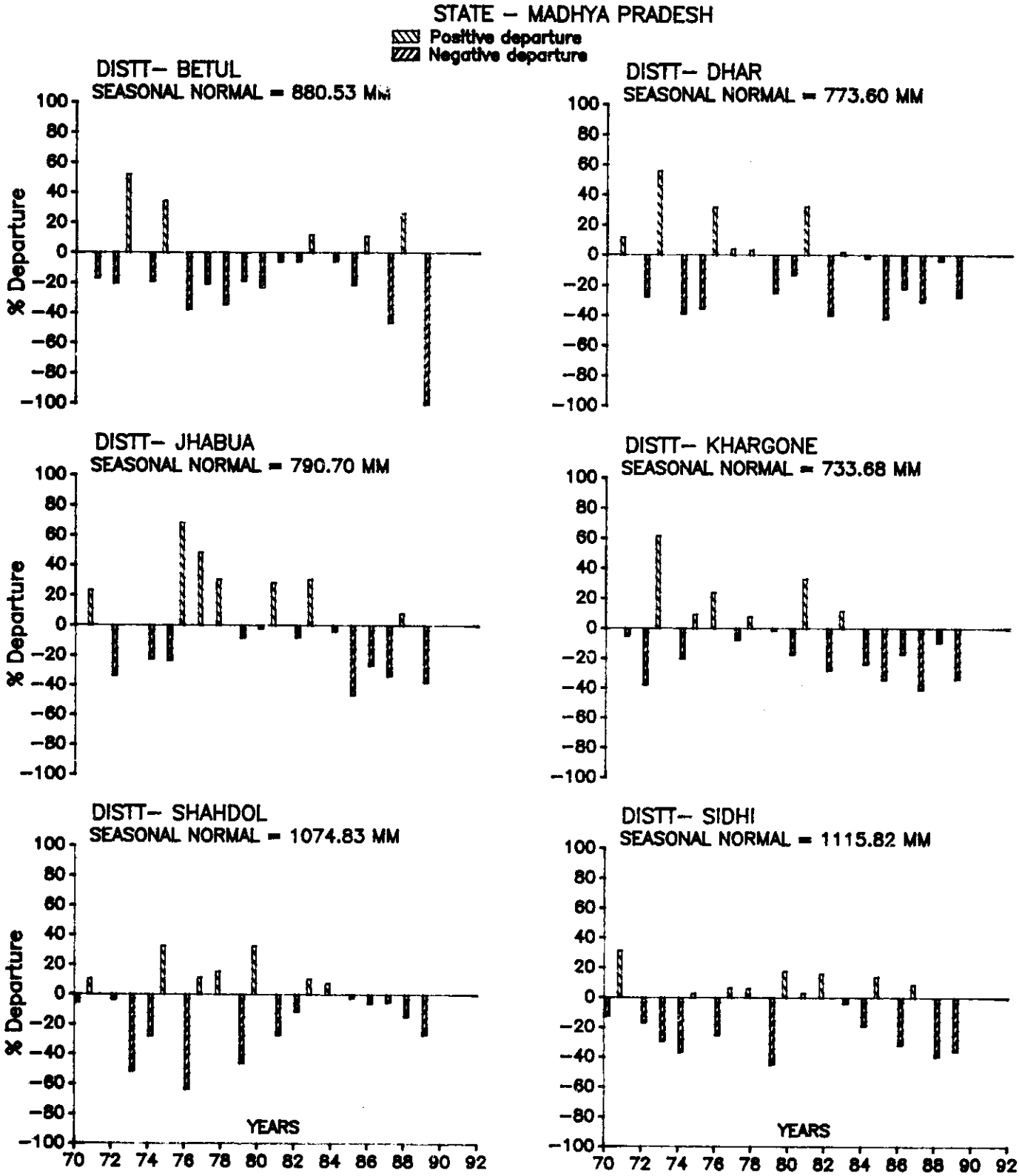


Fig.3·1: Districtwise seasonal rainfall departure.

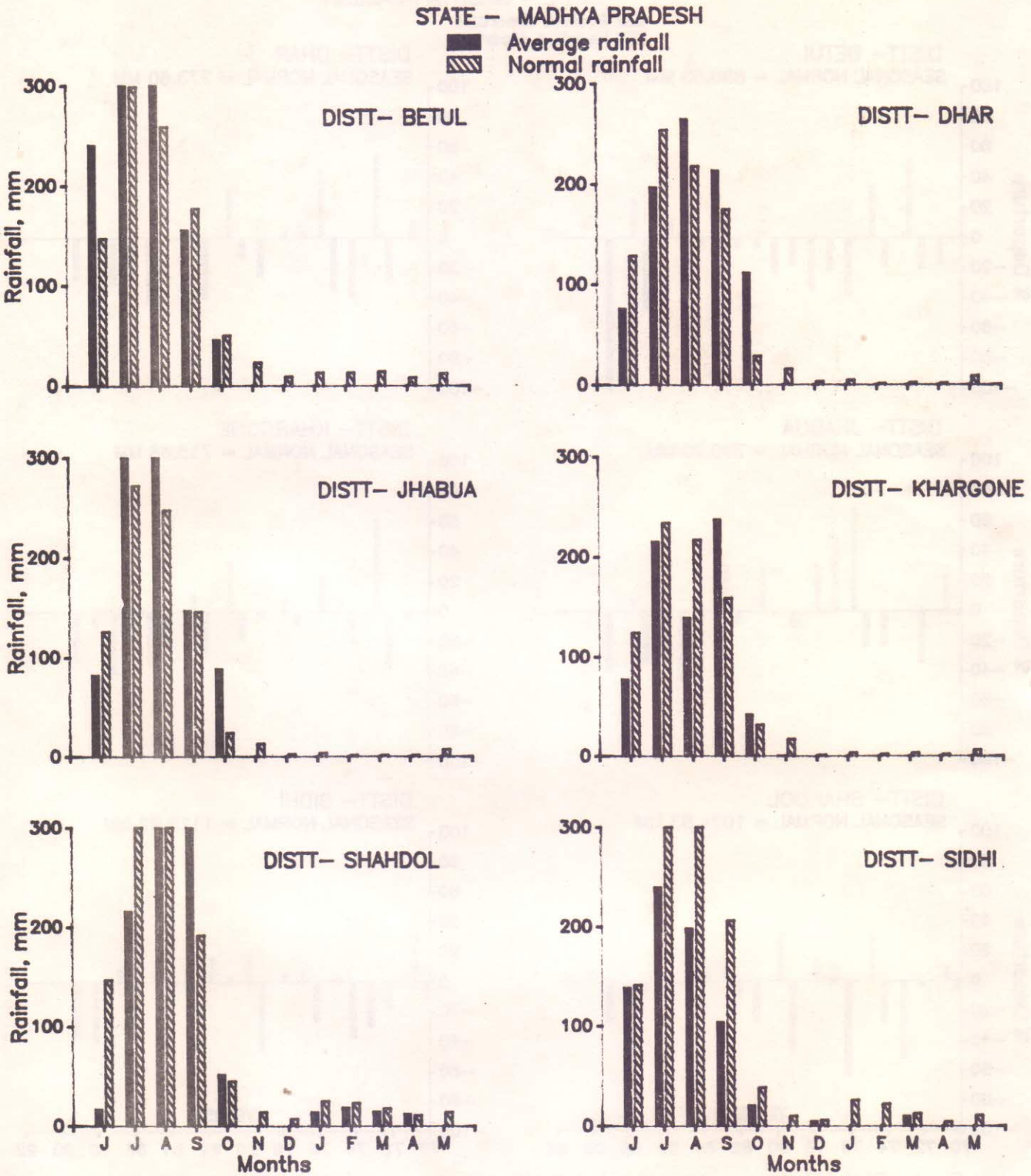


Fig.3.2 Districtwise monthly rainfall departure for year 1988 – 89.

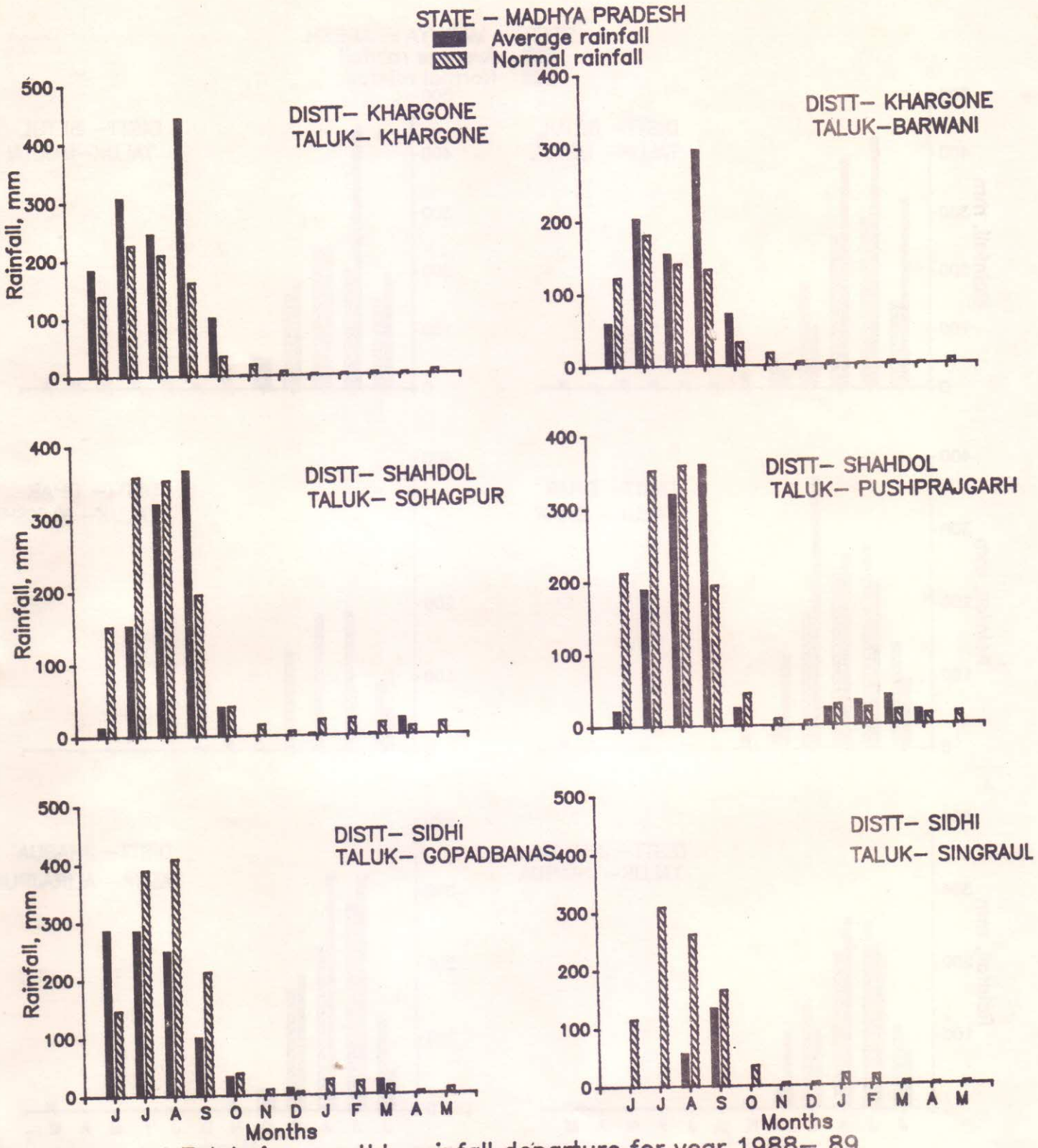


Fig. 3·3 (a):Talukwise monthly rainfall departure for year 1988– 89.

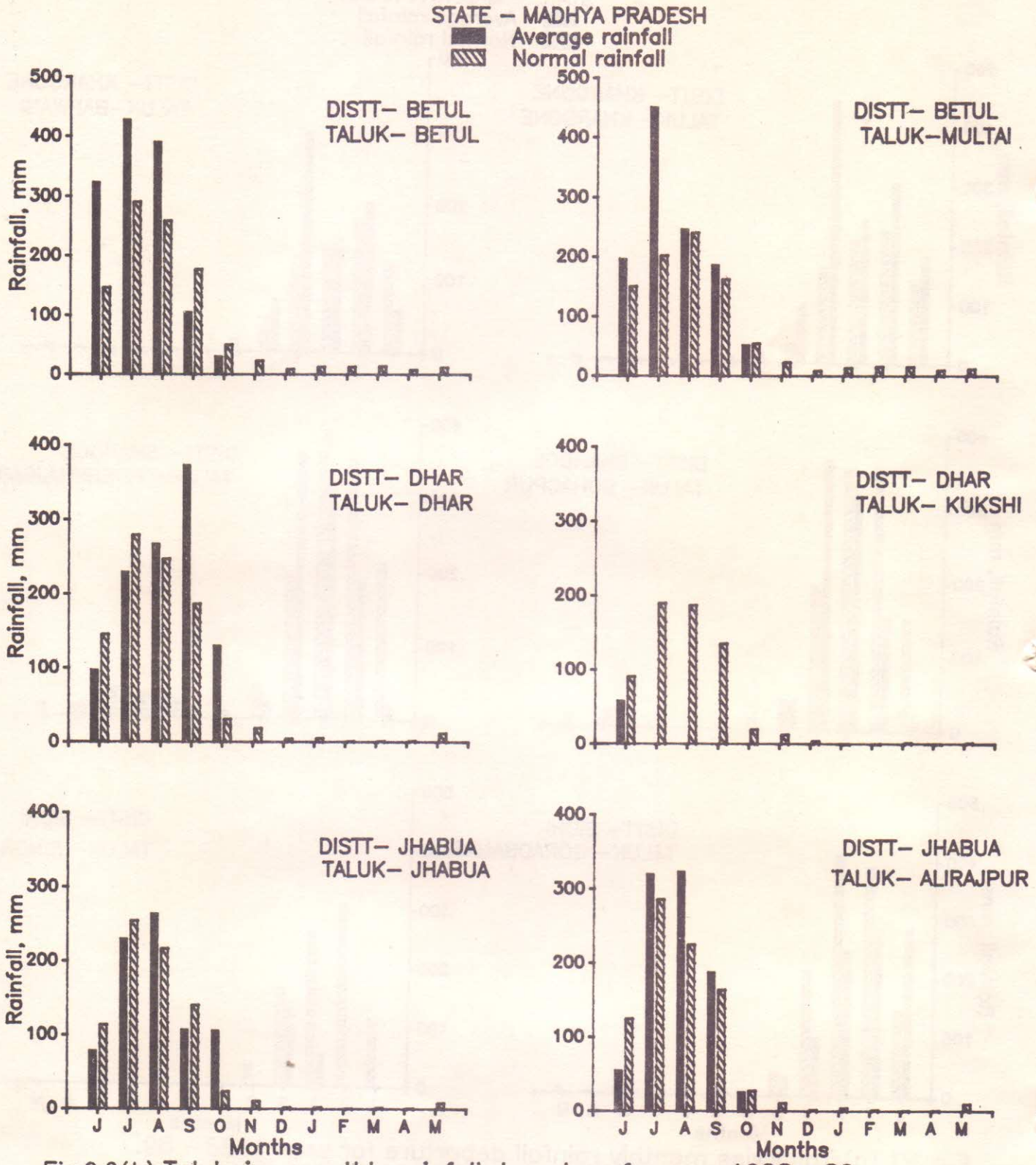


Fig.3·3(b):Talukwise monthly rainfall departure for year 1988– 89.

Table 3.2: Monthly rainfall deficits in districts 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
M.P.	June 1988	Jhabua, Khargone, Dhar	Shahdol
(No. of districts taken - six)	July	Sidhi, Shahdol, Dhar	-
	August	Khargone, Sidhi,	-
	September	Sidhi	
	October	Sidhi	-
	November		Shahdol, Jhabua, Khargone, Dhar, Sidhi, Betul
	December		Betul, Dhar, Shahdol, Jhabua, Khargone
	January 1989		Betul, Jhabua, Dhar, Khargone, Sidhi, Shahdol
	February		Jhabua, Dhar, Khargone, Sidhi, Betul, Shahdol
	March	Shahdol	Betul, Jhabua, Dhar, Khargone, Sidhi
	April		Betul, Dhar, Khargone, Sidhi, Jhabua, Shahdol
	May		Betul, Jhabua, Dhar, Khargone, Sidhi, Shahdol

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/ taluk/ 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. A 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 cummulative probability in respect of various groups at their corresponding midpoint. The cummulative 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 of each district have been shown in Figures 3.4 and 3.5 respectively.

The range of rainfall group for the taluks and district at 75% probability distribution are tabulated in Table 3.3. It can be seen from table that probability of occurrence of rainfall equivalent to 75% of normal in districts Jhabua, & Khargone and Sidhi, Shahdol are in the group range of 600 - 700 and 1000 - 1100 mm respectively. Similar inferences can be drawn for other districts and their taluks from Table 3.3 which is self explanatory.

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

For identification of drought proneness of the district/taluks, the %age 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 the values are presented in Table 3.3. 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 in 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 3.3 are as below:

The probability values of occurrence of 75 % normal rainfall in all the districts namely Jhabua, Khargone & Dhar, of state Madhya Pradesh are 79, 79, 78 respectively i.e. below 80, indicating that above mentioned three districts are drought prone based on this analysis as per IMD criteria. It can also be stated that these three districts i.e. Jhabua, Dhar and Khargone experienced rainfall less than 75 % of normal. However in case of districts of Betul, Sidhi & Shahdol the probability value of occurrence of 75 % normal rainfall is 87, 84 & 89 respectively i.e. above 80, indicating the district can not be classified as drought prone based on this analysis as per IMD criteria. The taluks of the six districts showed similar results indicating that these taluks as well as district as a whole are drought affected as per IMD criteria.

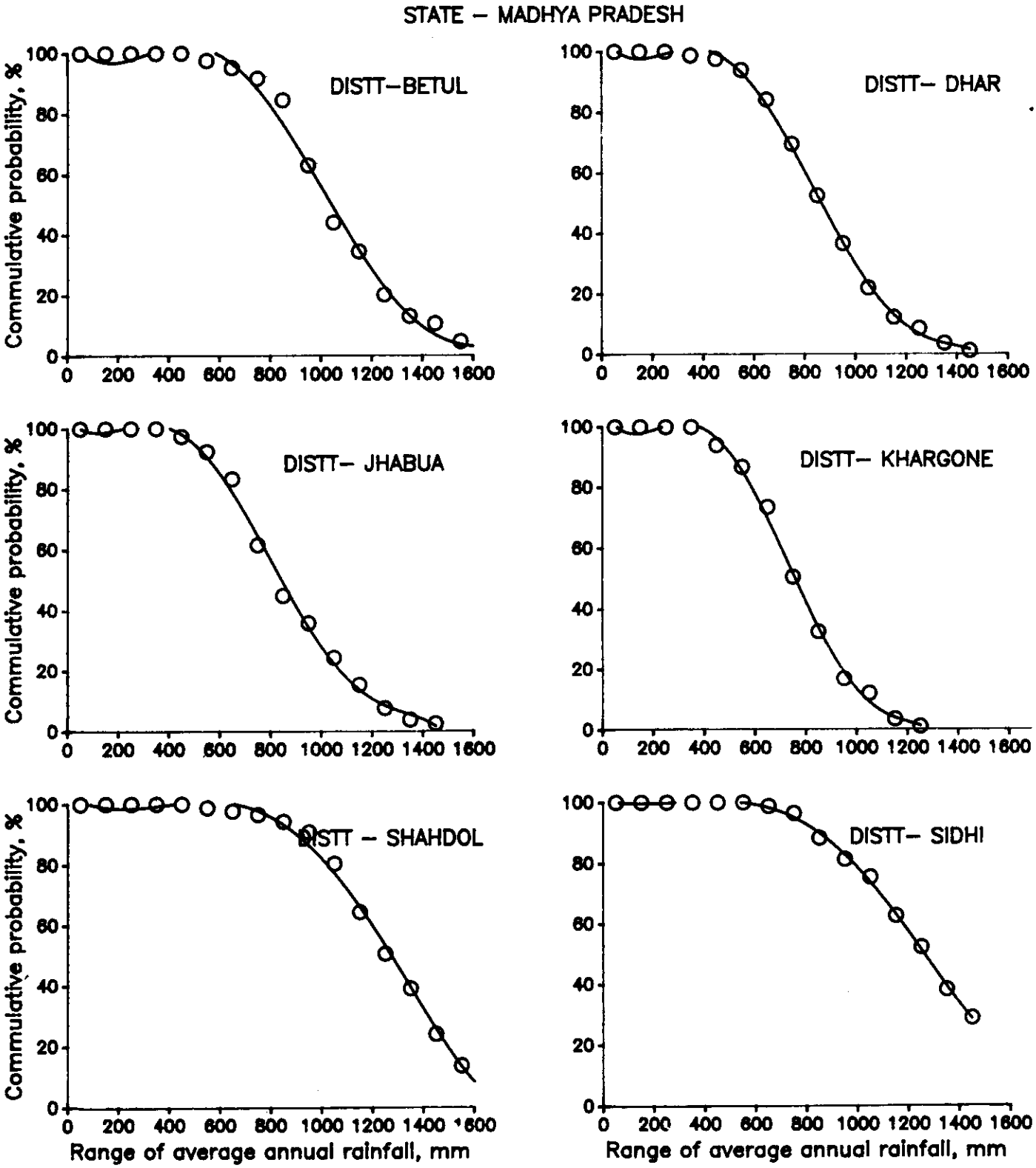


Fig.3·4:Districtwise probability of annual rainfall.

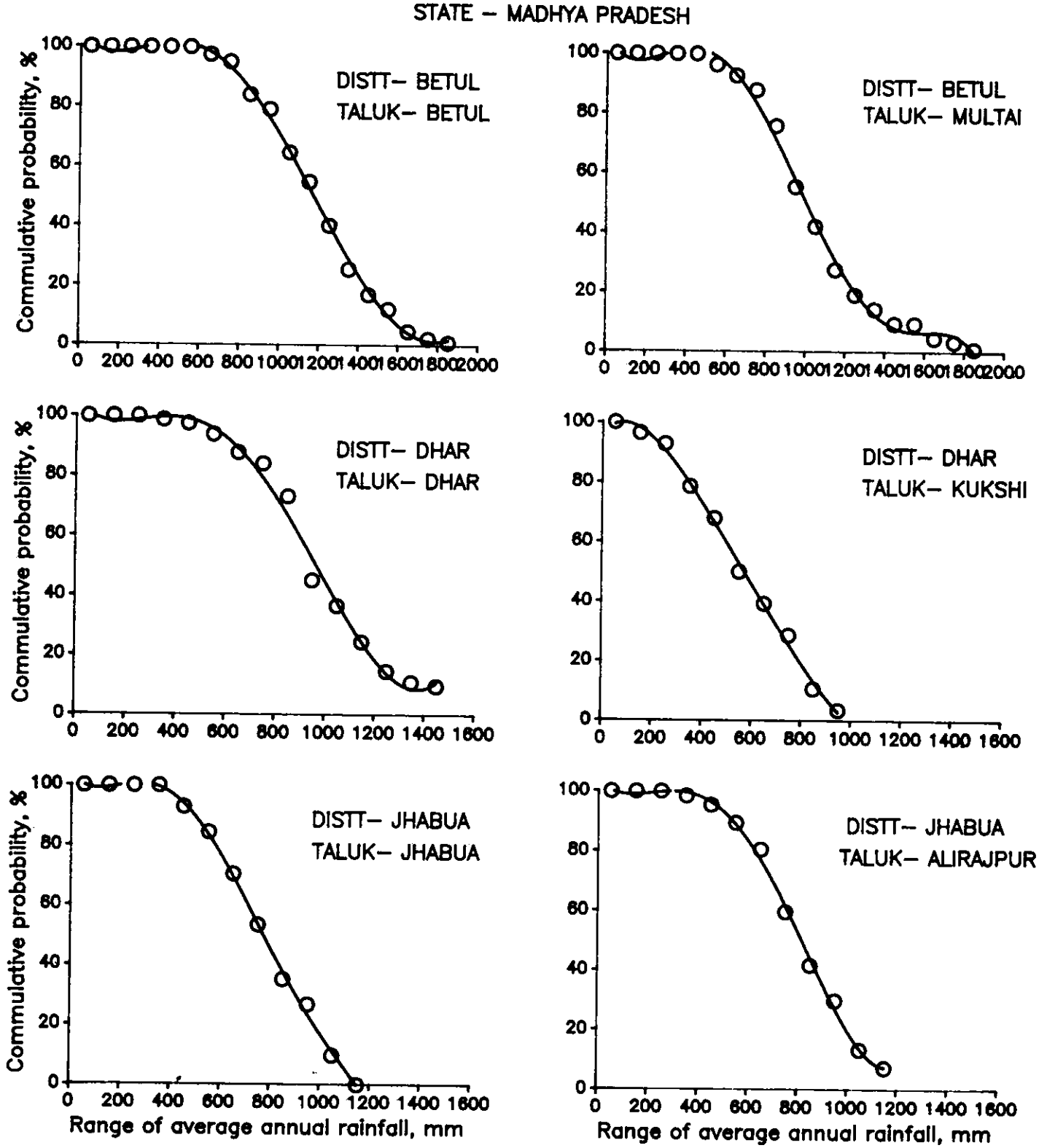


Fig.3·5(a):Talukwise probability of annual rainfall.

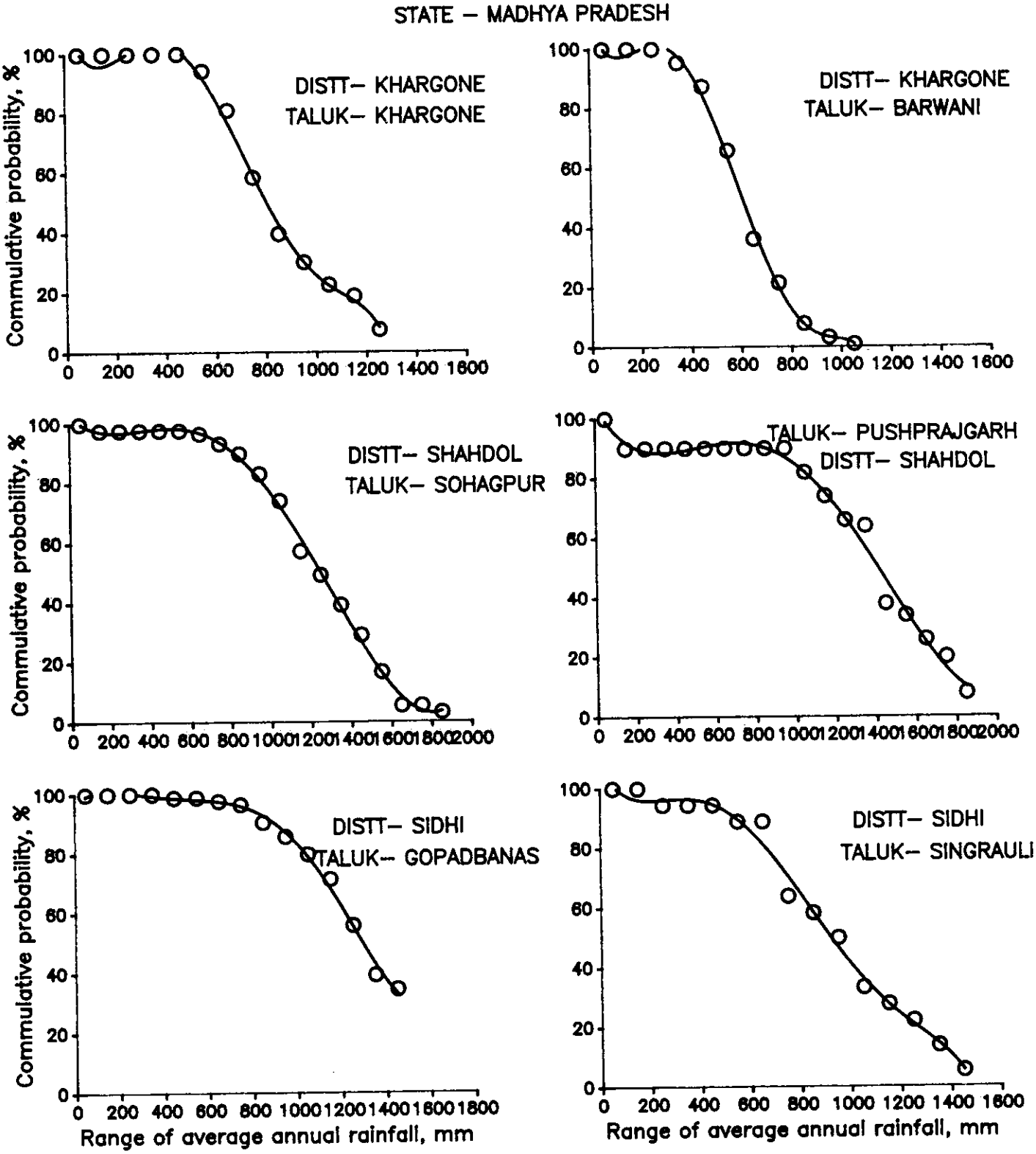


Fig.3·5(b):Talukwise probability of annual rainfall.

Table 3.3: Probability distribution of annual rainfall of state Madhya Pradesh.

Sl. No.	District (State)	Name of Taluks & District unit	75% Probability and above (Range in mm)	Normal rainfall	Probability of occurrence of rainfall equivalent to 75% of normal (in %age)
1	2	3	4	5	6
1.	Jhabua	1. Jhabua	600-700		76
		2. Alirajpur	600-700		78
		3. District as a whole	600-700	827.31	79
2.	Khargone	1. Khargone	600-700		79
		2. Barwani	500-600		76
		3. District as a whole	600-700	804.20	79
3.	Dhar	1. Dhar	700-800		80
		2. Kukshi	400-500		70
		3. District as a whole	700-800	837.80	78
4.	Sidhi	1. Gopad Banas	1100-1200		85
		2. Singrauli	700-800		78
		3. District as a whole	1000-1100	1245.82	84
5.	Betul	1. Multai	800-900		83
		2. Betul	900-1000		88
		3. District as a whole	900-1000	1022.19	87
6.	Shahdol	1. Pushprajgarh	1100-1200		84
		2. Sohagpur	1000-1100		87
		3. District as a whole	1000-1100	1232.28	89

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 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:

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

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 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).

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

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

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

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

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,

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

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'.

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

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 positive differences (i.e., negative deficits) which are taken as zero and thus included in the computation.

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

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

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

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

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

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

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 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^{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 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 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 state Madhya Pradesh. Monthly rainfall data for period 1951 to 1988 of selected raingauge station located at taluk headquarters of each district have been used for analysis. As has been described in earlier section the computational program using the approach has been developed at the institute. The analysis has yielded in monthly and overall drought intensity values. The results of drought intensity (monthly and average) are show in Figures 3.6 in respect of all the six selected districts i.e. Jhabua, Khargone, Dhar, Sidhi, Betul and Shahdol of State M.P.

The following inferences can be drawn from the analysis:

The analysis shows 3-9 drought spells indicating that the districts are drought prone. The districts of Sidhi & Shahdol which lie in the Eastern part of the state showed similar trends in the analysis that a 8-9 drought spells while the districts of Jhabua, Khargone, Dhar & Betul which lie is western part of the state showed similar trends that a 3-5 drought spell. This indicates that the districts of Sidhi & Shahdol are more drought prone than rest of the four districts taken up for this study. The analysis also showed the maximum drought duration of 94 months in the district of Betul during 1978 to 1986 and maximum drought intensity of 3.38 in district Khargone during 1951 to 1957.

All the six districts have shown over two drought spells during 1984-88. In the year 1988 only Sidhi has showed a drought

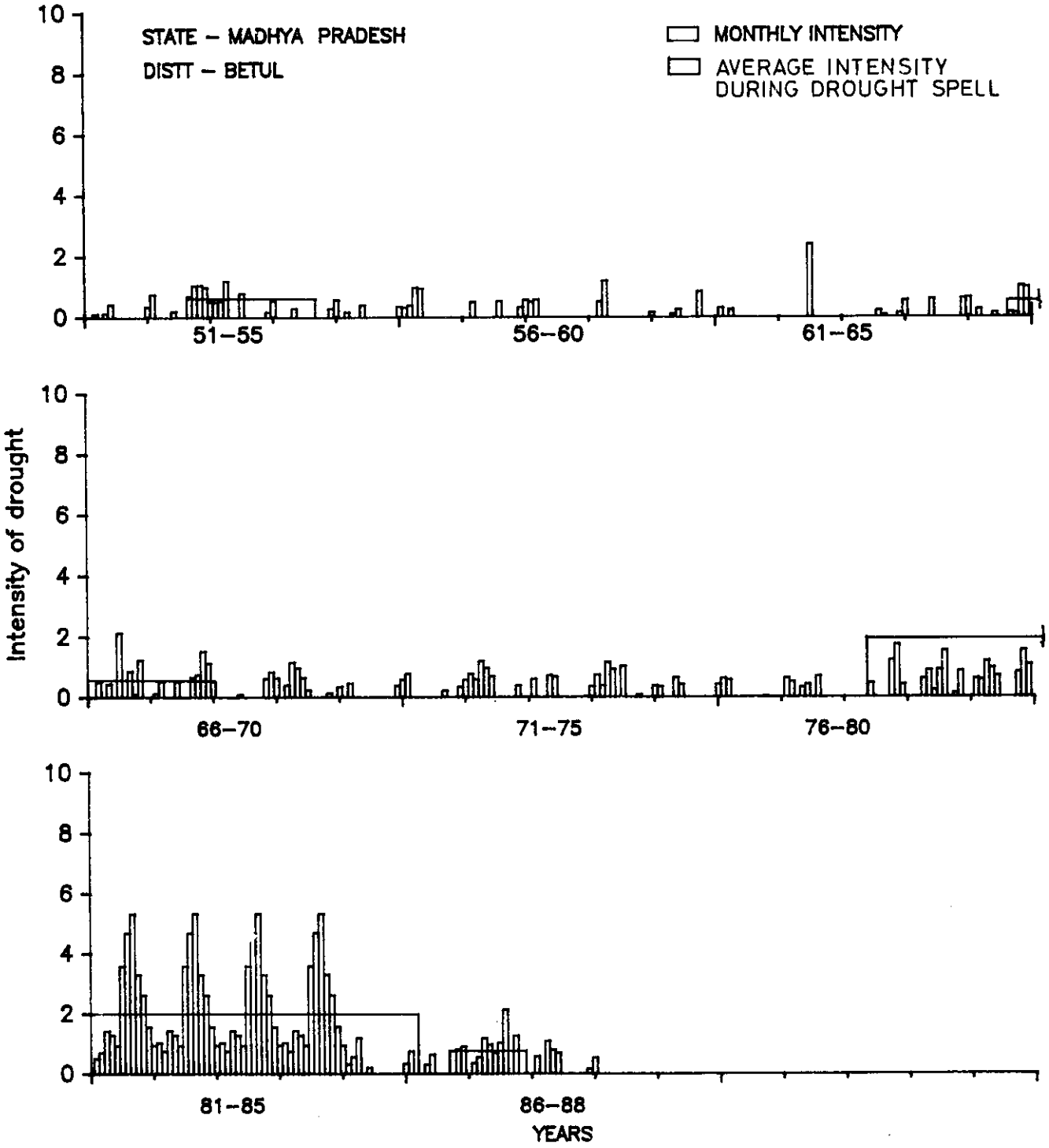


FIG:3·6: MONTHLY AND AVERAGE INTENSITY DURING DROUGHT SPELL

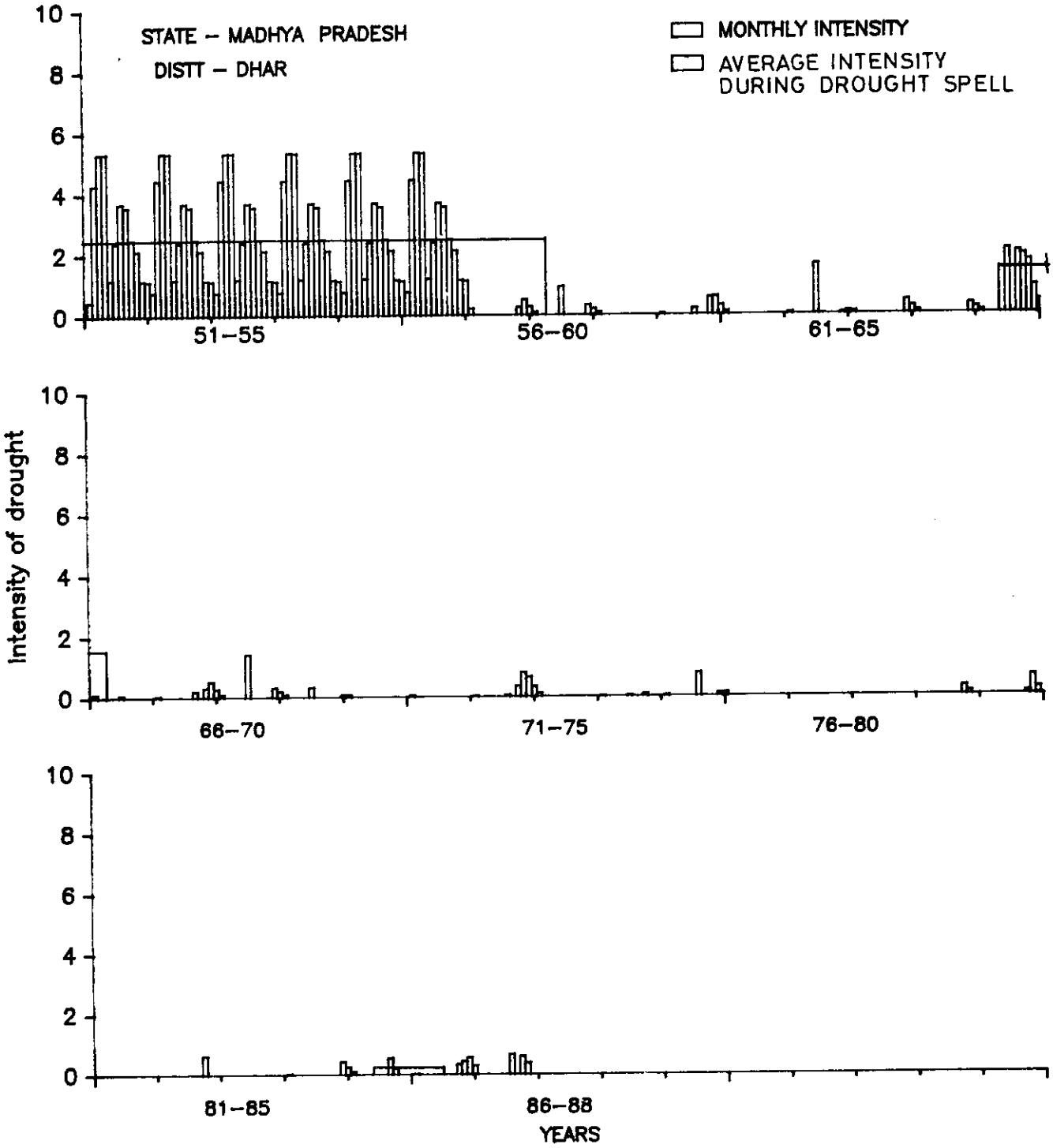


FIG: 3.6: MONTHLY AND AVERAGE INTENSITY DURING DROUGHT SPELL

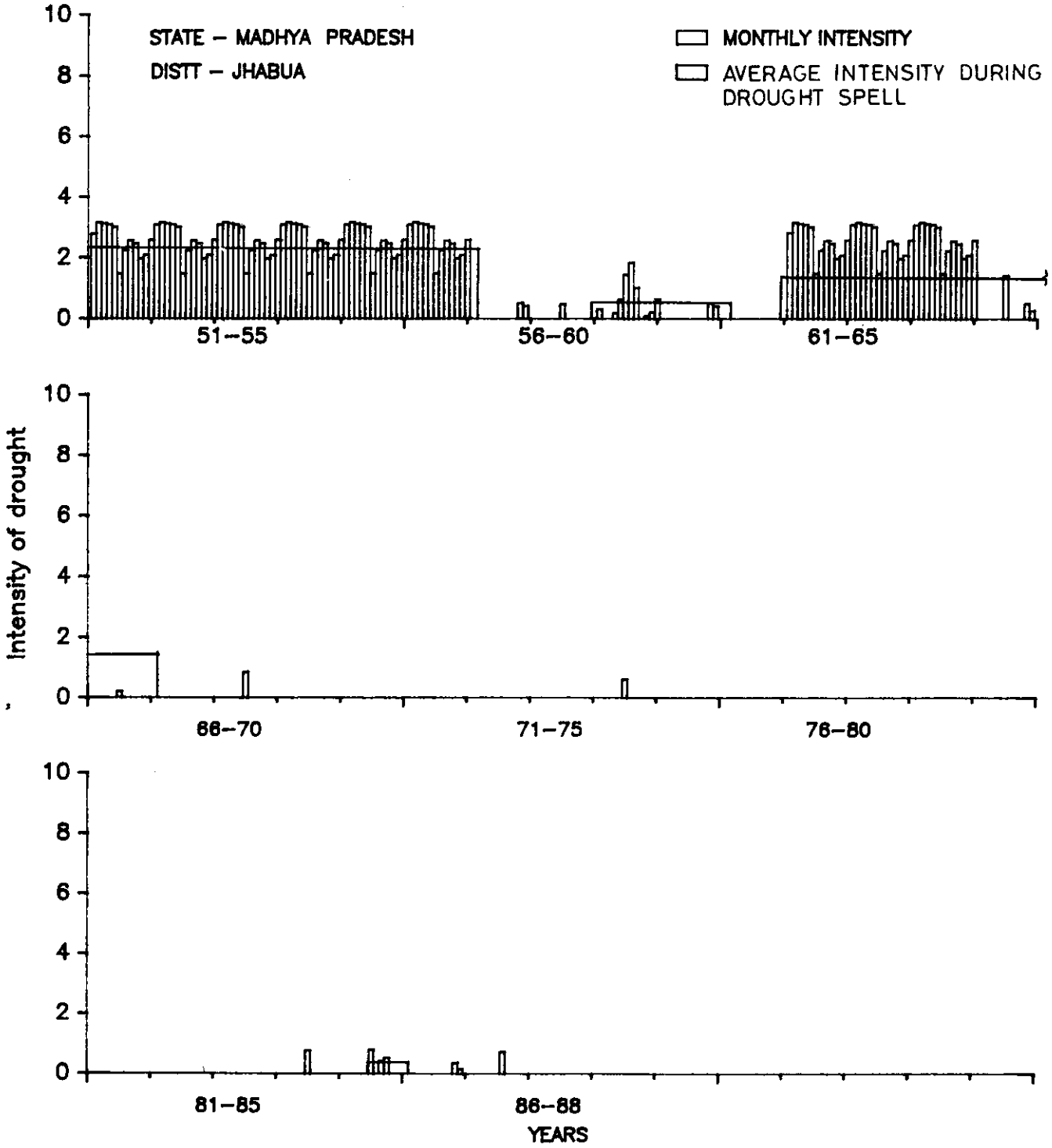


FIG:3·6 MONTHLY AND AVERAGE INTENSITY DURING DROUGHT SPELL

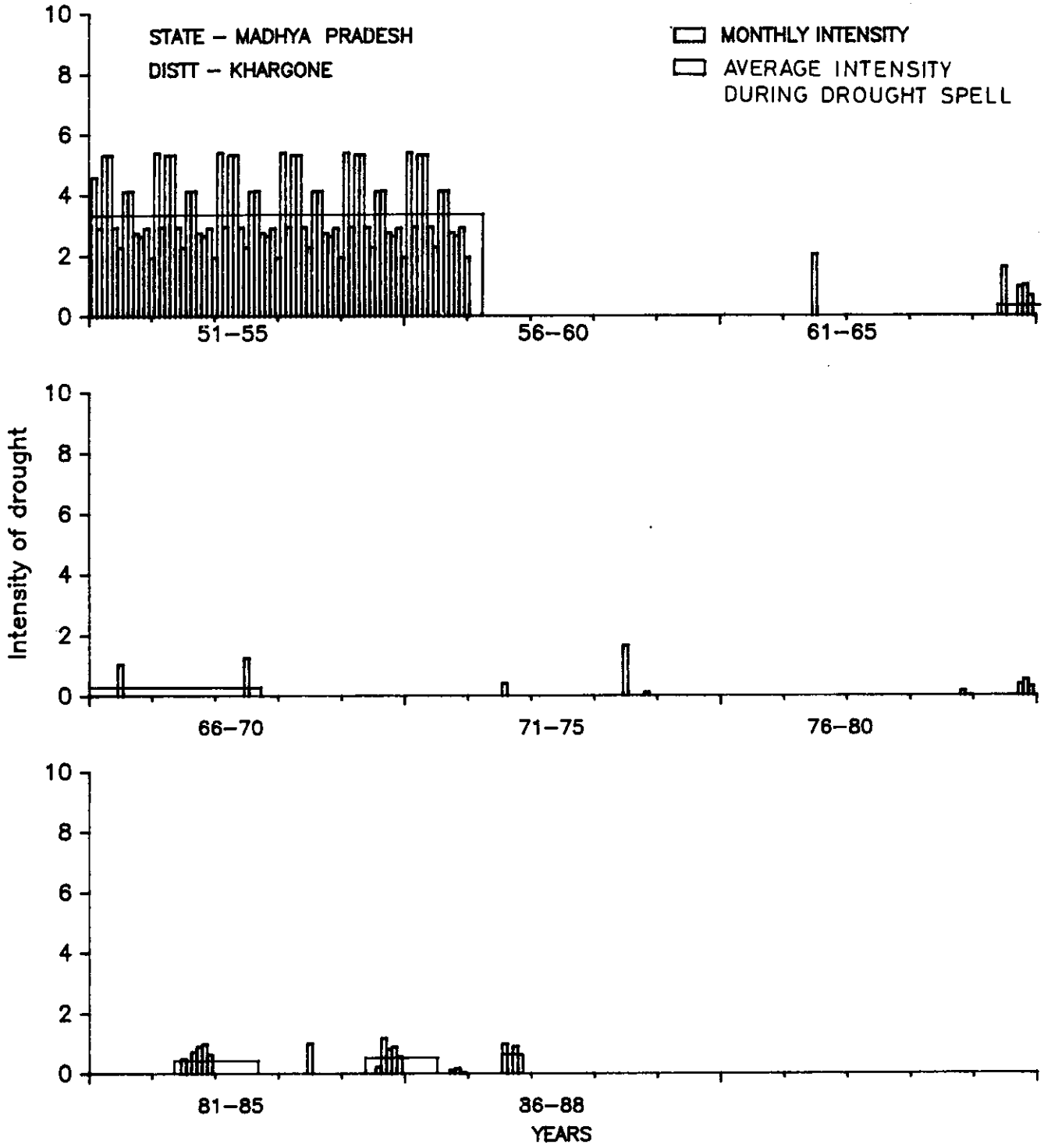


FIG: 3.6 MONTHLY AND AVERAGE INTENSITY DURING DROUGHT SPELL

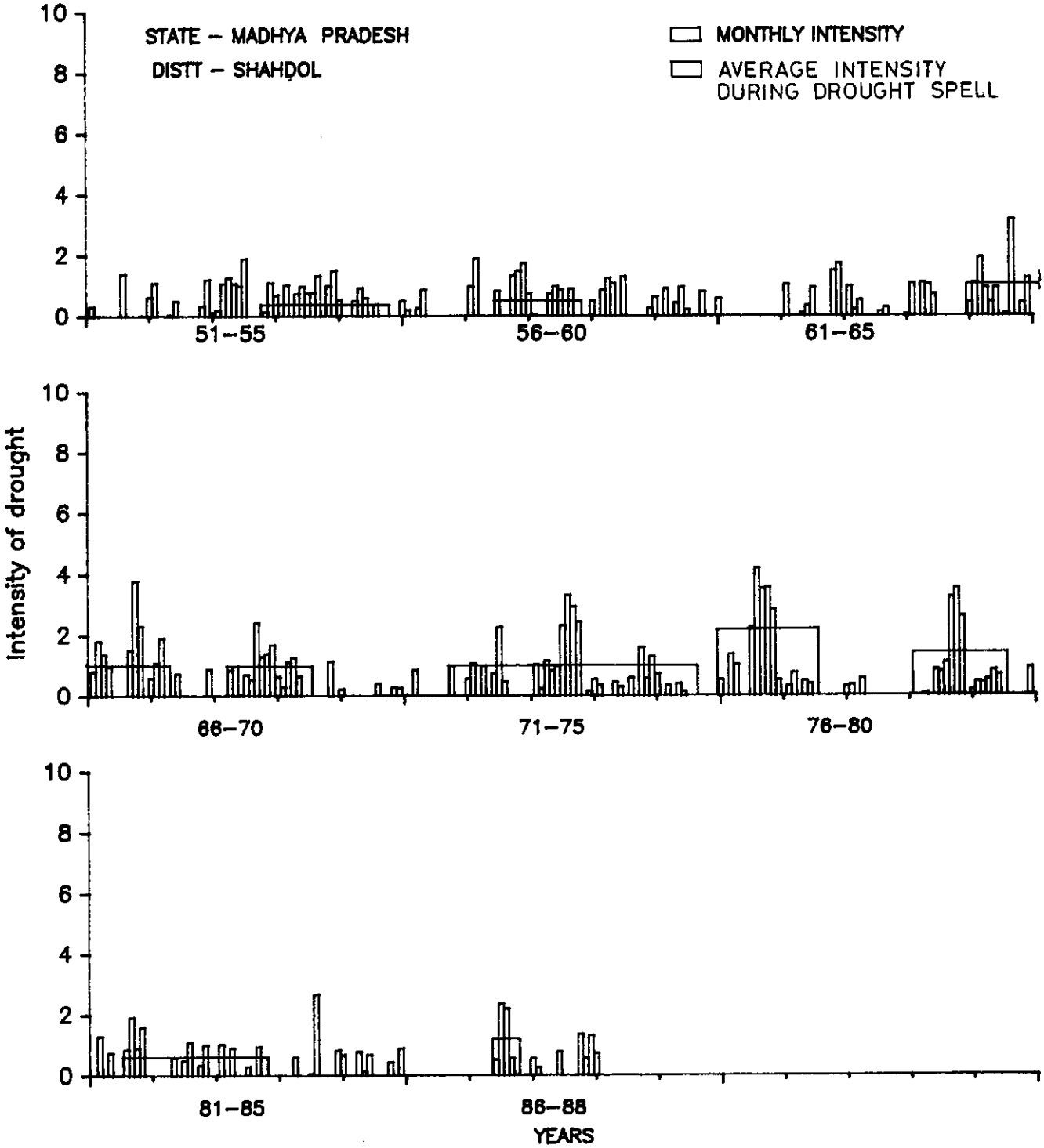


FIG: 3.6 MONTHLY AND AVERAGE INTENSITY DURING DROUGHT SPELL

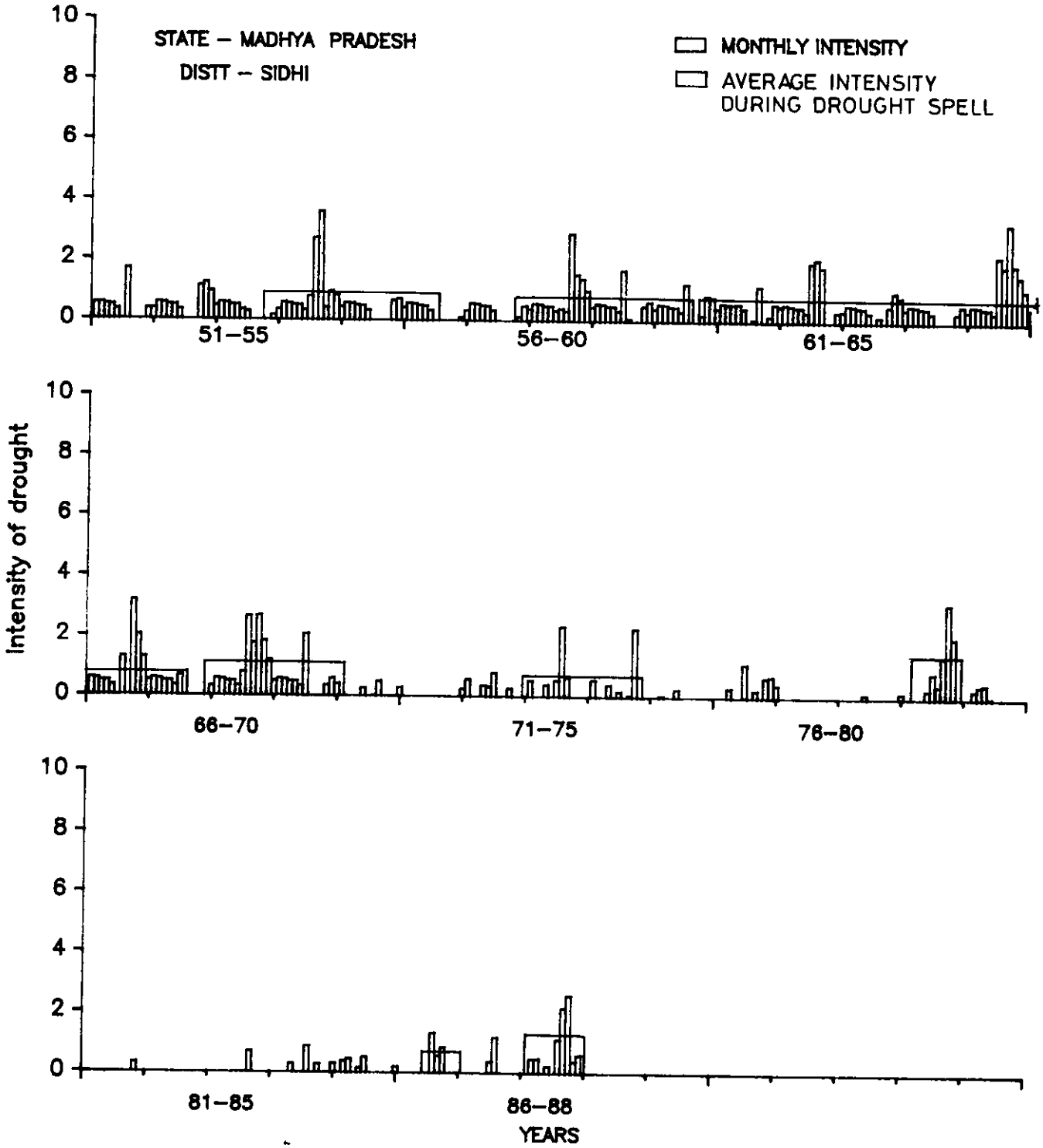


FIG:3.6. MONTHLY AND AVERAGE INTENSITY DURING DROUGHT SPELL

spell of all the 12 months of 1.29 drought intensity indicating that in the year 1988 only Sidhi faced drought conditions among the six districts selected for the analysis. Other analysis have also indicated the same. The approach has yielded comparable results of drought - analysis and has further scope of improvement taking into account the revision of monthly weightage factors keeping in view the agriculturable 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 results 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 6 districts of the state of Madhya Pradesh.

The criteria for selection of dry spell 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 atleast 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 number of dry spells have been presented in Appendix I. The number of dry spells have been counted starting from the monsoon season of 1981 to 1988. However, in case of some of the districts, the daily rainfall data for some of the years were not available and so the analysis could not be done.

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 1981-88 and commulative percentage was obtained starting from the maximum duration of dry spell group downwards adding successive percentage (Appendix II). The probability curves have been drawn showing range of duration of dry spells on the abscissa and cummulative 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 3.4. 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 selected taluks of all the six selected districts respectively except the taluks Dhar (Dhar) and Gopad Banas (Sidhi) where the duration of dry spells was expected at 75% probability range from 14-21 days.

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

Table 3.4: Range of duration of dry spells for 75 % probability.

S.No.	Taluk	At 75% Probability duration of dry spells (in days)
1.	Alirajpur (Jhabua)	21-28
2.	Barwani (Khargone)	21-28
3.	Dhar (Dhar)	14-21
4.	Gopad Banas (Sidhi)	14-21
5.	Betul (Betul)	21-28
6.	Sohagpur (Shahdol)	21-28

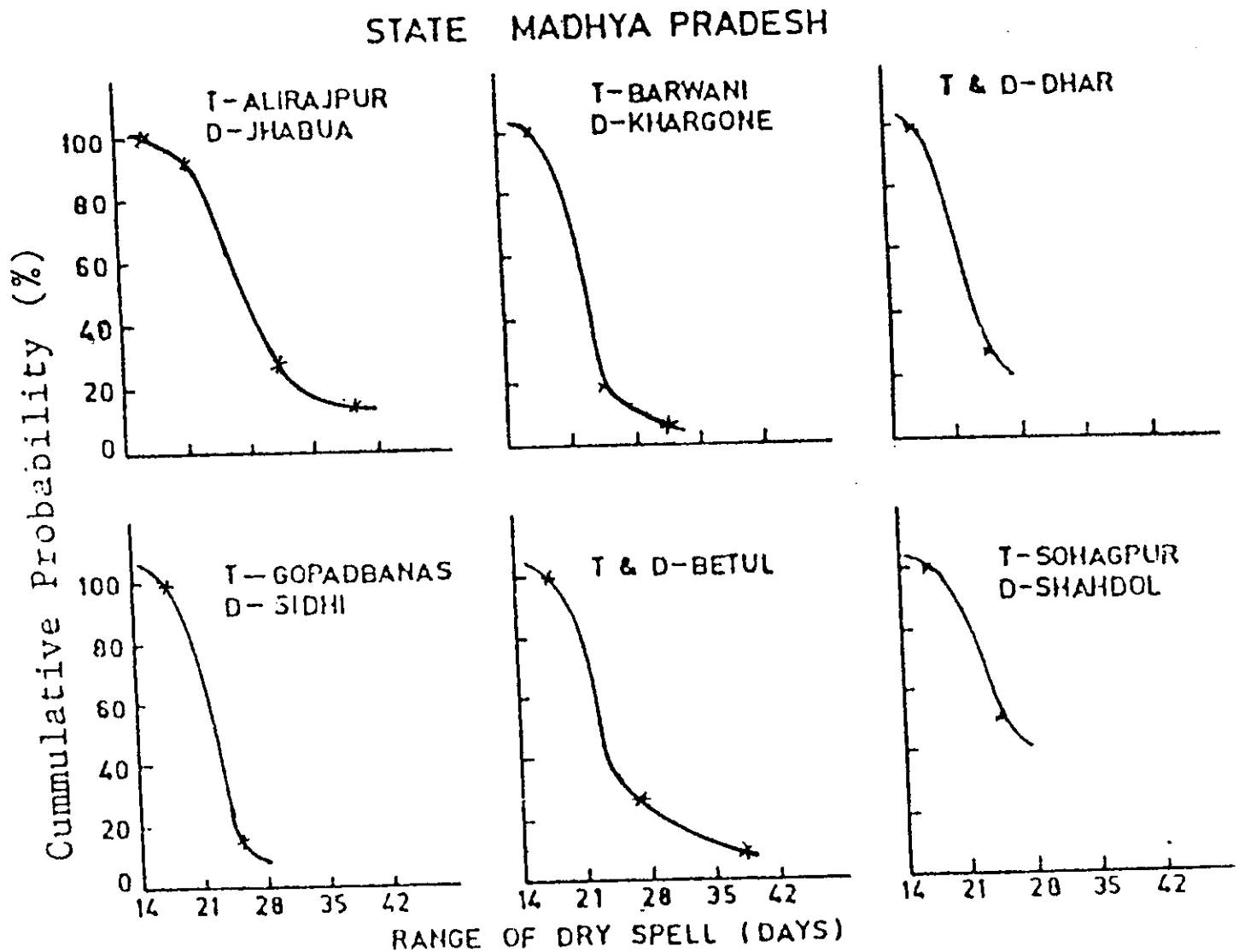


Fig.3.7 : Probability Distribution of Dry Spells

4.0 GROUND WATER DEFICIT

4.1 General

The main objective of ground water management is to ensure availability of ground water in appropriate time and in an appropriate quantity and quality to meet the most important demand of the society. The measurement of groundwater level and their evaluation can play an important role in management of this underground resource of water. The fluctuations of water table, reflect the effects of infiltration, precipitation and of discharge of groundwatrer 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 or droughts, more dependence comes on groundwater storages and sharp decline in groundwater levels are experienced. Because of improper management of groundwater 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 groundwater and surface water show that in a number of states groundwater 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 groundwater should be restricted to average annual recharge. This will conserve water from over-exploitation during drought periods.

Therefore, there is a long standing need to 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 measurements. Besides, information regarding well, abstractions, should be available for evaluating effects on water table due to reduced precipitation.

In order to see the effects of scarce rainfall as experienced during three successive drought years (1985-87) on groundwater regime, statistical analysis of groundwater level data vis-avis precipitation has been carried out for five districts namely Jhabua, Khargone, Dhar, Betul and Shahdol selected of Madhya Pradesh. However, due to non-availability of abstraction data, the effects of withdrawal could not be introduced in the analysis.

4.2 Groundwater level Analysis

The data concerning groundwater level fluctuations were collected in respect of observation well in the five districts namely, Jhabua, Khargone, Dhar, Shahdol and Betul of state Madhya Pradesh. The information regarding period of data used, number of observation wells and the source of data is given in table 4.1.

Table 4.1: Status of groundwater data of state M.P.

S.No.	Name of district	Data available for the years	Number of wells taken	Source of data availability
1.	Jhabua	1975-89 (Pre & Post)	11	State G.W. Board
2.	Khargone	- do -	14	- do -
3.	Dhar	1976-89 (Pre & Post)	5	- do -
4.	Sidhi	Data not available	-	-
5.	Betul	1975-89 (Pre & Post)	3	- do -
6.	Shahdol	1975-89 (Pre & Post)	7	- do -

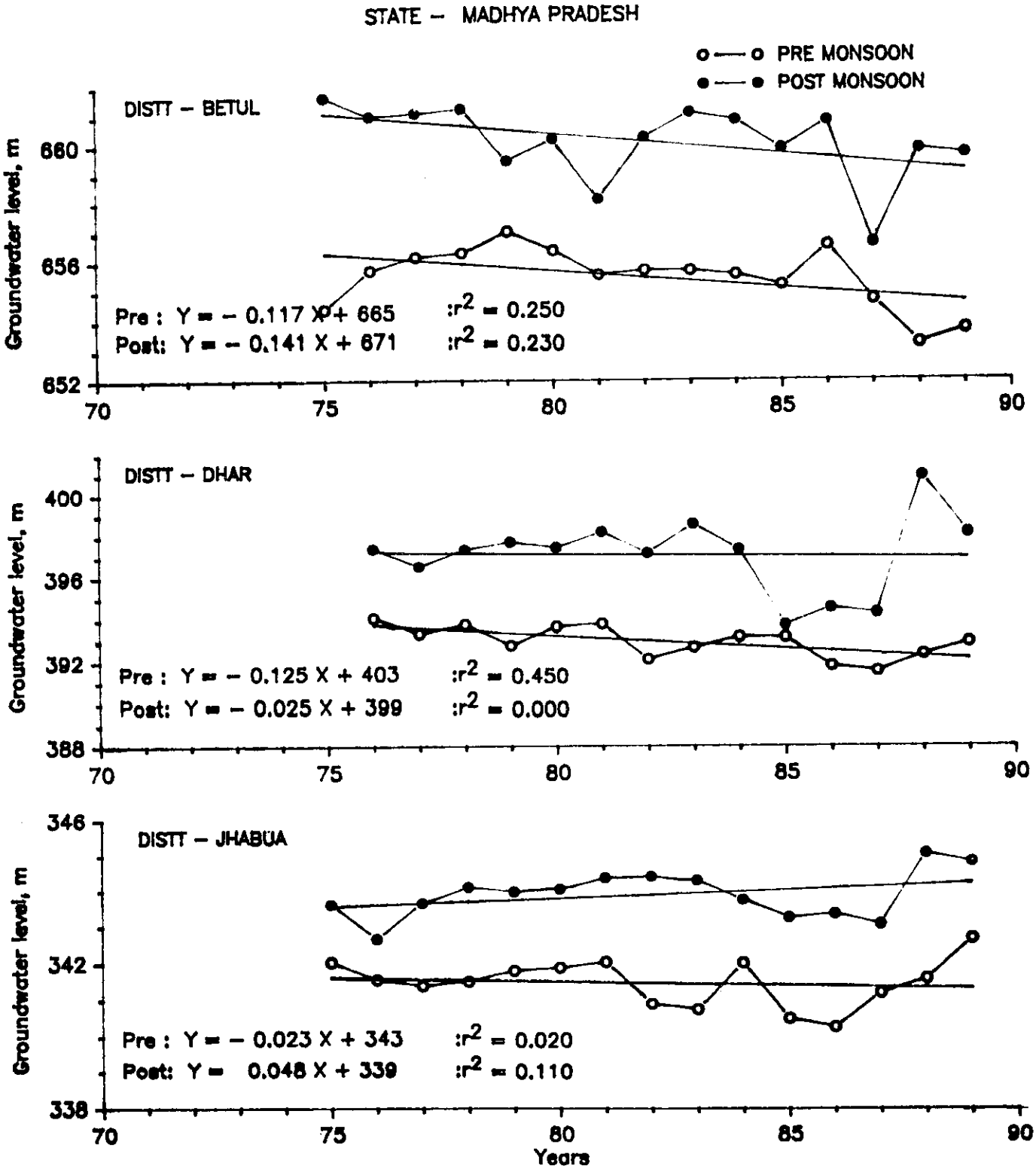
As can be seen from the table that about 3 to 14 wells evenly distributed over the district were chosen for the analysis keeping in view data availability constraints. The location of the wells on the district map have already been shown in the figures presented in chapter 2. The ground water level analysis for the five district namely Jhabua, khargone, Dhar, Betul and Shahdol was attempted with help of pre and post monsoon ground water level data collected from State Groundwater Board of Madhya Pradesh. Appendix III gives the details of various observation wells spread over districts of Jhabua, Khargone, Dhar, Betul and Shahdol along with their latitude and longitude.

The analysis has been carried out for groundwater level data from 1975-89.

The water levels in the wells have been calculated with respect to mean sea level and for each district average groundwater level has been calculated using Thiessen Polygon Method. The Thiessen weight of all the wells considered in each district was established and groundwater level calculated with respect to mean sea level multiplied by Thiessen weight gave average groundwater level for the district. Based on the values of water levels in wells, computed with respect to MSL, average groundwater level for the district was obtained. The values so obtained were plotted against each year to derive trend in groundwater fluctuation. The trend was established for two periods namely, premonsoon and post monsoon. A simple regression line has been fitted to show the trend of water levels. As has already been mentioned that due to non-availability of data the effects caused due to over exploitation of ground water during drought periods could not be introduced in the study and it is presumed that decline in ground water level is caused solely due to failure of rainfall. Also a district has been taken as a unit for analysis groundwater levels. Ideally, a hydrogeological boundary will need to be established for such an analysis. However, it has been presumed that the district has no inflow or outflow of groundwater into & from its aquifer. Based on the

analysis, following inferences can be drawn.

The results of ground water level analysis based on water table fluctuation data of past 15 years have been presented in Figure 4.1. It is evident from the figure that the ground water levels for pre monsoon season shows a falling trend in Betul, Dhar, and Jhabua,. The pre monsoon ground water levels in Khargone and Shahdol district are indicating more or less stable trend. But the post monsoon ground water level records shows a falling trend in all the districts except Jhabua.



Flg.4 1:Groundwater level fluctuation for pre and post monsoon seasons.

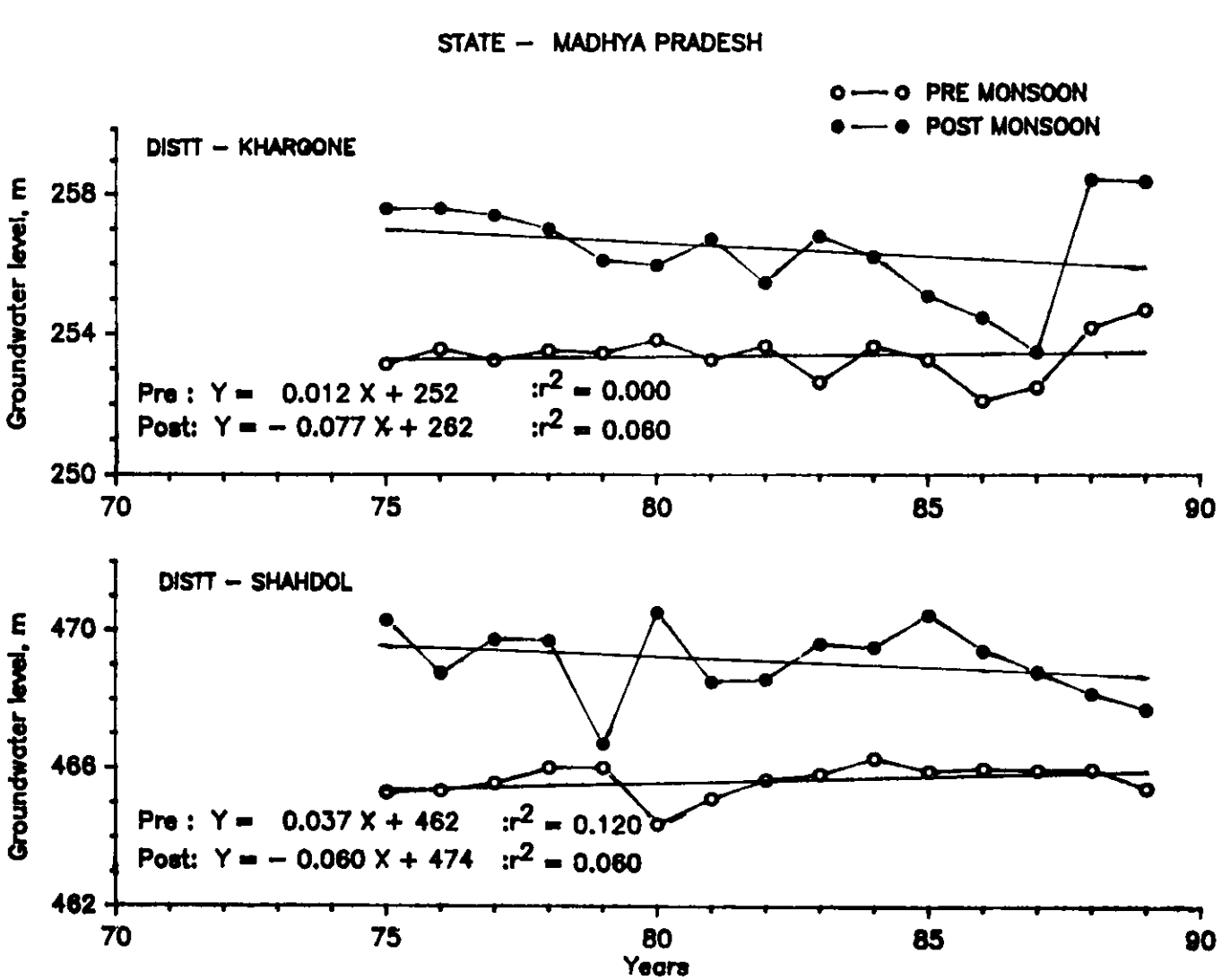


Fig.4·1:Groundwater level fluctuation for pre and post monsoon seasons.

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 levels for two selected reservoirs, i) Tawa, Narmada Basin and ii) Gandhisagar, Chambal Basin. For this purpose, the live storages and corresponding reservoir level in some selected months have been plotted against time and the relationship between live storage and reservoir levels is also shown for respective reservoirs. The weekly reservoir level data as supplied by Central Water Commission from 1985 till 1989 have been used for the analysis. As can be observed from fig. 5.1 that in Gandhisagar reservoir during May 1986 the live storage was recorded lower than that of May 1987 and also than that of previous years further the same was lowest in May 1988. On the other hand, live storages from August 1987 till August 1988 were continuously lower. The storages during October 1987 in Gandhisagar reservoir was lowest to that of October month in any other year. It was 55% to the previous year. In case of Tawa the live storage was lower in the month of May during all the years and the same was more or less equal in October during all the years of record.

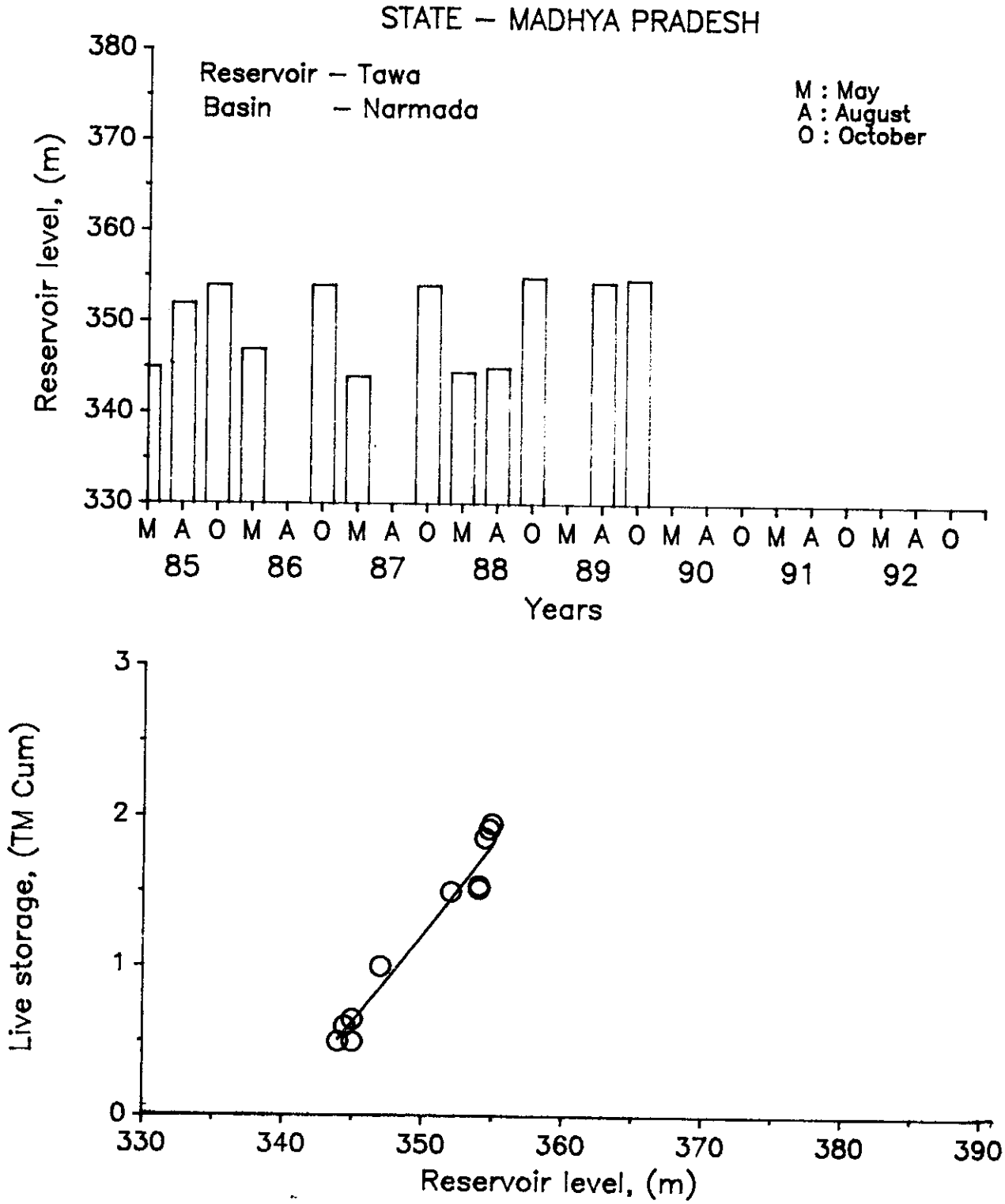


Fig.5·1: Reservoir level with time and the relationship between reservoir level and live storage.

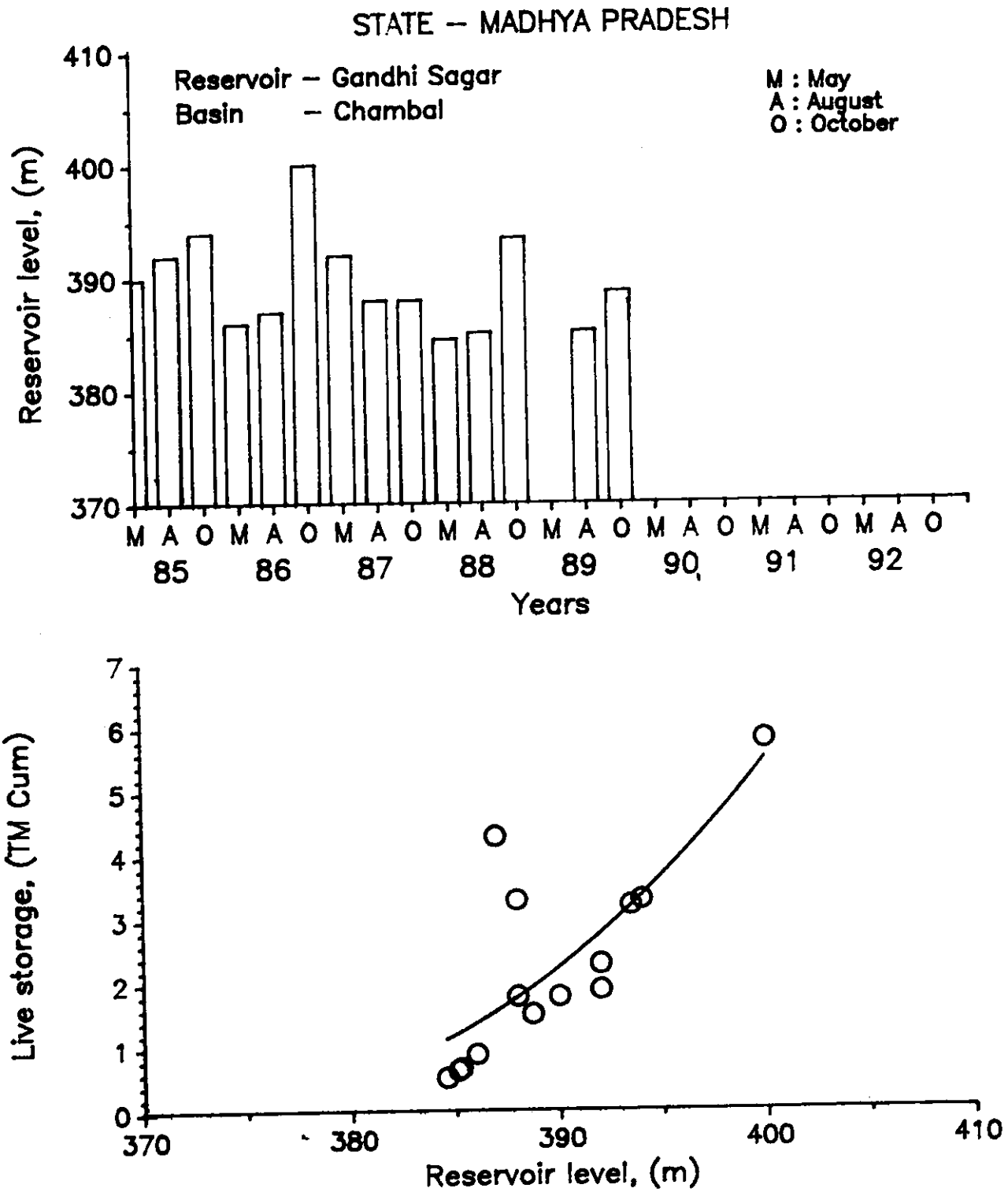


Fig.5·1: Reservoir level with time and the relationship between reservoir level and live storage.

6.0 SUMMARY & CONCLUSION

1. The report presents the analysis of monthly/daily and seasonal rainfall data for six selected districts in the state of Madhya Pradesh, with the objective to find deficiency in the rainfall (monthly and seasonal) in order to classify drought conditions. The data have been collected by undertaking field trips from various government organisations.

2. The analysis of rainfall data on seasonal basis (June - September) for these districts indicate that during 1988-89 the deficiency was in the order of 10-40%. However, in 1988 the departure from seasonal normal were positive in case of Betul and Jhabua.

3. The monthly departure for the water year 1988-89 in rainfall values were also worked out for all districts and the departure values were characterised in two ranges from 20-50% and more than 50%. The departure values indicated that Sidhi district received less rainfall during all the months. The recorded deficiency in monthly rainfall was in the order of 5-40%. It was further noticed that the monsoon rainfall was more or less good in all the district except Sidhi.

4. Analysis of probability of occurrence of annual rainfall at 75% level and occurrence of 75% of the normal rainfall for two taluks and district as a whole, at 75% probability level the district Jhabua, Khargone and Dhar fall in the group range of 700-800 mm rainfall, where as Sidhi and Shahdol can be grouped under 1000-11000 mm. In order to identify drought proneness of the district, the percentage probability of occurrence of the 75% of the rainfall was worked out based on the probability of analysis. The results indicated that the corresponding probability actual for the districts Jhabua, Khargone & Dhar are of the order of 79, 79, and 78% respectively. This indicates thereby that for more than 20 years in 100 years period, the rainfall would be less than 75% of the normal rainfall which further identifies drought proneness of these districts. The districts of Jhabua, Khargone & Dhar lie in the western part of the state, however, the districts Sidhi & Shahdol lie in the Eastern part of the state, which may be one of the reason for not showing similar results.

5. The analysis based on monthly rainfall data using Herbst Approach indicated that almost all six districts had more than two spells of drought during period 1985-89. However, the district of Sidhi showed a maximum number of dry spells while in general 4-6 spells of drought were experienced since 1981 in these districts. The maximum intensity of drought was found in case of Khargone district while the longest spell was experienced in Betul district, during analysis period.

6. The dry spell analysis was attempted to work out the dry spells likely to occur in the district at various probability levels it was found that at 75% level of probability duration of dry spell ranges from 21-28 days for all the six selected taluks of six selected districts of the state, except the selected taluks of Dhar and Sidhi districts. The results of these analysis

may be useful for planning cropping pattern for these districts.

7. As per the objectives of the study, the impacts of drought on ground water regime were evaluated by analysing the data of observation wells as obtained from various departments of the state. The average water table levels in all the five districts at pre and post monsoon stages were recorded and it was attempted to fit a straight line representing pre and post monsoon levels. The trend of the best fit line was observed and a falling line indicating decline in water table due to less recharge from the surface as a result of rainfall failure. The continuous decline in water table can be attributed to successive decline in rainfall over the years. It was observed that except Shahdol all districts have recorded lowest water table in post monsoon of 1987 and it has raised in later years. The regression lines of water table showed clearly decline trent in all the district except Jhabua and Shahdol.

8. The analysis has been carried out in the state of M.P. taking district as the boundary. It would be however useful to extent the study on basin scale as water shed has been well deficient of the size for carrying out such investigations. Some stream flow sites should also be chosen to highlight impacts of drought on stream flow regime.

REFERENCES

1. Central Water Commission (1982), 'Report on Identification of Drought Prone Areas for 99 districts', New Delhi.

2. Herbst, Ph, D.B. Bredenkamp and M.H.G. Barker (1966), 'A Technique for the evaluation of drought from Rainfall Data' Journal of Hydrology, 4, pp. 264-272.

3. 'Hydrological Aspects of Drought 1985-86',- A case study prepared by NIH (CS-21).

4. 'Hydrological Aspects of Drought 1985-86', A case study prepared by NIH (CS-24).

5. Institute of Hydrology, Wallingford, OXON, (1980) Research Report, Low Flow Studies.

6. Land use Statistics, 1987 Directorate of Economics & Statistics, M.P. Govt.

7. Land Record Statistics, 1987, Directorate of Economics & Statistics, M.P. Govt.

8. Linsley, R.K., Kohler, MAA and Paulhus, J.L.H., Hydrology for Engineers 1975,Second Edition McGraw Hill Publications.

9. McMohan T.A. and Arenas A.D. (1982) Method of Computation of Low Stream Flow, UNESCO, Paris.

10. Report on Groundwater in M.P., 1980, Irrigation Dept. M.P.

11. Sampath, T.V. (1989), 'Effect of Drought on Indian Agriculture' paper presented in International Symposium on Groundwater Resources Management in Drought Prone Areas 27 Nov. to 1 Dec. 1909, New Delhi.

12. Singh, R.D. (1987) Hydrological Aspects of Drought R.N. 37, National Institute of Hydrology.

13. Upadhyaya, D.S. & Gupta D.K. (1989), 'Droughts in India', - A historical review paper presented in International Symposium on Ground water Resources Management in Drought Prone Areas', 27 Nov. to 1 Dec. New Delhi.

14. Water Resources of India, Central Water Commission (CWC),1988.

APPENDIX -I

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

Alirajpur(Jhabua)

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
24.06.81	04.06.81	20	1
20.06.82	04.06.82	16	3
	21.06.82	22	
	25.08.82	16	
03.07.83	04.06.83	29	1
18.6.84	04.06.84	14	2
	21.08.84	26	
07.06.85	08.06 85	38	2
	07.08.85	40	
06.06.86	no dry spell		
17.06.87	18.07.87	19	2
	02.09.87	14	

BARWANI(KHARGONE)

1	2	3	4
24.6.81	4.6.81	20	2
	21.7.81	16	
20.6.82	4.6.82	16	3
	21.6.82	20	
	17.8.82	24	
16.6.83	31.8.83	15	1
15.6.84	16.6.84	15	1
24.6.85	4.6.85	20	4
	27.6.85	20	
	18.8.85	14	
	30.8.85	17	
15.6.86	26.6.86	22	2
	17.8.86	30	
16.6.87	18.6.87	21	3
	16.7.87	14*	
	2.9.87		

GOPADBANAS (SIDHI)

1	2	3	4
6.6.81	7.6.81	16	1
5.6.82	-	-	nil
13.6.83	-	-	-
11.6.84	-	-	-
12.6.85	13.6.85	14	1
21.6.86	4.6.86	17	1
29.6.87	4.6.87	25	2
	14.7.87	15	
2.6.88	3.6.88	17	1

DHAR (DHAR)

1	2	3	4
24.6.81	4.6.81	20	2
	18.8.81	15	
16.6.82	23.6.82	16	2
	24.8.82	23	
16.6.83	-	-	-
9.6.84	15.6.84	14	1
6.6.85	8.6.85	19	3
	28.6.85	20	
	17.8.85	27	
16.6.86	29.8.86	18	1
15.7.87	9.7.87	28	2
	1.9.87	15	
16.6.88	-	-	NIL

BETUL (BETUL)

1	2	3	4
21.6.81	4.6.81	17	2
	17.8.81	16	
5.6.82	1.7.82	31	1
12.6.83	-	-	-
7.6.84	12.6.84	19	1
6.6.85	-	-	-
19.6.86	4.6.85	15	2
	19.6.86	18	
16.6.87	14.7.87	15	1
4.6.88	5.6.88	14	2
	6.7.88		

SOHAGPUR (SHAHDOL)

1	2	3	4
1981	- Data Not available		
14.6.82	No Dry Spell		
9.6.83	do		
5.6.84	do		
26.6.85	4.6.85	22	1
20.6.86	4.6.86	16	2
	22.8.86	20	
26.6.87	4.6.87	22	1

Probability Analysis of Dry Spells.

Taluk (Dist.)	Class Interval (days)	No. of Spells	Percentage	Cumulative Probability
Alirajpur (Jhabua)	14-21	6	54.5	100.0
	22-28	2	18.2	95.5
	29-35	1	9.1	27.3
	> 35	2	18.1	18.2
		11		
Barwani (Khargone)	14-21	13	81.3	100.0
	22-28	2	12.5	18.8
	29-35	1	6.3	6.3
	> 35	-	-	-
		16		
Dhar (Dhar)	14-21	8	72.7	100.0
	22-28	3	27.3	27.3
	29-35	-	-	-
	> 35	-	-	-
		11		
Gopad Banas (Sidhi)	14-21	5	83.0	100.0
	22-28	1	16.6	16.6
	29-35	-	-	-
	> 35	-	-	-
		6		
Betul (Betul)	14-21	7	77.7	100.0
	22-28	-	-	33.3
	29-35	1	11.1	22.2
	> 35	1	11.1	11.1
		9		
Sohagpur (Shahdol)	14-21	2	50.0	100.0
	22-28	2	50.0	50.0
	29-35	-	-	-
	> 35	-	-	-
		4		

LIST OF OBSERVATION WELLS

STATE - MADHYA PRADESH
DISTT - JHABUA

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.		KATHIWADA	22 30 00	74 12 00	220.390	613.00	0.904
2.		UDAIGARH	22 32 00	74 35 00	402.980	603.00	0.0978
3.		KATHIWAD	22 08 00	74 16 00	322.170	1133.00	0.1671
4.		DUNGRIPADA	22 03 00	74 22 00	284.165	246.00	0.0363
5.		ALIRAJPUR	22 18 00	74 22 00	279.230	621.00	0.0916
6.		RANAPUR	22 40 00	74 33 00	351.735	874.00	0.1289
7.		NANPUR	22 17 00	74 33 00	250.705	425.00	0.0627
8.		BHAMEL	23 08 00	74 41 00	395.745	279.00	0.0411
9.		THANDLA	23 02 00	74 35 00	398.180	589.00	0.0868
10.		RALIYAWAN	22 58 00	74 47 00	398.690	819.00	0.1208
11.		UMARKOT	22 44 00	74 49 00	496.355	519.00	0.0765

STATE - MADHYA PRADESH
DISTT. - KHARGONE

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.		BHASANER	21 44 00	75 31 00	267.250	1507	0.1117
2.		BISTAN	21 43 00	75 43 00	309.410	1317	0.0976
3.		BALKAWADA	22 00 00	75 32 00	216.930	928	0.0688
4.		SEGAON	21 51 00	75 21 00	270.360	661	0.0490
5.		SENDHWA	21 14 00	75 03 00	397.675	1314	0.0974
6.		KHETIYA	21 40 00	75 36 00	199.940	851	0.0631
7.		RAJPUR	21 56 00	75 08 00	234.900	611	0.0453
8.		BARWANI	22 02 00	74 52 00	179.095	924	0.0685
9.		DAWANA	21 05 00	75 19 00	162.670	517	0.0383
10.		BHIKANGAON	21 52 00	75 58 00	276.515	905	0.0671
11.		ZIRMA	21 39 00	75 59 30	363.150	1435	0.1101
12.		BARWAHA	22 15 00	76 04 00	188.680	1075	0.0797
13.		BARWAHA	22 24 00	75 53 00	240.285	642	0.0476
14.		MAHESHWAR	22 13 00	75 35 00	156.675	753	0.0558

STATE - MADHYA PRADESH
DISTT - DHAR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.		BADNAWAR			550.350	1098	0.1340
2.		SARDARPUR			530.000	1480	0.1806
3.		KUKSHI			195.310	1464	0.1786
4.		MANAWAR			195.340	1859	0.2268
5.		DHAR			557.350	2295	0.2800

STATE - MADHYA PRADESH
DISTT. - SHAHDOL

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	18	KHAIRAHA	23 08 00	81 26 00	504.011		0.2124
2.	25	JAISINGHNAGAR	23 41 30	81 23 30	503.018		0.1327
3.	32	BUDAWA	24 13 00	81 24 45	306.825		0.0973
4.	34	JUMUNIHA	23 17 45	81 47 30	522.271		0.1947
5.	40	BANDHAWABARA	23 18 00	81 14 30	471.277		0.0885
6.	43	SASTARA	23 24 00	80 58 15	450.703		0.1416
7.	49	TALA	23 43 00	81 02 00	472.329		0.1328

STATE - MADHYA PRADESH
DISTT - BETUL

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.PT.(Mts)	AREA INFLUENCED BY WELL(Sq.Km.)	AREA WEIGHT
1.	42	MULTAI			757.360		0.2525
2.	4	BHAINEDEHI			524.45		0.3267
3.	25	BETUL			047.345		0.420

LIST OF OFFICES AND PLACES FROM WHERE DATA AND INFORMATION WERE COLLECTED IN STATE MADHYA PRADESH

Bhopal	Engineer in Chief, Irrigation Department
	Director (D&H) Bodhi, Central Design Organisation
	Chief Engineer, State Ground Water Survey Board
	Dy. Commissioner, Rural Development Commission
	Additional Director, Department of Agriculture
	Dy. Director Statistics, Department of Agriculture
	Chief Engineer, Public Health Engineering, Satpura
	Regional Meteorological Centre of IMD
	SE/EXN/AE, Narmada Tapti Basin, Irrig. Dept. Bhopal
	S.E., Narmada Control Authority
	Regional Director, Centrals Ground Water Board
Dhar	District Collector
Jhabua	District Statistical Officer
Betul	Supt. Land Records
Shahdol	
Sidhi	Superintending Engineer (Irrigation Circle)
	Deputy Director, Agriculture
	Assistant Geo-Hydrologist
	Executive Engineer, Public Health Engg. Division

DIRECTOR : DR. S. M. SETH

HEAD OF DIVISION : K.S.RAMASASTRI
Scientist 'F'

STUDY GROUP

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3. YATVEER SINGH, S.R.A.