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HYDROLOGICAL ASPECTS OF DROUGHT UP TO 1991 - A CASE STUDY IN KARNATAKA

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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 Karnataka state. These districts are Belgaum, Bijapur, Gulburga, Raichur, Bellary and Dharwar.

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.

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ABSTRACT

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

In view of the severity of drought problem and inadequate understanding of the hydrological aspects associated with droughts, the National Institute of Hydrology started studies in the year 1986 for gaining a better understanding of the drought impact from hydrologic point of view. In this direction, the Institute started collection, from field organizations, of data concerning rainfall and groundwater in selected areas, covering the period 1951 to 1991. Six states of Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Madhya Pradesh & Rajasthan were selected for the study. This report covers the analysis of rainfall, groundwater, & reservoir level data in respect of six selected districts Bijapur, Belgaum, Gulburga, Raichur, Bellary and Dharwar of Karnataka for the assessment of drought impact.

1.0 INTRODUCTION

1.1 General

In spite of all the inconveniences and hardship that droughts cause 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.). One of the most important factors in understanding drought, often not included in the definitions, is that it is a "supply and demand" phenomenon. A definition of drought which does not have a reference to the water requirements or demand can be regarded as inadequate. In general terms, the chief characteristics of drought are 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 is prone to droughts. 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 that of the 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) reported that during 1987, 21 meteorological subdivisions out of the 35, recorded deficient/scanty rains leading to drought conditions. It has been further reported that these subdivisions 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 shows the dependability of agricultural activities on rainfall.

The incidence of drought leads to reduction in stream flows, depletion of soil moisture storages, decline of reservoir and tank levels and fall in water-table. This in turn leads to reduced agricultural and fodder production. The drought characteristics and the associated problems vary from area to area, depending upon the extent of variability of the available water supplies and the demand of water for specified uses.

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 therefore, initiated studies in 1985, duly laying emphasis on the Hydrological Aspects of Droughts. Keeping in view the three successive drought years of 1985, 1986 and 1987 in major part of the drought prone areas of the country, study areas were chosen in six states viz., Andhra Pradesh, Maharashtra, Karnataka, Rajasthan,* Gujarat and Madhya Pradesh. Studies laying focus on hydrological aspects of drought for 1985-86 in two districts in each of the chosen states and for 1986-87 in four districts were completed. The studies for year 1987-88; 1988-89 and 1991-92 have been carried out in six districts in each of the above six states.

This report presents results of studies carried out for six districts of Karnataka for 1991-92. The districts included for the study are Belgaum, Bijapur, Gulburga, Raichur, Bellary and Dharwar. The report includes analysis of rainfall and groundwater level data for finding the impact of deficit in rainfall and its consequent effects on groundwater levels. In order to evaluate the impact on surface water storages, the storage figures in Tungbhadra reservoir and Ghatprabha reservoir located in the state, have been included in the report. The report is an attempt towards developing comprehensive hydrological drought indices for characterizing drought situations. List of offices and places from where data and information have been collected are reported in Appendix-II.

2.0 DESCRIPTION OF STUDY AREA

2.1 General

There are 99 districts spread over 13 states which have been identified as drought prone districts in the country as shown in Fig. 2.1. This report covers the study of six selected drought prone districts of Karnataka viz., Bijapur, Belgaum, Gulburga, Raichur, Bellary and Dharwar. The location of districts is shown on the state map (Fig. 2.2). The physiographic divisions into which the state can be divided are coastal plains, Western Ghats and the Karnataka Plateau. Karnataka State extends over an area of 1.92 lakh sq. km. which is about 5.84 percent of the total geographical area of the country. Karnataka state lies between 74° -78° 30'E longitude and 10° 58'-18° 30' N latitude in the peninsular India. In terms of area, it holds 8th place among the states of the country.

2.2 Population

The population of the state, according to 1991 census, is 448.07 lakhs, comprising 228.42 lakhs of males and 219.60 lakhs of females. Of the total population, 309.56 lakhs live in the villages and the rest, comprising 138.51 lakhs, live in the urban towns and cities. Out of the total population of the state, as many as 149.44 lakhs are workers. Out of working force, around 60 percent are engaged in agricultural occupation. The growth rate of population annually and the population are given in Table 2.1.

Table 2.1 : Details of population growth.

Sl. No.	Year of census	State's total population (million)	Approx. rural population (million)	Av.annual growth rate (%)
1.	1951	19.40	14.95	1,93
2.	1961	23.59	18.32	2.16
3.	1971	29.30	22.18	2.42
4.	1981	37.13	26.40	2.67
5.	1991	44.80	30.95	1.92

Source: Directorate of Economics and Statistics, Bangalore,1984.

2.3 Land Use & Vegetal Cover

The status of land utilization over 25 years span of development from the year of formation of enlarged Karnataka in 1956-57 and the year 1981-82 is presented in Table 2.2. From the Table 2.2 it can be seen that the percentage of net area sown moved up by hardly one percent from the level of 54 percent of the corresponding geographical area in 1981-82 after 25 years of development. This situation can be attributed to the impact of the vagaries of monsoon as large extents of state are cultivated under rain fed condition in the state.

2.4 Soils

More than three-fourth of the area in the state is covered by the most ancient crystalline schists and granite rocks

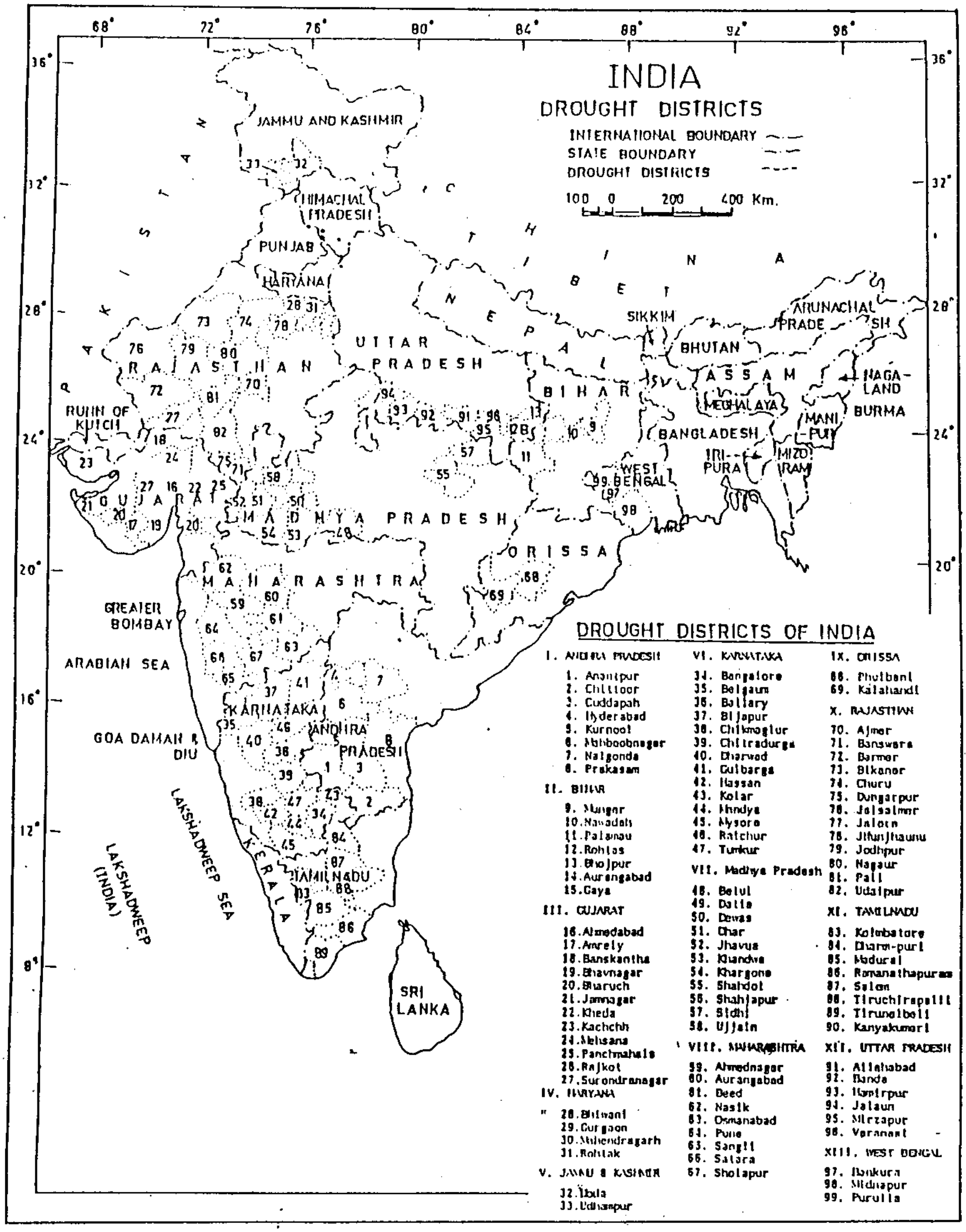


Fig. 2.1 DROUGHT PRONE DISTRICTS IN INDIA

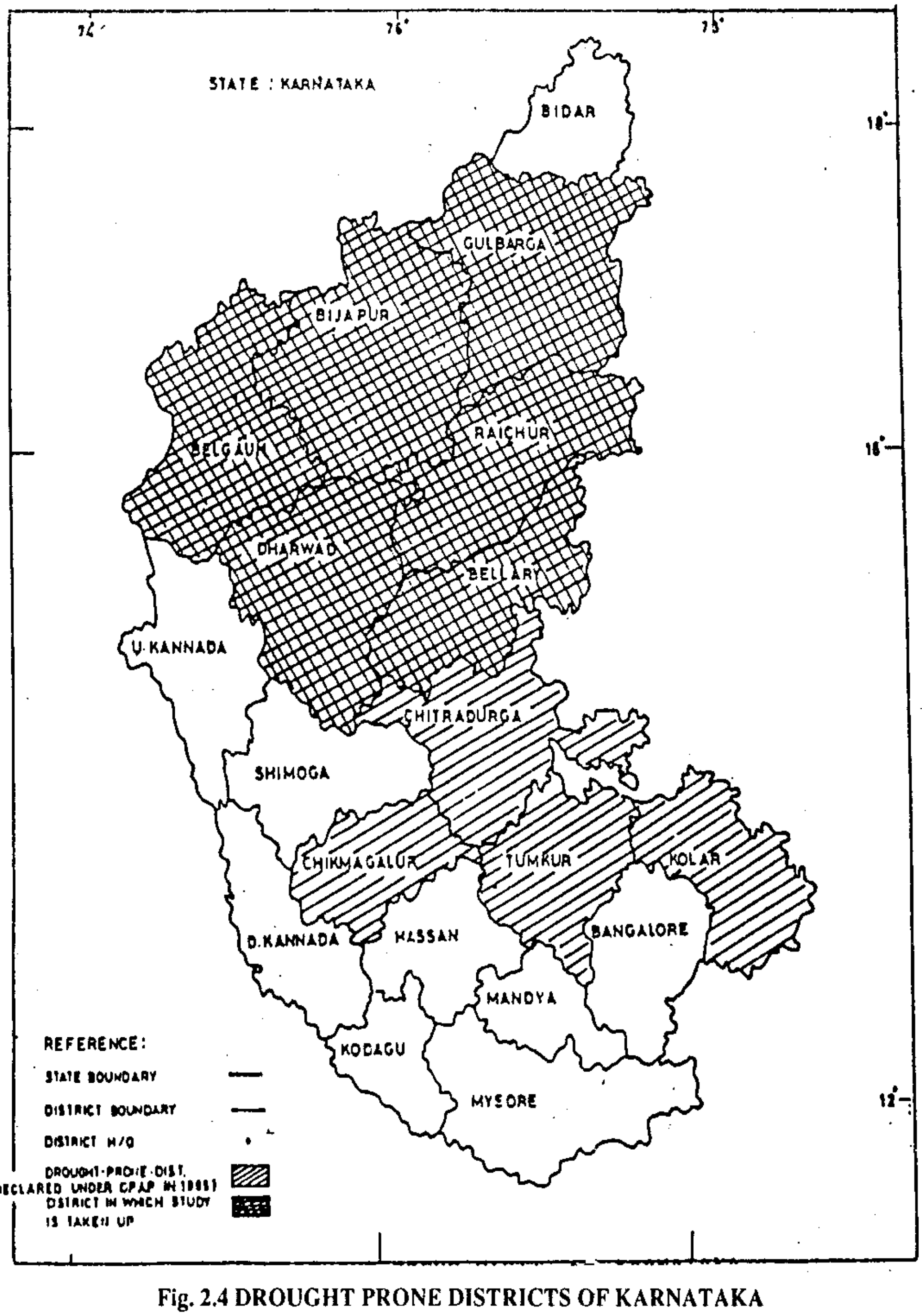


Fig. 2.4 DROUGHT PRONE DISTRICTS OF KARNATAKA

of Archean system. At present, 8 important rock formations are recognised in the state which give rise to different soils. Mainly six broad soil groups have been identified and details of their distribution in the state are shown in Fig. 2.3.

These soil groups are :

(A) Black Soils
  i) Shallow black soils
  ii) Medium black soils
  iii) Deep black soils
(B) Red Soils
(C) Red Loamy Soils
(D) Mixed Red and Black Soils
(E) Laterite Soils
(F) Coastal Alluvials
(G) Dark Brown Clayey Soils

2.5 Surface Water Availability

The average annual flow of all the river systems in India is of the order of 1,700,000 M.cum. Karnataka shares around 6 percent of the water resources of India through the several river systems that drain the state. The average annual flow in the state is estimated to be of the order of 97,800 or around 1,00,000 M.cum. Out of this, about 60 percent or 60,000 M.cum., is available in the East flowing rivers and the remaining 40 percent or 40,000 M.cum. is drained into Arabian Sea, from the narrow coastal belt through the west flowing rivers. This available water resource is amenable for utilization as a source of irrigation (consumptive) and as a source of hydropower development (non-consumptive).

Table 2.2 : Comparative status of land utilization in Karnataka.

Sl. No.	Land use particulars	1956-57		1981-82		1989-90	
		Area (in lakh hectares)	%age of geographical area	Area (in lakh hectares)	%age of geographical area	Area (in lakh hectares)	%age of geographical area
1.	Forest	26.9	14	30.3	16	30.74	16.2
2.	Land not available for cultivation	16.7	10	19.3	10	19.82	10.2
3.	Other uncultivated land (excluding fallows)	28.6	15	21.4	11	18.64	9.5
4.	Fallow land	13.8	7	15.6	8	14.22	7.3
5.	Net area sown	100.8	54	103.9	55	107.98	56.7
6.	Geographical area (by village papers)	186.8	100	190.5	100	190.5	100

Source: Directorate of Economics & Statistics, Bangalore, 1984, 1990-91.

The river flows that are available as water resources and that can be put to use on a dependable basis in the different

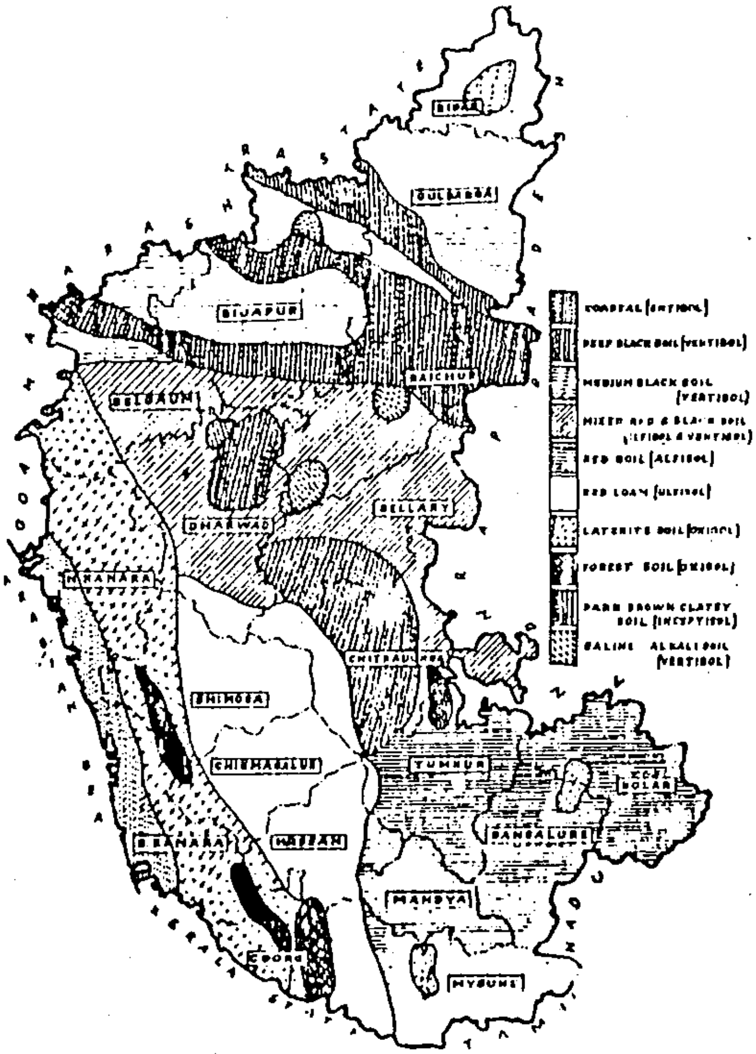


Fig 2.3 Soils of Karnataka

(Source : Soils of India & Their Management, 1985) river systems of the state through projects have been presented in Table 2.3. It may be seen from the estimates worked out in the Table 2.3 that only around 70 percent of the surface water resources available through the flow of the different river systems in the state is utilisable on a dependable basis leaving the balance of 40 percent not amenable for utilization and allowed to flow as runoff. However, above river systems are interstate systems and the extent of utilisation in Karnataka state is governed by the allocations.

Table 2.3 : Utilisable water resources in Karnataka.

S.No.	Water Resources	Estimated Average flow in M.cum.	Estimated Utilisable Water Resources through Projects (approximate)
1.	Krishna System	27,500	26,800
2.	Godavari System	1,400	560
3.	The Cauvery System	11,000	11,000
4.	The West Flowing Rivers	57,000	22,000
5.	The Palar North Pennar and South Pennar	900	900
6.	Total Water Resources Available	97,800	61,260

Source: Water Resources & Development Organisation, Bangalore.

2.6 Ground Water Availability

Ground water in the state occurs, under water-table conditions in the hard rock aquifers of the state. The state with an average elevation of 700 m above the mean sea level, is almost wholly composed of metamorphic hard, compact and crystalline rocks which are weathered and decomposed near surface due to continuous exposure to action of rain and water and have become sufficiently porous to hold moderate quantities of groundwater. But, due to greater part of the state being arid with an average annual rainfall below 750 mm, the occurrence and distribution of groundwater in the state is limited.

Groundwater get annually recharged mainly as a result of infiltration of rain water and to a limited extent through seepage from the surface water sources like streams, tanks, reservoirs and applied irrigation. The fluctuation in the water-table experienced during the dry seasons indicates good recharge potential of groundwater in metamorphic rocks of the state.

Studies carried out by state groundwater cell have estimated the district-wise groundwater recharge through infiltration of rainfall, and extent of utilization. Table 2.4 gives the district-wise estimates of groundwater potential & utilization. As per estimates worked out, the overall utilization of the groundwater of the state is hardly 25 percent or one fourth of its availability.

2.7 Water Use

The annual water requirements of the state for domestic and live stock purposes during 1981 was of the order of 0.0868 M.ha.m. which has been estimated to increase to a level of

0.1365 M.ha.m. by the year 1991 (CWC, 1988). The details of water availability and water requirements for drought prone districts of Karnataka are given in Table 2.5.

2.8 Crops and Fodder

Due to large scale variations in topography, climate, soils, vegetation and crops, rainfall etc., the state has been divided into 10 agroclimate zones as shown in Fig. 2.4. It may be seen from the figure that in as many as 10 districts more than one agroclimatic characteristics as per the criteria is noticed. The cropping pattern of the state Karnataka is shown in Table 2.6. Also the major crops grown in different agroclimatic zones regions, districts and soils have been detailed in Table 2.7.

The status of irrigation in the state according to the different sources is presented in the Table 2.8.

2.9 Districts Selected for Study

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

2.9.1 Belgaum

Belgaum district is situated in the northern part of Karnataka state. Its geographical location is between 15° 22' N and 16° 58' N latitude and 74° 2' E and 75° 25' E longitude.

It has a geographical area of 13460.8 sq.km. The district consists of ten taluks. The district has 1158 inhabited villages, 6 uninhabited villages and 19 towns. The population of the district is found to be 2974861 and the density of the population is found to be 221 persons per sq.km. as per 1981 census data. The soils of the district are generally of five types viz., Medium black, Deep black, mixed black and red soil, Red loamy soil and Laterite soil. The land use in the district is, forests in 191095 ha, barren and uncultivable lands 47117 ha, land put to nonagricultural uses 50841 ha and culturable area, 1027281 ha. as per data from 1971-72 to 1979-80. The total irrigated area in the district is 127932 ha. The main river flowing through Belgaum district is Krishna. As per CWC studies of 1982, the normal annual rainfall of the district is 813.74 mm. Normally there are 52.75 rainy days in a year according to the data analysis for 1901-1980. There are 36 raingauge stations located in the District and density of raingauge stations is 373.91 sq.km. per raingauge station as per data of year 1982. The maximum annual rainfall in the district is reported as 1220.36 mm in 1914. The south west monsoon gives about 67.38% of annual rainfall in the district. The coefficient of variation for annual rainfall has been estimated to be 24.31% for the district. As per C.G.W.B. data, the utilisable of ground water resources are of the order of 718.74 M.cum. while the draft is 302.9 m.cum. and balance potential is 416.84 m.cum. The district faced 8 hydrological drought years during the period 1951 to 1980 according to CWC (1982) observation. The map of the district showing location of raingauges and groundwater observation wells which have been choosen for analysis is shown in Fig. 2.5.

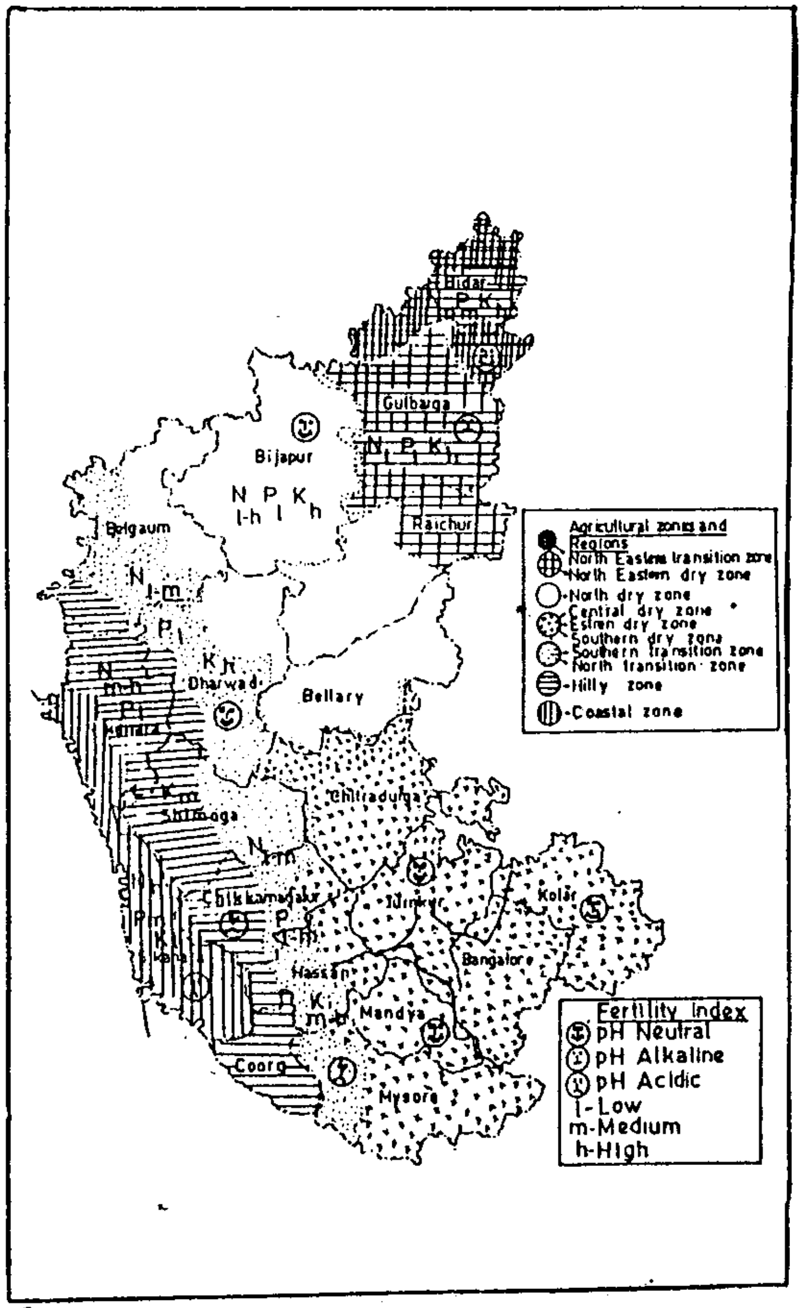


Fig 2.4Agricultural zones of Karnataka

(Source : Soil of India & Their Management, 1985)

Table 2.4 : Districtwise ground water potential and utilisation in Karnataka

Sl. No.	District	Normal rain-fall (in mm)	Infiltration (in percent)	Recharge (in cu. mm).	Discharge (in cu. mm)	Available potential (in cu. mm)	Percentage of utilisation
1	2	3	4	5	6	7	8
1.	Bangalore	793.6	8	509	262	247	51
2.	Belgaum	784.7	7	740	300	440	41
3.	Bellary	574.9	8	439	61	378	14
4.	Bidar	907.5	10	495	175	320	35
5.	Bijapur	552.8	6	568	281	287	49
6.	Chikmagalur	1989.8	4.5	637	17	620	3
7.	Chitradurga	579.3	8	500	162	338	32
8.	Dakshina Kannada	3932.4	3	1073	251	822	23
9.	Dharwad	691.1	8	751	95	656	13
10.	Gulbarga	702.3	8	905	94	811	10
11.	Hassan	1040.7	7.5	512	17	495	3
12.	Kodagu	2725.5	3	336	3	333	0.9
13.	Kolar	730.5	8	432	302	130	70
14.	Mandya	691.2	8	275	242	233	15
15.	Mysore	761.9	8	680	70	610	10
16.	Raichur	601.6	8	671	120	551	18
17.	Shimoga	1520.3	3	476	30	446	6
18.	Tumkur	687.9	8	584	351	233	60
19.	Uttara Kannada	2764.1	3	843	108	735	13
	Karnataka	1354.7		11,426	2,941	8,685	24.57

Source: Department of Mines and Geology, Groundwater Cell, Bangalore.

Table 2.5 : Water availability and water requirements for drought prone districts of Karnataka.

Sl. No.	District	Water Availability 50% dependability	75% dependability	Total Requirements
1	2	3	4	5
1.	Bangalore	1.87	1.38	1.27
2.	Belgaum	4.00	3.28	2.86
3.	Bellary	2.39	2.04	1.78
4.	Bijapur	5.38	4.85	4.54
5.	Chikmagalur	3.48	2.65	1.98
6.	Chitradurga	2.21	2.01	1.78
7.	Dharwad	4.03	3.78	1.63
8.	Gulburga	6.36	5.40	3.28
9.	Hassan	1.83	1.47	1.20
10.	Kolar	0.98	0.86	0.89
11.	Mandya	2.92	2.76	2.57
12.	Mysore	3.33	3.03	3.19
13.	Raichur	5.93	5.21	4.88
14.	Tumkur	2.54	1.98	1.87

Source: Water Resources of India, CWC, 1988.

Table 2.6 : Status of cropping pattern in Karnataka.

Sl. No.	Crops	1956-57		1981-82		1989-90	
		Area (in lakh) hectares	Percentage to total cropped area	Area (in lakh) hectares	Percentage to total cropped area	Area (in lakh) hectares	Percentage to total cropped area
1	2	3	4	5	6	7	8
A.	FOOD CROPS						
I	Cereals						
1.	Paddy	9.2	9	11.7	10	11.6	9.8
2.	Jowar	25.0	25	21.1	19	21.5	18.2
3.	Ragi	8.8	8	11.5	10	10.5	8.2
4.	Maize	0.1	Neg	1.6	1	-	-
5.	Bajra	5.3	5	6.4	6	4.2	3.6
6.	Wheat	3.1	3	3.3	3	1.9	1.6
7.	Other Cereals	4.8	5	3.8	4	4.0	3.4
	Total	57.1	55	59.4	53	53.99	45.5
II	Pulses						
8.	Bengalgram	1.6	1	1.4	1	2.2	1.9
9.	Tur	2.9	3	3.7	4	4.6	3.9
10.	Other pulses	8.3	8	10.4	9	7.9	6.6
	Total Pulses	12.8	12	15.5	14	14.83	12.5
	Total food grains	69.9	67	74.9	67	68.82	58.0
11.	Other food crops	3.9	4	6.5	6	31.98	26.9
	Total food crops	73.8	71	81.4	73	100.8	84.9
B	NON FOOD CROPS						
III	Oil seeds						
12.	Groundnut	9.4	9	8.6	8	11.8	10.0
13.	Sesamum	0.6	2	1.1	1	-	-
14.	Other oil seeds	4.0	4	5.8	5	-	-
	Total oil seeds	14.0	14	15.5	14	11.86	10.0
15.	Cotton	11.8	11	10.4	9	5.9	5.0
16.	Other Fibres	0.4	Neg	0.3	Neg	-	-
17.	Other non crops	4.0	4	4.6	4	-	-
	Total non food crops	30.2	29	30.8	27	17.82	15.0
	Total of all Crops	104.0	100	112.2	100	118.62	100

Source: Directorate of Economics & statistics, Bangalore, 1984, 1990-91.

Table 2.7 : Major crops generally grown in different Agroclimatic zones, districts and soils.

Region	Zone	District	Traditional Nomenclature of soil	Major crops grown
I	1,2	Bidar, Gulbarga and parts of Raichur	Red soil, Laterite soil, Black soil	Sorghum,red gram,bengal gram,groundnut,saf-flower,niger,pearl millet,rice,cotton, sugarcane and chillies.
II	3	Bijapur,Bellary and parts of Raichur, Dharwad and Belgaum	Black soil,Red soil	Sorghum,pearl millet, groundnut,bengal gram, cotton,wheat and sunflower.
III	4,5,6	Chitradurga,Tumkur, Mandya,Bangalore, Kolar and parts of Hassan Chikma-galur and Mysore	Black soil,Red soil,Red Sandy soil,Laterite soil	Finger millet,pulses, sorghum(Kharif),rice, groundnut,sugarcane, cotton and millets
IV	7,8	Parts of Belgaum, Dharwad,Shimoga, Chikmagalur,Hassan and Mysore	Red soil,Red sandy soil, Laterite soil Black soil	Sorghum,finger millet, rice,oilseeds,pulses, cotton,wheat,tobacco, millets and aromatic plants
V	9	Coorg and parts of Hassan,Chikmagalur Shimoga,Uttara Kannada and Dharwad	Red soil, Red sandy soil, Laterite soil	Rice,plantation and horticultural crops
VI	10	Dakshina Kannada and parts of Uttara Kannada	Red soil Alluvial soil,Laterite soil	Rice,pulses,groundnut, plantation and horti-cultural crops

Source: Soils of India and Their Management, 1985.

Table 2.8 : Status of irrigation in Karnataka.

Sl. No.	Source of Irrigation	1901		1956-57		1981-82		1989-90	
		Area (lakh hecta-res)	Percent-age to total	Area (lakh hecta-res)	Percent-age to total	Area (lakh hecta-res)	Percent-age to total	Area (lakh hecta-res)	Percent-age to total
1	2	3	4	5	6	7	8	9	10
1.	Canals	0.56	11	1.65	22	5.80	40	8.41	43.0
2.	Tanks	2.6[illegible]	52	3.28	44	3.21	22	2.81	14.5
3.	Wells	0.60	12	1.29	18	4.01	27	5.1	26.7
4.	Other sources	1.28	25	1.18	16	1.68	11	2.9	15.4
Total of all sources		5.04	100	7:40	100	14.70	100	19.41	100

Source: Directorate of Economics & Statistics, Bangalore, 1984, 1990-91.

2.9.2 Bijapur

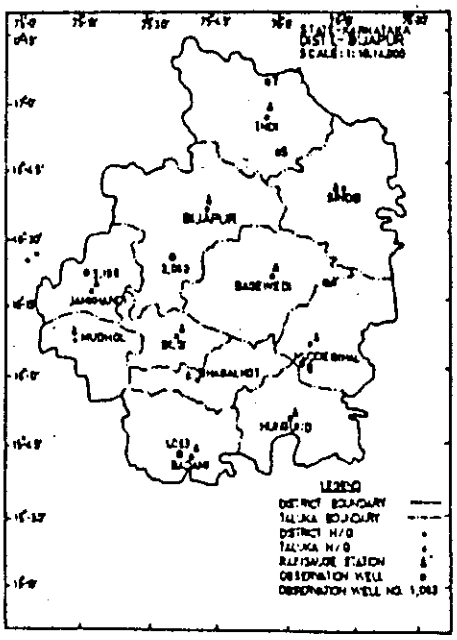
Bijapur district is located in the northern plains of Karnataka state. Geographically, it is located between 15° 20' N to 17° 28' N latitude and 74° 50' E to 76° 28' E longitude. The geographical area of the district is 17069 sq.km. The district consists of eleven talukas and has 1239 inhabited villages, 29 uninhabited villages and 17 towns. Population of the district is estimated to be 23,99,124 and the density of population is reported as 140 persons per sq.km. according to the data available for 1981. There are two types of soils generally found in the district viz., Black, Mixed red and black soils. The land use in the district as per data from 1971-72 to 1980-81 is forests in 831103 ha., barren and uncultivable lands 51344 ha, land put to nonagricultural uses 44881 ha and culturable area 1515921 ha. The total irrigated area in the district is 96410 ha with the source wise distribution of 35137 ha. by surface water and 61273 ha. by ground water. The main rivers flowing through Bijapur district are Krishna and Bhima. The catchment area of main Krishna river in the district is 8620 sq.km.

As per CWC studies of 1982, the normal annual rainfall of the district is 575.31 mm. Normally there are 44.06 rainy days in a year according to the data analysis from 1901 to 1980. There are 52 raingauge stations located in the district and density of raingauge stations is 328.71 sq.km. per raingauge station as per data of year 1982. The maximum annual rainfall in the district was measured as 1097.00 mm in 1916. The south west monsoon gives about 63.74% of annual rainfall in the district. The coefficient of variation for annual rainfall has been found to be 24.55% for the district. As per C.G.W.B. data, the utilisable groundwater resources are of the order of 360.46 m.cum. while the draft is 275.06 m.cum. and the balance potential is 113.30 m.cum. The district faced 13 hydrological droughts during the period 1951 to 1980 according to CWC (1982) observation. A map of the district showing location of raingauges and observation wells which have been choosen for analysis is shown in Fig. 2.5.

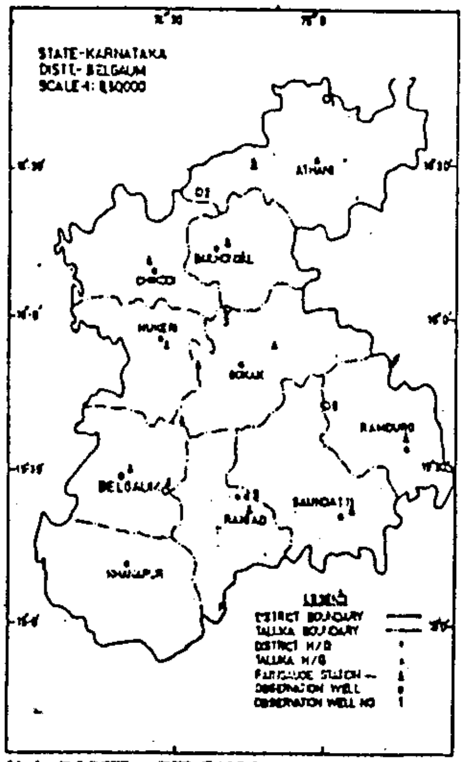
2.9.3 Gulburga

Gulburga district lies in the northern part of Karnataka state and the geographical location of the district is between 16° 12' to 17° 46' latitudes and 76° 04' to 77° 42' longitudes. The district has geographical area of 16167.8 sq.km. and this district is one of the drought affected districts of the state. The district consists of ten talukas and has 1305 inhabited villages, 82 uninhabited villages and 14 towns. The population of Gulburga district is 2075368 and density of population is 128 persons per sq.km. according data available for 1981.

It has been reported that generally the district has three types of soils viz. red soils, black soils and alluvial soils. The land use in the district as per data from 1970-71 to 1979-80 is forests in 70172 ha., land put to non agricultural uses 47538 ha., barren & unculturable land 75059 ha. and culturable area 1,362,577 ha. As per the data available from 1970-71 to 1979-80 the total irrigated area in the district is 26598 ha. with the source wise distribution of 10314 ha. by surface water and 16284 ha. by groundwater. The main rivers



(a) DISTT. BIJAPUR



(b) DISTT. BELGAUM

FIG. 2.5 : LOCATION OF RAINGAUGE STATION & OBSERVATION WELLS

that flow through Gulburga district include the Krishna and Bhima.

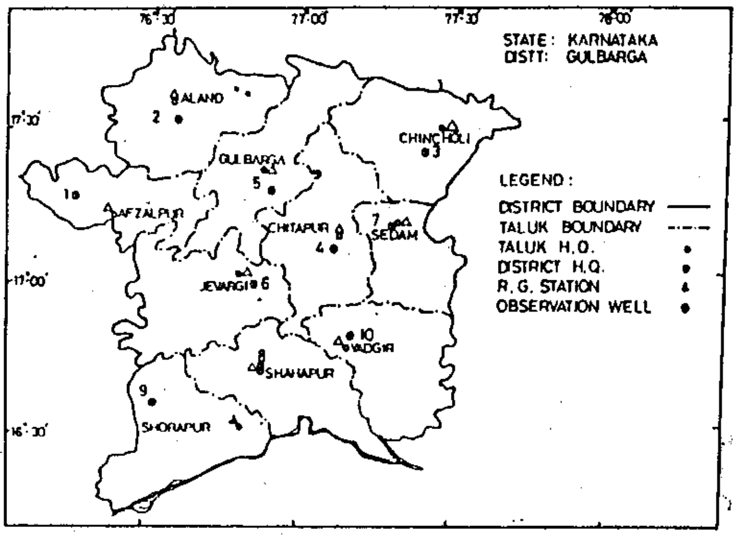
As per CWC studies of 1982, the normal annual rainfall of the district is 768.63 mm. Normally, there are 51.49 rainy days in a year according to analysis of data from 1901 to 1980. There are 53 raingauge stations located in the district and density of rain gauge stations is 305.05 sq.km./ per raingauge station as per data of year 1982. The maximum annual rainfall in the district was experienced as 1431.9 mm in year 1903. The south-west monsoon gives about 76.28% of annual rainfall in the district. The coefficient of variation for annual rainfall has been reported as 27.26% for the district. The utilisable groundwater resources of the district as per CGWB data are 1295.76 m.cum. while the draft is 183.60 m.cum. and the balance potential is 1112.16 m.cum. As per CWC (1982) observations, the district faced 12 hydrological droughts during the period 1951 to 1980. A map of the district showing location of raingauges and observation wells which have been selected for analysis is shown in Fig. 2.6.

2.9.4 Raichur

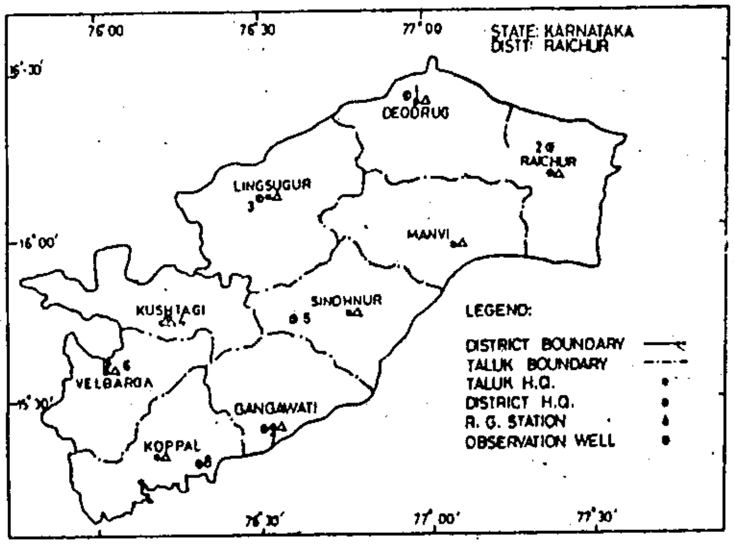
Raichur district is situated in the North Eastern fringe of Karnataka state. The geographical location of the district is between 15° 9' to 16° 34' N latitudes and 75° 46' E to 77° 35' E longitudes. The area of the district is 14005 sq.km. The district consists of nine talukas and has 1387 inhabited villages, 129 uninhabited villages and 10 towns. The population of Raichur district is 1779942 and density of population is 127 person per sq.km. as per 1981 census.

The soils in the district are generally of three types viz., black cotton, red, & grey sandy soils. The land use in the district as per data from 1970-71 to 1978-79 is, forests in 32424 ha., land put to non agricultural uses 51717 ha., barren & unculturable land 51385 ha., and culturable area 1213479 ha. The total irrigated area in the district is 153381 ha. with the source-wise distribution of 138894 ha. by surface water and 13793 ha. by ground water and 698 ha. by other sources. Krishna & Tungabhadra are the two main rivers flowing through Raichur district. The catchment areas of these rivers in the district are 4221 sq.km. for Krishna and 9617 sq.km. for Tungbhadra.

As per CWC studies of 1982, the normal annual rainfall of the district is 604.21 mm. Normally, there are 40.08 rainy days in a year according to analysis of data from 1901 to 1980. There are 43 raingauge stations located in the district and density of rain gauge stations is 325.70 sq.km. per raingauge station as per data of year 1982. The maximum annual rainfall in the district was 1224.02 mm in year 1916. The southwest monsoon gives about 69.66% of annual rainfall in the district. The coefficient of variation for annual rainfall has been reported as 25.90% for the district. The utilisable groundwater resources of the district, as per CGWB data are 296.05 m.cum. while the draft is 124.84 m.cum. and the balance potential is 176.84 m.cum. As per CWC (1982) observations, the district faced 14 hydrological droughts during the period 1951 to 1980. A map of the district showing location of raingauges and observation wells which have been chosen for analysis is shown in Fig. 2.6.



(a) DISTT. GULBARGA



(b) DISTT. RAICHUR

FIG. 2. 6 : LOCATION OF RAINGAUGE STATION & OBSERVATION WELLS

2.9.5 Bellary

Bellary district is situated in the North Eastern fringe of Karnataka state. Its geographical location is between 14° 30' to 15° 50' N latitudes and 75° 40' E to 77° 11' E longitudes. The geographical area of the district is 9898 sq.km. The district consists of eight talukas and has 589 inhabited villages, 34 uninhabited village and 12 towns. Population of the district is 1487062 and the density of population is calculated to be 150 persons per sq.km. as per data of 1981 census.

Three types of soils are generally found in the district. They are Red and Black soils, and mixed soils. The land use in the district as per data from 1976-77 to 1979-80 is, forests 117,416ha., barren and uncultivable lands 61554 ha, land put to non agricultural uses 79649 ha., and culturable area 690615 ha. The total irrigated area in the district is 97223 ha. with the sources wise distribution of 79395 ha. by canals, 6899 ha. by tanks, 10960 ha. by wells and 2969 ha. by other sources. The main river flowing through the district is Tungabhadra. The catchment area of the River Tungabhadra is 6780 sq.km.

As per CWC studies of 1982, the normal annual rainfall of the district is 629.45 mm. Normally there are 43.23 rainy days in a year according to analysis of data from 1901 to 1980. There are 36 raingauge stations located in the district and density of rain gauge stations is 274.94 sq.km. per raingauge station, as per data of year 1982. The maximum annual rainfall in the district was measured as 964.02 mm in year 1933. The normal rainfall in the southwest monsoon is 59.79% of the total annual rainfall. The coefficient of variation for annual rainfall has been found to be 21.62% for the district.

The utilisable groundwater resources of the district are 261.93 m.cum. while the draft is 81.93 m.cum. and balance potential is 182.09 m.cum., as per C.G.W.B data of 1982. The district faced 10 hydrological drought years during the period from 1951 to 1980 according the CWC (1982) observations. A map of the district showing the location of raingauges and observation wells which have been chosen for analysis is shown in Fig. 2.7.

2.9.6 Dharwad

Dharwad, a district of Karnataka, exists in the Northern plains of the state. The geographical location of the district is 14° 17' N to 15° 50' N latitudes and 75° 48' E to 76° 0' E longitudes. The geographical area of the district is 13,738 sq.km. The district consists of seventeen talukas and has 1337 inhabited villages, 112 uninhabited villages and 18 towns. Population of the district is reported to be 2939988 and the density of population is found to be 214 persons per sq.km., as per data available for 1981. Three types of soils are generally found in the district viz., Black, and Mixed Red & Black soils and Red sandy soils. The land use in the district as per data from 1971-72 to 1980-81 is, forests 111866 ha., barren and uncultivable lands 29909 ha, land put to non agricultural uses 27962 ha., and culturable area 1170465 ha. The total irrigated area in the district is 80300 ha. with the sources wise distribution of 69250 ha. by surface , water and 11050 ha. by groundwater. The main rivers flowing through Dharwad district is Krishna and Tungbhadra. The catchment areas of Tungabhadra river within the district is 3382 sq.km.

As per CWC studies of 1982, the normal annual rainfall of the district is 729.61 mm. and normally, there are 55.45 rainy days in a year according to the data analysis from 1901 to 1980. There are 66 raingauge stations located in the district and density of rain gauge stations is 208.15 sq.km. per raingauge station as per data of year 1982. The maximum annual rainfall in the district was reported as 996.29 mm in year 1979. The southwest monsoon contributes about 60.21% of normal annual rainfall in the district. The coefficient of variation for annual rainfall has been measured as 17.10% for the district.

As per C.G.W.B. data, the utilisable groundwater resources of the district 576.88 m.cum. while the draft is 101.71 m.cum. and balance is 485.18 m.cum. The district faced 10 hydrological droughts during the period from 1951 to 1980 according the CWC (1982) observations. A map of the district showing the location of raingauges and observation wells which have been chosen for analysis is shown in Fig. 2.7.

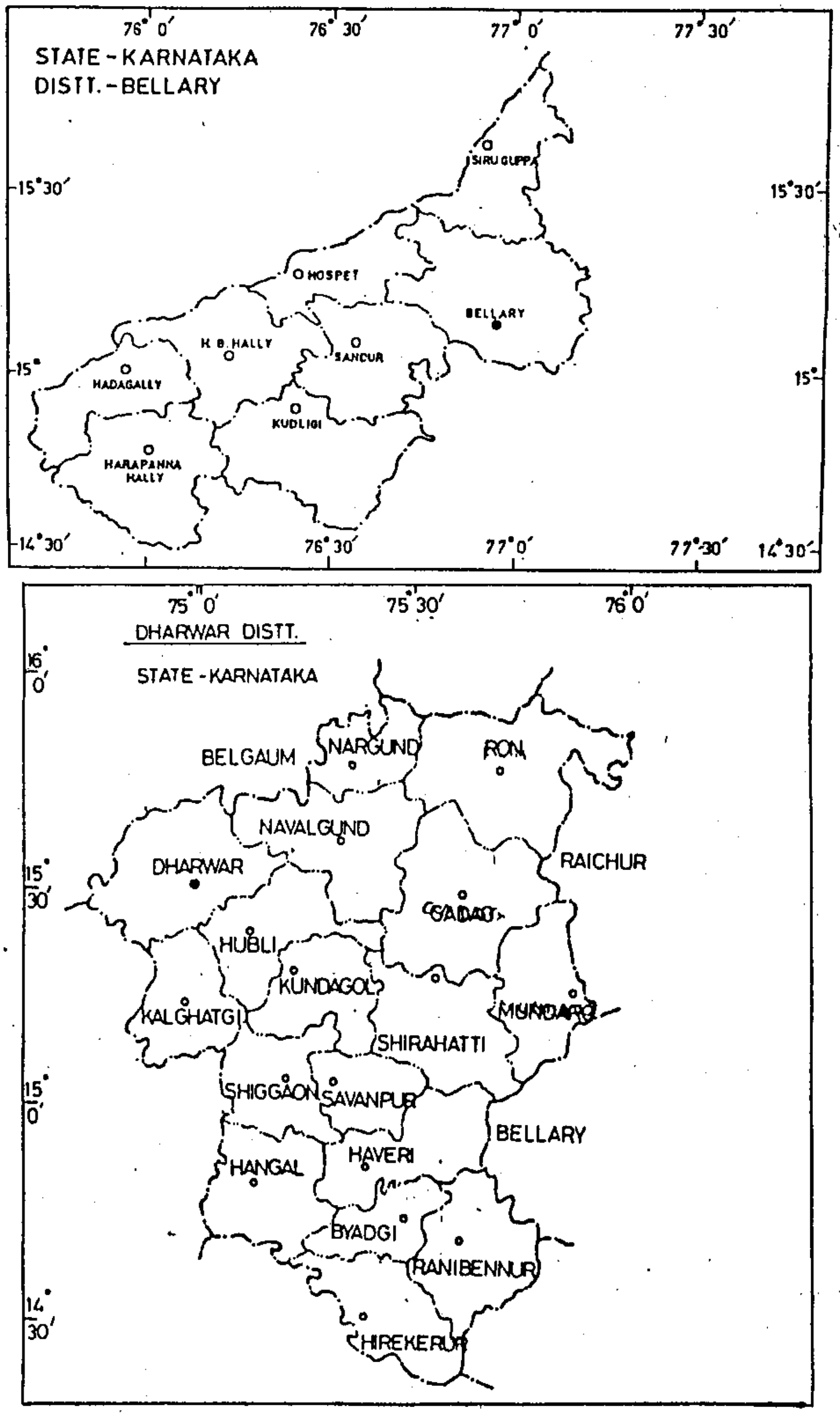


Fig. 2.7 LOCATION OF RAINGAUGE STATION & OBSERVATION WELLS

3.1 General

As has already been described in chapter 2.0, Six districts, viz., Belgaum, Bijapur, Gulburga, Raichur, Bellary and Dharwar from the state of Karnataka 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 1901-1991. The data from 1901 to 1980 have been extracted from CWC reports (CWC 1982). The remaining data from 1981 to 1991 have been collected during visits of scientific teams to various central/state Govt. offices in Karnataka.

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 Karnataka 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, August and September are taken in account while estimating seasonal normals. The results are reported in Table 3.1 and presented in Fig.3.1. The major inferences that could be drawn from the seasonal analysis are:

All six districts except Bellary experienced deficient seasonal rainfall in three consecutive years from 1984 to 1986. In year 1987, only Belgaum experienced negative departure that too in the range 20 to 30 percent. In year 1988, only two districts Raichur and Dharwar showed negative departure in the range of 0.0 to 20 percent. In year 1989, all the districts but Bijapur showed negative departure in the range of 0.0 to 40 percent. In year 1990, all the districts faced negative departure except Dharwar in the range of 20% and in year 1991, only Raichur faced negative departure.

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 same 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 in the district. Monthly normals of districts have been directly taken from reports of CWC (CWC,1982). It may be mentioned that in case of some districts/taluks, monthly departure analysis has

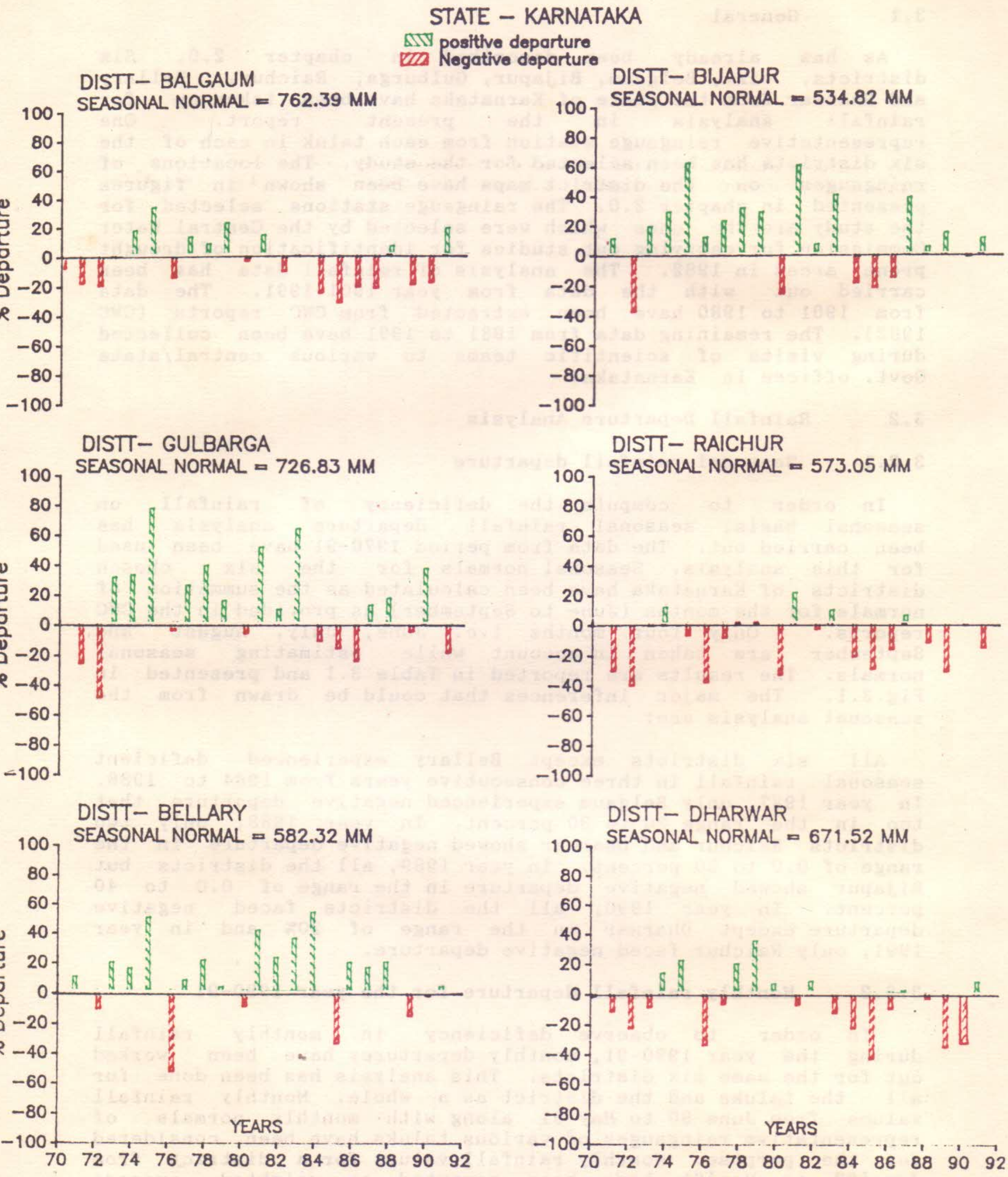


Fig.3.1:Districtwise seasonal rainfall departure.

been limited to some months only due to data availability constraints.

Table 3.1 : Percent departure of seasonal rainfall for the districts of Belgaum, Bijapur, Gulburga, Raichur, Bellary and Dharwar.

	Districts					
Year	**Belgaum**	**Bijapur**	**Gulburga**	**Raichur**	**Bellary**	**Dharwar**
Seasonal normal, mm	762.39	534.82	726.83	573.05	582.32	671.52
70	-6.94	15.50	2.45	2.28	24.32	-1.59
71	-16.86	10.00	-42.77	-30.61	8.82	-11.63
72	-18.60	-37.60	-47.75	-40.36	-9.83	-22.78
73	0.10	18.20	30.30	-0.37	18.36	-8.66
74	16.29	28.20	31.83	10.70	14.38	12.11
75	32.43	61.70	76.17	-7.07	48.71	20.49
76	-13.38	-33.70	-2.90	-38.33	-51.82	-33.94
77	11.79	22.20	24.97	-8.67	6.66	-6.77
78	7.03	30.90	38.32	1.38	19.94	18.25
79	21.38	28.10	14.73	1.30	2.14	33.55
80	-2.67	-26.00	-5.01	-33.47	-8.05	5.14
81	12.88	59.99	50.78	20.60	40.15	-7.44
82	-9.75	6.08	8.99	-3.19	21.82	6.81
83	0.09	- 0.65	63.07	8.62	34.62	-12.69
84	-24.55	-19.06	-9.98	-21.57	52.44	-22.78
85	-30.69	-22.22	-14.90	-29.83	-32.92	-43.34
86	-20.31	-15.38	-23.40	-16.64	18.58	-9.92
87	-21.24	38.25	12.03	5.18	15.29	0.92
88	5.44	4.39	16.72	-12.36	18.95	-3.13
89	-18.82	13.95	-4.17	-31.61	-14.65	-35.27
90	-17.39	-0.62	38.32	-0.04	-1.49	-33.97
91	17.69	10.35	14.73	-15.51	2.77	6.78

The variations in rainfall, month wise (monthly rainfall and corresponding normals) have been plotted for all the six districts for water year June'90 to May'91 and are shown in Figure 3.2. The departure figures for two representative taluks of all the six districts are shown in Figures 3.3. The results of monthly departure analysis for the districts as a whole are presented in Table 3.2. Based on the monthly departure values, two categories of monthly departure i.e. 20-50% and more than 50% have been made for deriving monthly deficiency inferences.

The following inferences can be drawn from the results presented in Figures 3.2, 3.3 and Table 3.3. It is clear that the monsoon did not perform well over the selected districts during the months of June, July, September, October and November 1990 resulting in negative departure in most of the cases. However, in the month of August, it was above normal, rainfall resulting in positive departures. As the months from December '90 to March '91 lies in non monsoon period and have a low normal rainfall, these do not count much. From the districtwise monthly rainfall departure analysis, it can be said that the overall effect of monsoon was not good as is also evident from seasonal rainfall departure analysis in section 3.2.1.

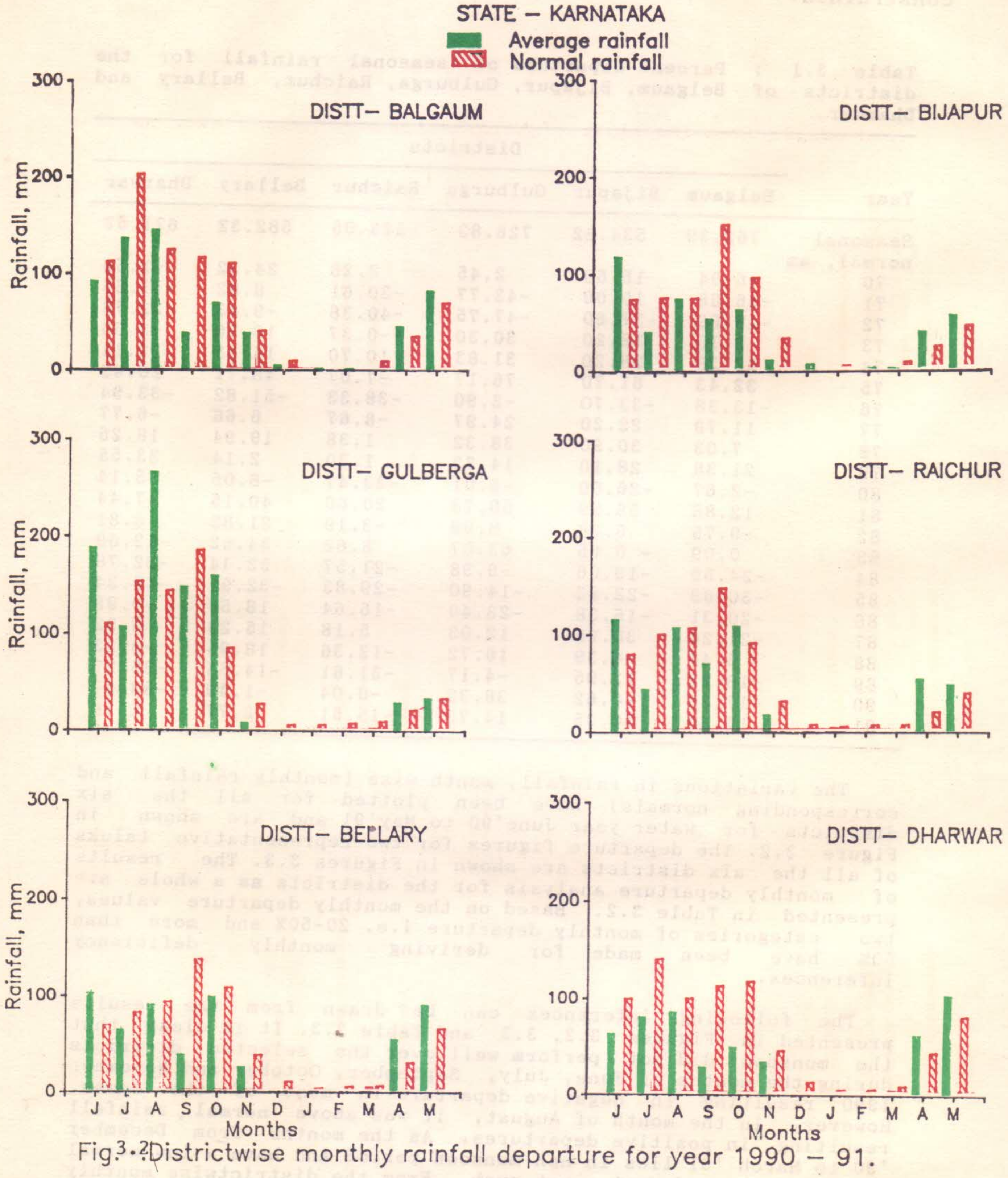


Fig. 3.2 Districtwise monthly rainfall departure for year 1990 – 91.

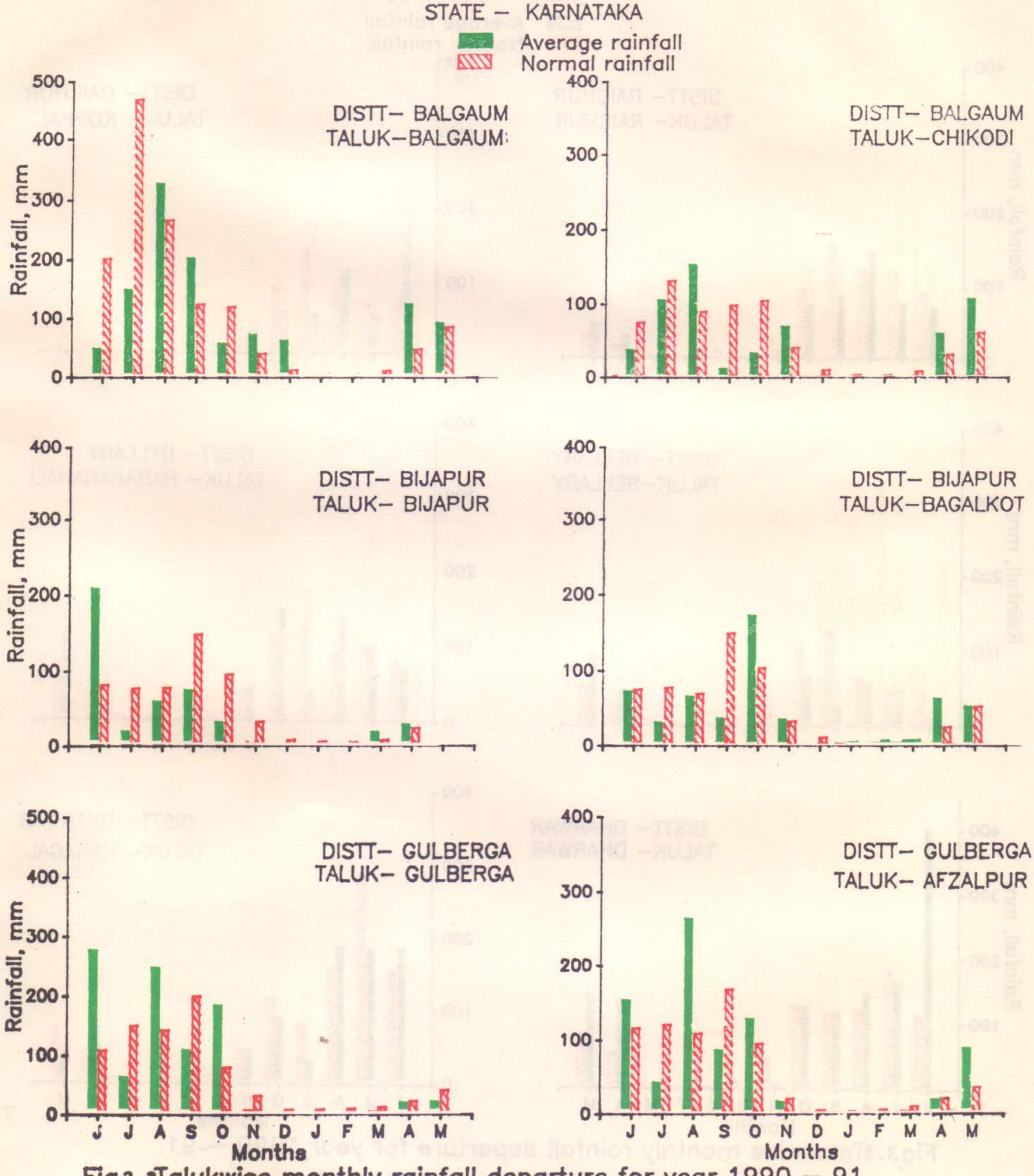


Fig.3.3 Talukwise monthly rainfall departure for year 1990 – 91.

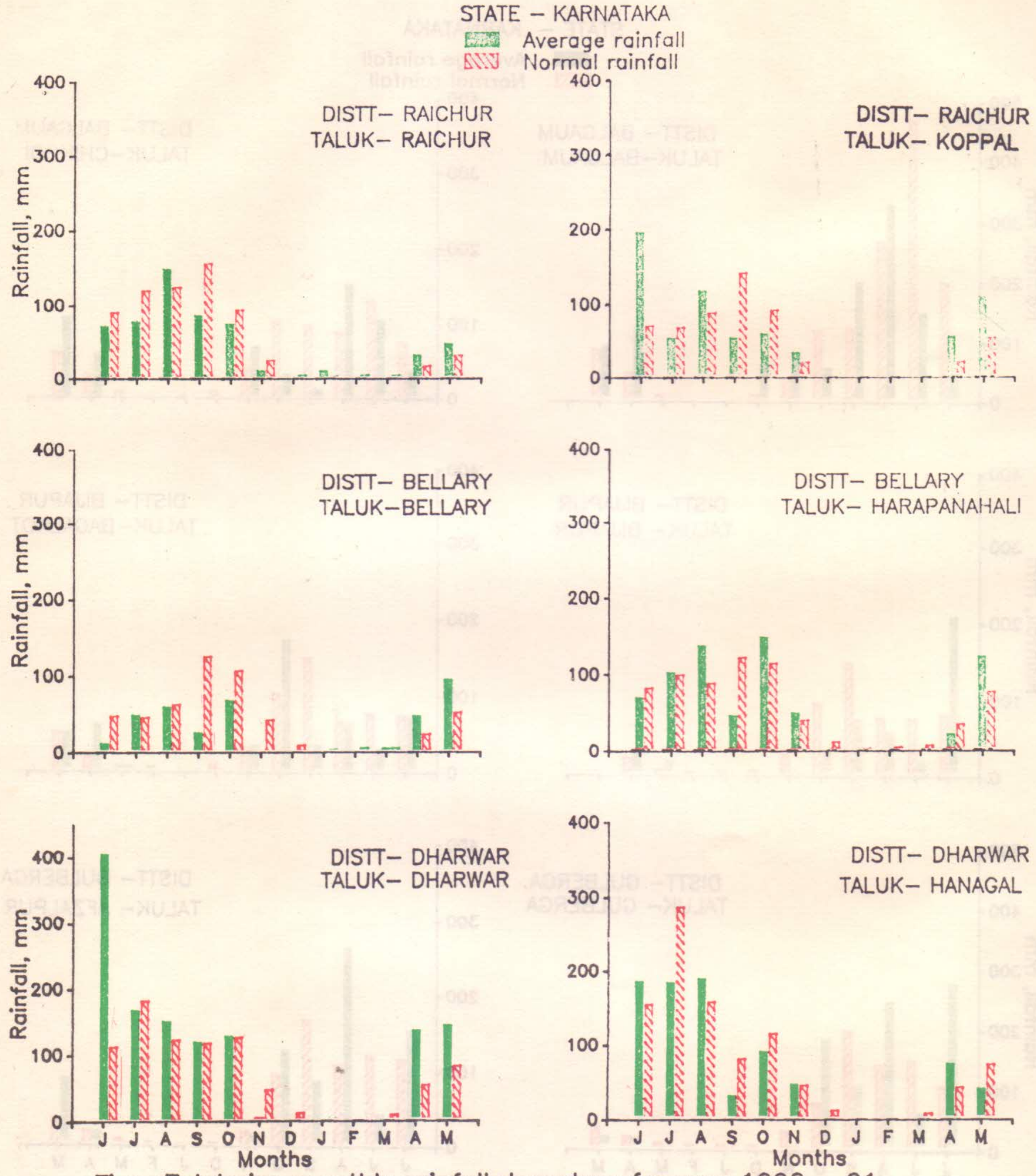


Fig.3.3 Talukwise monthly rainfall departure for year 1990 – 91.

Table. 3.2 : Deficiency of rainfall in six districts of Karnataka.

Year/month	Districts of Karnataka, Percent departure					
	Belgaum	Bijapur	Gulburga	Raichur	Bellary	Dharwar
1990 June	-16.27	64.32	73.84	50.98	54.50	-34.80
1990 July	-32.05	-43.88	-29.17	-54.57	-19.63	-41.68
1990 Aug.	18.26	3.60	87.42	3.55	-0.66	-11.46
1990 Sept.	-65.92	-62.93	-19.05	-51.54	-71.21	-74.23
1990 Oct.	-35.40	-31.43	92.86	23.68	-6.78	-57.32
1990 Nov.	0.26	-61.46	-65.41	-37.24	-27.17	-19.56
1990 Dec.	-26.53	-86.02	-100.00	-100.00	-89.81	-97.04
1991 Jan.	-91.39	-100.00	-89.66	-29.71	-100.00	-100.00
1991 Feb.	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00
1991 March	-100.00	-46.67	-90.19	-100.00	-13.81	-68.47
1991 April	39.00	81.85	51.40	209.23	95.04	54.27
1991 May	22.69	33.25	9.37	31.37	43.84	33.49

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

Month/ year	Group Range of Deficiency in rainfall (expressed has percentage of normal)	
	20 to 50%	50% and above
June 1990	Dharwar	Nil
July	Belgaum, Bijapur, Gulburga, Dharwar	Raichur
August	Nil	Nil
September	Nil	Belgaum, Bijapur, Raichur, Bellary, Dharwar
October	Belgaum, Bijapur,	Dharwar
Nov.	Raichur, Bellary,	Bijapur, Gulburga
Dec.	Belgaum	Raichur, Bellary, Bijapur, Gulburga Dharwar
Jan. 1991	Raichur	Belgaum, Bellary, Bijapur, Gulburga, Dharwar
Feb.	Nil	All
March	Bijapur	Belgaum, Gulburga, Raichur, Dharwar
April	Nil	Nil
May	Nil	Nil

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. 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 have been shown in Figures 3.4 and 3.5 respectively. The range of annual rainfall at 75% probability level can be established using these graphs and such values for all districts and two taluks in each district are given in Table 3.4 along with the percentage

Table 3.4 : Observation of probability distribution analysis for Karnataka.

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.	Belgaum	Belgaum	1100-1200		99
		Chikodi	500-600		65
		District as a whole	700-800	610.30	92
2.	Bijapur	Bijapur	400-500		82
		Bagalkot	500-600		83
		District as a whole	500-600	431.48	83
3.	Gulburga	Gulburga	600-700		87
		Afjalpur	500-600		78
		District as a whole	600-700	576.47	88
4.	Raichur	Raichur	500-600		92
		Koppal	500-600		82
		District as a whole	500-600	453.15	90
5.	Bellary	Bellary	400-500		67
		Harapanshalle	500-600		88
		District as a whole	500-600	472.08	92
6.	Dharwad	Dharwad	700-800		95
		Hanagal	800-900		98
		District as a whole	600-700	547.20	98

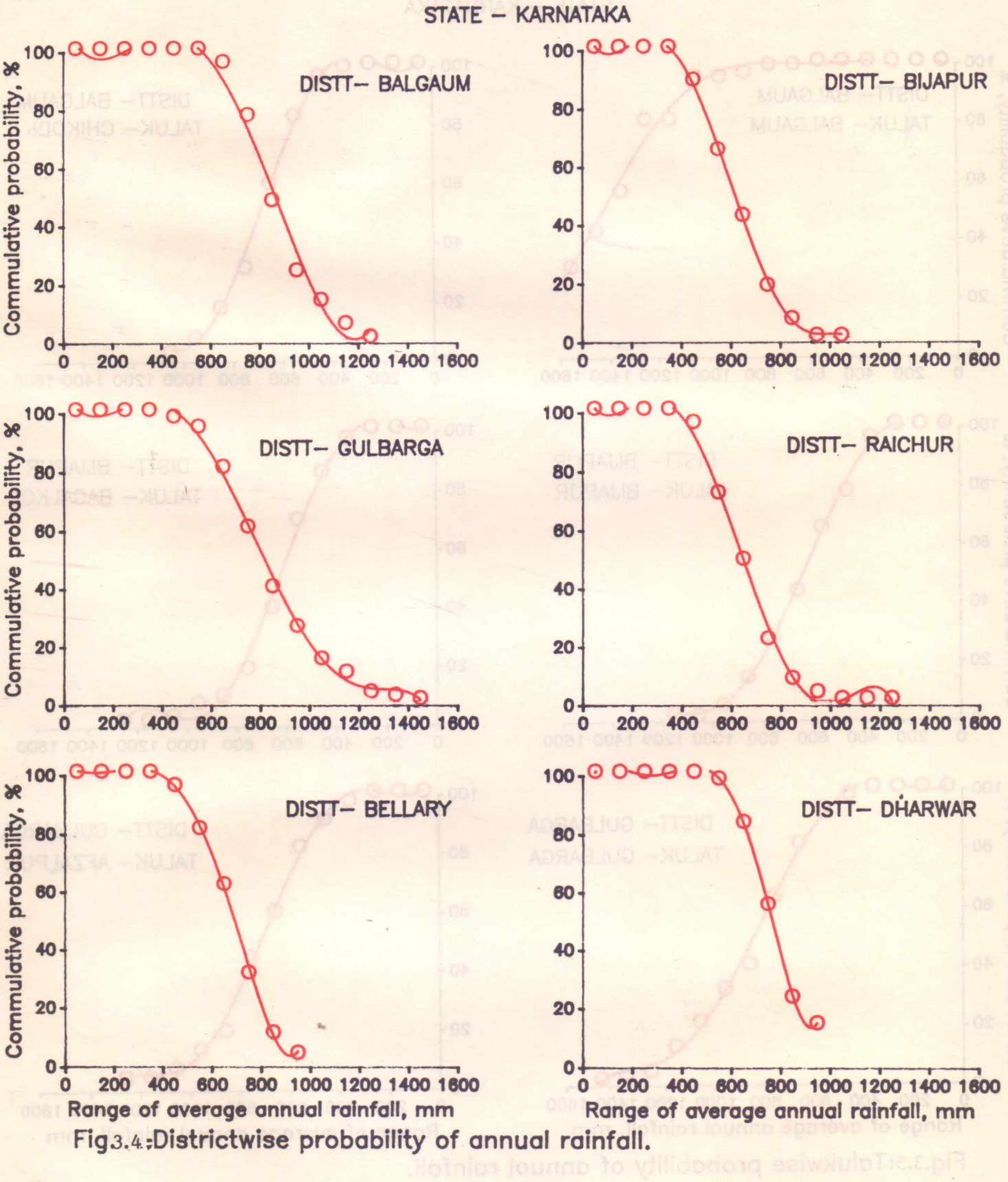


Fig3.4:Districtwise probability of annual rainfall.

STATE — KARNATAKA

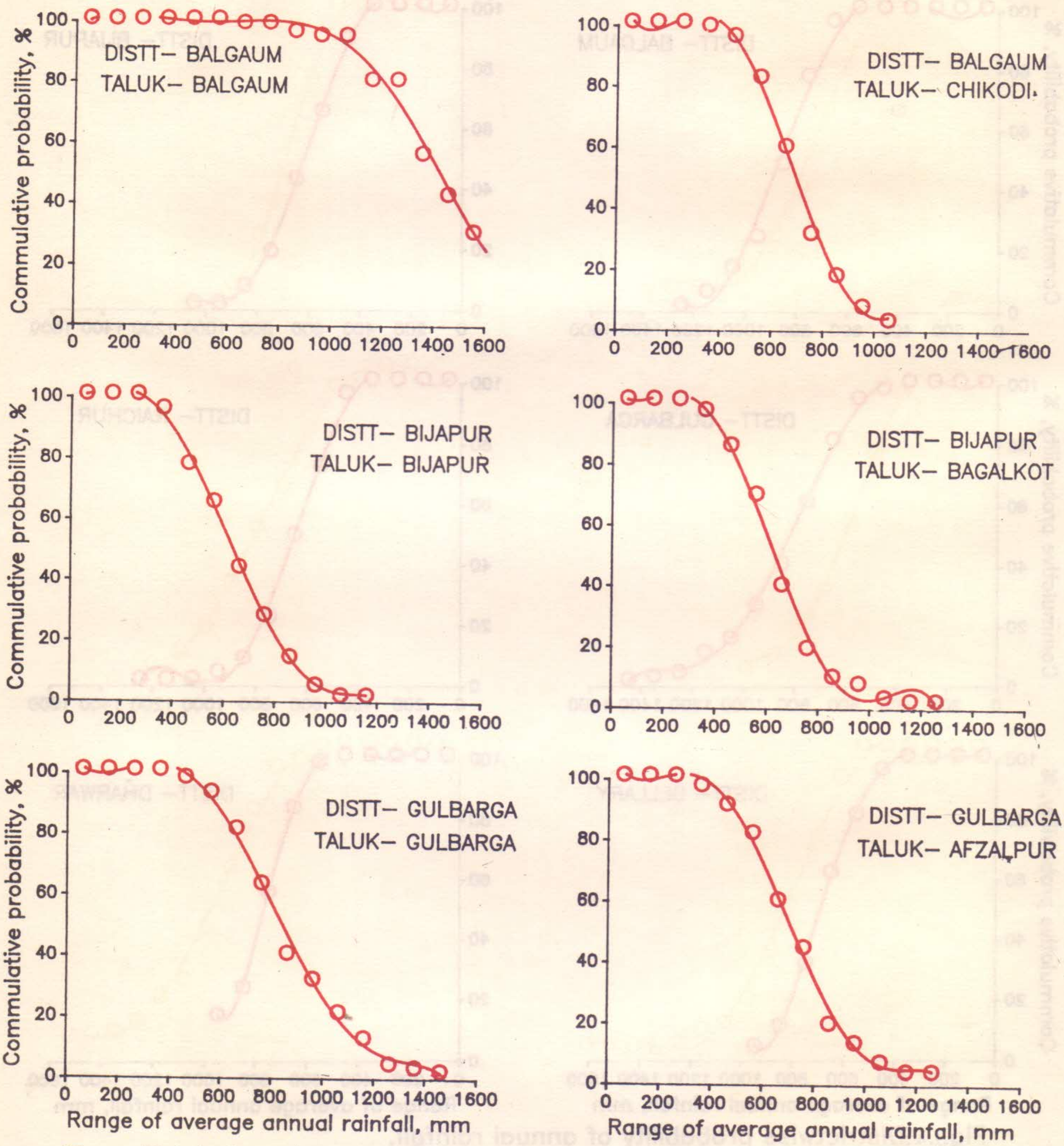


Fig.3.5:Talukwise probability of annual rainfall.

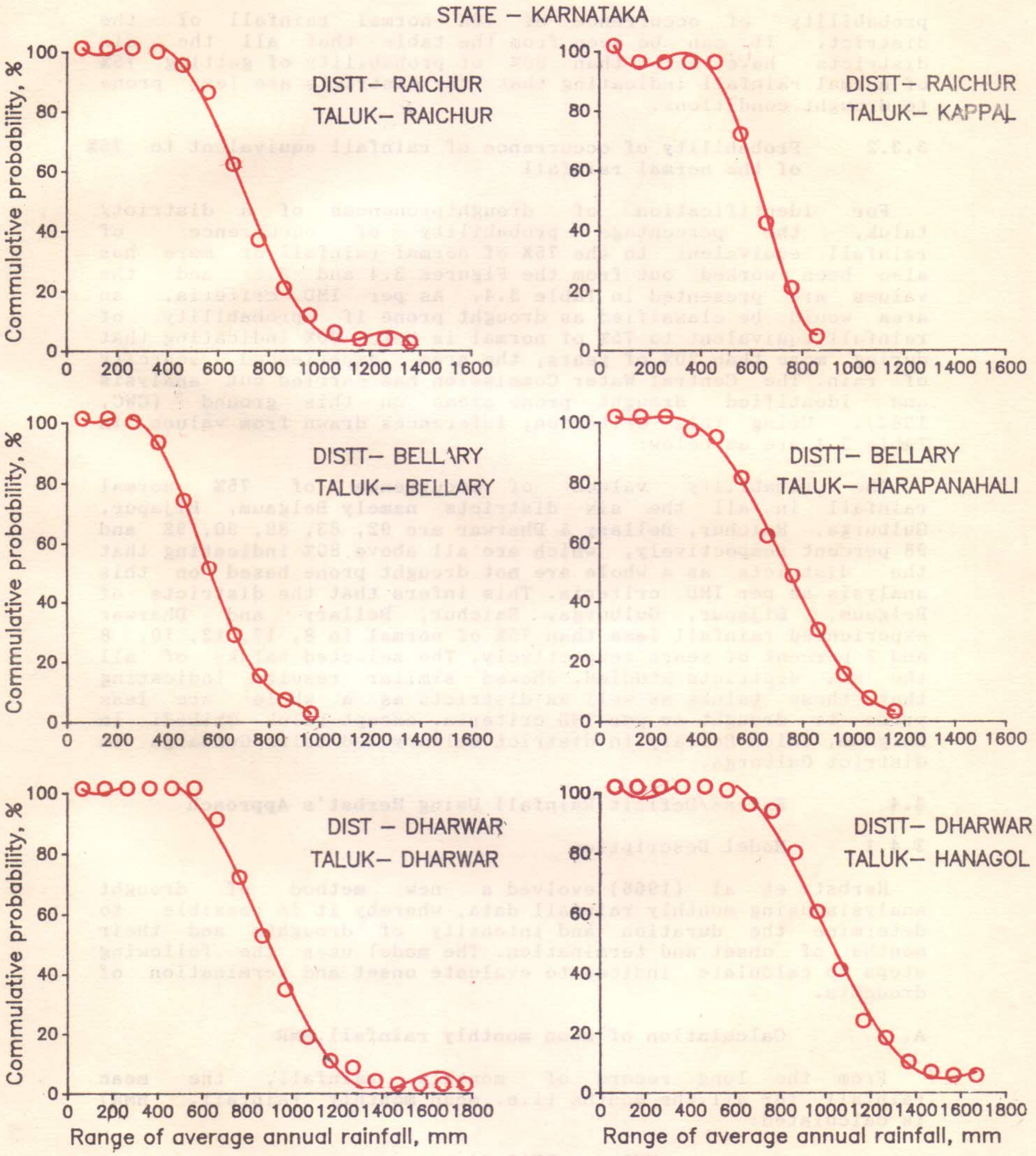


Fig.3.5:Talukwise probability of annual rainfall.

probability of occurrence of 75% normal rainfall of the district. It can be seen from the table that all the six districts have more than 80% of probability of getting 75% of normal rainfall indicating that the districts are less prone to drought conditions.

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 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:

The probability values of occurrence of 75% normal rainfall in all the six districts namely Belgaum, Bijapur, Gulburga, Raichur, Bellary & Dharwar are 92, 83, 88, 90, 92 and 98 percent respectively, which are all above 80% indicating that the districts as a whole are not drought prone based on this analysis as per IMD criteria. This infers that the districts of Belgaum, Bijapur, Gulburga, Raichur, Bellary and Dharwar experienced rainfall less than 75% of normal in 8, 17, 12, 10, 8 and 2 percent of years respectively. The selected taluks of all the six districts studied, showed similar results indicating that these taluks as well as districts as a whole are less prone to drought as per IMD criteria, except taluk Chikodi in Belgaum, taluk Bellary in district Bellary and taluk Gulbarga in district Gulbarga.

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:

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

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

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

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

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

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

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,

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

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:

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

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.

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

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

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

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 details of the onset, termination, duration and intensity of drought for all the districts are reported in Figures 3.6. 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 analysis shows that all the districts experienced 8-14 drought spells of intensity ranging from 0.47 to 2.0 during the period. This shows that the districts are drought prone. Over the entire period of analysis, the highest drought duration was 122 months and corresponding drought intensity was 1.06, observed during 1962 to 1972 in Gulburga district. All the six districts faced successive drought years in continuation from 1984 to 1991 leading to a disastrous drought situation in these districts. It is clear from the analysis that in the year 1988, all the six districts do not show any drought spell indicating that it was not a drought year which have also been indicated by other analysis of rainfall data. The year 1991 also showed the drought spells except Dharwar. The other analysis of rainfall also supports the drought spells in year 1991.

The approach is more relastic as compared to probability analysis, since in this approach the results are based on monthly rainfall data. On the other hand the results of the probability analysis are based on the 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

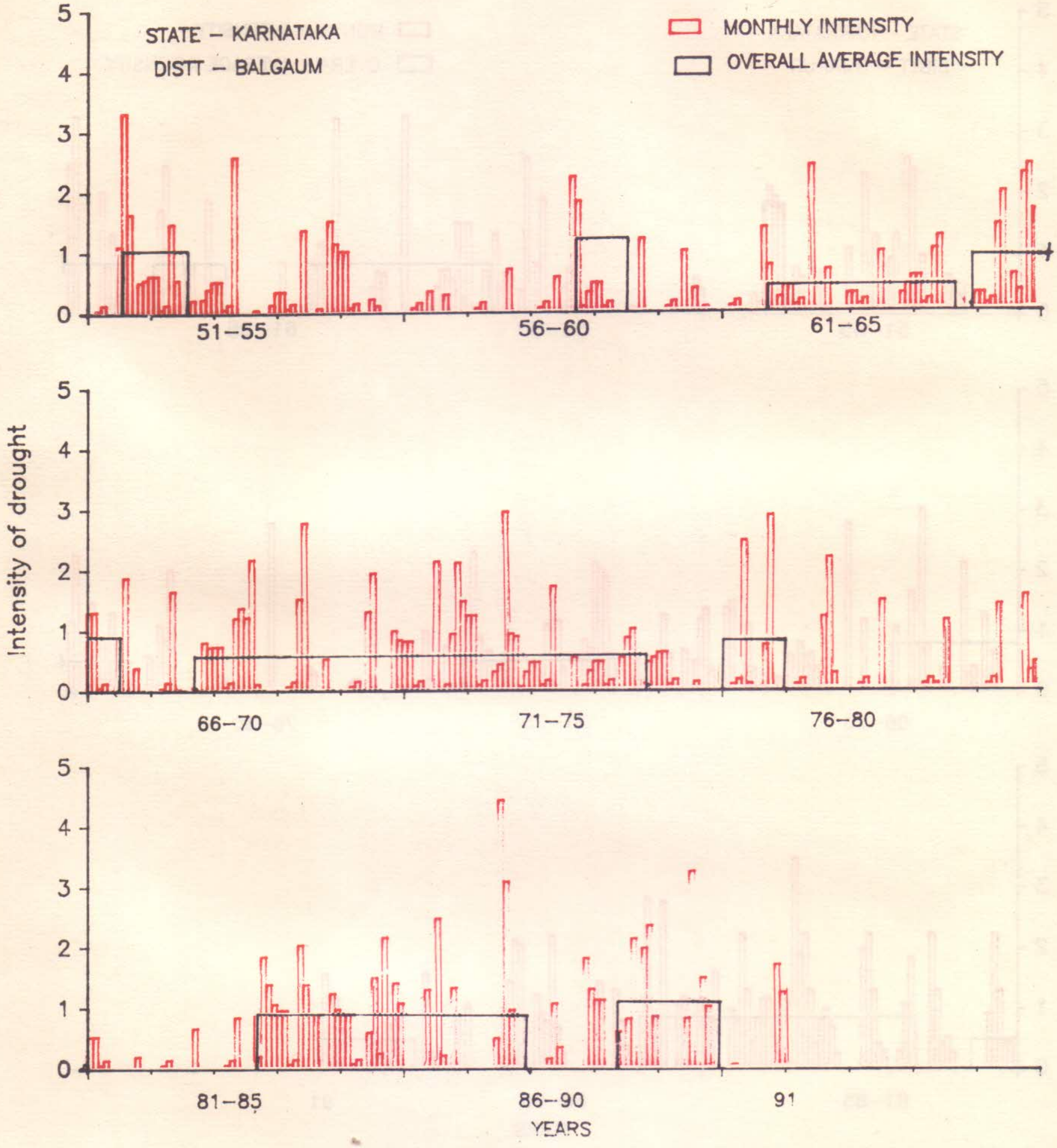


FIG:3.6 Overall average and monthly intensity of drought.

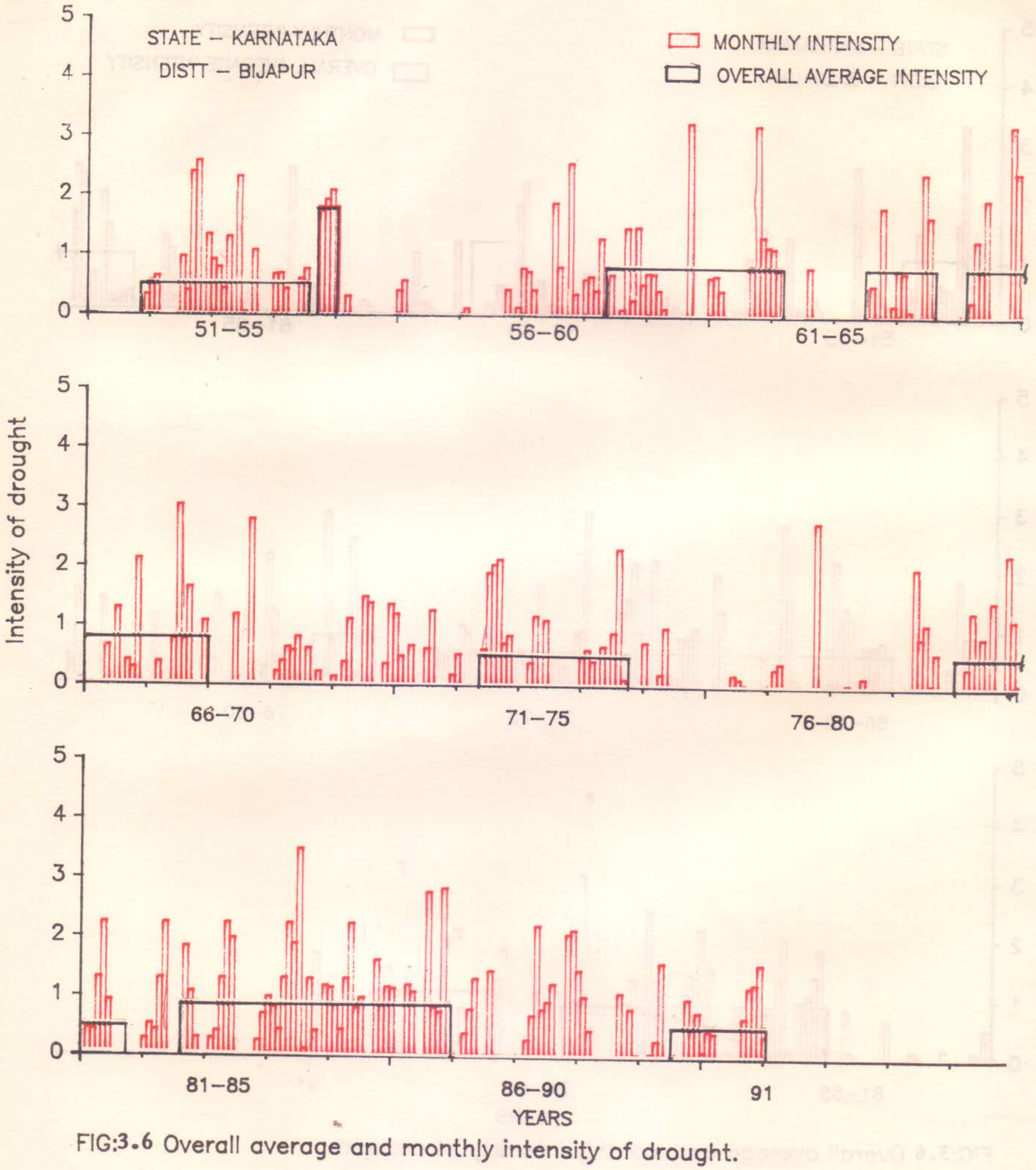


FIG:3.6 Overall average and monthly intensity of drought.

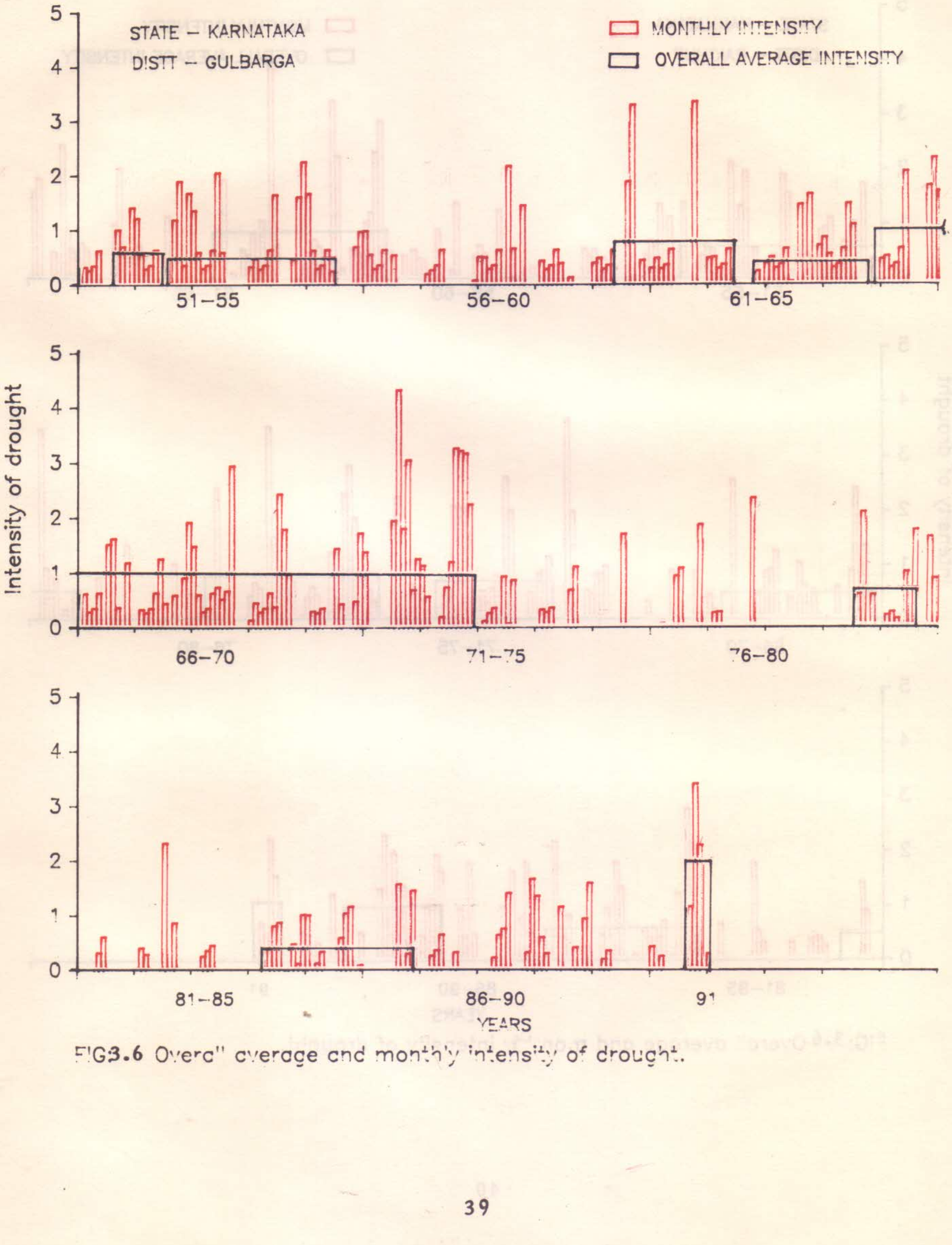


FIG3.6 Overall average and monthly intensity of drought.

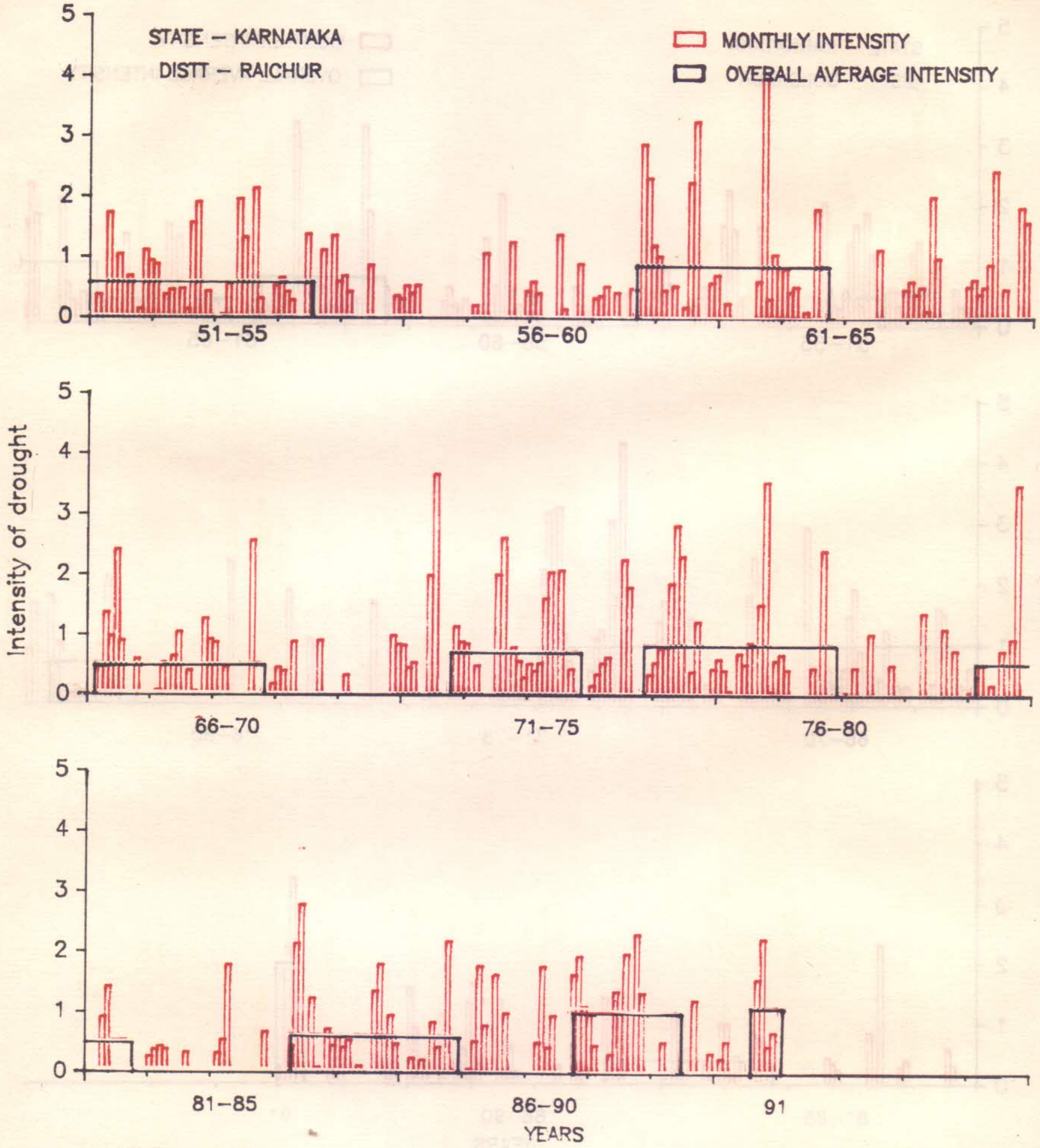


FIG: 3.6 Overall average and monthly intensity of drought.

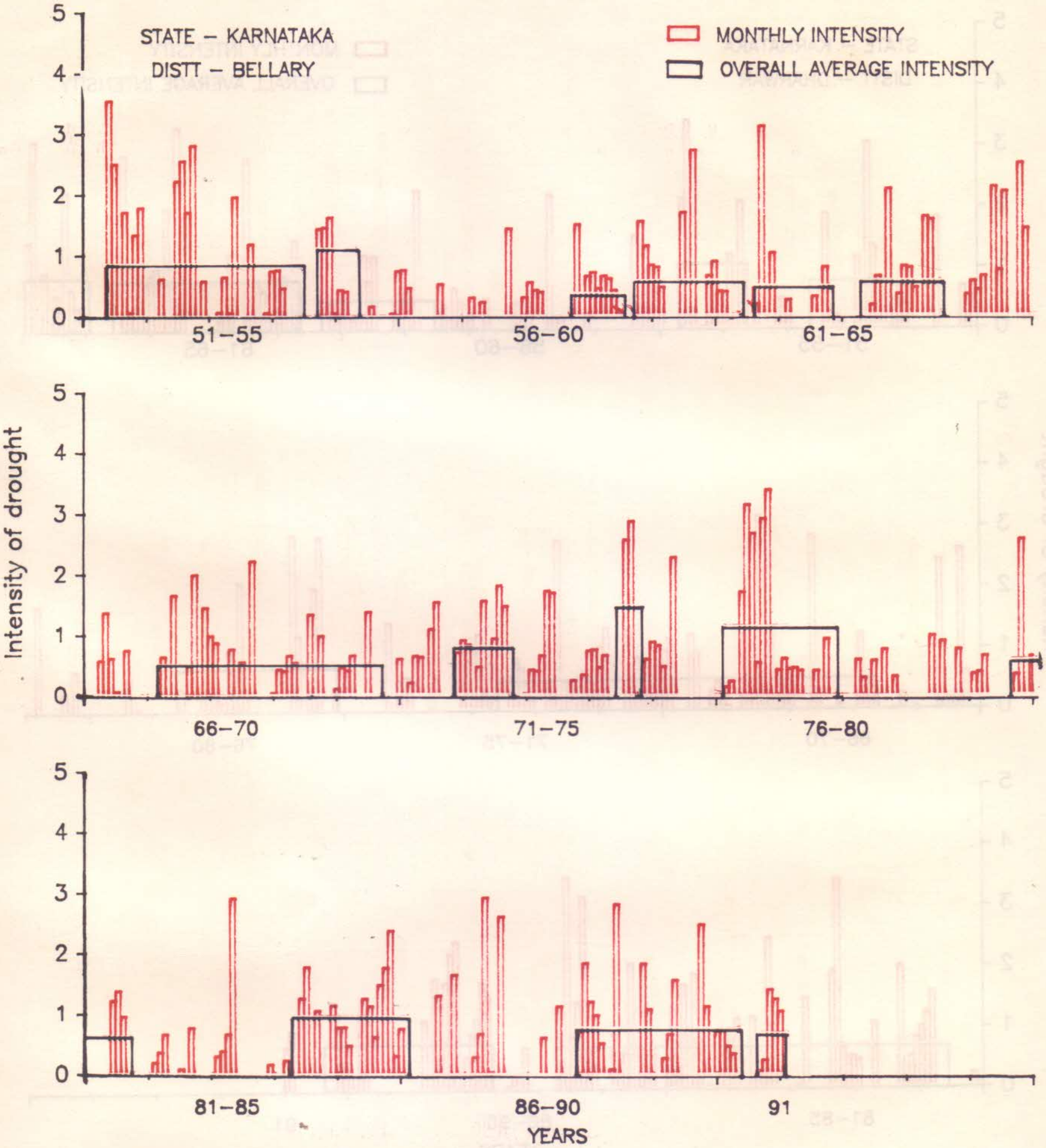


FIG:3.6 Overall average and monthly intensity of drought.

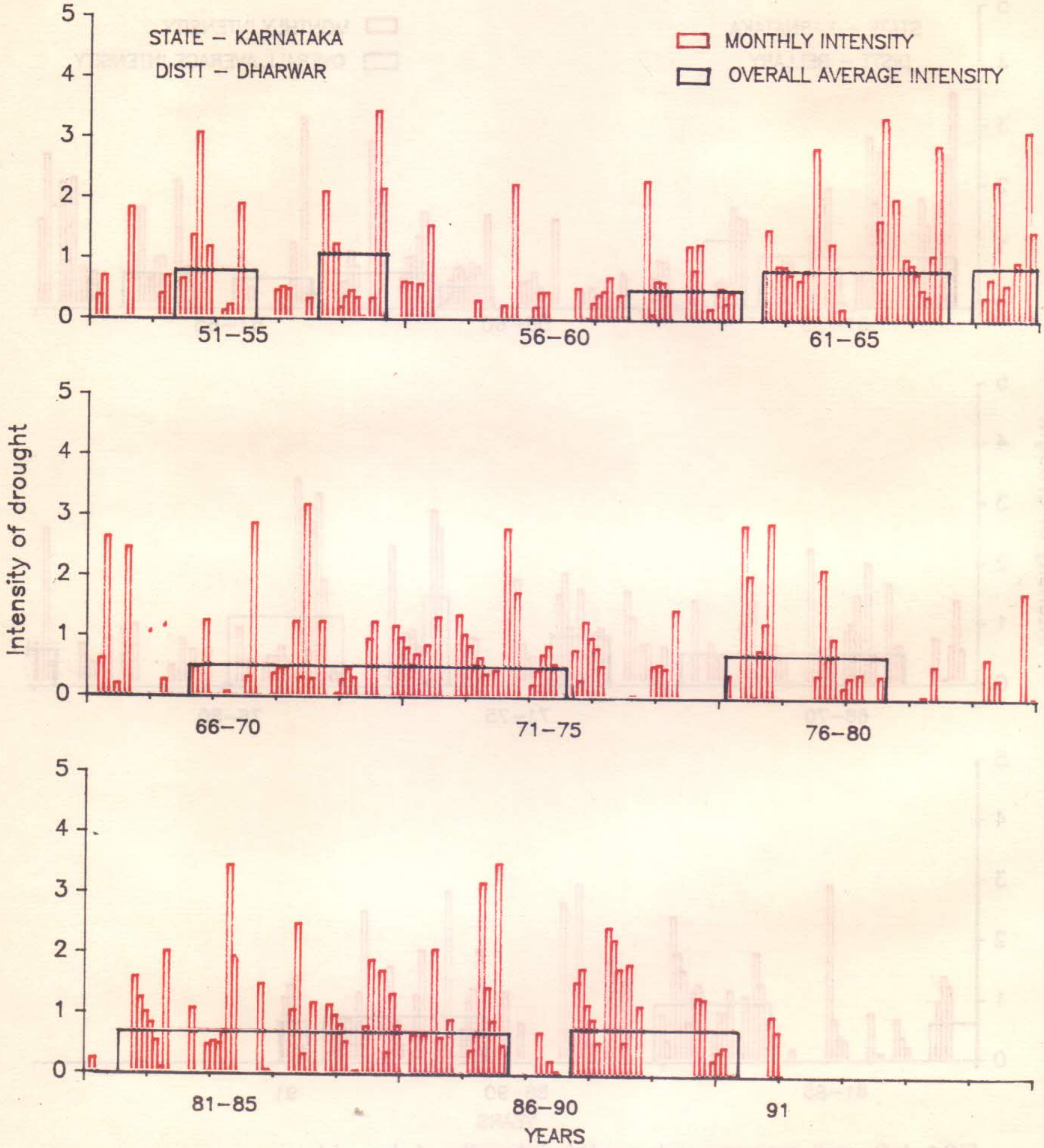


FIG: 3.6 Overall average and monthly intensity of drought.

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 Karnataka.

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 (a day is assumed as rainy day if daily rainfall exceeds 5 mm 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 III-(A). The number of dry spells have been counted, starting from the monsoon season of 1981 to 1991. 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 1981-1991 and cumulative percentage was obtained starting from the maximum duration of dry spell group downwards, adding successive percentage (Appendix III-(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.	Belgaum (Belgaum)	Karnataka	21-28
2.	Bijapur (Bijapur)	-do-	21-28
3.	Gulburga (Gulburga)	-do-	21-28
4.	Raichur (Raichur)	-do-	21-28
5.	Bellary (Bellary)	-do-	21-28
6.	Dharwar (Dharwar)	-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.

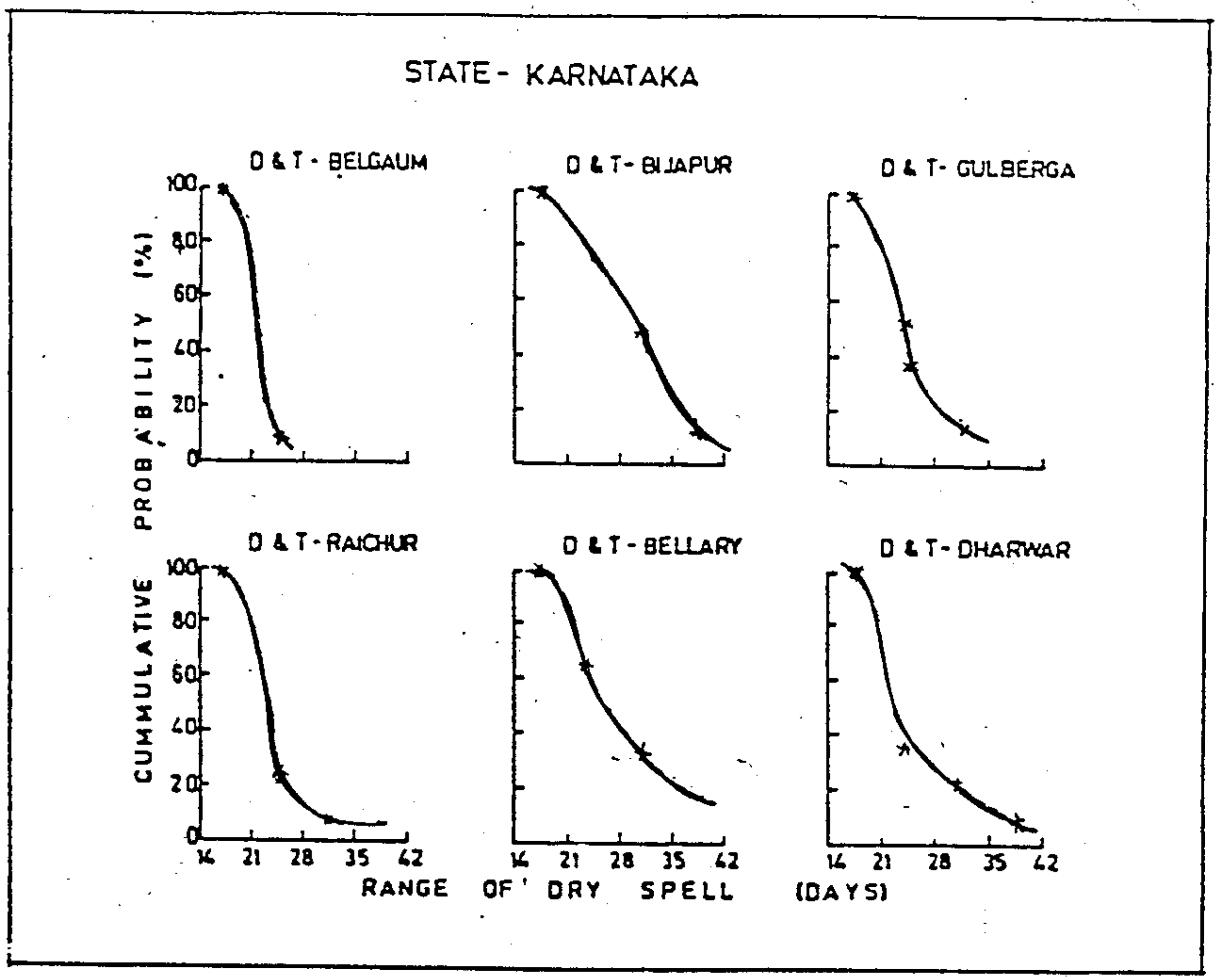


Fig.3.7 : Probability Distribution of Dry Spells

4.0 GROUND WATER DEFICIT

4.1 General

The main objective of groundwater management is to ensure that groundwater is available at the 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 overexploitation 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 (1985-1991) on groundwater regime, statistical analysis of groundwater level data has been carried out. The groundwater level analysis was restricted to only four districts namely Bijapur, Belgaum, Gulbarga and Raichur. The analysis for Dharwar and Bellary could not be done due to lack of data. 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 the four districts of Belgaum, Bijapur, Gulbarga, and Raichur of. 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 Karnataka.

Sl. No.	Districts	Period of data availability	No. of obs. well	Source of data availability
1.	Belgaum	1976-91	6	State Groundwater Board
2.	Bijapur	1974-91	7	-do-
3.	Gulburga	1975-91	10	-do-
4.	Raichur	1975-91	8	-do-

As is evident from Table 4.1, about 6-10 wells were chosen in each district for evaluating impact of droughts 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 IV-1 gives the details of various observation wells spread over 4 selected drought prone districts of Karnataka state with their latitude and longitude. The analysis has been carried out for ground water level data up to 1991.

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.

4.3 Inferences

The trend of pre and post monsoon watertable in respect of four districts are shown in Figures. 4.1.

The analysis of ground water levels based on the water-table fluctuation data of past 16-17 years has yielded the groundwater level trends (pre & post) as a result of seasonal rainfall departure. It is evident from the Figures 4.1, that average trends of seasonal ground water levels in the three districts namely Belgaum, Bijapur and Gulbarga are declining, where as it is rising in case of Raichur district. The continuous decline in watertable is certainly attributable to failure of monsoon due to which the draft of ground water also gets increased because of increase in demand. The rising trend of watertable, as found in Raichur, 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.

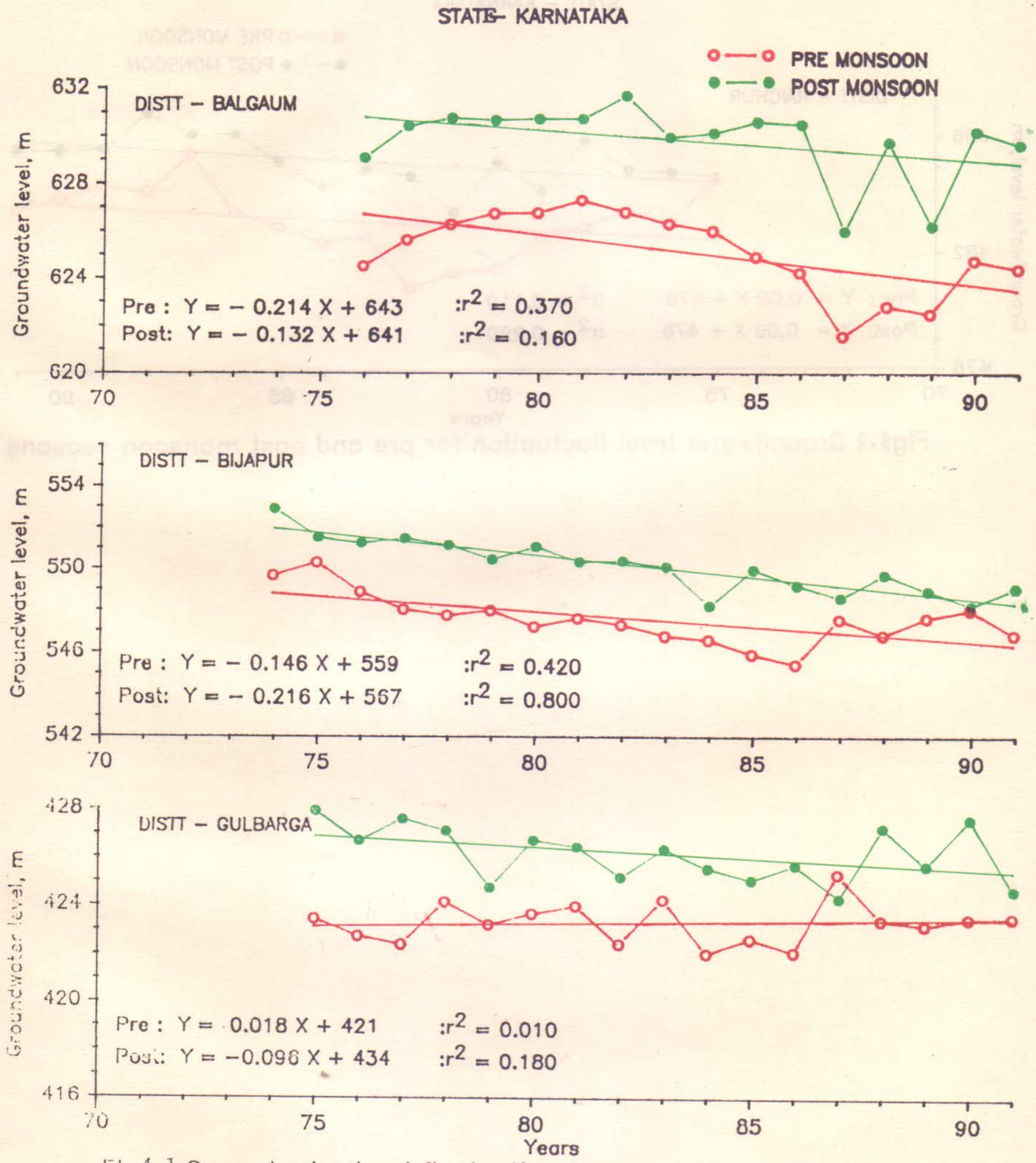


Fig.4.1 Groundwater level fluctuation for pre and post monsoon seasons

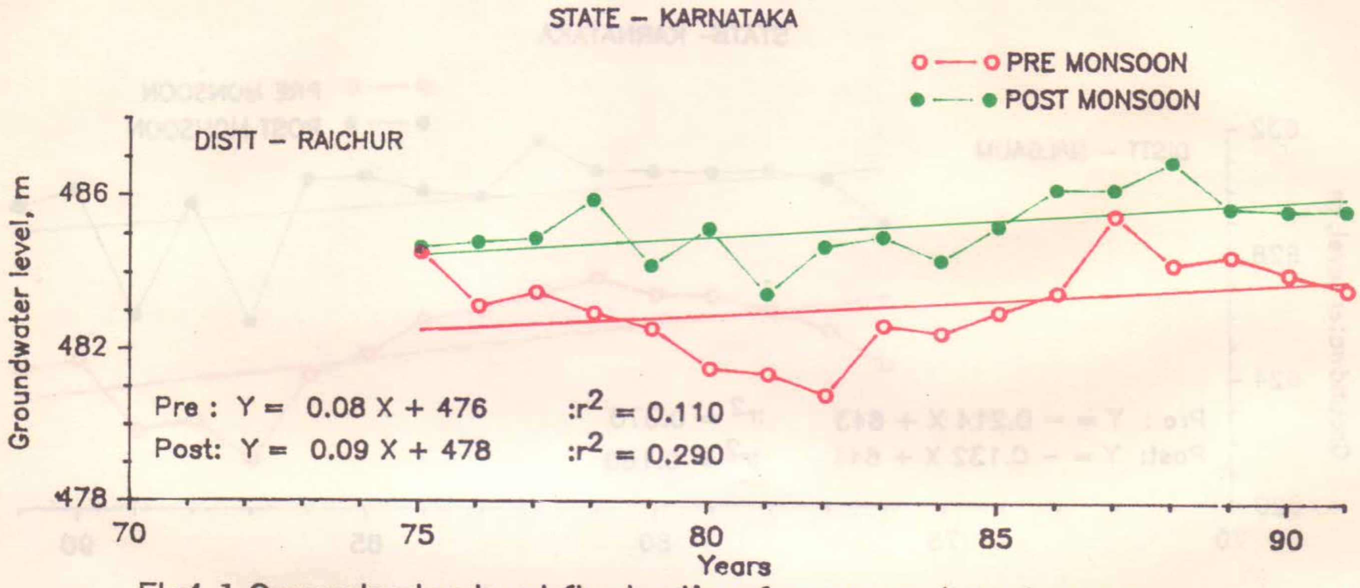


Fig4.1 Groundwater level fluctuation for pre and post monsoon seasons

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 level in Ghatprabha and Tungabhadra reservoirs of the state of Karnataka. For this purpose, the live storages and 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 1985-1991 have been used for this analysis. Figures 5.1 shows the position of storages during 1985 to 1991 in the reservoir. The following inferences can be drawn from Figure 5.1.

Both the reservoirs have shown less storage value during 1987 and 1988, as compared to previous three years and years 1988 to 1991. The storages by the end of Nov. in Tungabhadra reservoir during 1987 was 6.3% of previous year storage for the corresponding period. In case of Ghatprabha, the storage by Nov.87 was 57% of the previous year's storage. This indicates that the reservoir storages were affected in 1987 and 1988, as compared to the other years.

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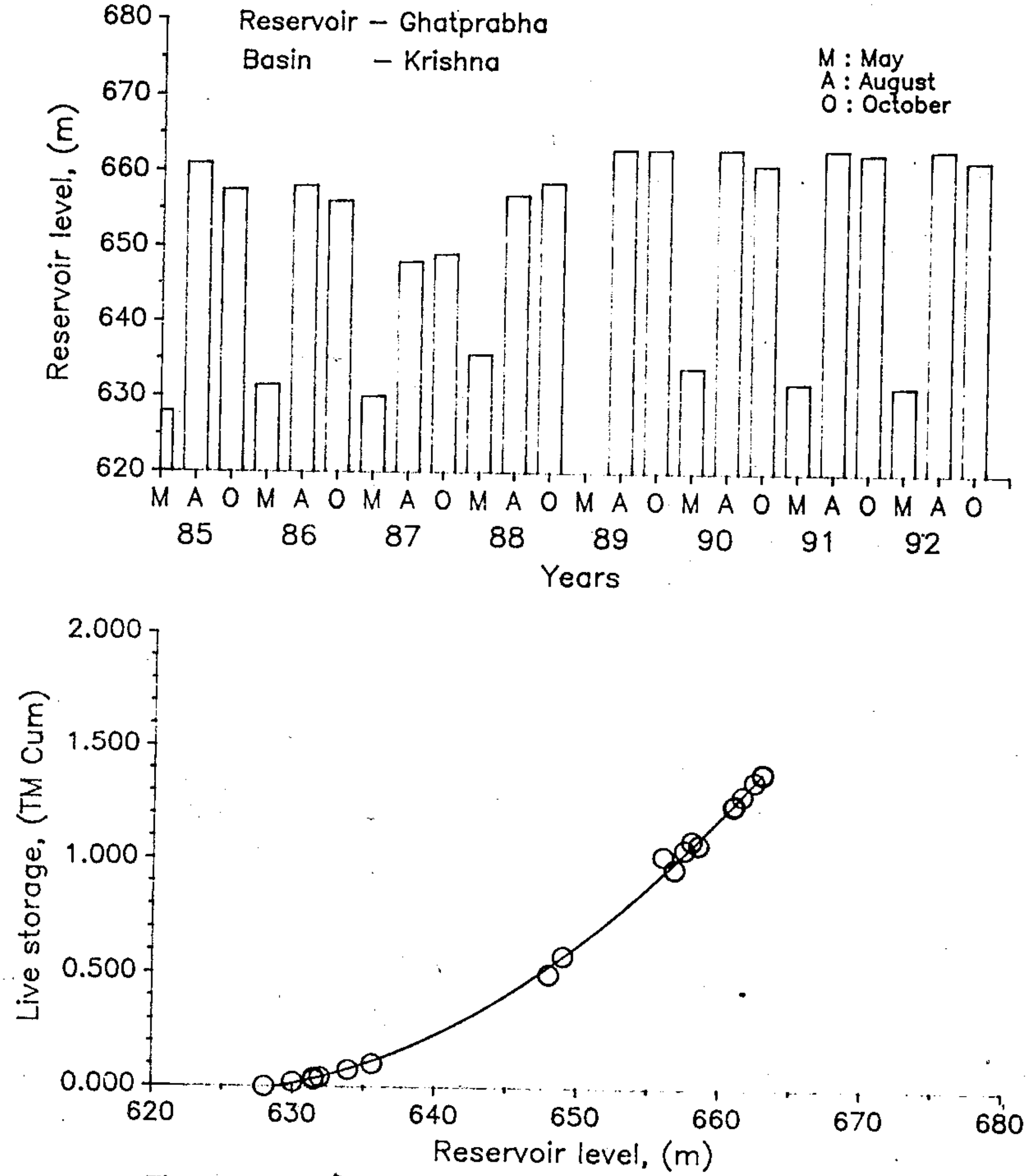

Fig. 5.1: Reservoir level with time and the relationship between reservoir level and live storage.

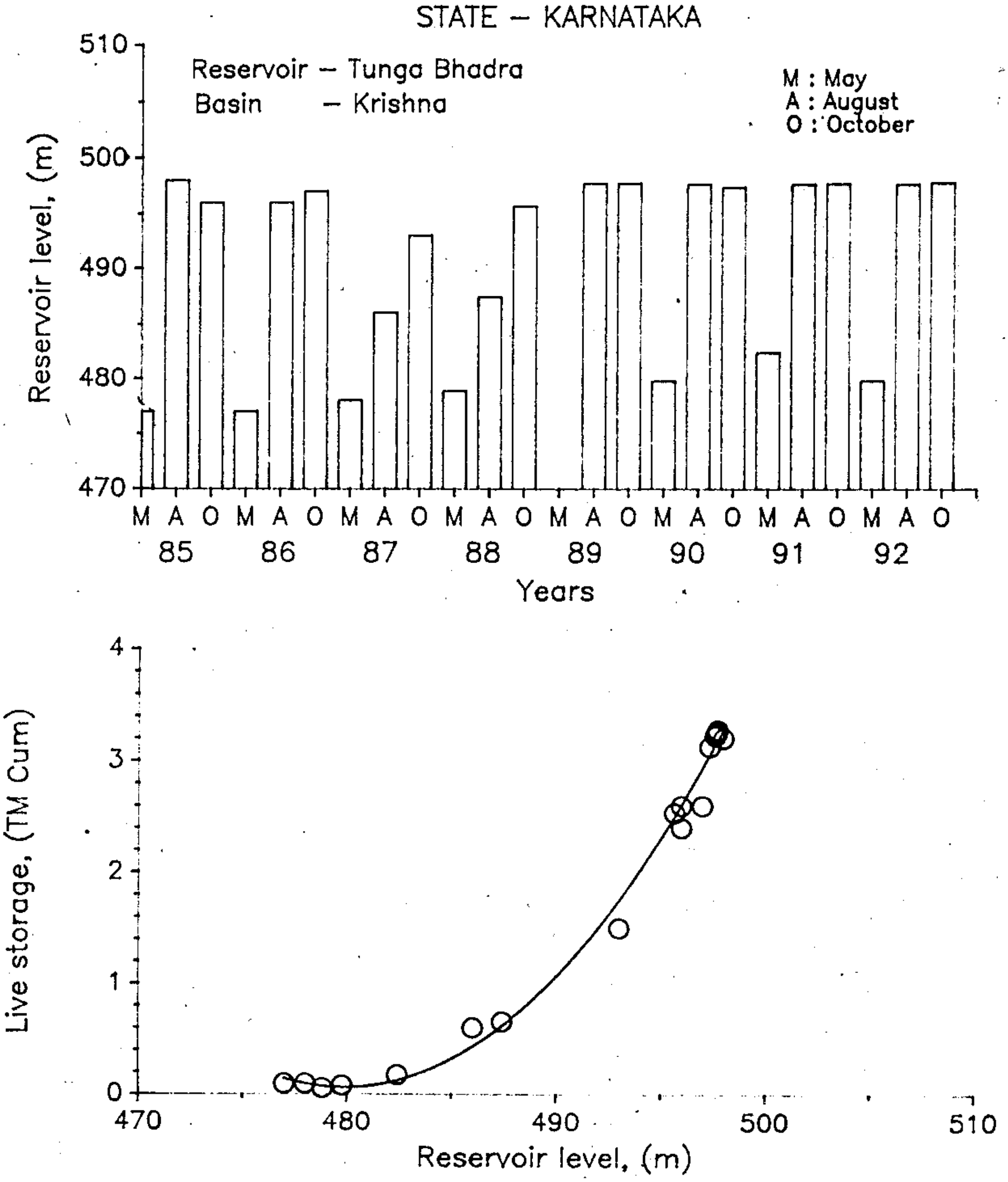

Fig.5.1:-Reservoir level with time and the relationship between reservoir level and live storage.

6.0 CONCLUSIONS & RECOMMENDATIONS

1. The present report gives analysis of data to assess impact of droughts in six selected districts of Karnataka state namely Belgaum, Bijapur, Bellary, Raichur, Dharwar & Gulbarga. The analysis includs rainfall analysis, groundwater analysis and reservoir level and storage analysis.

2. The seasonal rainfall departure analysis of year 1991 indicated for most of the districts, the departure in seasonal rainfall has been on slightly positive side for five out of six districts. Only in case of Raichur district, a deficiency in rainfall on seasonal basis has been observed.

3. Analysis of monthly rainfall data for all the six districts for the water year 1990-91 has been done by comparison with the monthly normal rainfall values. It has been observed (Table 3.2) that during the month of June 90, Belgaum and Dharwar observed deficiency rainfall from monthly consideration. In the months of July, and September 1990, the average rainfall is lower than the normal, indicating a deficiency of rain fall. Combining the results of June 1990 to March 1991 indicates that the monsoon was deficient in general. The Month of April and May 1991 indicated a positive rainfall departure in all districts.

4. Probability analysis of annual rainfall data has been done using the data available from 1901-89 in order to find the group range of rainfall like to occur. It has been found that for the districts of Bijapur, Raichoor and Bellary, this range works out to be 500-600 mm. While for other Gulbarga and Dharwar districts, it is in the range of 600-700 mm. and Belgaum stands high in order of 700-800. This analysis has also yielded values of probability of occurrence of 75% annual rainfall in the district. It has been found that all the districts had the probability level more than 80% which means that for less than 20 years out of 100 years, the rainfall is likely to be less than 75% of the normal in these districts. The districts of Belgaum, Bijapur, Gulburga, Raichur, Bellary & Dharwar experienced less than 75% of normal rainfall in 8, 17, 12, 10, 8 and 2 percent of years, respectively, indicating that all the six districts are less drought prone, based on this analysis as per IMD criteria.

5. Analysis of monthly rainfall data using Herbst's Approach has been carried out to identify the drought spells for which data of year 1951-91 have been used. It was observed that all districts recorded drought spells during the period 1984-91. In year 1991 the drought spells are observed in Bijapur, Gulbarga, Raichur and Bellary. However, the district of Dharwar experienced longest duration of drought spell while Bellary seemed to have experienced shortest spell of drought as per this analysis. In general, 8-14 drought spells were observed in these district with Gulburga experiencing minimum no. of drought spells.

6. Analysis of rainfall data for dry spell identification has been carried out and duration of likely dry spells at 75% of probability has been worked out. It was found that most of the districts had 75% probability of having a dry spell of the duration of 21-28 days. A dry spell was assumed as a period

in which daily rainfall should not have exceeded 5 mm on any day in a continicus period of 14 days or more.

7. Groundwater level analysis was carried out in respect of four districts for evaluateing the impact of drought on groundwater regime. It was observed that for the districts of Belgaum, Bijapur and Gulbarga, the pre and post monsoon Water levels.are found to show a declining trend and in the case of Raichur, both pre and post monsoon levels, are found rising. It can be said that the ground water level did not undergo a significant change as a result of rainfall deficiency, considering the low rate of decline of watertable observed.

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

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

KARNATAKA

PLACE	
Bengalore	Director, Deptt. of Mines and Geology, Govt. of Karnataka.
	Director, C.G.W.B., Southwestern Region
	Director, DPAP/Rural Development
	Chief Engineer, W.R.D.O.
	Director, Bureau of Economics & Statistics
	Chief Engineer, Minor Irrigation
	Director, Deptt. of Revenue
	Director, Deptt. of Agriculture, Govt. of Karnataka
	Directorate of Survey Settlement & Land Records
	Directorate of State Groundwater Cell, R.C. Road
	C.E., Public Health Engg. & PWD, Govt. of Karnataka
	Central Water Commission
Kolar	E.E., Minor Irrigation
	Deputy Commissioner (Special)
	DRDA, Soil Conservation Deptt.
	Irrigation Deptt.
Tumkur	E.E., Minor Irrigation
	Deputy Commissioner
	DRDA, Soil Conservation Deptt.
	Irrigation Deptt.
Chitradurga	E.E., Minor Irrigation
	Incharge of the DPAP Projects
	DRDA, Soil Conservation Deptt.
	Irrigation Deptt.
Belgaum	E.E., Minor Irrigation
	Incharge of the DPAP Projects
	DRDA, Soil Conservation Deptt.
	Irrigation Deptt.
	Asstt.Geologist, SGWC,Belgaum

Dharwar	E.E., Minor Irrigation DRDA, Soil Conservation Deptt. Irrigation Deptt.

APPENDIX -III-(A)

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

Belgaum (Belgaum)

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
5.6.81	-	-	-
14.6.82	31.8.82	16	1
16.6.83	3.7.83	15	2
	1.9.83	14	2
9.6.84	-	-	-
10.6.85	26.8.85	21	1
8.6.86	22.8.86	26	1
9.6.87	30.8.87	17	1
6.6.88	-	-	-
4.6.89	1.7.89	18	-
	26.8.89	21	2
12.6.90	26.7.90	18	1
4.6.91	11.6.91	18	-
	25.8.91	19	2
			13

Bijapur (Bijapur)

1	2	3	4
6.6.81	18.7.81	34	2
	6.8.81	29	
7.6.82	21.6.82	23	2
	30.8.82	17	
6.6.83	14.6.83	14	3
	15.7.83	23	
	9.7.83	24	
9.6.84	10.6.84	33	2
	3.8.84	30	
4.6.85	27.6.85	23	2
	26.7.85	19	
4.6.86	18.6.86	26	2
	23.7.86	55	
4.6.87	5.6.87	21	3
	27.6.87	33	
	18.8.87	29	
6.6.88	-	-	-
4.6.89	25.7.89	32	1
6.6.90	18.6.90	52	-
	19.8.90	28	2
6.6.91	11.6.91	17	-
	29.7.91	49	2
			21

Gulburga (Gulburga)

1	2	3	4
4.6.81	6.7.81	17	2
	15.8.81	18	
17.6.82	18.6.82	16	2
	9.8.82	32	
5.6.83	25.6.83	17	1
11.6.84	18.6.84	15	2
	9.6.84	20	
6.6.85	19.6.85	32	1
4.6.86	22.6.86	25	2
	14.8.86	25	
15.6.87	18.7.87	20	1
4.7.88	-	-	-
4.6.89	25.7.89	26	1
6.6.90	15.6.90	24	-
	26.7.90	14	-
	18.8.90	19	3
6.6.91	21.8.91	26	1
			16

Raichur (Raichur)

1	2	3	4
7.6.81	8.7.81	15	1
22.6.82	4.6.82	18	3
	5.8.82	18	
	27.8.82	19	
16.6.83	-	-	-
10.6.84	6.8.84	36	1
15.6.85	1.7.85	18	3
	31.7.85	14	
	15.8.85	25	
1986	date not available		
1987	date not available		
9.6.88	-	-	-
7.6.89	8.6.89	17	-
	25.7.89	19	2
9.6.90	17.6.90	18	-
	17.7.90	22	-
	19.8.90	16	3
6.6.91	23.8.91	19	1
			14

Dharwar (Dharwar)

1	2	3	4
4.6.81	-	-	-
8.6.82	21.6.82	25	2
	24.8.82	33	
13.6.83	2.7.83	15	2
	26.7.83	15	
12.6.84	3.8.84	44	1
17.6.85	-	-	-
5.6.86	1.7.86	14	2
	14.8.86	33	
17.6.87	10.7.87	27	2
	26.8.87	20	
9.6.88	-	-	-
4.6.89	27.7.89	16	-
	29.8.89	17	2
1990	Data not available	-	
5.6.91	30.6.91	15	-
	30.8.91	14	2
			13

Bellary (Bellary)

1	2	3	4
7.6.81	18.6.81	33	2
	3.8.81	23	
8.6.82	13.6.82	26	2
	3.8.82	43	
14.6.83	26.6.83	15	2
	26.7.83	17	
18.6.84	4.6.84	14	4
	27.6.84	16	
	3.8.84	20	
	1.9.84	15	
6.6.85	10.6.85	42	2
	29.7.85	41	
4.6.86	17.6.86	16	3
	4.7.86	28	
	6.8.86	35	
24.6.87	4.6.87	20	3
	29.6.87	37	
	16.8.87	20	
8.7.88	4.6.88	37	2
	21.7.88	25	
4.6.89	5.6.89	22	1
14.6.90	15.6.90	23	-
	17.7.90	23	-
	15.8.90	22	3
6.6.91	13.6.91	15	-
	30.6.91	32	-
	4.8.91	43	3
			27

APPENDIX III-(B)

Probability Analysis of Dry Spells.

Taluk (Distt.)	Class Interval (days)	No. of Spells	Percentage	Cumulative Probability
Belgaum (Belgaum)	14-21	12	82.3	100.0
	22-28	1	7.7	7.7
	29-35	-	-	-
	> 35	-	-	-
		13		
Bijapur (Bijapur)	14-21	5	23.8	100.0
	22-28	6	28.6	76.2
	29-35	7	33.4	47.6
	> 35	3	14.2	14.2
		21		
Gulburga (Gulburga)	14-21	9	56.3	100.0
	22-28	5	31.2	43.7
	29-35	2	12.5	12.5
	> 35	-	-	-
		16		
Raichur (Raichur)	14-21	11	78.6	100.0
	22-28	2	14.3	21.4
	29-35	-	-	7.1
	> 35	1	7.1	7.1
		14		
Bellary (Bellary)	14-21	10	37.1	100.0
	22-28	8	29.6	62.9
	29-35	3	11.1	33.3
	> 35	6	22.2	22.2
		27		
Dharwar (Dharwar)	14-21	8	61.5	100.0
	22-28	2	15.4	38.5
	29-35	2	15.4	23.1
	> 35	1	7.7	7.7
		13		

LIST OF OBSERVATION WELLS

STATE-KARNATAKA

DISTT-BIJAPUR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUINCED BY WELL(Sq.Km.)	AREA WEIGHT
1.		DADAMI	15 54 00	75 37 00	593.95	2487	0.1457
2.		BILGI	16 26 51	75 36 55	555.75	3393	0.1988
3.		MALAPUR	16 21 26	75 16 34	561.00	1852	0.1085
4.		MUDDEBEHAL	16 20 14	76 08 06	548.10	2692	0.1577
5.		SHIVANGI	16 48 47	75 59 12	570.95	3148	0.1844
6.		HUNGUND	16 03 38	76 03 26	570.70	2385	0.1397
7.		RUGI	17 05 15	75 57 00	468.90	1113	0.0652

STATE-KARNATAKA

DISTT-BELGAUM

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUINCED BY WELL(Sq.Km.)	AREA WEIGHT
1.		ATHANI	16 43 45	75 03 37	564.00	1529.51	0.1136
2.		CHIKKODI	16 35 25	74 35 25	643.00	1721.70	0.1279
3.		ANKALAGI	16 01 30	74 41 45	670.00	2824.23	0.2038
4.		LONDA	15 26 58	74.29 48	610.00	3038.10	0.2257
5.		RAIBHAG	15 29 40	74 46 35	664.00	1835.85	0.1364
6.		KARI KATTI	15 43 55	75 01 30	655.00	2511.41	0.1866

STATE-KARNATAKA

DISTT-RAICHUR

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUINCED BY WELL(Sq.Km.)	AREA WEIGHT
1.		DEODURGA	16 25 00	76 56 30	440.00	1751	0.1250
2.		RAICHUR	16 13 00	77 21 30	416.00	2335	0.1667
3.		LINGASUGUR	16 09 30	76 31 30	530.00	1985	0.1417
4.		KUSHTAGI	15 45 30	76 11 10	672.00	1401	0.1000
5.		TURVIHAL	15 46 15	76 36 00	420.00	2685	0.1917
6.		YELBURGA	15 37 00	76 01 00	639.00	1517	0.1083
7.		GANGAVATHI	15 25 00	76 31 30	420.00	1050	0.0750
8.		HOSAHALLI	15 18 30	76 19 00	470.00	1283	0.0916

STATE-KARNATAKA

DISTT-GULBERGA

SL. NO.	WELL NO.	WELL NAME	LAT.	LONG.	R.L.OF M.P.(Mts)	AREA INFLUINCED BY WELL(Sq.Km.)	AREA WEIGHT
1.		AFZALPUR	17 16 30	26 13 00	399.00	915	0.0566
2.		ALAND	17 00 33	76 34 30	504.00	2068	0.1279
3.		CHINCHOLI	17 27 50	77 25 30	409.00	1513	0.0936
4.		CHITTAPUR	17 07 30	77 05 00	424.00	818	0.0506
5.		GULBERGA	17 20 30	76 49 30	457.50	2015	0.1246
6.		JEWARGI	17 00 30	76 47 00	415.00	1764	0.1091
7.		SEDAM	17 10 45	77 17 38	430.00	1030	0.0637
8.		SHAHPUR	16 42 00	76 50 00	410.00	1499	0.0927
9.		NADWAR	16 36 30	76 29 30	500.00	1799	0.1113
10.		YADGIR	16 45 00	77 07 00	367.00	2747	0.1699

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