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DROUGHT CHARACTERISATION IN SUB-HUMID CLIMATIC REGION

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PREFACE

A regional climatic anomaly characterised by deficient supply of moisture is referred as drought. Drought is a natural, recurring feature of climate; it occurs in virtually all-climatic regimes. The droughts normally recur in continental/regional scale spreading its consequences in to entire regional or national economy. In the twentieth century, India has faced its share of drought. One could argue that the early 1980s were a turning point in Indian awareness about the need to understand better the drought phenomenon, its causes and consequences and to develop mitigation strategies to cope with its consequences. The past experiences show that the existing systems of national/state governments have not been appropriate in recognising the significance of the drought events for critical decisions in a timely fashion. Natural resources managers often may not know how sensitive their response systems have been to drought, what impacts to expect from a sever drought, or the full range of options available for adjusting their activities. Despite a decade of growing interest in the social and economic impacts of climatic fluctuations, the nation remains ill prepared to cope with unusual climate conditions.

The Drought Studies Division of National Institute of hydrology has carried out a number of studies on ' hydrological aspects of drought' in various drought prone districts of the country. These studies did evoke some successful lessons from past droughts, by diagnosing the past events of droughts, need to be profitably applied in next cases. This study was aimed to relate drought characteristics with climatic parameters in sub-humid climatic regions of the country.

This report is a part of research programme of the Drought Studies Division of this Institute. The study has been carried out by **Shri Rajendra Prasad Pandey**, Scientist C, under the Guidance Dr. Bhupendra Soni, Scientist E & Head, Drought Studies Division. Shri Y. K. Dhama, Research Assistant has provided necessary help in data compilation and processing. I hope, it will point the way towards better understanding of regional drought characteristics and improved management of drought in the future.

(S. M. Seth)

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Abstract

The climatic regions are defined in terms of two readily available climatic parameters: (1) ratio of mean annual precipitation to global terrestrial mean annual precipitation, and (2) ratio of mean annual potential evapotranspiration to mean annual precipitation (E_p/P_a). As a first part of the study of drought characteristics across the climatic regions, this study has been limited to sub-humid climatic regions falling over different parts of the country. The study revealed that the drought frequency, and intensity have significant relationship with the above regional climatic parameters. Average drought frequency (yr) is seen to increase gradually from dry to wet regions, from 4 years in the regions with $E_p/P_a \geq 2$ to >8 years in the regions with $E_p/P_a \leq 1$.

For a given meteorological drought year, the areas with E_p/P_a ratio between 1.5-to-2.0 faced relatively more intense drought (i.e., severe drought) than the areas with E_p/P_a ratio between 1.0-to-1.5. The occurrence of severe or extreme droughts are much rare in the regions having E_p/P_a ratio less than 1.0. This revealed that the sub-humid region with greater mean annual deficit are susceptible to face relatively more intense drought.

The drought duration is seen to vary between 1 and 5 years in the sub humid climatic regions. The median value of drought of longest drought persistence among the different locations in sub-humid regions is 2 years. However no relationship could be established between drought duration and E_p/P_a ratio.

These results of drought characterization can be used as a framework for the systematic analysis of droughts and planning of drought management strategies in sub-humid climatic regions in India.

1.0 Introduction

Drought is a natural climatic phenomenon characterized by a deficiency of precipitation which has an adverse effect on plants, animals, or humans. Palmer (1965) has defined a drought at a given location, as a period of time, lasting months or years, during which the actual moisture supply consistently falls short of the climatically expected moisture supply. There are several types of droughts. Meteorological drought refers to a deficiency of precipitation, without regard to the application. Hydrological drought is associated with a long term lack of water in soil profiles and fresh water bodies, in an amount sufficient to affect their normal use. Agricultural drought refers to a short term soil moisture deficiency in an area which normally receives sufficient moisture to sustain crops and livestock (Karl and Young, 1987). Socioeconomic drought is associated with a deficiency of water needed to meet the demand for industrial and urban activities.

Droughts are intimately connected with the human experience, i.e., they are relatively better documented in subhumid and semiarid regions, where humans tend to concentrate (Lugo and Morris, 1982). Data for droughts in hyperarid regions is likely to be scant, since very few people will be actually affected (Campbell, 1968). Likewise, droughts in hyperhumid regions will go largely unnoticed, since the supply of water is likely to far exceed the actual demand.

Droughts are characterized by their duration, intensity, and frequency. Drought duration is the period of time when there is a deficiency of precipitation, preceded and followed by periods when there is no deficiency. Drought intensity refers to the extent to which actual precipitation is lesser than the mean, i.e., the precipitation deficit, when the precipitation deficit is accumulated through out the drought duration. Drought frequency refers to the number of years that it would take a drought of a certain intensity to recur, in units of yr; for instance, once in 10 yr. The reciprocal of the frequency is the return period or recurrence interval. In common usage, however, frequency and return period are often used interchangeably, for instance, a frequency of 10 yr.

Droughts are regional in nature, i.e., they are driven by regional climatic conditions. Therefore, their occurrence is related to regional climatic parameters. The most common climatic parameter is mean annual precipitation, which depends on several factors, among them: (1) latitude, (2) season, (3) orographic factors, (4) proximity to oceans, (5) mesoscale atmospheric circulation, (6) atmospheric pressure, and (7) character of the Earth's surface. Another common climatic parameter is mean annual potential evapotranspiration, which depends on: (1) net solar radiation, (2) vapor pressure deficit, (3) surface roughness, and (4) leaf area index (Monteith, 1965).

Here an attempt has been made to relate drought characteristics with climatic parameters in subhumid climatic regions. The climatic regions are defined in terms of mean annual precipitation, or alternatively, in terms of mean annual potential evapotranspiration. It is believed that a characterization in terms of either of these two parameters provides an appropriate framework for the systematic analysis of droughts.

Droughts are recurring natural phenomena; therefore, they cannot be prevented. However, coping with droughts is possible through proper forecast and planning. To reduce the impact of drought hardship, it is necessary to develop a capability to forecast its characteristics, i.e., its duration (How long will it last?), its intensity (How severe will it be?), and its frequency (How often will it recur?). Once these characteristics are known for a given climatic region, they can be used as a management tool for drought mitigation.

While there is an extensive global literature on droughts, but its systematic documentation is lacking, and this has led to some confusion. We have reviewed the literature in support of a relationship between the drought characteristics and the regional climatic parameters. Since we are attempting to relate the drought variability with regional climatic variability, it is expected that climatic changes will lead to changes in drought characteristics. Climatic changes attributable to anthropogenic activities are now being examined throughout the world (IPCC, 1996). There is a wide belief that climatic changes will intensify floods and droughts even before the changes in temperature are severe enough to be noticed (Bruce, 1994; Houghton, 1994).

2. 0 Drought Prone areas in India

In terms of geographical area and population, drought prone area accounts for nearly One-Third of total area of the country and 29% of the population (Sikka, 1986; CWC, 1982). Drought prone areas fall in three broad regions of the country. The plateau region embodies states of Andhra Pradesh, Karnataka, Maharastra, Madhya Pradesh, Orissa, Tamil Nadu, Bihar, West Bengal and Uttar Pradesh; second, desert region encompasses the states of Rajasthan and Gujrat; and third, few districts in the states of Haryana and Jammu & Kashmir also encompass drought prone areas. Statewise, percentage of the geographical areas identified as drought prone are presented in Table 1.0 (CWC, 1982).

Table 1.0: Percentage of geographical drought prone area in different states in India

Sl. No.	Name of the State	% of drought prone area to the total geographical area of the state
1	Andhra Pradesh	45%
2	Bihar	25%
3	Gujrat	62%
4	Haryana	38%
5	Jammu & Kashmir	3%
6	Karnataka	79%
7	Madhya Pradesh	20%
8	Maharashtra	40%
9	Orissa	15%
10	Rajasthan	63%
11	Tamil Nadu	64%
12	Uttar Pradesh	15%
13	West Bengal	30%

3.0 Climatic Classification

The climatic spectrum is defined in terms of two readily identified parameters: (1) mean annual precipitation, and (2) mean annual potential evapotranspiration. This type of characterization is particularly useful for midlatitudinal regions, where droughts are shown to be more intense (Karl, 1983). To characterize the climatic spectrum in midlatitudinal regions, the ratio of local mean annual precipitation (P_a) to global terrestrial mean annual precipitation (P_g) has been used. The global terrestrial mean annual precipitation is subjected to interpretation. The average moisture in the atmosphere depends on latitude and climate, varying typically in terrestrial regions in the range 2 - 50 mm (2 -15 mm for polar and arid regions, to 45-50 mm for humid regions) (Unesco, 1978). Thus, we can assume a mean global terrestrial value of 25 mm. This moisture recycles every eleven days on the average, for a total of 33 annual cycles (L'vovich, 1979), which results in the global terrestrial mean annual precipitation of P_g = 825 mm.

For comparison, L'vovich's (1979) has estimated a value of 910 mm for exorheic drainages (78.4 percent of total terrestrial area), and 238 mm for endorheic drainages (21.6 percent). This amounts to a weighted value P_g = 765 mm. Here we assume a value P_g = 800 mm (i.e., at the middle of the climatic spectrum the global terrestrial mean annual precipitation amounts to 800 mm).

The middle of the climatic spectrum is taken as $P_a/P_g = 1$. Thus, regions with $P_a/P_g < 1$ have less average moisture. Conversely, regions with $P_a/P_g > 1$ have more average moisture. Terrestrial mean annual precipitation varies typically in the range 100-6000 mm (Baumgartner and Reichel, 1975). Thus, the climatic spectrum is divided into the following eight regions:

1. Superarid, with $P_a/P_g < 1/8$.
2. Hyperarid, with $1/8 \le P_a/P_g < 1/4$.
3. Arid, with $1/4 \le P_a/P_g < 1/2$.

4. Semiarid, with $1/2 \leq P_a/P_g < 1$.

5. Subhumid, with $1 \leq P_a/P_g < 2$.

6. Humid, with $2 \leq P_a/P_g < 4$.

7. Hyperhumid, with $4 \leq P_a/P_g < 8$.

8. Superhumid, with $P_a/P_g \geq 8$

The climatic spectrum can also be characterized by the ratio of mean annual potential evapotranspiration (E_p) to mean annual precipitation. Potential evapotranspiration of a terrestrial ecosystem is the amount of evapotranspiration that would take place under the assumption of an ample supply of moisture at all times (Thornthwaite et al.,1944).

To determine suitable E_p/P_a ratios, we have used the estimated value mean annual potential evapotranspiration for midlatitudinal regions, across the climatic spectrum, based on experience (Vysotskii, 1905; Ivanov, 1948; WMO, 1975). For instance, we estimate E_p = 3000 mm at the limit between superarid and hyperarid regions. Since in this case $P_a/P_g = 1/8$, and P_g = 800 mm, then P_a = 100 mm. Therefore, the ratio $E_p/P_a = 30$. Corresponding estimates of mean annual evapotranspiration for other climatic regions led to the E_p/P_a values are detailed below:

1. Superarid, with $E_p/P_a \geq 30$.

2. Hyperarid, with $30 > E_p/P_a \geq 12$.

3. Arid, with $12 > E_p/P_a \geq 5$.

4. Semiarid, with $5 > E_p/P_a \geq 2$.

5. Subhumid, with $2 > E_p/P_a \geq 3/4$.

6. Humid, with $3/4 > E_p/P_a \geq 3/8$.

7. Hyperhumid, with $3/8 > E_p/P_a \geq 3/16$.

8. Superhumid, with $E_p/P_a < 3/16$.

These limits are to be taken as an indication of general trends, and not necessarily as exact values separating climatic regions. For P_a/P_g , the values vary between 1/8 and 8, increasing gradually in a geometric progression. This classification closely matches existing classifications (Bull, 1991; Dutt, 1986). For E_p/P_a the values vary between 30 and 3/16, decreasing gradually based on experience.

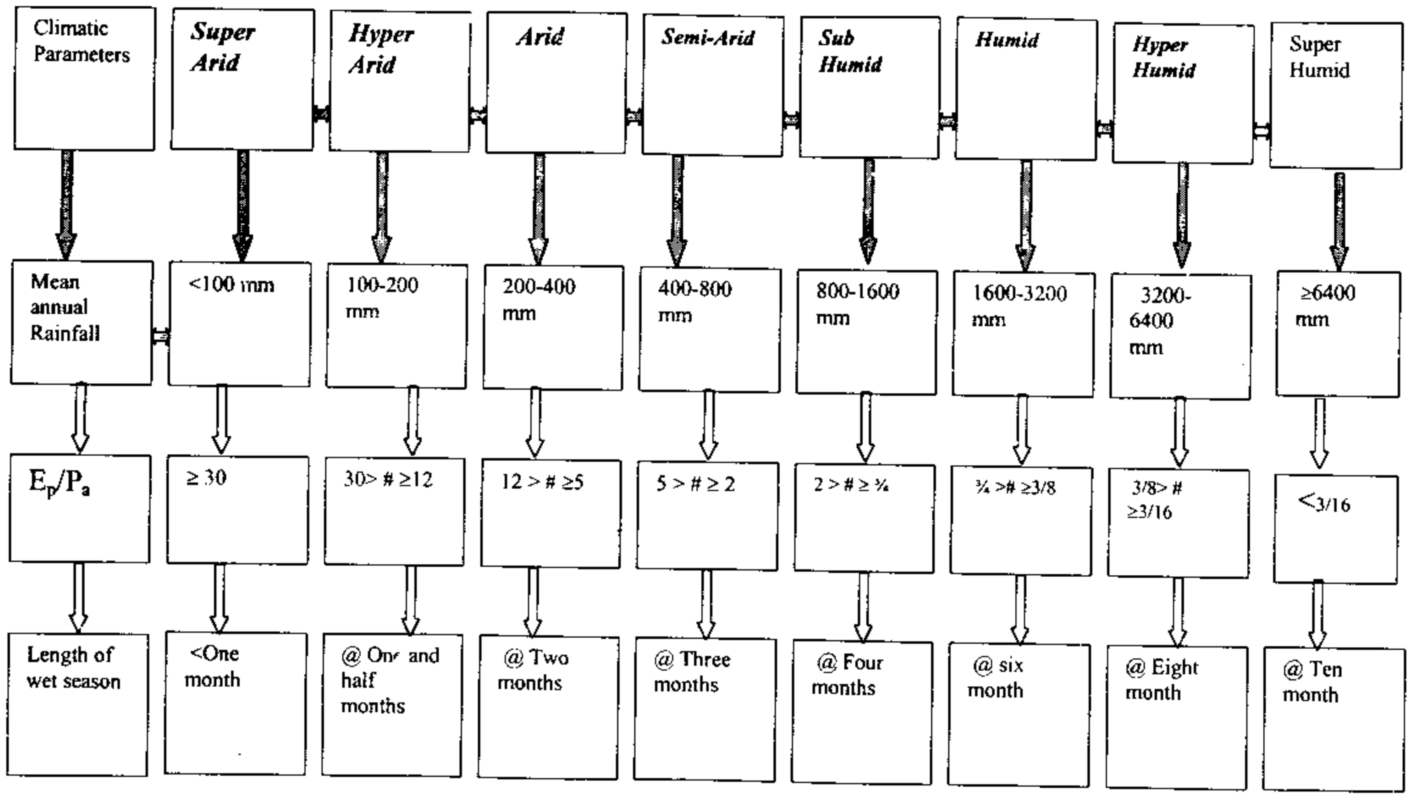
In view of the Indian conditions, the above classification is completely justified as the high rates of evapotranspiration prevail over arid Rajastan, in western India, with annual rates exceeding 2000 mm and reaching 2500 mm in some parts of Northwest Rajastan (Abbi, 1974). Low rates of evapotranspiration prevail over humid Assam and the Himalayan Bengal, in northeastern India, with annual rates in the range of 1200 to 1500 mm. Over the central parts of India, which are semiarid to subhumid, evapotranspiration rates vary in the range 1400-1800 mm (Abbi, 1974; Rao, 1971).

Mean annual precipitation and potential evapotranspiration data from Australia also supports the values chosen in climatic classification (Fig.1). For instance, in hyperarid William Creek, in south Australia, precipitation is 127 mm and potential evapotranspiration is in the order of more than 2540 mm. In arid Alice Springs, in the Northern Territory, precipitation is 250 mm and potential evapotranspiration is 2460 mm. In semiarid/subhumid Perth, in Western Australia, precipitation is 890 mm and potential evapotranspiration is 1670 mm. In subhumid Sydney, in New South Wales, precipitation is 1200 mm, and evapotranspiration exceeds 1220 mm (Kendrew, 1961).

The middle of the climatic spectrum has four months of wet season. The length of the wet season is shortest in arid regions (one month), and longest in humid regions (ten months) (Sinha et al., 1987).

The following flowchart (Fig.1) presents climatic classification at a glance.

Fig. 1 : Flow Chart Showing Climatic Classification at a Glance



4.0 Drought characteristics

A drought year is one with less than average precipitation. A drought event is a series of one or more consecutive drought years. A meteorological drought can have a duration of one or more years. Drought persistence is the tendency of a drought event to last more than one year. For instance, a 4 yr drought is a very persistent drought.

Drought intensity refers to the extent of the precipitation deficit. There are many methods to measure drought intensity (WMO, 1989). A popular method in the United States is the Palmer Drought Severity Index (PDSI), which is strictly applicable to midlatitudinal regions (Gregory et al., 1997). The PDSI classifies drought intensity into six classes (Alley, 1984):

1. Near normal, $0 \geq$ PDSI > 0.5,
2. Incipient, $-0.5 \geq$ PDSI > 1.
3. Mild, $-1 \geq$ PDSI > -2
4. Moderate, $-2 \geq$ PDSI > -3
5. Severe, , $-3 \geq$ PDSI > -4
6. Extreme, PDSI ≥ -4

To determine drought intensity, the moisture deficiency is accumulated over the drought duration. Therefore, drought intensity is related to drought duration. Since dry periods are generally followed by corresponding wet periods. it follows that drought frequency is always greater than drought duration. Since the minimum duration of a meteorological drought is one year, the minimum frequency is two years.

The experiences reported in literature show that the tendency of droughts to last longer in the middle of the climatic spectrum (WMO, 1975; Karl, 1983; Johnson and Kohne, 1993). Here, the middle of the climatic spectrum refers to the semi-arid and sub-humid regions. The drought duration (D) vary between 1 and 4 yr, reaching a maximum towards the middle of the climatic spectrum (4 yr), and decreasing towards either extream (1 yr). The changes in drought duration across the climatic spectrum point to the regional, rather than local, nature of persistence (Unesco-WMO, 1985).

Using long term series of rainfall data (Koteswaram, 1970; Dutt, 1986) reported the periodicity of drought broadly in different meteorological sub-divisions as follows:

Meteorological sub-divisions	**Recurrence of the period of high deficient rainfall**
Assam	Very rare, Once in more than 15 years.
Weast Bengal, Coastal Andhra Pradesh, Madhya Maharashtra, Kerala, Bihar and Orissa	Once in 5 years.
South Interior Karnataka, Eastern Uttar Pradesh and Vidarbha	Once in 4 years.
Gujrat, Eastern Rajasthan, Western Uttar Pradesh, Tamil Nadu, Rayalseema, Telengana and Kashmir	Once in 3 years.
Western Rajasthan	Once in 2.5 years.

The documented experiences on drought indicate that the more intense droughts (in terms of total losses) are normally faced at the semi-arid and sub-humid climatic regions, and the intensity decreases toward the wet site.

Based on the experience it can normally be stated that the arid regions, with mean annual rainfall rainfall about 400 mm or less, are expected to face more frequent drought (once in every 3-4 years on average) as compared to sub-humid or humid regions (Sastry, 1986)

Drought duration, intensity, and frequency are known to vary across the climatic spectrum (Gregory, 1989). The origin of this study is based on the following facts derived from experience:

1. Drought duration reaches a maximum of 4-5 years in the arid and semi arid regions, a typical duration to the wet side normally one year. Longer durations, i.e., persistent droughts, prevail toward the dry side of the climatic spectrum

2. Since drought intensity is actually related to amount of deficit mounted over the drought duration, droughts of higher intensities are experienced at the middle of the climatic spectrum (semiarid and subhumid regions) and intensity decreases toward both extremes (superarid and superhumid regions).

3. Average drought frequency (in terms of returned period, i.e. years) increases gradually from the dry side to the wet side of the climatic spectrum. A typical drought frequency to the dry side can be 2 yr; therefore, arid regions are subject to frequent droughts. On the other hand, a typical drought frequency to the wet side may vary from 15 yr to even 50 or 100 yr, i.e., humid regions are not subject to frequent droughts .

5.0 Review of Literature

The existing literature has been reviewed in support of the concept of this study. Drought data for the continental United States supports our statement that droughts are longer and more intense toward the middle of the climatic spectrum. Karl (1983) has shown that drought, as defined by the PDSI, has a tendency to be more persistent in the interior of the United States (High Plains and Rocky Mountain States) than in areas farther east or west. For these regions, drought duration for moderate and severe droughts varied between 3 and 5 yr. Laird et al. (1996) have documented greater drought persistence in the Great Plains of central North America than in any other part of the United States. On the other hand, Johnson and Kohne (1993) have shown that drought persistence is greater in the interior of the United States, including the states of Wyoming, Colorado, North Dakota, and Montana.

Horn (1989) studied the spatial variability of droughts in Idaho, where the mean annual precipitation varies between 250 and 1500 mm, with an average of about 800 mm (NOAA, 1980). He concluded that the median drought durations varied between 5.6 to 6.4 yr throughout the state. This confirms that typical drought duration toward the middle of the climatic spectrum may be even 6 yr.

Nearly fifty percent of the world's agricultural areas, especially the semiarid and subhumid regions, are susceptible to droughts (Gol'tsberg 1972). Thus, drought impact, as measured by drought intensity, is likely to be greater around the middle of the climatic spectrum (Lugo and Morris 1982). Over the past 1000 yr of Russian history, catastrophic droughts have occurred with a frequency of 8-12 per century, i.e. every 10 years on the average. In Kazakhstan, which is mostly hyperarid and arid (Zonn et al. 1994), around 35 severe droughts have occurred in the last 100 years, i.e., every 3 yr on the average. In the Ukraine, where climate and soils are more favorable for agricultural production than in Kazakhstan, droughts affect the area every 4-5 yr (Kogan 1997).

French (1987) has analyzed long term series of annual rainfall for Georgetown, in North Central of South Australia, where the mean annual rainfall is 475 mm. The records from 1874 to 1985 show 20 drought events, i.e. an average frequency of 5.6 yr. Ponce (1995a) has documented the drought events in the drought polygon of Northeastern Brazil during the twentieth century: 1903-04, 1915, 1919, 193032, 1942 1953,1958, 1970, 1979-83, and 1990-93. The polygon contains a variety of biogeographical regions, ranging from arid (serido'), to semiarid (caatinga and sertao), to subhumid (agreste and mata). The data suggests a drought frequency varying from 4 to 12 yr, with an average frequency of 10 yr. The drought durations varied between 1 and 5 yr. The mean annual precipitation varies between 395 mm in arid regions (caatinga) to 1831 mm in subhumid regions (mata).

Klugman (1978) has studied droughts in the Upper Midwest of the United States from 1931 to 1969. His analysis showed that while the 1930's and the 1950's were decades of drought, the 1940's and the 1960's were wet periods. This indicates an average drought frequency of 20 yr, appropriate for the subhumid climatic conditions in this region, with mean annual precipitation of about 1500 mm (NOAA, 1980).

Karl and Young (1987) have reported on drought frequency in the Southeastern United States, ranging from 20 to 60 yr. These locations are in the states of North Carolina, Georgia, and Tennessee, which have humid climates (NOAA, 1980). Ponce (1995b) has reported that hydrological droughts in the Upper Paraguay river basin, in central western Brazil, recur every 28 to 30 yr on the average, and last 3 to 6 yr. The mean annual precipitation in the Upper Paraguay river basin varies between 900 and 2000 mm, with an average of 1380 mm. This confirms that this subhumid to humid region is subject to persistent droughts at approximately 30 yr intervals.

Gregory (1989) has reported that droughts in humid regions of India such as Assam are very infrequent, and that the last documented drought in the region dates back to 1900. This confirms that droughts in humid regions are very infrequent.

Australian experience has shown that droughts are most serious where rainfall ranges between 250 and 750 mm, i.e., in arid and semiarid regions (Kendrew, 1961). This confirms that arid and semiarid regions are most susceptible to droughts.

6.0 The locations selected for study in subhumid climatic regions in the country

As a first part in the series, this study has been limited to the selected locations in subhumid climatic regions falling in the states of Madhya Pradesh. Orissa, Andhra Pradesh, West Bengal, Bihar, Maharashtra, Gujrat and Karnataka. The Long term meteorological data for 34 stations falling in subhumid climatic regions have been used for drought analysis in the 20^{th} century. All the above 34 locations belong to the drought prone areas, in the country, identified by Central Water Commission (1982). The details of the data used have been presented in Table 2.0. The years for which rainfall data is not available, have not been accounted in the analysis. To estimate potential evapotranspiration rates in midlatitudinal regions, we have used evapotranspiration data for various stations published in IMD Sci. Report No. 136 (Rao, et al. 1971). The locations selected for this study are also shown in Fig.2.

Table 2.0: Selected locations and details of data analysed for drought characterization in subhumid climatic regions

Sl. No.	Name of district	Location	Length of rainfall records Analysed	Missing data	Mean annual Precipitation (mm)	Mean annual Potential Evapotrans-piration (mm)
	(1)	(2)	(3)	(4)	(5)	(6)
1.	Betul M.P.	21° 55'N 77° 54'E	87 yrs 1901-87	--	1005.44	1372.10
2.	Dhar M.P.	22° 33'N 75° 18'E	83 yrs 1901-89	1951-56	919.31	1813.20
3.	Jhuabua M.P.	22° 47'N 74° 35'E	77 yrs 1901-87	1951-56, 62-64, 73	827.32	1518.90
4.	Khargoan M.P.	21° 49'N 75° 31'E	53 yrs 1931-89	1951-56	804.24	1728.5
5.	Sidhi M.P.	24° 24'N 81° 53'E	87 yrs 1901-89	1916, 21	1266.24	1471.90
6.	Suhagpur Shahdol, M.P.	23° 25'N 81° 26'E	80 yrs 1901-80	--	1219.99	1471.2
7.	Umaria Shahdol, M.P.	23° 35'N 80° 54'E	89 yrs. 1901-89	--	1301.72	1471.2
8	Dewas, M.P.	22° 40'N 86° 23'E	68 yrs. 1913-80	--	1071.0	1813.2
9	Datia, M.P.	25° 40'N 78° 28'E	67 yrs. 1905-77	1936, 37, 38, 48, 49, 50	803.45	1516.0
10	Shajapur, M.P.	23° 27'N 76° 16'E	67yrs. 1907-80	1925, 26, 27, 28, 63, 66, 67	1033.93	1553.0
11.	Bhawanipatna Kalahandi (Orissa)	19° 55'N 83° 10'E	84 yrs. 1901-96	1949-60	1434.3	1595.3
12.	Nawapara (Orissa)	20° 17'N 82° 46'E	67 yrs. 1918-96	1948-55, 86, 90-92,	1205.43	1496.8
13.	Phulwani (Orissa)	20° 29'N 84° 14'E	84 yrs. 1901-96	1949-60	1424.68	1481.0
14.	Balangir (Orissa)	20° 22'N 83° 29'E	36 yrs. 1961-96	--	1306.41	1872.96
15.	Boudh (Orissa)	20° 50'N 84° 19'E	80 yrs. 1903-96	1949-61, 77	1307.24	1652.0
16	Mahboob-nagar A.P.	16° 44'N 77° 59'E	85 yrs. 1901-85	--	827.63	1675.9

	(1)	(2)	(3)	(4)	(5)	(6)
17	Prakasam A.P.	15° 34'N 80° 03'E	85 yrs. 1901-85	--	840.88	1674.9
18	Chittoor A.P.	13° 13'N 79° 09'E	85 yrs. 1901-85	--	869.41	1656.2
19	Bankura, W.B.	23° 14' N 87° 04' E	60 yrs. 1901-78	1943, 46, 47, 50-52, 55-65, 77	1306.58	1408.3
20	Midnapur, W.B.	22° 25' N 87° 19' E	81 yrs. 1901-81	--	1525.27	1463.8
21	Purulia, W.B.	23° 20' N 86° 23' E	75 yrs. 1902-80	1911, 15, 23, 48	1313.45	1405.1
22	Nawada, Bihar	24° 53' N 85° 33' E	77 yrs. 1901-80	1971-73	1033.25	1661.4
23	Gaya, Bihar	24° 45' N 84° 57' E	70 yrs. 1901-74	1970-73	1130.9	1661.4
24	Munger, Bihar	25° 23' N 86° 40' E	75 yrs. 1901-80	1961-64, 67	1247.91	1458.5
25	Sasaram, Rohtas, Bihar	25° 57' N 84° 02' E	74 yrs. 1901-80	1960, 63, 65, 70-72	1141.74	1500.1
26	Aurangabad, Bihar	24° 45' N 84° 23' E	65 yrs. 1901-70	1963-65, 67, 68	1186.31	1660.8
27	Bhojpur, Bihar	25° 34' N 84° 40' E	68 yrs. 1901-69	1965	1073.81	1504.3
28	Palamu, Bihar	24° 03' N 84° 04' E	79 yrs. 1901-80	1970	1179.24	1388.3
29.	Satara, Maharastra	17° 41' N 73° 59' E	73 yrs. 1901-77	1966-69	1082.46	1687.8
30.	Hulsi, Pune, Maharastra	18° 32' N 73° 37' E	77 yrs. 1901-77	--	1587.0	1474.6
31.	Osmanabad, Maharastra	18° 10' N 76° 02' E	74 Yrs. 1901-78	1963-66	834.8	1801.3
32	Bharuch, Gujrat	21° 41' N 72° 59' E	80 Yrs. 1901-80	--	853.52	1727.8
33	Kalol, Panchmahal, Gujrat	22° 37' N 73° 38' E	79 Yrs. 1901-80	1962	1005.82	1731.20
34.	Belgaum Karnataka	15° 49'N 74° 51'E	88 yrs 1901-88	--	1349.99	1481.3

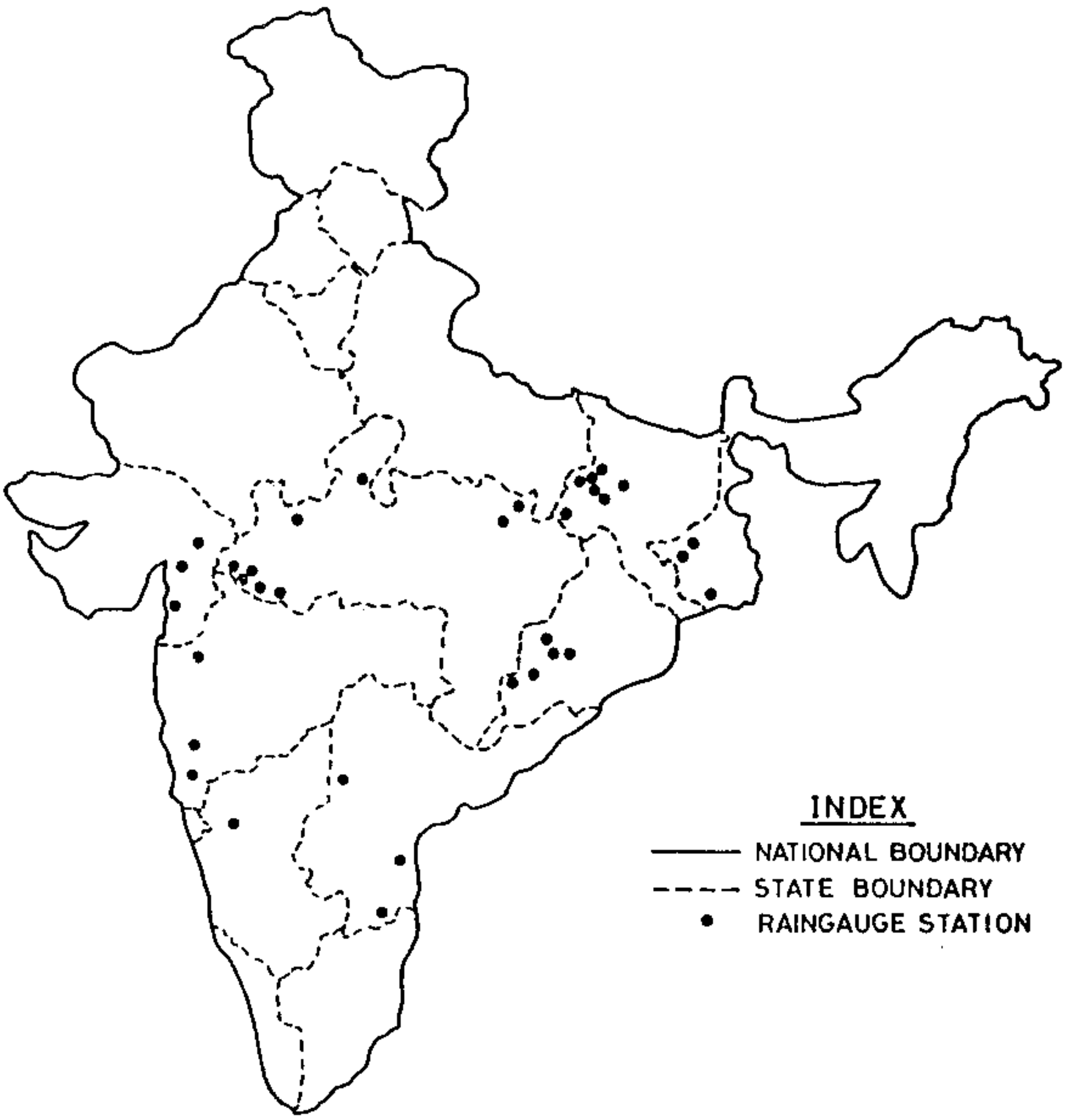


FIG. 2: LOCATION OF SELECTED STATIONS FALLING IN SUB-HUMID CLIMATIC REGIONS IN INDIA.

7.0 Methodology

Different methods have been proposed from time to time for characterization of meteorological drought. The present study is confined to meteorological drought which is solely determined by rainfall. Since drought condition is related to normal expectancy of rainfall departures from their mean at different percentage levels have been used to describe rainfall deficiency at a place or over the region. Being a percentage, it is purely qualitative and descriptive in nature which is useful to express the magnitude of drought severity in terms of rainfall deficiency.

The meteorological drought year has been identified using the criteria suggested by India Meteorological Department, i.e., "if a meteorological station/division receives total rainfall (seasonal/yearly) less than 25 percent of the normal, it is considered as a drought". For a given place with mean annual rainfall P_a and a drought year with precipitation P, a moderate drought year is defined as P/P_a between 0.75 to 0.50, a severe drought year as P/P_a between 0.50 to 0.25, and an extreme drought year as P/P_a lesst than 0.25 (Central Water Commission, 1982, National Institute of Hydrology, 1990).

In view to identify the variability of drought characteristics in selected subhumid climatic regions we have consider the following variables:

1. Ratio of local mean annual precipitation to global terrestrial mean annual precipitation P_a/P_g . The method for estimation of acceptable value of global terrestrial mean annual precipitation (P_g) has been discussed in section 3.0.
2. Ratio of local mean annual potential evapotranspiration to local mean annual precipitation E_p/P_a.
3. Median drought duration D (yr).
4. Drought intensity index I
5. Average drought frequency F (yr).
6. Drought susceptibility index S.
7. Length of the wet season L_w(mo).

The average drought frequency has been obtained as numbers of years of record analysed divided by numbers of meteorological drought years. For a given drought year, we define drought intensity (I) as the ratio of the deficit (P_a - P) to the mean (P_a). The drought intensity index I has been divided in to three categories; Moderate I_m; Severe I_s; and Extreme I_e . For a given drought event, intensity is defined as the summation of the annual intensities over the drought duration, as follows:

$$\mathbf{I} = \Sigma\left((\mathbf{P_a} - \mathbf{P}) / \mathbf{P_a}\right) \qquad (1)$$

Drought susceptibility index (S). defined as the ratio of severe drought intensity index Is to drought frequency F (yr).

$$\mathbf{S} = \mathbf{I_s} / \mathbf{F} \qquad \mathbf{(2)}$$

The long term records of annual rainfall for 34 stations in sub-humid climatic regions in India have been analysed. The length of these records varies from 36 to 89 years as given in Table 2.0. The Samples of plots of rainfall departure and drought intensity are shown in Fig. 3_a-3_j. The relationship between average drought frequency and the ratio of mean annual potential evapotranspiration E_p to mean annual precipitation P_a has been obtained. The observations have been drawn on drought intensity and drought duration in relation to climatic parameters.

Fig. :3a-3j : Plots of annual rainfall, percentage departure and drought intensity against time

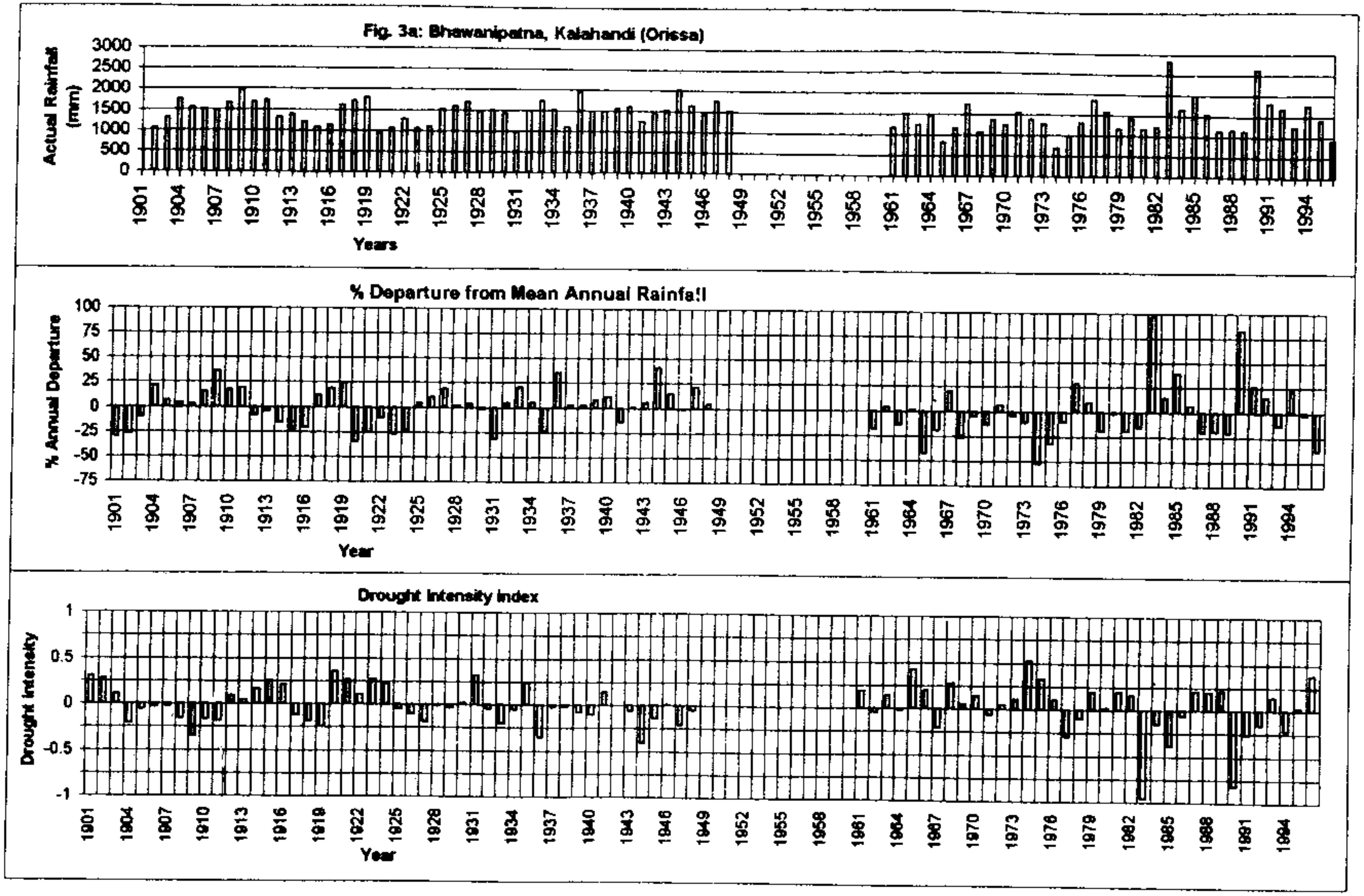
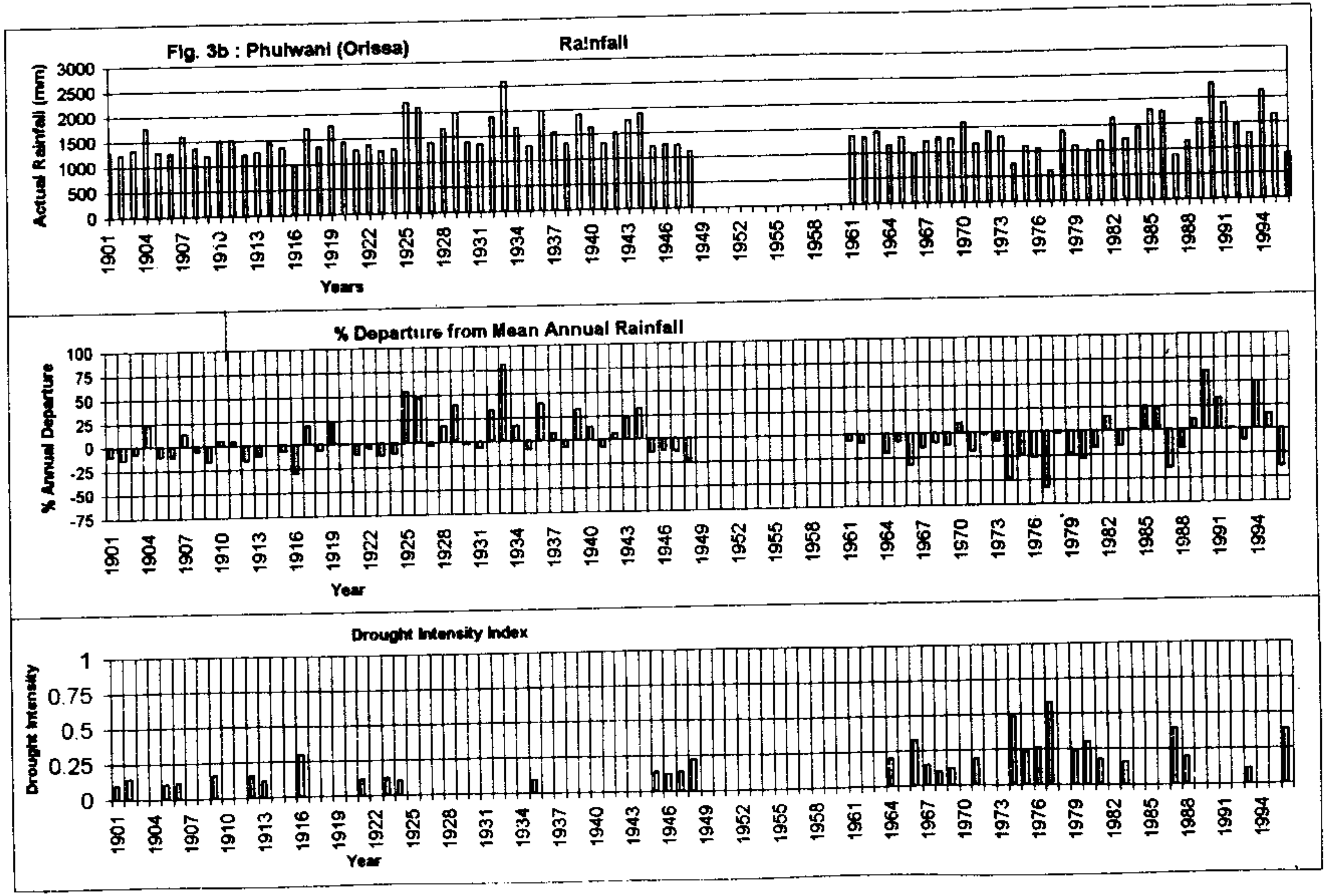


Fig. :3a-3j : Continue....



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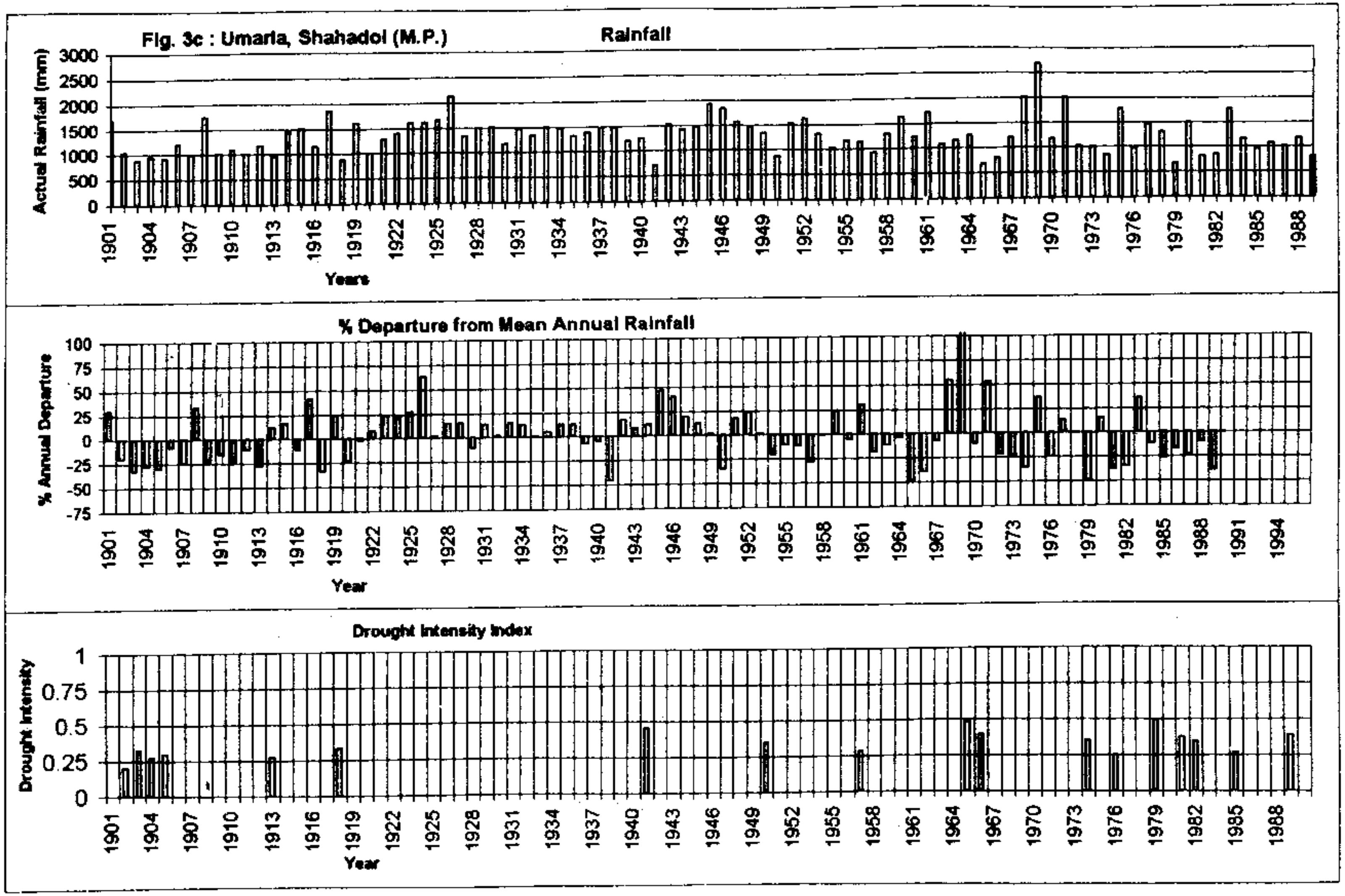

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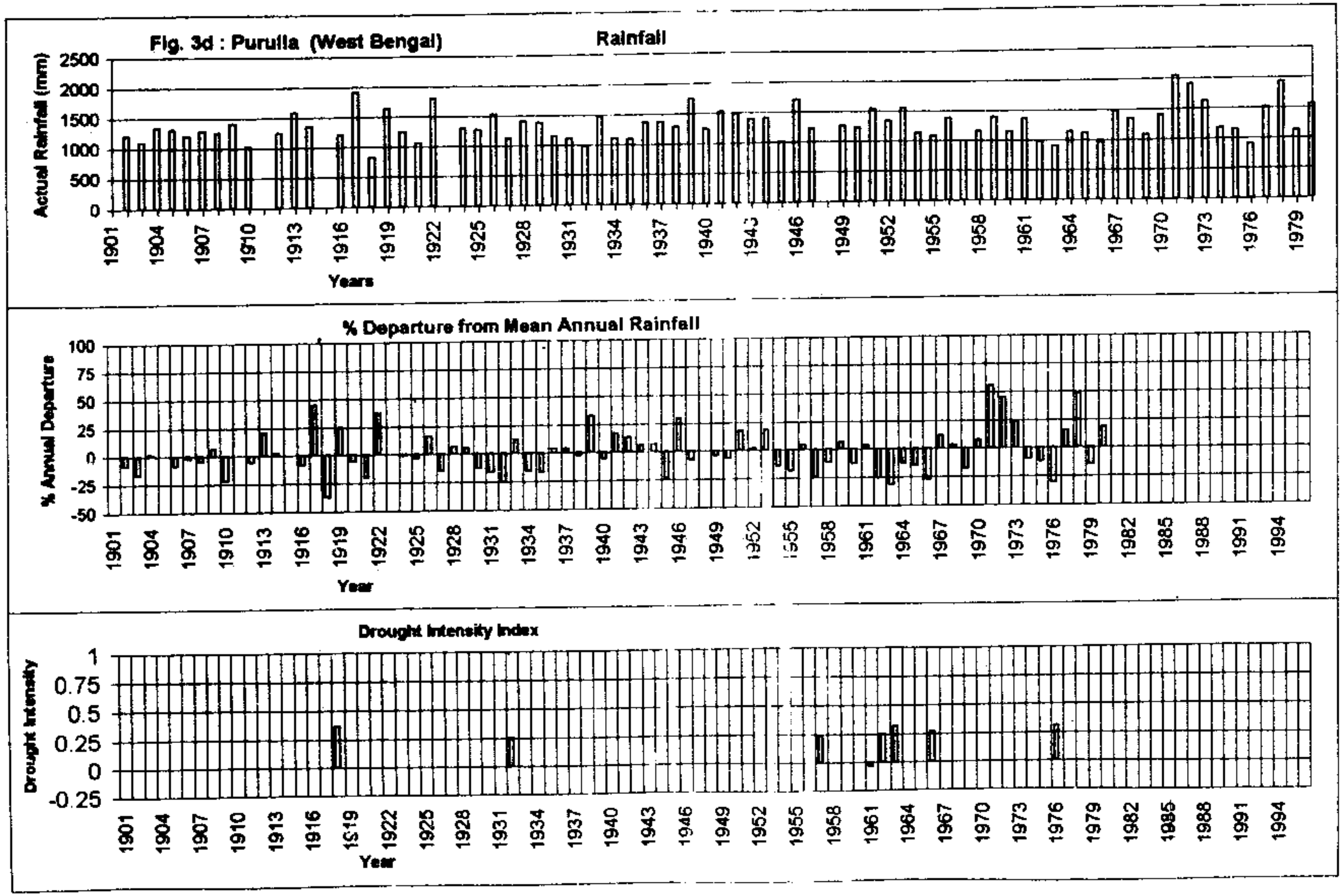

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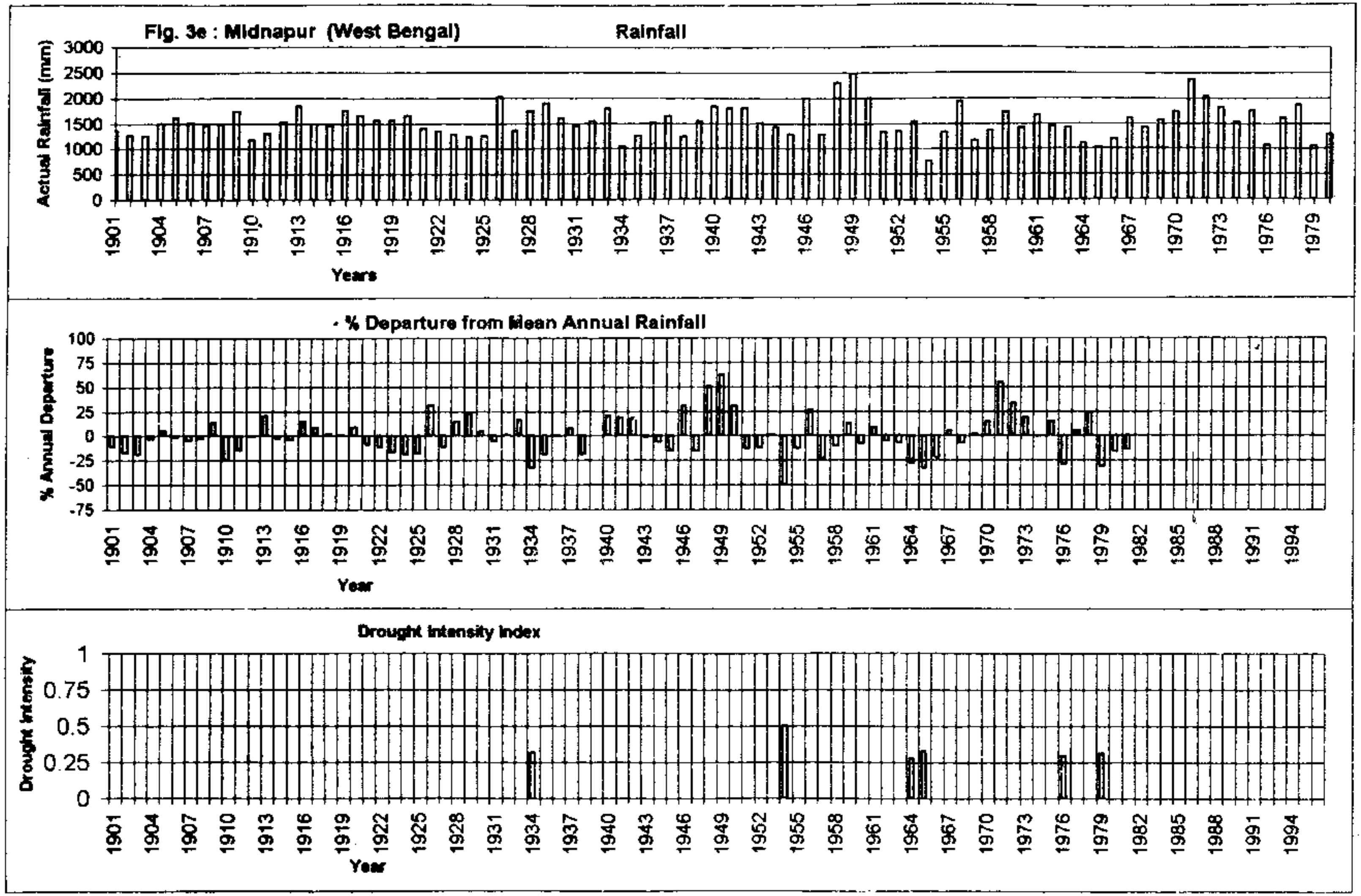

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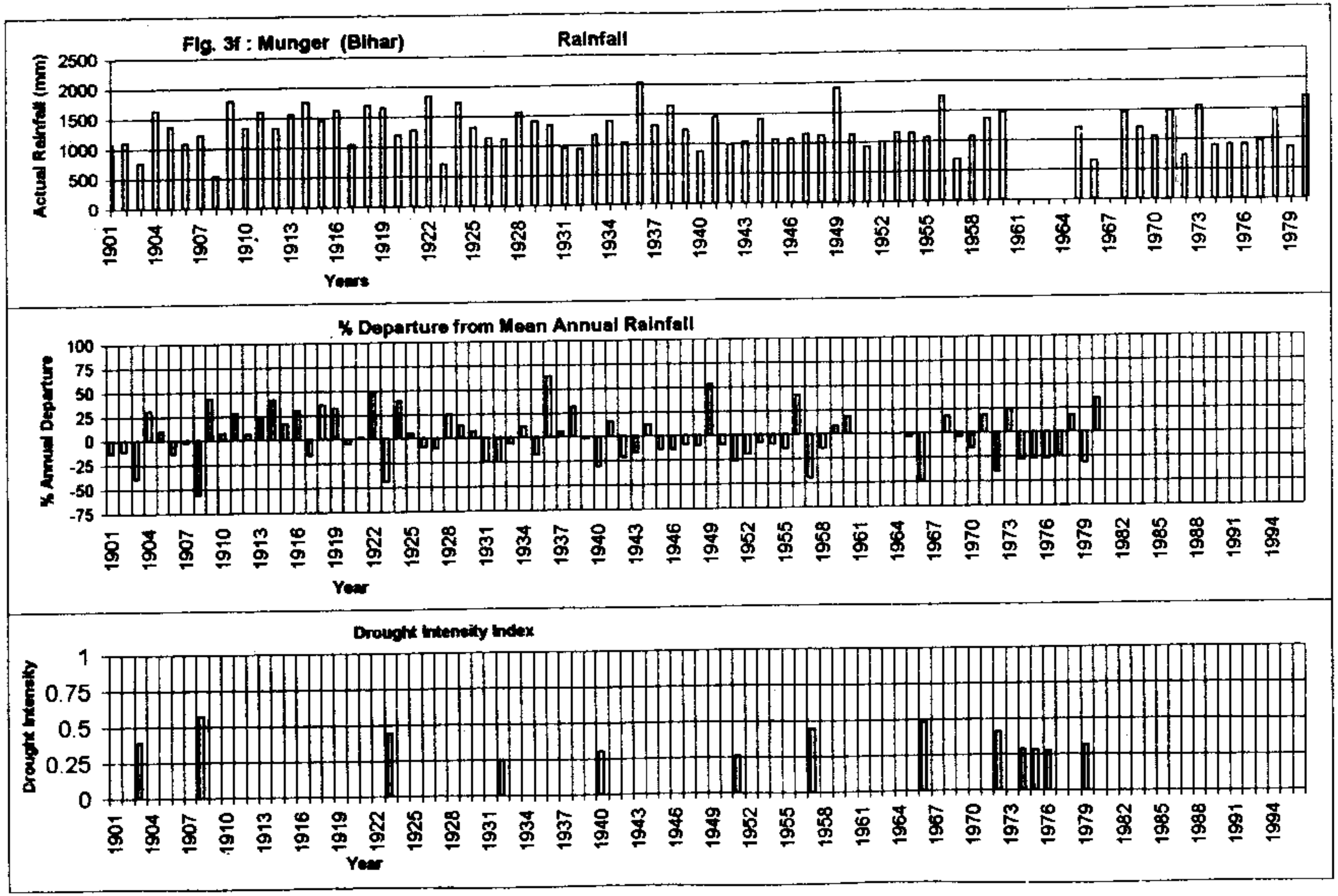

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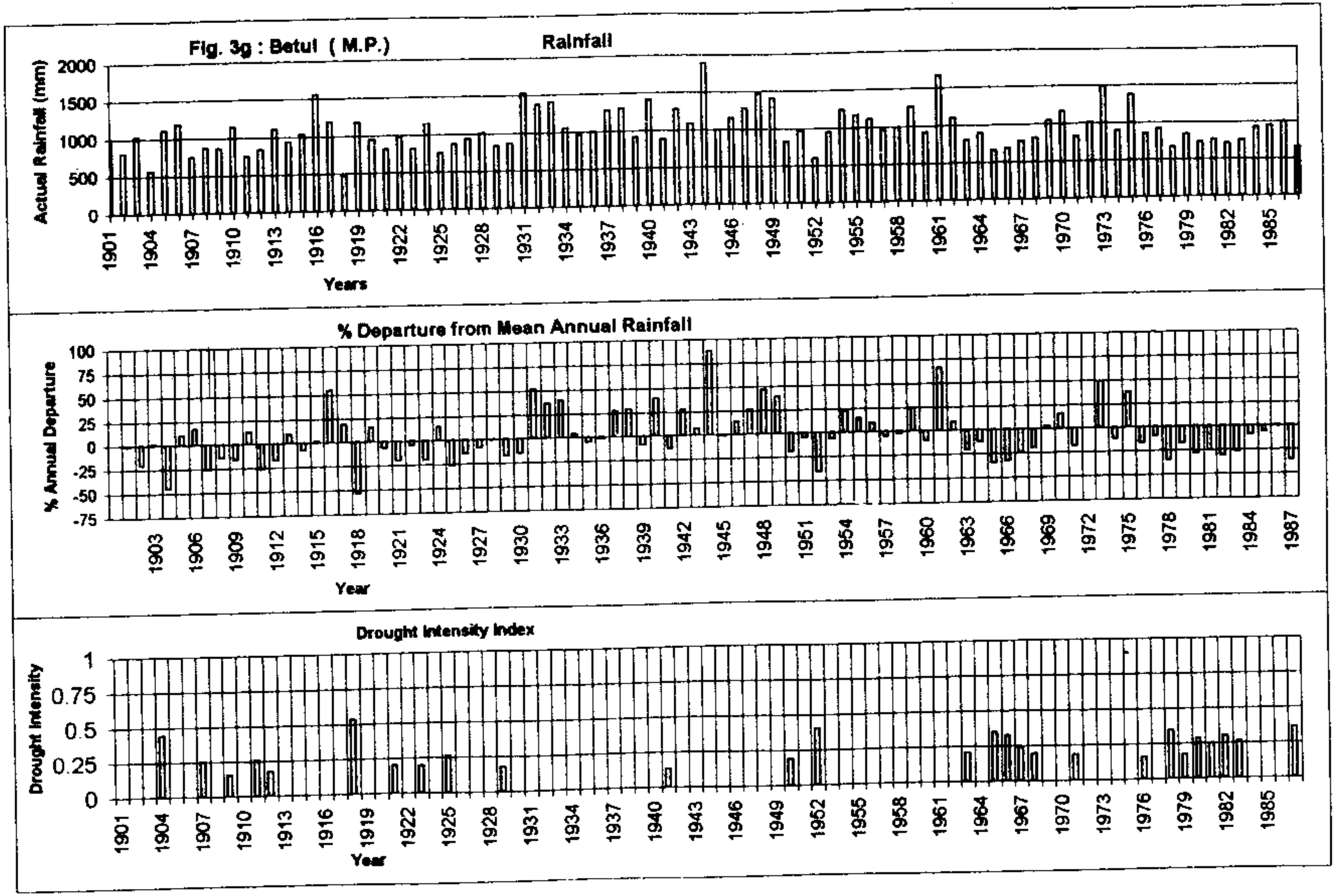


Fig. 3a-3j : Continue....

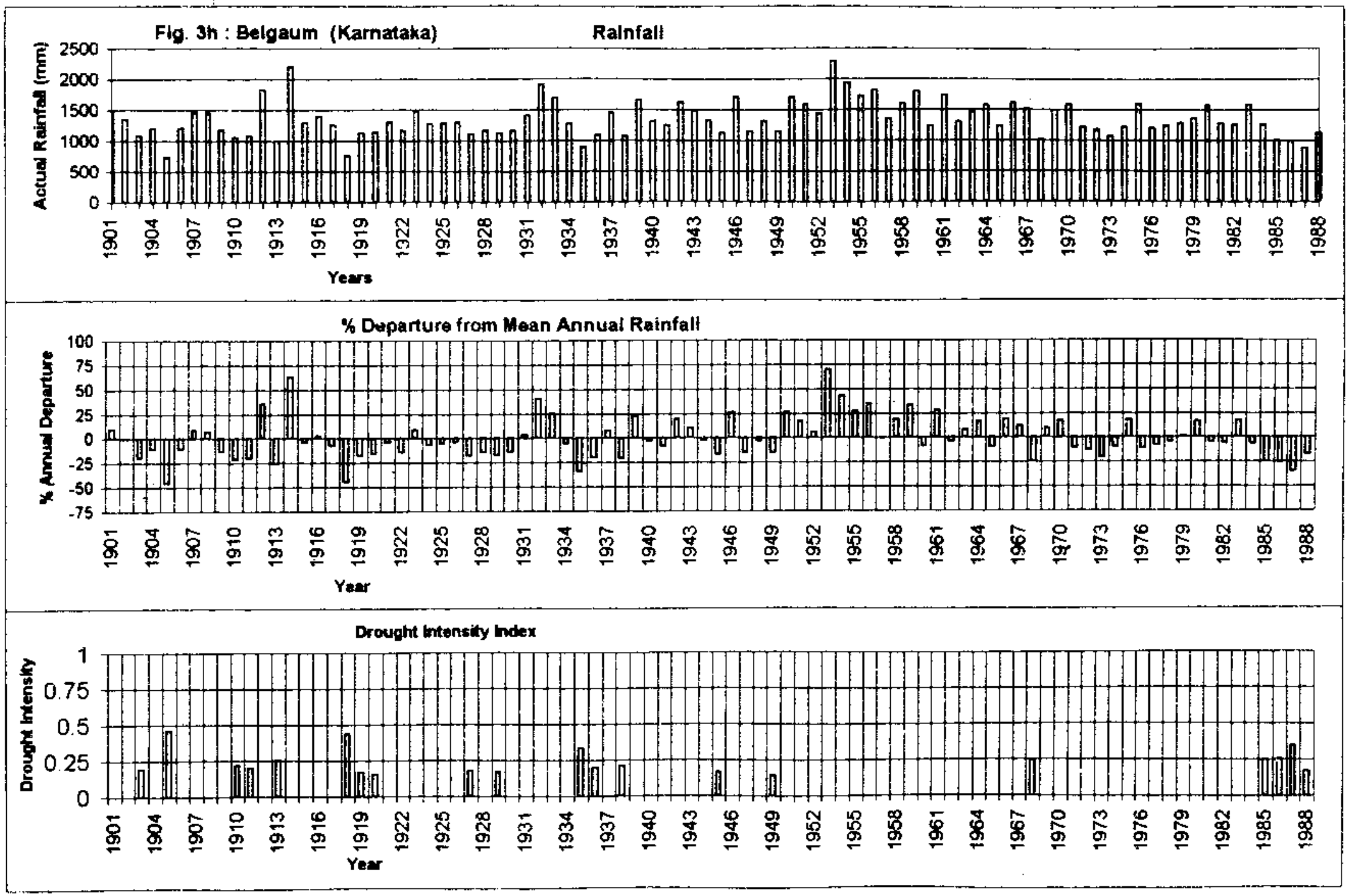


Fig. : 3a-3j : Continue...

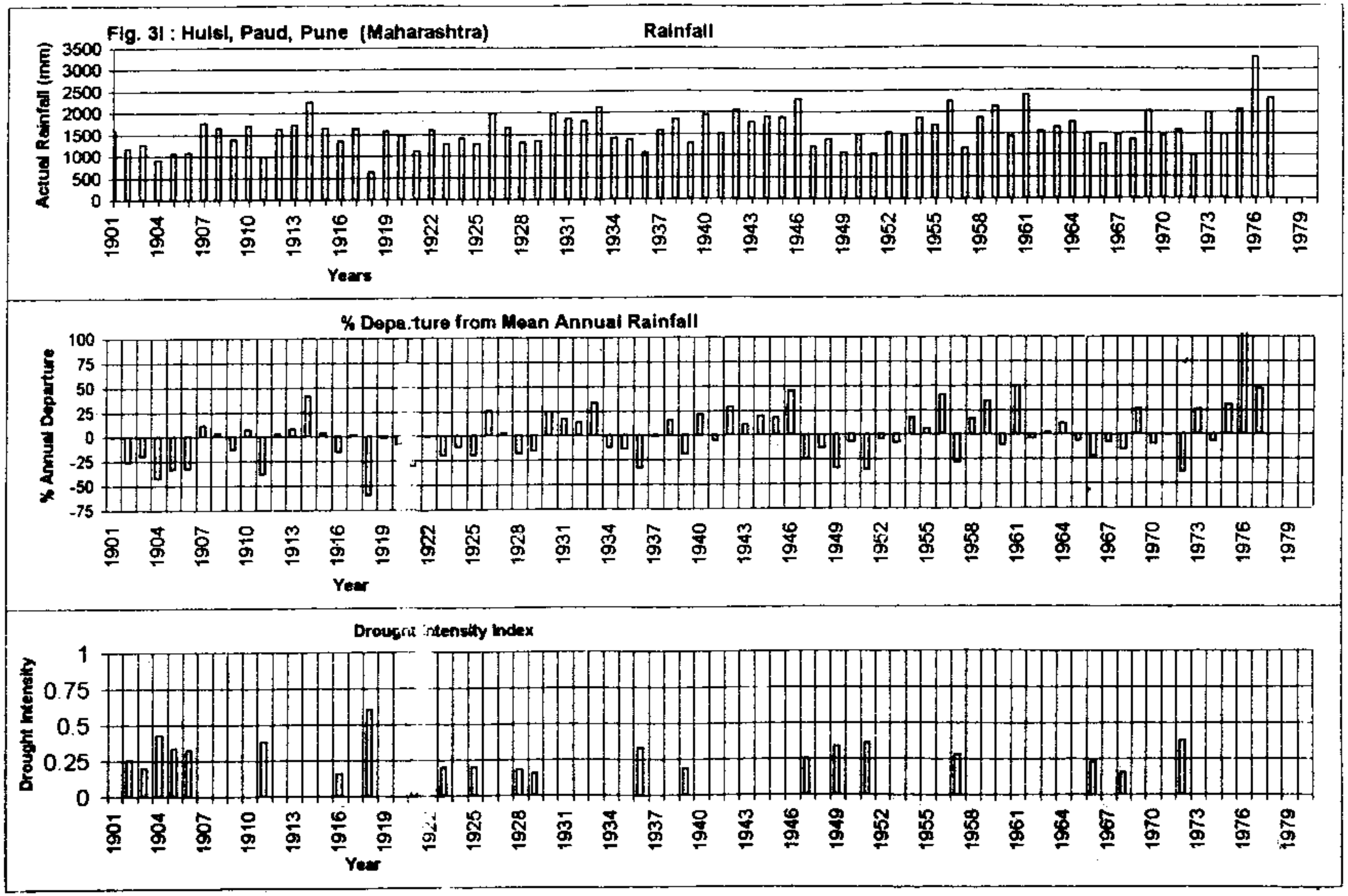
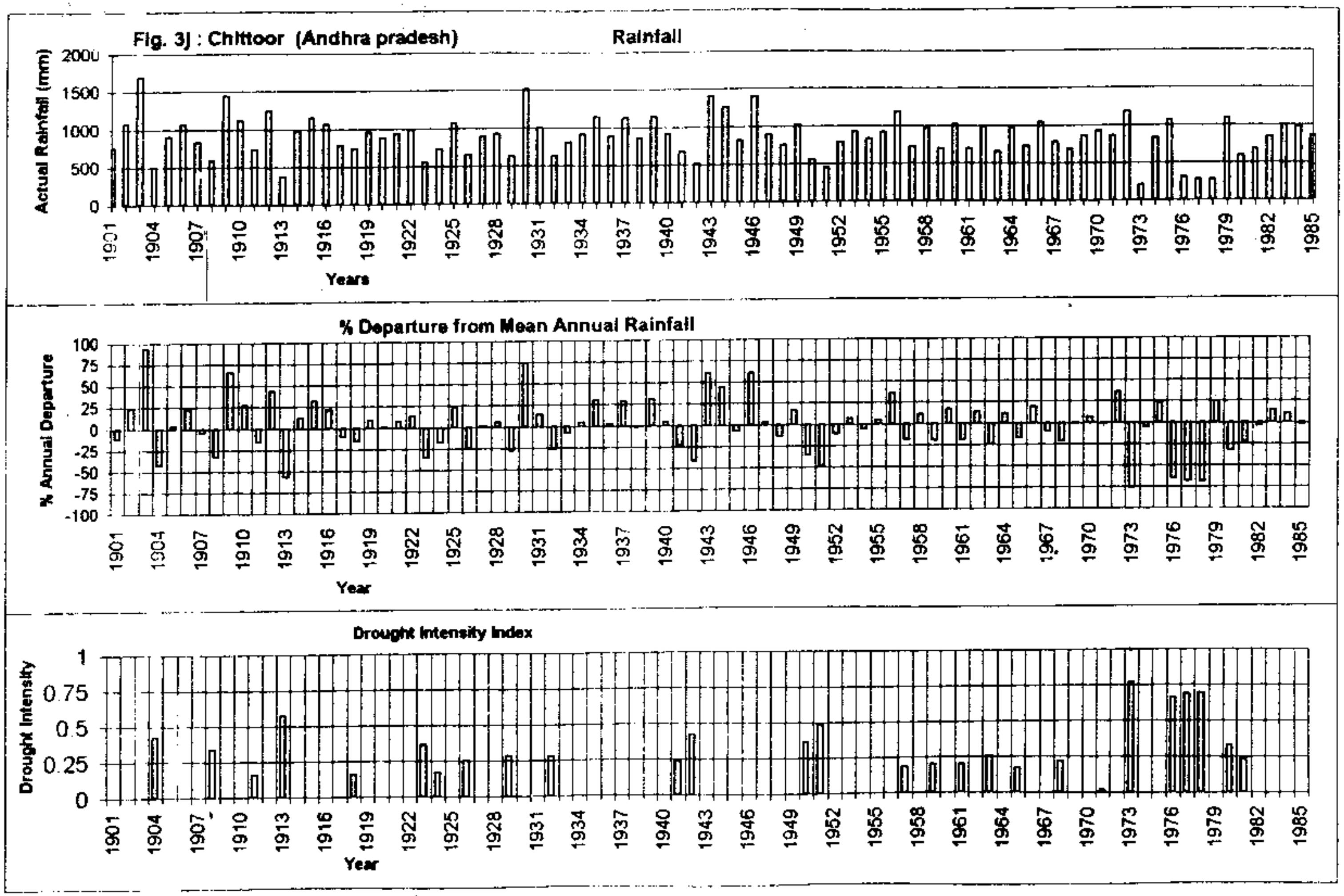


Fig. : 3a-3j : Continue....



8.0. Results and Discussions

The sub-humid climatic regions have been categorized as the areas with the mean annual rainfall between 800 mm to 1600 mm and mean annual potential evapotranspiration/precipitation ratio between 0.75 to 2.0, and having the length of wet season between three to four months. Here in this study the mean annual rainfall in the selected stations in sub-humid climatic regions of the country ranges from 803.45 mm to 1588.77 mm and the potential evapotranspiration varies from 1372.1 mm to 1872 .96 mm. The data show that there are large interannual variability of rainfall in sub-humid regions. The long-term annual rainfall series, percentage annual rainfall departure and drought intensity for different stations have been presented in Fig. 3a –3j. The average drought frequency, the maximum length of drought duration noticed in different stations/areas have been obtained from the Fig. 3a –3j. The stationwise details of analysis have been presented in Table 3.0.

A regression analysis has been carried out to relate average drought frequency with the ratio of mean annual potential evapotranspiration/precipitation (E_p/P_a). The power type regression gives better correlation as compared to the logarithmic or exponential type regression. The relationship between average drought frequency and the ratio of mean annual potential evapotranspiration to precipitation (E_p/P_a) has been shown in Fig. 4.0.

The results show that the sub-humid regions of the country have a large range of the average drought frequency i.e., from once in 4 years to the once in 14 years. Fig . 4.0 revealed that the sub-humid areas with E_p/P_a ratio between 0.75 to 1.0 have observed less frequent drought. The average drought frequency in these areas has been once in more than 8 years. For example, Midnapur, Purulia, and Bankura in West Bengal, Phulwani in Orissa and Belgaum in Karnataka state receive their mean annual rainfall in the order of more or less equal to the local mean annual potential evapotranspiration and have experienced drought with an average frequency of 14, 8, 13, 12 and 11 years respectively (*see* Table 3.0). The areas which receive total annual rainfall lesser than the local mean annual potential evapotranspiration, have experienced drought once in less than 8 years. The results show that in the sub-humid areas with E_p/P_a ratio greater than 1.75, the drought recur after every 4-5 years. For the regions with E_p/P_a ratio between 1.75 to 1.5 and 1.5-to-1.25, the average drought frequency is found to be 5 and 6 years respectively.

The estimated drought intensity for respective drought years for different stations are shown in Fig 3a-3j. The drought intensity ranges have been taken from 0.25-to-0.5 as moderate, 0.50-to-0.75 as severe and > 0.75 as extreme. A comparison of inter-station drought intensity for a given meteorological drought year indicate that the areas with E_p/P_a ratio between 1.5-to-2.0 faced relatively more intense drought than the areas with E_p/P_a ratio between 1.0-to-1.5. Also, the areas with E_p/P_a ratio between 1.5-to-2.0 faced relatively more number of severe drought as compared to the areas with E_p/P_a ratio between 1.0-to-1.5. The occurrence of severe droughts are much rare in the regions having E_p/P_a ratio less than 1.0. This revealed that the sub-humid region with greater mean annual deficit are susceptible to face relatively more intense drought.

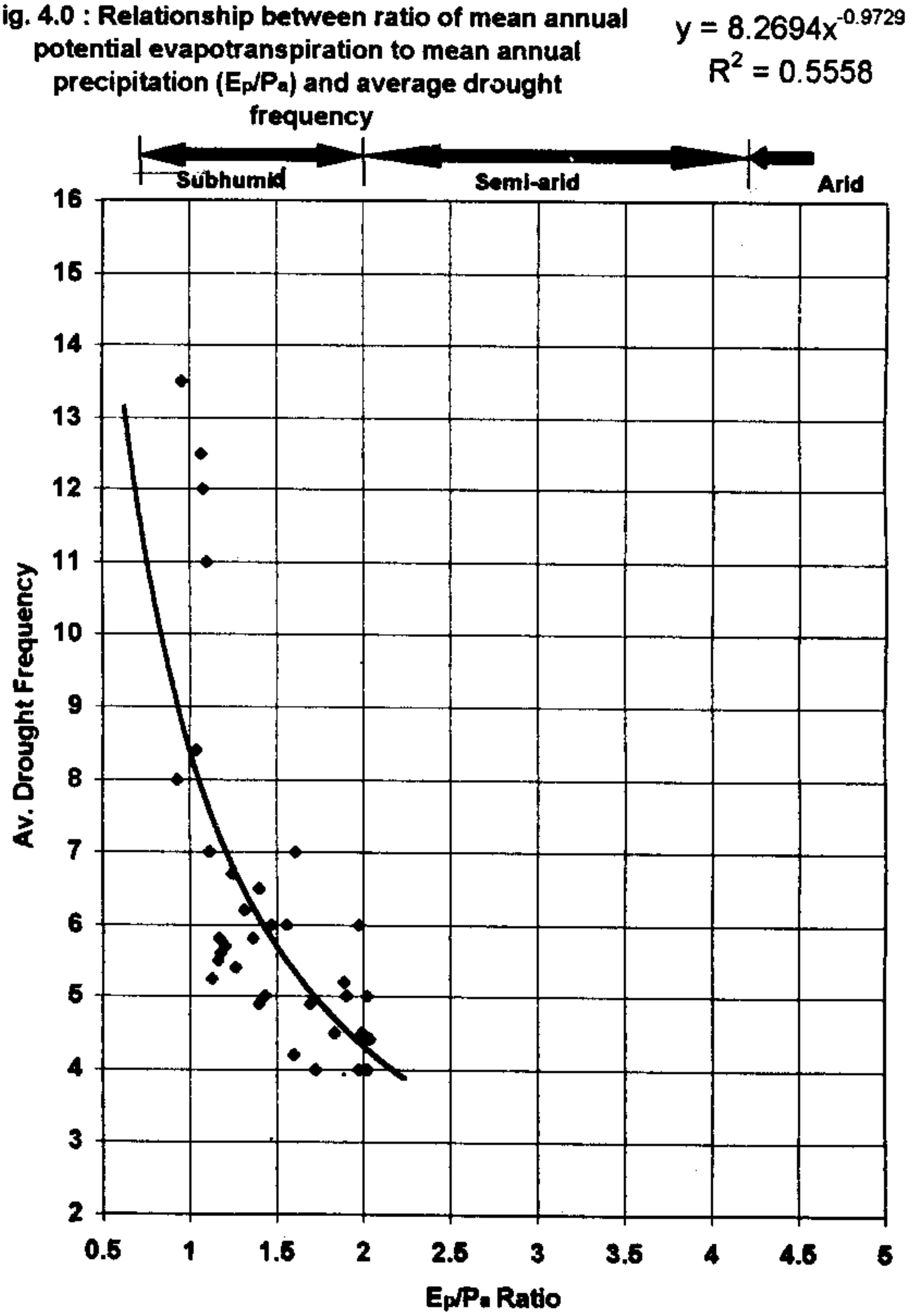
The drought duration is seen to vary between 1 and 5 years in the sub humid climatic regions. This observation confirms the statement made by Rasool (1984) " In sub-humid regions, the drought duration can approach as long as 4-5 yr due to greater interannual precipitation variability (Rasool, 1984). The maximum drought duration observed, for different stations, over the period of record under analysis are given in Table 3.0. The median value of longest droughts persistence in sub-humid regions is two years. However no relationship could be established between drought duration and E_p/P_a ratio.

A comparison of results with drought data and experience throughout the world shows that these results can be used as a base for further critical analysis of drought and for planning of drought management strategies for a given areas. The work's strength is its climatic basis, i.e., its ability to depict regional variability.

Table 3.0 : Drought frequency and maximum drought duration at different selected locations in sub-humid regions arranged in ascending order against E_p/P_a Ratio.

Sl. No.	Name of Location	P_a (mm)	E_p (mm)	E_p / P_a	Av. drought. Frequency	Mx. drought duration
1	Hulsi, Paud, Pune, Maharastra	1588.77	1474.6	0.928139	8	3
2	Midnapur, W.B.	1525.27	1463.8	0.959699	13.5	2
3	Phulwani (Orissa)	1424.68	1481	1.039532	8.4	4
4	Purulia, W.B.	1313.45	1405.1	1.069778	12.5	2
5	Bankura. W.B.	1306.58	1408.3	1.077852	12	2
6	Belgaum Karnataka	1349.99	1481.3	1.097267	11	3
7	BhawanipatnaKalahandi (Orissa)	1434.3	1595.3	1.11225	7	2
8	Umaria Shahdol M.P.	1301.72	1471.2	1.130197	5.24	3
9	Sidhi M.P.	1266.24	1471.9	1.162418	5.5	2
10	Munger, Bihar	1247.91	1458.5	1.168754	5.8	3
11	Palamu, Bihar	1179.24	1388.3	1.177284	5.6	2
12	Suhagpur Shahdol M.P.	1219.99	1471.2	1.205912	5.7	4
13	Nawapara (Orissa)	1205.43	1496.8	1.241715	6.7	3
14	Boudh (Orissa)	1307.24	1652	1.263731	5.4	3
15	Rohtas, Bihar	1141.74	1500.1	1.313872	6.2	4
16	Betul M.P.	1005.44	1372.1	1.364676	5.8	4
17	Aurangabad, Bihar	1186.37	1660.8	1.399901	6.5	2
18	Bhojpur, Bihar	1073.81	1504.3	1.4009	4.9	4
19	Balangir (Orissa)	1306.41	1872.9	1.433669	5	2
20	Gaya, Bihar	1130.9	1661.4	1.469095	6	2
21	Satara, Maharashtra	1082.46	1687.8	1.559226	6	2
22	Shajapur, M.P.	1033.93	1653	1.598754	4.2	3
23	Nawada, Bihar	1033.25	1661.4	1.607936	7	2
24	Dewas, M.P.	1071	1813.2	1.692997	4.9	2
25	Kalol, Panchmahal, Gujrat	1005.82	1731.2	1.721183	4	3
26	Jhuabua M.P.	827.32	1518.9	1.835928	4.5	2
27	Datia, M.P.	803.45	1516	1.886863	5.2	3
28	Chittoor, A.P.	869.41	1656.2	1.90497	5	3
29	Dhar M.P.	919.31	1813.2	1.972349	6	2
30	Nasik, Maharashtra	897.88	1773.8	1.975542	4	2
31	Prakasam, A.P.	840.88	1674.9	1.991842	4.5	3
32	Bharuch, Gujrat	853.52	1727.8	2.024323	4	2
33	Mahboob-nagar A.P.	827.63	1675.9	2.024939	5	4
34	Khargoan M.P.	804.24	1728.5	2.149234	4.42	2

Fig. 4.0 : Relationship between ratio of mean annual potential evapotranspiration to mean annual precipitation (E_p/P_a) and average drought frequency



9.0 Conclusions

We considered drought frequency as a function of dimensionless climatic parameter derived as the ratio of mean annual potential evapotranspiration to mean annual precipitation. The sub-humid areas which receive their mean annual rainfall in the order of equal to or more than the local mean annual potential evapotranspiration ($E_p/P_a \leq 1.0$) face less frequent drought (i.e., once in more than 8 years). In the sub-humid areas with E_p/P_a ratio greater than 1.75, the drought recur after every 4-5 years

It is clear from the above discussions that the drought frequency is significantly related with the difference between the local mean annual potential evapotranspiration and mean annual rainfall. Average drought frequency (yr) is seen to increase gradually from dry to wet site of sub-humid regions, from 4 years in the regions with $E_p/P_a \geq 2$ to >8 years in the regions with $E_p/P_a \leq 1$. Thus, it can be concluded that the areas having higher mean annual deficit are supposed to face more frequent drought.

For a given meteorological drought year, the areas with E_p/P_a ratio between 1.5-to-2.0 faced relatively more intense drought (i.e., severe drought) than the areas with E_p/P_a ratio between 1.0-to-1.5. The occurrence of severe or extreme droughts are much rare in the regions having E_p/P_a ratio less than 1.0. This revealed that the sub-humid region with greater mean annual deficit are susceptible to face relatively more intense drought.

The drought duration is seen to vary between 1 and 5 years in the sub humid climatic regions. However no relationship could be established between drought duration and E_p/P_a ratio.

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Notations

Av. = Average

D = median drought duration;

E_p = mean annual potential evapotranspiration;

F = average drought frequency;

I = drought intensity index;

I_e = extreme drought intensity index;

I_m = moderate drought intensity index;

I_s = Severe drought intensity index;

L_w = average length of wet season;

Mx. = Maximum

P = annual precipitation;

P_a = mean annual precipitation;

PDSI= Palmer Drought Severity Index;

P_g = global terrestrial mean annual precipitation; and

S = drought susceptibility index.