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DROUGHT CHARACTERIZATION IN ARID AND SEMI ARID CLIMATIC REGIONS OF INDIA

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PREFACE

Drought is a natural, recurring feature of climate; it occurs in virtually all-climatic regimes. Drought means scarcity of water, which adversely affects various sectors of human society e.g., agriculture, hydropower generation, water supply, industrial, and other allied sector. 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 at national/state level have not been competent enough for timely decisions at higher level. 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 drought events, need to be profitably applied in next cases. This study was aimed to relate drought characteristics with climatic parameters in arid and semi-arid climatic regions of the country.

This report is a part of research programme of the Drought Studies Division of the Institute. The study has been carried out by **Shri Rajendra Prasad Pandey**, Scientist C, under the Guidance **Dr. K.S. Ramasastri** , Scientist F & 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.

(K.S. Ramasastri)

DIRECTOR

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Abstract

Prediction of regional drought characteristics forms a major concern in the planning of drought management strategies in drought prone areas in India. This study attempts to characterize droughts (frequency, intensity and duration) in arid and semiarid regions of the country using two readily available climatic parameters: (i) ratio of mean annual precipitation (P_a) to global terrestrial mean annual precipitation (P_g), and (ii) ratio of mean annual potential evapotranspiration (E_p) to mean annual precipitation (P_a). Average return period (yr) is found to increase gradually from arid to semiarid regions. The return period varies from two to three years in the arid regions ($12 > E_p/P_a \geq 5$) and three to five years in semi-arid regions ($5 > E_p/P_a \geq 2$). Furthermore, relationships describing the probability of occurrence of moderate, severe, and extreme intensity droughts, defined in terms of the magnitude of annual deficit, are developed. The semiarid and arid climatic regions of the country are found more susceptible to suffer from relatively more intense droughts than the humid and sub humid regions.

1.0 Introduction

Droughts are natural climatic phenomenon characterized by a deficiency of precipitation, which has an adverse effect on plants, animals, or humans. Dracup et al. (1980a) defined drought as a period of time (month/year) with rainfall/runoff below a mean truncation level which is derived from long term rainfall/runoff series. Konstantinov (1968) believed that drought should be studied using an analysis of deficit of evapotranspiration, which is defined as the difference between the potential and the real evapotranspiration. 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. The concept of the definition of drought also varies with the subject of interest. A meteorological drought refers to a deficiency of precipitation, without regard to the application. Hydrological drought is associated with a lack of available 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; Dracup et al., 1980b). Socioeconomic drought is associated with a deficiency of water needed to meet the demand for industrial and urban activities.

Droughts are characterized by their duration, intensity and frequency. These characteristics form a basis in the planning of management strategies to cope with drought hardships. Drought duration (D) is the period of time when there is a deficiency of precipitation, preceded and followed by periods when there is no deficiency. Drought intensity (I) refers to the magnitude to which actual precipitation is lesser than the mean, i.e., the precipitation deficit. Drought frequency (F) 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. Another term, which is normally found in literature, is the drought severity. Drought severity (S) refers to the accumulated precipitation deficit through out the drought duration (i e. $I=S/D$) Dracup et al. (1980a&b). While, defining drought intensity (I), Dracup et al. (1980b) have indicated that drought intensity is nearly independent of the duration and this fact is well supported in literature (Sharma, 1997a&b; Bonacci, 1993 and Woo & Tarhule, 1994). In other words, if one can predict duration and intensity then the severity can be predicted using simple law of multiplication of duration and intensity.

Droughts are regional in nature, i.e., they are driven by regional climatic conditions. Therefore, their occurrence is related to regional climatic parameters (Dracup et al., 1980a; Ponce & Pandey, 2000). 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).

A number of researcher have used precipitation as the principal indicator in drought analysis (Bogardi et al. 1994; Mohan and Rangacharya, 1991; Herbst et al., 1966; Sharma, 1997b). Dracup et al. (1980a) recommended that if one is interested in determining causes (or characteristics) of drought, the attention should be focussed on the precipitation droughts. However, if one is interested in determining the effect or impact of drought, attention should be focussed on streamflow and agricultural drought. The commonly used time unit for drought analysis is the year followed by season and month (Sen, 1980; Dracup et al. 1980a; Dracup and Kendal, 1988). Annual precipitation records can be successfully used to characterize droughts (Dracup et al. 1980b and Bonacci, 1993).

Here an attempt has been made to relate drought characteristics with climatic parameters in the arid and semiarid climatic regions in India. The basic assumption in this study is that the main cause of drought is a precipitation deficit in an area compared with the average precipitation in that same area in an analysed period of time. All other characteristics are more or less directly influenced by the precipitation deficit in space and time. The climatic regions are defined in terms of mean annual precipitation, or alternatively, in terms of mean annual potential evapotranspiration (Ponce & Pandey, 2000). It is believed that a characterization in terms of either of these two parameters provides an appropriate framework for the systematic analysis of droughts. The association of drought characteristics and the regional climatic parameters are also compared with documented drought experiences in literature.

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 (Ponce & Pandey, 2000).

The climatic variables at a given location are strongly influenced by the atmospheric circulation pattern (ACP). The researchers have also demonstrated that the ACP plays major role in precipitation occurrence, amount and distribution especially in temperate zone (Lamb, 1977; Bogardi, 1994). 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). Since we are attempting to relate the drought characteristics with regional climatic variability (i e. evapotranspiration/ precipitation ratio), it is expected that climatic changes will lead to predict changes in drought characteristics (Bogardi, 1994).

2.0 Drought prone areas and the data analyzed

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; Central Water Commission, 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 (Central Water Commission, 1982).

The data used in this study included 46 rainguage stations located in drought prone areas in India, which give variety of rainfall records in arid and semi arid climatic regions. The details of the data used are presented in Table 1.0. The years, for which rainfall data is not available, have not been accounted in the analysis. To estimate potential evapotranspiration rates, 30 years daily meteorological data from various stations were used. The evapotranspiration were estimated using Penman (1963) method and compared with the data published by India Meteorological Department (IMD) in Sci. Report No. 136 (Rao, et al. 1971). The locations selected for this study are also shown in Fig.1.0.

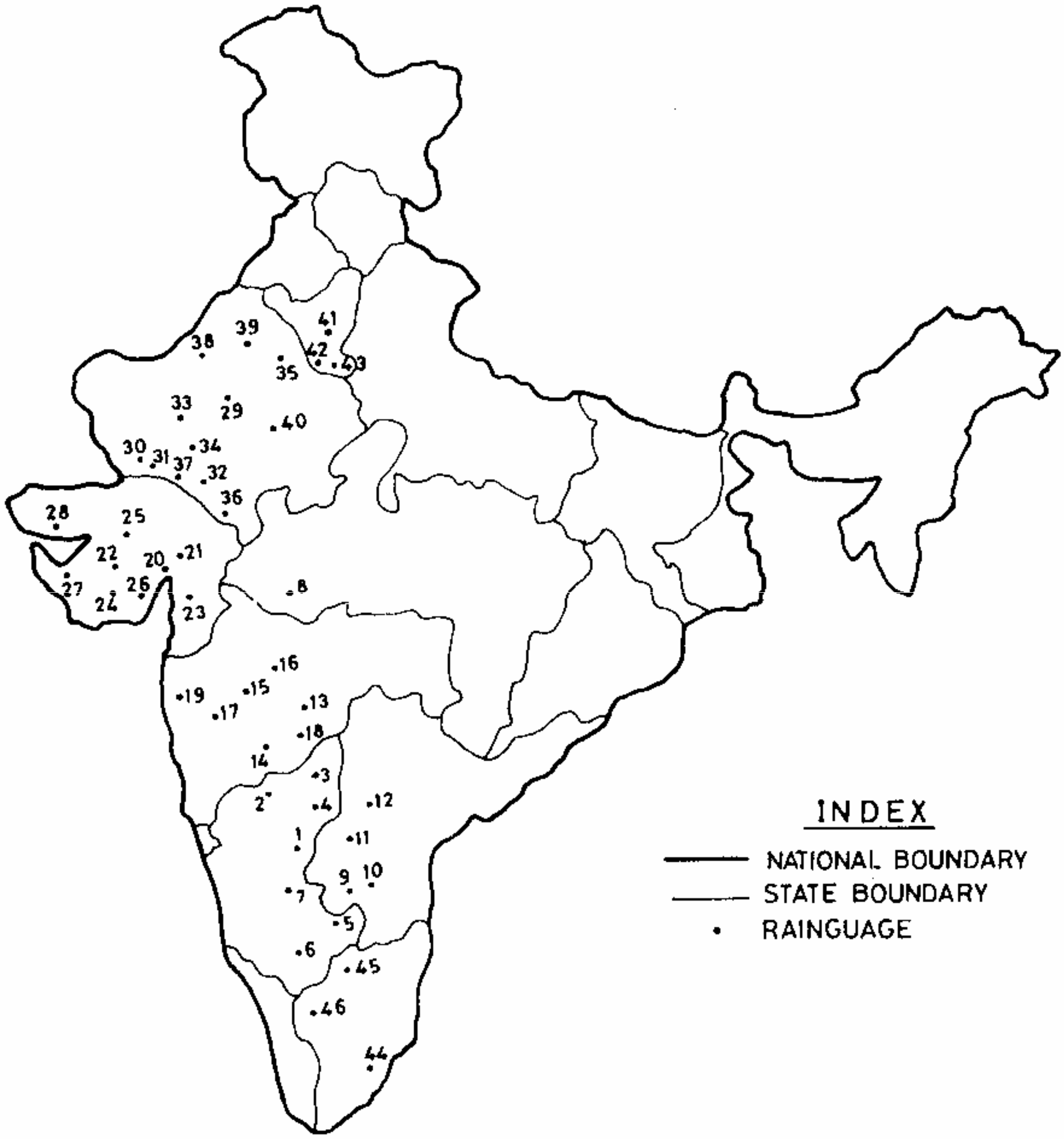


FIG. 1: LOCATION OF SELECTED RAINGUAGE STATIONS IN ARID AND SEMI ARID CLIMATIC REGIONS IN INDIA.

Table 1.0: Details of selected locations and data analyzed for drought characterization in arid and semi arid climatic regions in India

Sl. No.	Name of place	Location	Length of rainfall records	Years of missing data	Mean annual precipitation (mm)	Mean annual potential evapotransp-iration (mm)
	(1)	(2)	(3)	(4)	(5)	(6)
1.	Bellary, (Karnataka)	15° 09'N 76° 51'E	87 yrs 1901-87	--	515.24	1738.1
2.	Bijapur, (Karnataka)	16° 49'N 75° 43'E	87 yrs 1901-87	--	579.7	1650.1
3.	Gulbarga, (Karnataka)	17° 21'N 76° 51'E	81yrs 1901-86	1945-47, 49, 72	783.68	1912.7
4.	Raichur, (Karnataka)	16° 12'N 77° 21'E	85 yrs 1902-86	--	665.16	1950.6
5.	Kolar, (Karnataka)	13° 00'N 78° 08'E	80 yrs 1901-80	--	711.54	1534.2
6.	Mandya, (Karnataka)	12° 32'N 76° 53'E	79 Yrs 1901-80	1904	765.49	1534.2
7.	Chitradurg, (Karnataka)	14° 17'N 76° 25'E	80 yrs 1901-80	--	637.47	1605.7
8.	Khargoan, (Madhya Pradesh)	21° 49'N 75° 31'E	53 yrs 1931-89	1951-56	804.24	1728.5
9	Anantpur, (Andhra Pradesh)	14°41'N 77° 37'E	76 yrs. 1910-85	--	560.12	1857.1
10	Cuddappa, (Andhra Pradesh)	14°29'N 78° 50'E	85 yrs. 1901-85	--	757.36	1834.4
11	Kurnool, (Andhra Pradesh)	15° 50'N 78° 04'E	85 yrs. 1901-85	--	633.62	1827.4
12	Mahboobnagar, (Andhra Pradesh)	16° 44'N 77° 59'E	85 yrs. 1901-85	--	827.63	1675.9
13	Bhir, (Maharashtra)	18° 59' N 75° 46' E	62 yrs. 1901-78	1957, 62-74, 76, 77	707.91	1773.5
14	Solapur (North), (Maharashtra)	17° 40' N 75° 54' E	69 yrs. 1901-78	1945, 57, 62, 64-67, 71, 76	705.5	1801.7
15	Ahmednagar. (Maharashtra)	19° 05' N 74° 48' E	78 yrs. 1901-78	--	607.2	1604.0
16	Aurangabad, (Maharashtra)	19° 53' N 75° 47' E	77 yrs. 1902-79	1976	729.72	1773.8
17	Pune, (Maharashtra)	18° 32' N 73° 51' E	75 Yrs. 1901-75	--	674.07	1473.6
18	Osmanabad, (Maharashtra)	18° 10' N 76° 02' E	74 Yrs. 1901-78	1963-66	834.8	1801.3
19	Nasik, (Maharashtra)	20° 00' N 73° 47' E	65 Yrs. 1901-76	1951, 63-70, 73, 74	697.88	1773.8
20	Ahmedabad, (Gujrat)	23° 09' N 72° 38' E	80 Yrs. 1901-80	--	783.0	1676.8

21	Mahmedabad, Kheda, (Gujrat)	22° 50' N 72° 45' E	79 Yrs. 1901-80	1960	848.97	1731.9
22	Rajkot, (Gujrat)	22° 18' N 70° 50' E	78 Yrs. 1901-80	1953, 55	618.25	2144.0
23	Bharuch, (Gujrat)	21° 41' N 72° 59' E	80 Yrs. 1901-80	--	853.52	1727.8
24	Jafrabad, Amreli, (Gujrat)	21° 36' N 71° 13' E	76 Yrs. 1901-80	1961, 62, 70, 73	598.83	2144.6
25	Dhrangadhra, Surendranagar, (Gujrat)	22° 59' N 71° 28' E	80 Yrs. 1901-80	--	531.32	2144.6
26	Bhavnagar, (Gujrat)	21° 45' N 72° 12' E	78 Yrs. 1901-80	1971, 72	613.7	1815.20
27	Jamnagar, (Gujrat)	22° 29' N 70° 04' E	68 Yrs. 1901-80	1915, 16, 51-60	499.44	1714.10
28	Bhuj, Kuchchh, (Gujrat)	23° 15' N 69° 48' E	79 Yrs. 1901-80	1960	351.73	1896.5
29	Nagaur, (Rajasthan)	27° 12' N 72° 45' E	87 Yrs. 1901-88	1978	342.92	1772.4
30	Jalor, (Rajasthan)	25° 21' N 72° 37' E	88 Yrs. 1901-88	--	386.94	1561.0
31	Bhinmal, Jalor, (Rajasthan)	25° 01' N 71° 46' E	86 Yrs. 1901-88	1951, 59	431.2	1561.0
32	Udaipur, (Rajasthan)	24° 35' N 71° 42' E	87 Yrs. 1902-88	--	629.98	1381.2
33	Jodhpur, (Rajasthan)	26° 18' N 73° 01' E	88 Yrs. 1901-88	--	359.79	1843.0
34	Pali, (Rajasthan)	25° 47' N 73° 20' E	87 Yrs. 1901-88	1971	414.73	1650.0
35	Jhunjhunu, (Rajasthan)	28° 08' N 75° 23' E	85 Yrs. 1901-88	1977-79	399.2	1515.6
36	Dungarpur, (Rajasthan)	28° 51' N 73° 43' E	87 yrs 1901-88	1978	721.1	1555.5
37	Barmer, (Rajasthan)	25° 45' N 71° 24' E	88 yrs 1901-88	--	260.76	1857.7
38	Bikaner, (Rajasthan)	28° 00' N 73° 18' E	88 yrs 1901-80	--	289.55	1772.4
39	Churu, (Rajasthan)	28° 18' N 74° 58' E	82 yrs 1906-88	1964	359.03	1772.4
40	Ajmer, (Rajasthan)	26° 27' N 74° 37' E	87yrs 1901-88	1972	475.03	1566.3
41	Rohtak	28° 54' N 76° 35' E	74Yrs. 1901-78	1966, 69, 70, 74	542.81	1658.2
42	Rewari Mahrndragarh	28° 12' N 79° 33' E	75Yrs. 1901-80	1966, 69, 70, 71, 74	655.83	1658.2
43	Gurgaon	28° 28' N 77° 02' E	75Yrs. 1901-80	1964, 71, 74, 77, 78	453.22	1658.2
44	Paremakudi Ramnathpuram	09° 23' N 78° 35' E	74 Yrs. 1901-74	--	766.39	1682.9
45	Dharmapure	12° 08' N 78° 10' E	80 Yrs. 1901-80	--	853.47	1728.3

46	Coimbatore	11° 0' N 76° 58' E	80 Yrs. 1901-80		594.50	1945.9

3.0 Climatic Classification

The climatic regions can be 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). Ponce and Pandey (2000) have characterized the climatic spectrum in midlatitudinal regions using the ratio of local mean annual precipitation (P_a) to global terrestrial mean annual precipitation (P_g) and the ratio of mean annual potential evapotranspiration (E_p) to mean annual precipitation (P_a). The global terrestrial mean annual precipitation (P_g) subjects 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) with a mean global terrestrial value of 25 mm (Unesco, 1978). 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. Ponce and Pandey (2000) have estimated that at the middle of the climatic spectrum the global terrestrial mean annual precipitation amounts to 800 mm. Here, a value P_g = 800 mm is assumed.

The middle of the climatic spectrum is taken as $P_a/P_g = 1$. Thus, regions with $P_a/P_g < 1$ have less than average moisture. Conversely, regions with $P_a/P_g > 1$ have more than average moisture. Terrestrial mean annual precipitation varies typically in the range 100-6000 mm (Baumgartner and Reichel, 1975). Based on P_a/P_g ratio, the climatic spectrum can be divided into the following eight regions (Ponce and Pandey, 2000):

1. Superarid, with $P_a/P_g < 1/8$.
2. Hyperarid, with $1/8 \leq P_a/P_g < 1/4$.
3. Arid, with $1/4 \leq P_a/P_g < 1/2$.
4. Semiarid, with $1/2 \leq P_a/P_g < 1$.
5. Sub-humid, 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 $P_a/P_g \geq 8$

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). The climatic spectrum can also be characterized by the ratio of mean annual potential evapotranspiration (E_p) to mean annual precipitation (Vysotskii, 1905; Ivanov, 1948; WMO, 1975). Ponce & Pandey (2000) have defined the suitable limits of E_p/P_a ratios across the climatic spectrum as 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. Sub-humid, 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 $E_p/P_a < 3/16$.

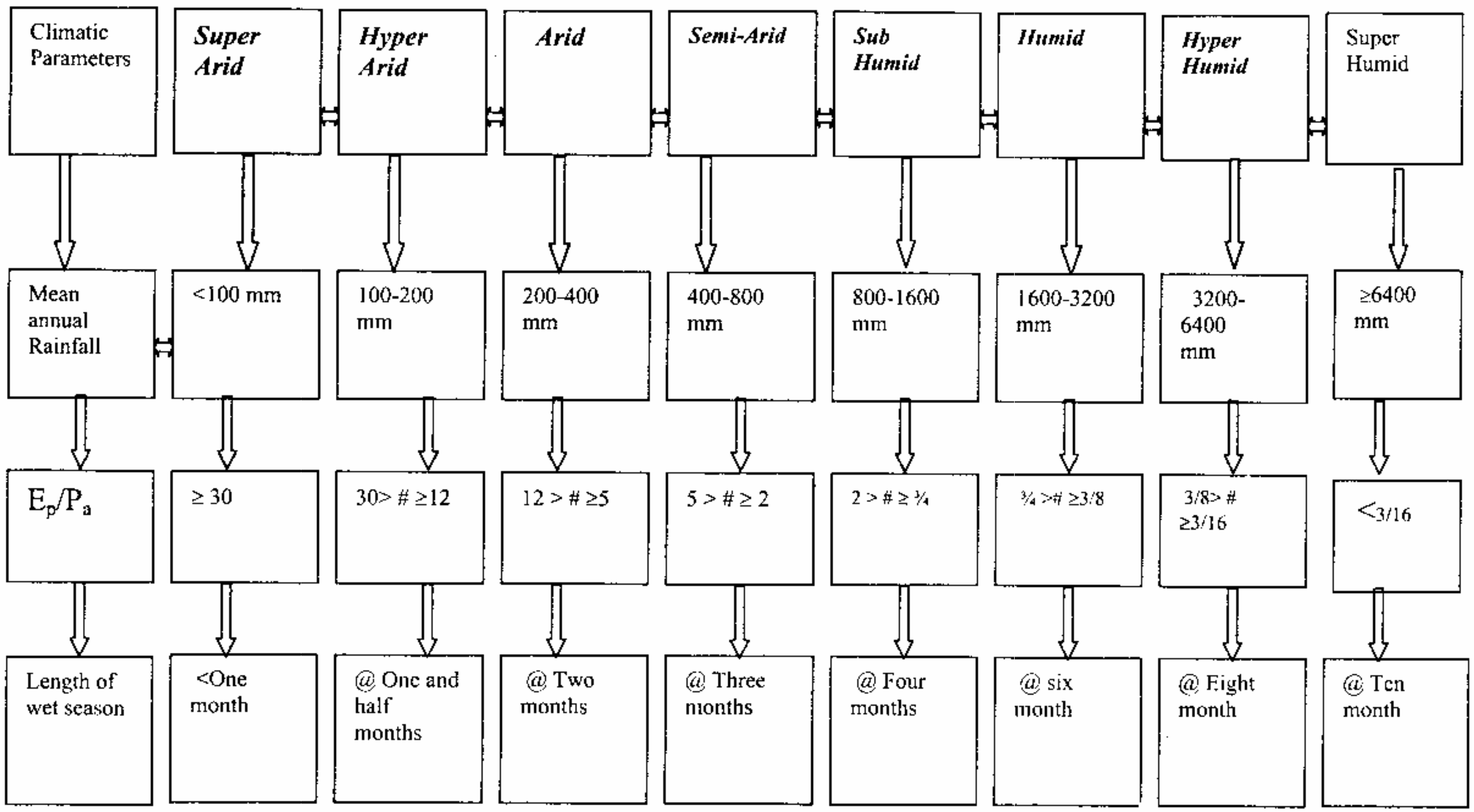
These limits are indicative of general trends, and not necessarily as exact values separating climatic regions. Also, the above classification closely matches with other existing classifications (Bull, 1991; Dutt, 1986).

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 sub-humid, 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. 2). 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/sub-humid Perth, in Western Australia, precipitation is 890 mm and potential evapotranspiration is 1670 mm. In sub-humid 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 dry regions (one month), and longest in wet regions (ten months) (Sinha et al., 1987). Based on the above discussions a summary of the characterization of climatic spectrum is presented in Fig 2.0.

Fig. 2 : 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. Drought duration, intensity, and frequency are known to vary across the climatic spectrum (Gregory, 1989; Dracup et al. 1980a; Ponce and Pandey 2000). 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. The experiences reported in literature show that the droughts have tendency to last longer in those climatic regions, which have greater interannual precipitation variability (WMO, 1975; Karl, 1983; Johnson and Kohne, 1993; Rasool, 1984). The changes in drought duration across the climatic spectrum point to the regional, rather than local nature of persistence (Unesco-WMO, 1985).

Drought intensity refers to the extent of the precipitation deficit. Dracup et al. (1980b), while defining drought intensity (I), have indicated that drought intensity is nearly independent of the duration and this fact is well supported in the literature (Bonacci, 1993; Woo and Tarhule, 1994; Sharma, 1997b). The drought severity is defined as the product of duration and intensity (Sharma, 1997b). There are several methods to define 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): Near normal (0 ≥ PDSI > 0.5), Incipient (- 0.5 ≥ PDSI > 1), Mild (-1 ≥ PDSI > -2), Moderate (-2 ≥ PDSI > -3), Severe (-3 ≥ PDSI > -4) and Extreme (PDSI ≥ -4).

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 side. 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.

5.0 Methodology

While there is an extensive global literature on droughts, but its systematic documentation is lacking, In the current hydrologic literature, devising a suitable universal definition of drought has proven to be an abstruse task (Yevjevich 1967; Dracup et al., 1980b). The most popular perception of a drought is as a 'meteorological phenomenon', characterized by lack of rainfall compared to expected amount for a given period of time. Different definitions of drought have been proposed from time to time depending on one's expectations about moisture needs for specific human activities. For some, a drought exists when rainfall is below 75% of long-term mean (Glantz, 1994), others might consider it to occur at 60 or 50% of normal. In this study we have considered a definition suggested by the India Meteorological Department (IMD), i.e., "for a given time period (seasonal/yearly), if a meteorological station/division receives total rainfall less than 75 percent of the normal, it is considered as a drought" (Central Water Commission, 1982).

The long-term records of annual rainfall for 46 stations, located in arid and semiarid climatic regions in India, have been analyzed. The length of the rainfall series vary from 65 to 89 years (Table 2.0). The rainfall series have been analyzed using percentage annual rainfall departure from their mean to identify the drought years and the drought events. Fig.3.0 presents an example of the percentage annual rainfall departure plots, prepared for identification of drought years and the drought events. The average drought return period has been obtained as numbers of years of rainfall records analyzed divided by numbers of meteorological drought years. For a given place with mean annual rainfall P_a and a drought year with precipitation P, we defined drought intensity (I) as the ratio of the deficit (P_a - P) to the mean (P_a). Based on the magnitude of deficits, the drought intensity index, I, has been divided in to three categories; Moderate I_m; Severe I_s; and Extreme I_e. A moderate intensity is defined as $0.25 \leq I < 0.50$, a severe intensity as $0.5 \leq I < 0.75$ and an extreme intensity as $I \geq 0.75$ (Banerji and Chhabra, 1963; Central Water

Commission and 1982, National Institute of Hydrology, 1990).

In order to relate the variability of drought characteristics with regional climatic characteristics, the following variables have been considered:

1. Ratio of local mean annual potential evapotranspiration to local mean annual precipitation E_p/P_a.
2. Average drought frequency F (expressed in terms of average return period)(yr).
3. Drought intensity index I.
4. Drought duration D (yr).
5. Drought Severity, S.
6. Drought susceptibility index C.

For a given drought event, severity is defined as the summation of the annual intensities over the drought duration, as follows:

$$S = \Sigma((P_a - P) / P_a) \quad (1)$$

where, P is actual precipitation in a given year and Pa is the mean annual precipitation

Drought susceptibility index (C) is defined as the ratio of severe drought intensity index I_s to drought frequency F (yr).

$$C = I_s / F \quad (2)$$

Regressions have been applied to develop the relationships between (1) average drought return period and E_p/P_a ratio, (2) average drought return period and mean annual deficit (E_p - P_a), (3) average drought return period and ratio of mean annual deficit to mean annual precipitation {(E_p - P_a)/P_a) and (4) probability of occurrence of moderate, severe and extreme intensity droughts, and E_p/P_a ratio. The observations have been drawn on average drought frequency, drought intensity and drought duration in relation to E_p/P_a ratio, (E_p - P_a) and {(E_p - P_a)/P_a). The results are compared with the documented experiences in literature.

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

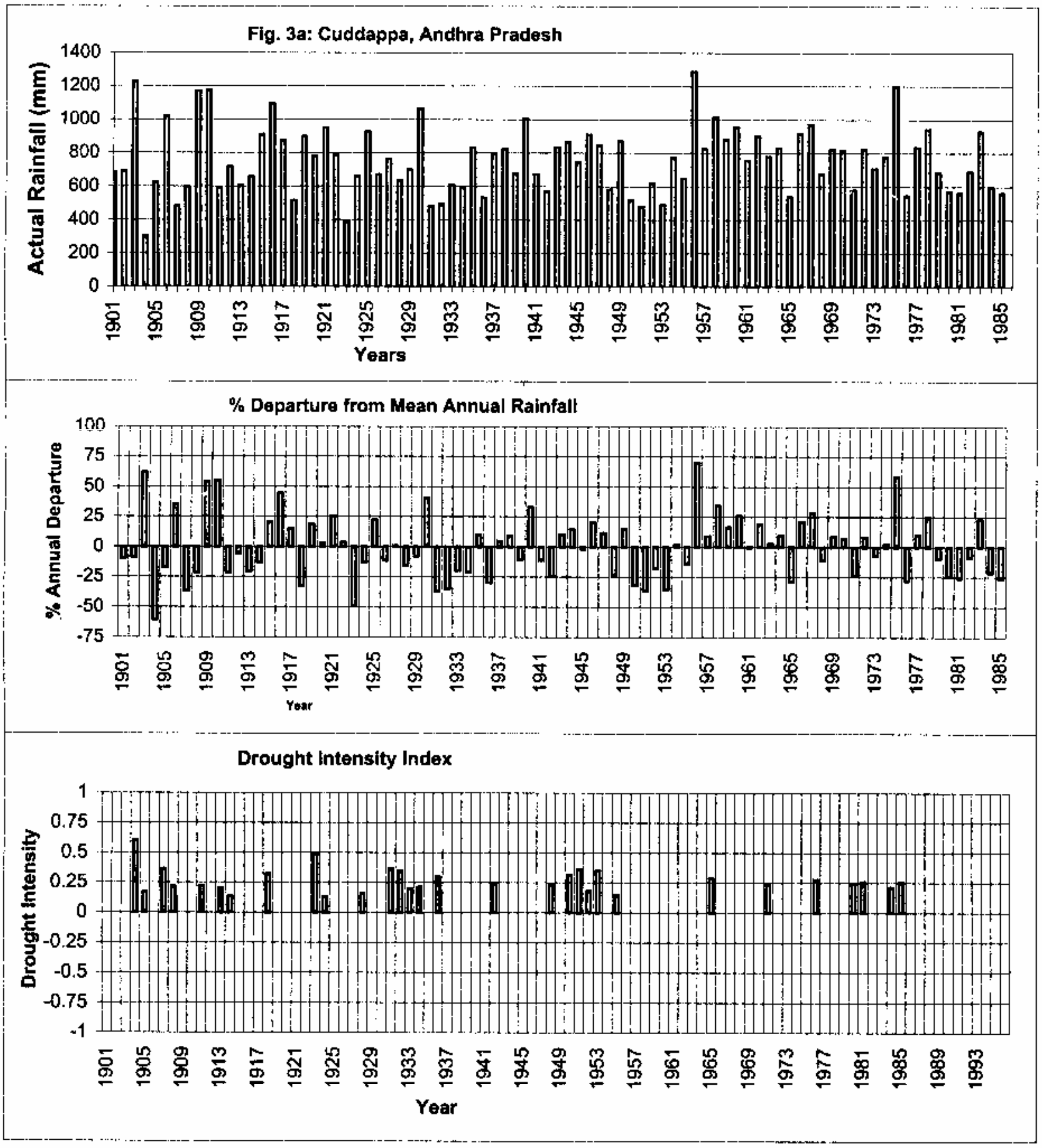
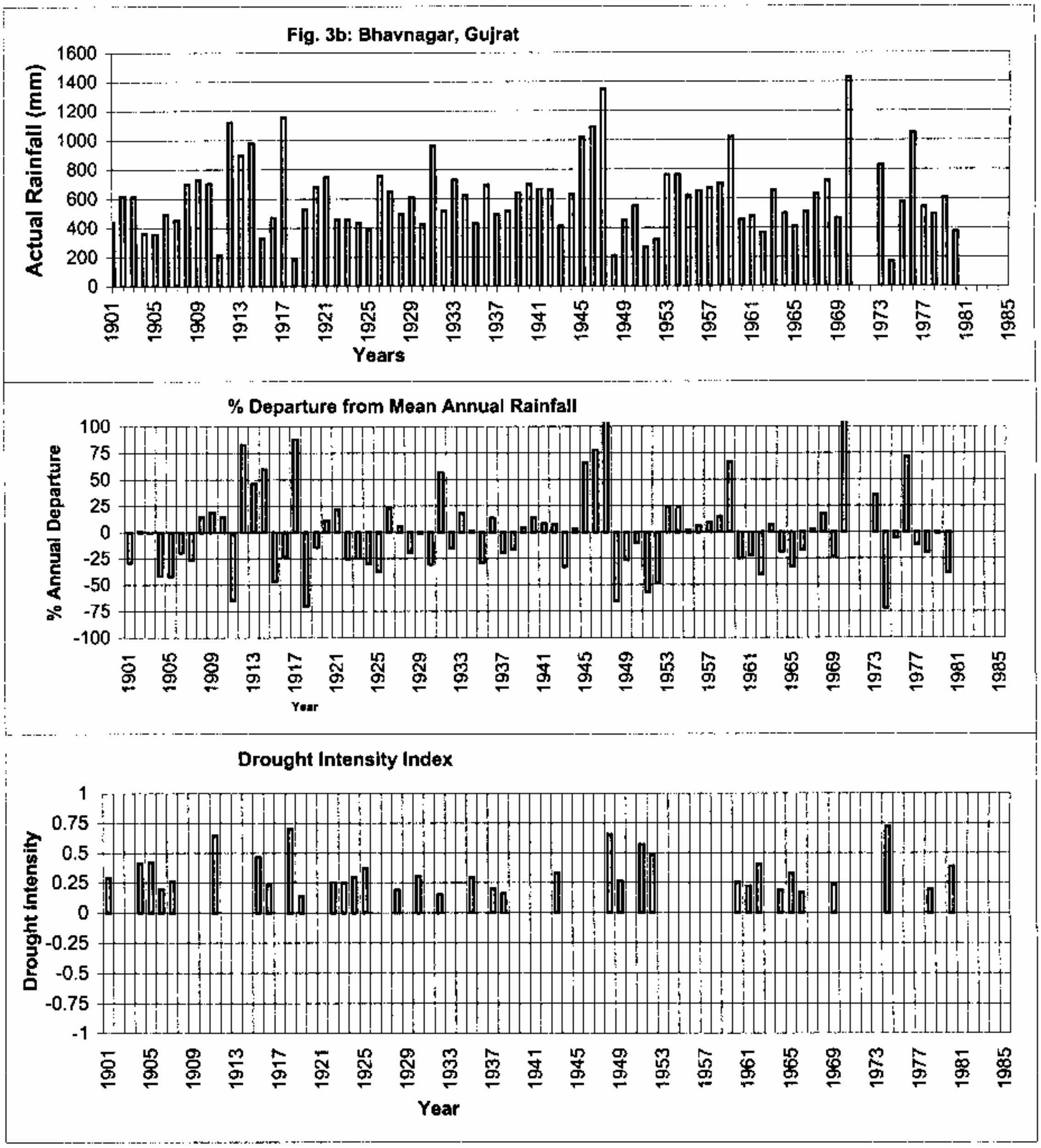


Fig. 3a - 3e: Countinue .....



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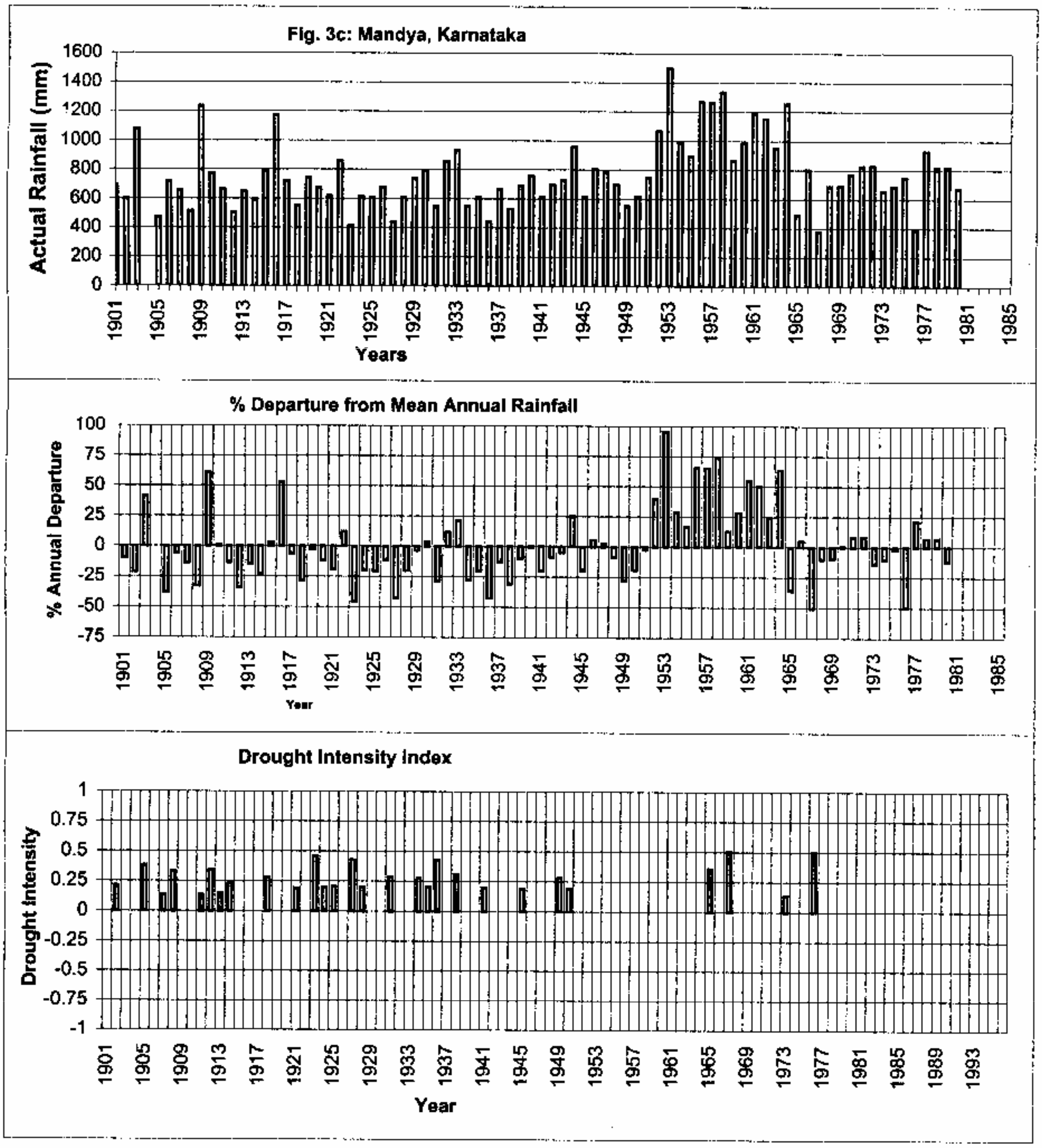


Fig. 3a - 3e : Countinue ....

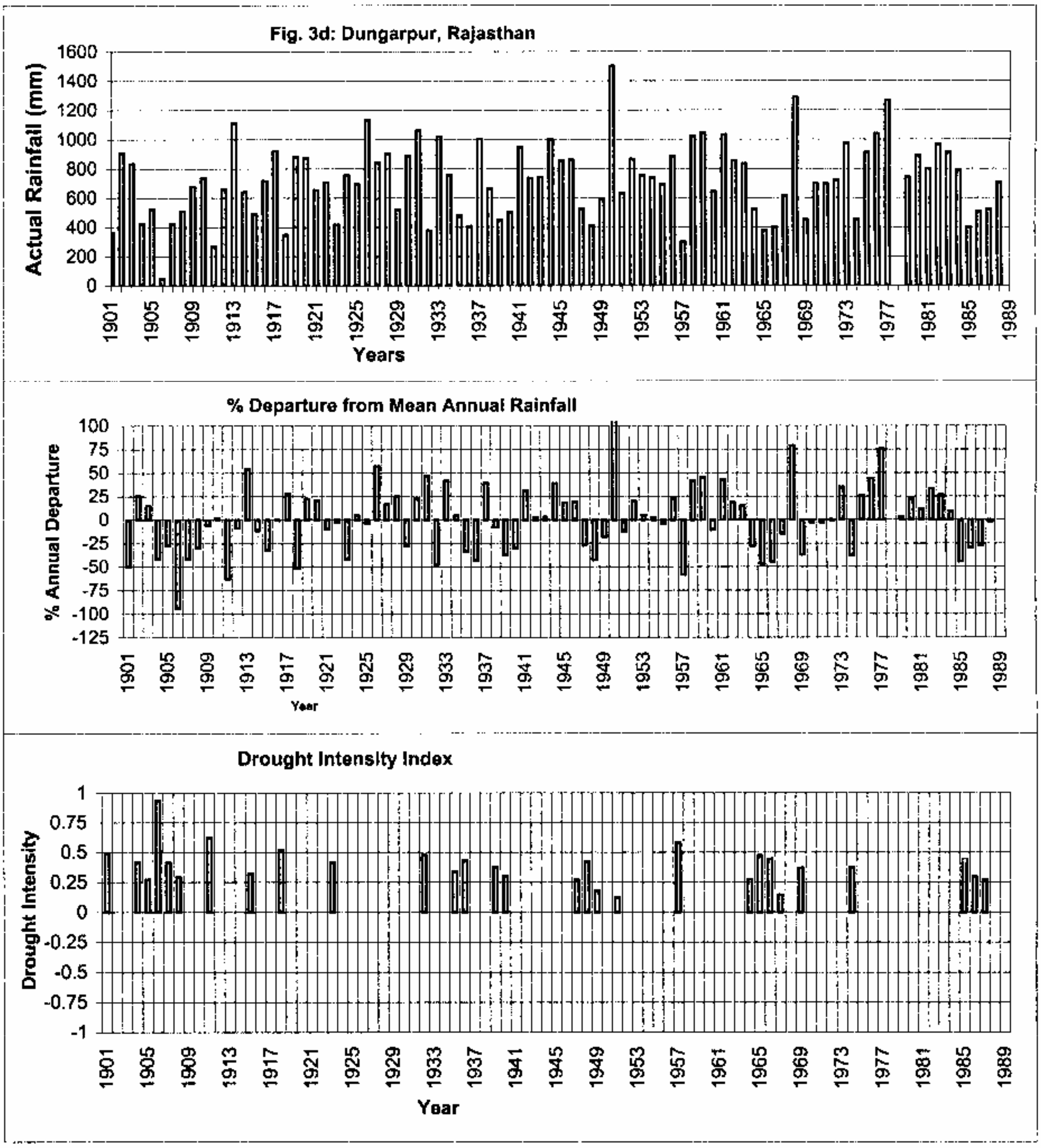
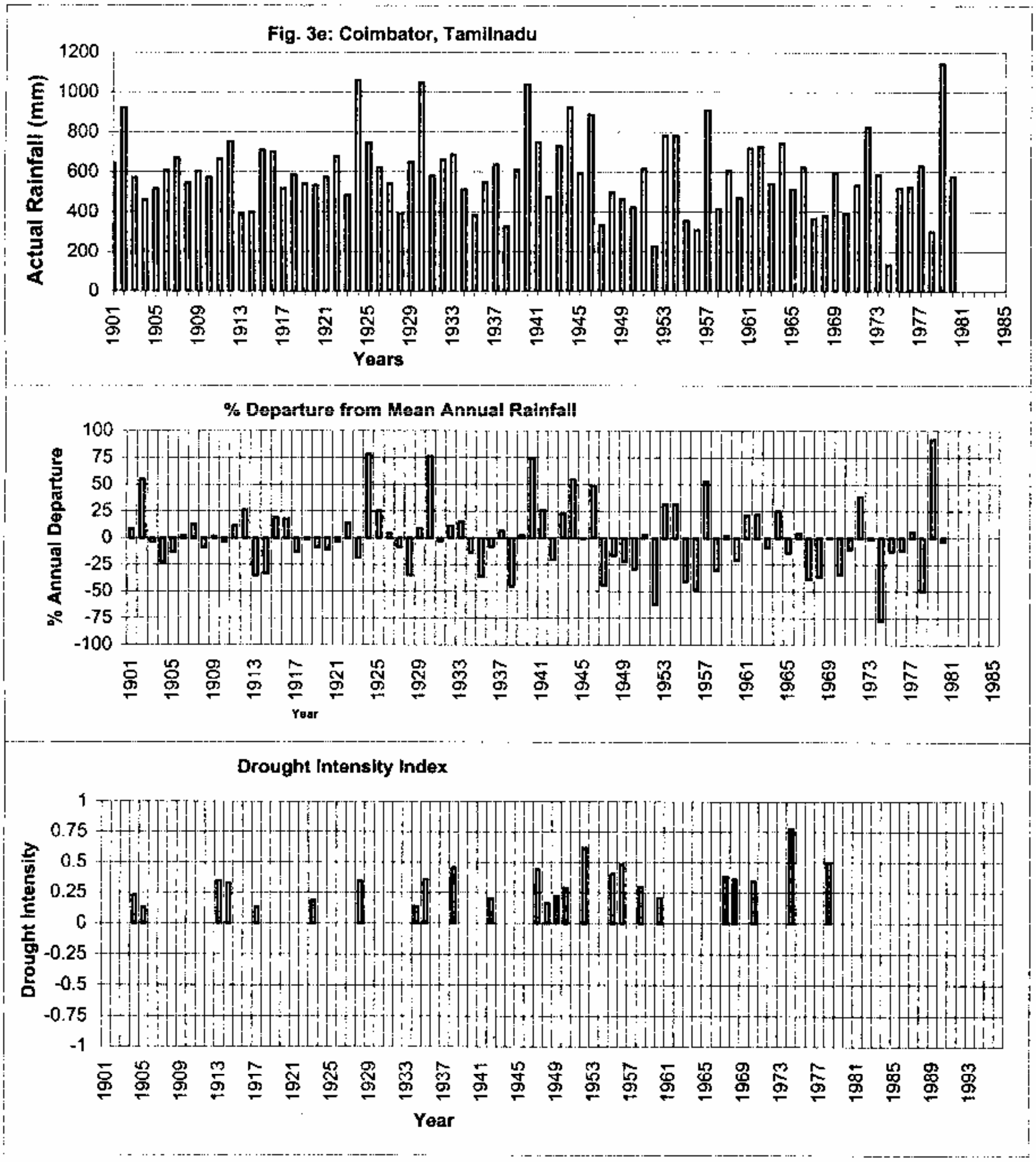


Fig. 3a - 3e : Countinue ....



6.0 Analysis and Results

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 (P_a/P_g), and (2) ratio of mean annual potential evapotranspiration to mean annual precipitation (E_p/P_a)

The arid and semi arid regions are categorized as the areas with the mean annual rainfall between 200-400 mm and 400-800 mm respectively, and mean annual potential evapotranspiration/precipitation (E_p/P_a) ratio between $5 \leq E_p/P_a < 12$ and $2 \leq E_p/P_a < 5$ respectively. These climatic regions have an approximate length of wet season as two and three months respectively. The mean annual rainfall (P_a) in the selected stations of the country ranges from 259.69 mm at Churu in Rajasthan to 853.47 mm at Dharampure in Tamilnadu and the potential evapotranspiration varies from 1381.2 mm at Udaipur in Rajasthan to 2144.6 mm at Jafrabad in Gujrat .

The average drought frequency and duration of drought events were obtained from percentage annual rainfall departure analysis. Identified drought events yielded the median and maximum duration of persistent droughts. For a given drought year the magnitude of annual deficit was computed to get the intensity. Being a percentage, it is purely qualitative and descriptive in nature which is useful to express the magnitude (i e. intensity) and severity of drought in terms of rainfall deficiency.

Regression has been applied to relate the ratio of mean annual potential evapotranspiration to mean annual precipitation (E_p/P_a) with (1) average drought return period and (2) percentage probability of occurrence of moderate, severe and extreme intensity droughts. The relationship between average drought frequency and E_p/P_a ratio is shown in Fig. 4.0. The power type regression showed better correlation ($R^2 = 0.5134$) as compared to the logarithmic or exponential type regression. Fig.4.0. shows that the frequency and intensity of meteorological droughts have significant relationship with the E_p/P_a ratio. Average drought frequency (expressed in terms of return period i.e. yr) is seen to vary from 2-3 years in the arid regions (with 12> $E_p/P_a \geq 5$), and 3-5 years in the semiarid regions (with $5>E_p/P_a \geq 2$). A relationship between the average drought return period and the ratio of mean annual deficit to mean annual precipitation $(E_p-P_a)/P_a$ (Fig. 6.0) shows equally better correlation. Also, a relationship between the average drought return period and the mean annual deficit (E_p-P_a) shows comparable results (Fig. 5.0).

Fig.4.0 revealed that the average drought frequency decreases from arid to semisrid regions. In the arid and semiarid regions it is decreasing gradually from once in 2.5 yrs. to once in 5 yrs. for a long range of E_p/P_a ratio from 2.0 to 10.0. Thus it can be stated that the drought frequency decreases gradually towards the region with decreasing mean annual deficit $(E_p-P_a.)$. i.e , the average drought period increases with the decrease in mean annual deficit.

Based on the extent of deficit, the droughts of moderate, severe and extreme intensity were identified and their percentage probability of occurrence were estimated. Fig. 7.0 shows relationships between E_p/P_a ratio and percentage probability of occurrence of moderate, severe and extreme intensity droughts. Fig. 7.0 indicates that the probability of occurrence of a severe or extreme intensity droughts increases gradually from the semi arid to arid regions, however, it decreases in the case of moderate intensity drought. For example, an area with E_p/P_a ratio equal to 2.5 has percentage probabilities of occurrence of moderate, severe and extreme drought intensities as 6%, 24% and 72% respectively, and for the area with E_p/P_a ratio as 5.0 these values are 10%, 31% and 60% respectively. This reveals that the areas located in arid regions are likely to suffer from relatively more intense meteorological drought conditions than the areas in semiarid climatic region. The occurrences of extreme droughts are much rare in the regions with E_p/P_a ratio less than 2.0. This confirms that the climatic regions with lesser mean annual deficit are less susceptible to suffer from intense droughts.

The drought duration is seen to vary between 1 and 5 years in the different climatic regions. Relatively a greater number of persistent drought events are observed in arid and semiarid climatic regions with E_p/P_a ratio between 3.0 to 10.0. The median

Fig . 4: Relationship between ratio of mean annual potential evapotranspiration to mean annual precipitation (Ep/Pa) and average drought return period in arid and semi arid regions

$y = 6.8877x^{-0.5073}$

$R^2 = 0.5987$

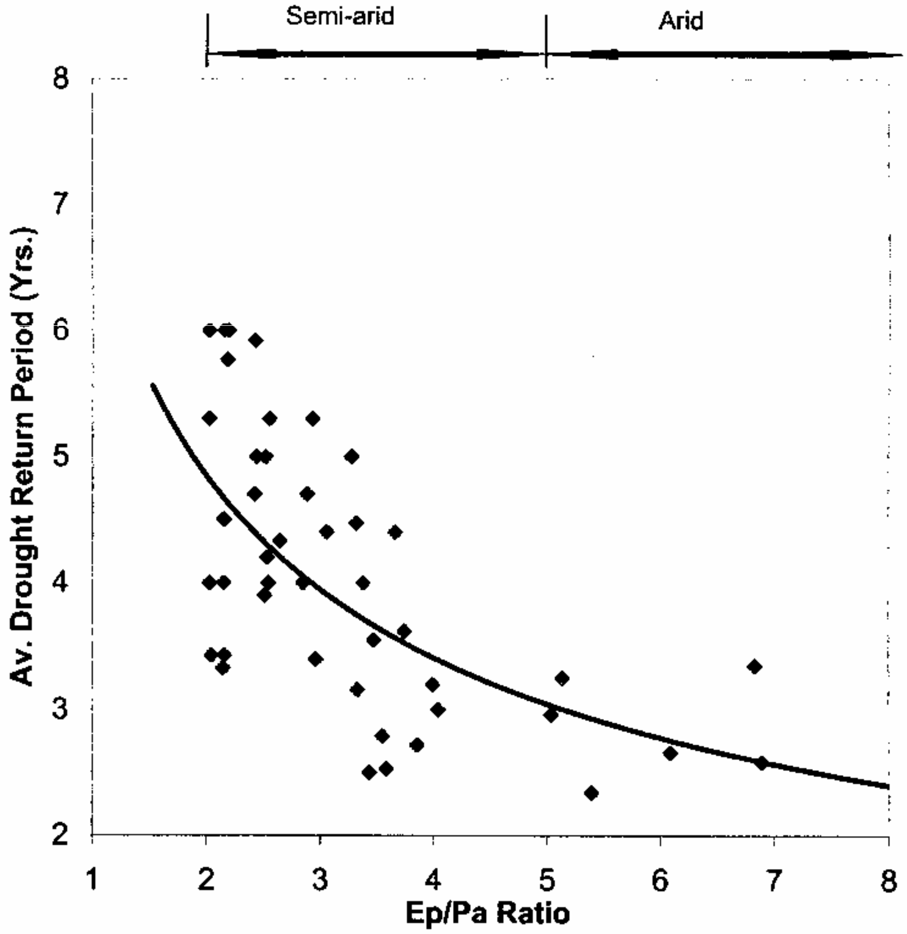


Fig . 5: Relationship between mean annual deficit (Ep - Pa) and average drought return period in arid and semi arid regions

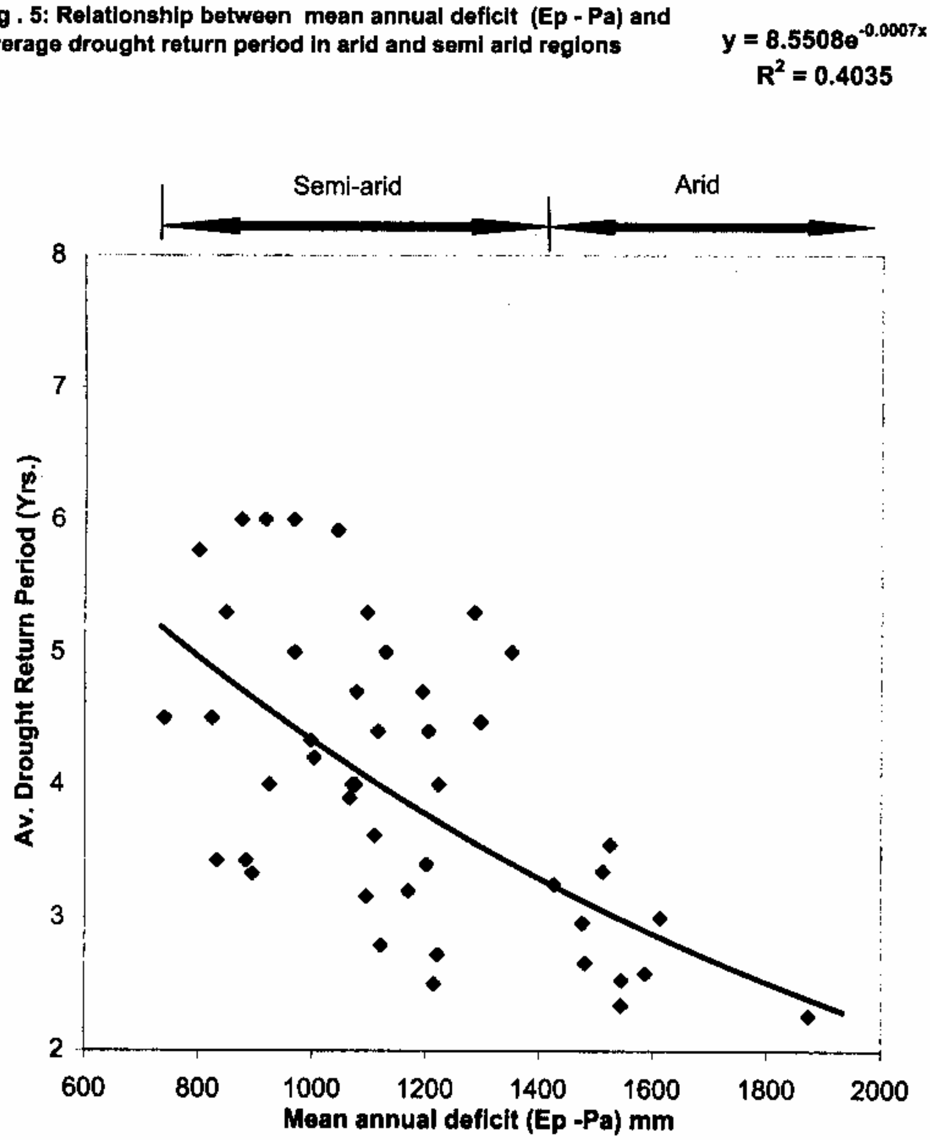


Fig. 6.0 Relationship between ratio of mean annual deficit to mean annual precipitation ($E_p - P_a/P_a$) and average drought return period in arid and semi arid regions

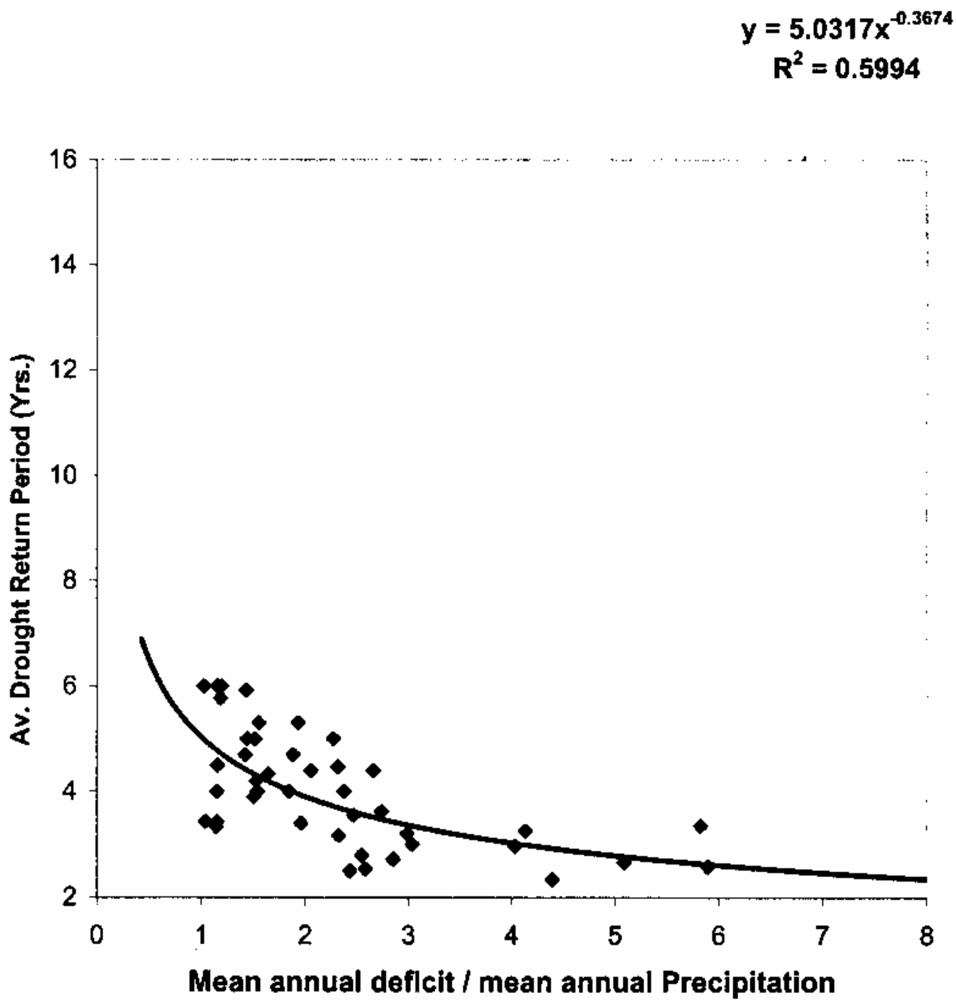
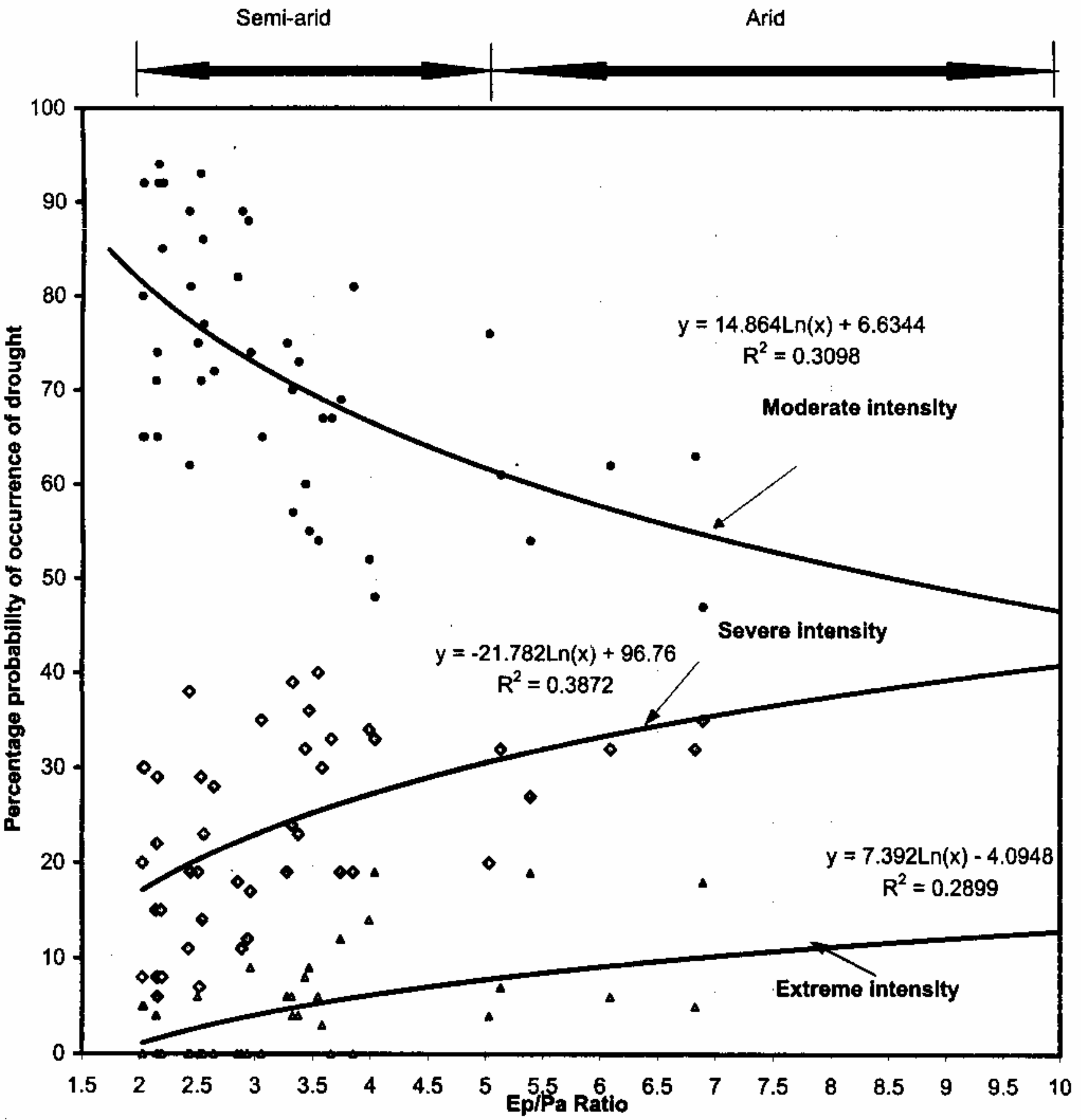


Fig. 7.0 : Relationship between ratio of mean annual potential evapotranspiration to mean annual precipitation (Ep/Pa) and Percent probability of occurrence of different intensity drought



value of longest drought persistence among the different climatic regions is observed as 2 yrs. However no relationship could be established between drought duration and E_p/P_a ratio.

7.0 Discussions

The relationship developed between average drought frequency and the E_p/P_a ratio (Fig.4.0) shows a close agreement with documented drought experience on drought periodicity as discussed below.

For the arid regions with $E_p/P_a \geq 5$, the average drought frequency is found to be once in every 2-3 yrs (Fig.4.0). This is comparable with the documented drought experience in arid climatic regions in Kazakhstan in Russia, and Sarido in Brazil. In Kazakhstan, which is mostly arid (Zonn et al., 1994), around 35 severe droughts have occurred in the last 100 years, i.e., every 3 yrs on the average (Kogan,1997). The Sarido, which belongs to an arid ecosystem with $E_p/P_a \cong 5.8$ (Ponce 1995a), experiences drought conditions in every 3 years (Magalhaes, 1994). Using long term series of rainfall data, Koteswaram, (1970) reported the periodicity of drought broadly for arid meteorological sub-divisions in West Rajasthan and Saurashtra & Kutch as 2-3 years, which was later suported by the Sastry (1986) and Dutt (1986).

The semi arid areas which receive total annual rainfall in the order of about half of the local mean annual potential evapotranspiration (i e. $E_p/P_a \cong 2$) have experienced drought once in 5 yrs (Fig. 4.0). In semiarid areas with E_p/P_a ratio between 2.0 to 3.0 and 3.0 to 5.0, the drought recur after every 4-5 and 3-4 yrs respectively (Fig. 4.0). This is comparable with drought recurrence in Ukraine in Russia, Caatinga and Saritao in Brazil, Georgetown in Australia and, Morocco, Tunisia and Algeria in Northwest Africa. In Ukraine, where climate and soils are favorable for agricultural production (i.e., semi arid) than in Kazakhstan, droughts affect the area after every 4-5 yrs (Kogan, 1997). In semi arid Caatinga and Saritao, where mean annual precipitation ranges between 395 mm to 800 mm and the E_p/P_a ratio varies from 2.2 to 4.8 (Ponce, 1995a), the drought recurs on the order of once in every 5 years (Magalhaes, 1994). 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 once in 5.5 yrs. The Morocco which belongs to a semiarid climatic region (P_a = 400-500 mm) has experienced approximately 25 years of drought during the period from 1901 to 1994 i.e., an average drought frequency of once in 3.5 yrs (Swearingen, 1994). The other Northwest African countries like Tunisia and Algeria also experience roughly the same frequency of drought (Swearingen, 1994). Droughts recur in Gujrat, Eastern Rajasthan and Rayalseema after every 3 years and in South Interior Karnataka, Eastern Uttar Pradesh and Vidarbh the average frequency is once in 4 years (Koteswaram, (1970).

The relationship between the E_p/P_a ratio and the percentage probability of occurrence of moderate, severe and extreme intensity droughts (Fig. 7.0) reveals that the areas located in arid regions suffer from relatively more intense meteorological drought conditions than the areas in semiarid climatic region. The occurrence of severe and extreme droughts are relatively lesser in the regions which receives mean annual precipitation in the order of about 50% of their local mean annual evapotranpiration (i.e., $E_p/P_a \cong 2$). in other words, it can be stated that the climatic region with less mean annual deficit are less susceptible to face intense droughts. Also, this statement is well supported in literature (Lugo and Morris 1982; Gol'tsberg 1972; Gregory, 1989 etc.). For instance, Magalhaes (1994) and Ponce, (1995a) stated that the Agreste (sub-humid) is affected by drought but not as severely as the Sertao (semiarid) in Brazillian Northeast. Also, the Australian experience has shown that droughts are most serious (i.e., intense) where rainfall ranges between 250 and 750 mm, i.e., in arid and semiarid regions (Kendrew, 1961). This confirms our statement that the arid and semiarid climatic regions are susceptible to more intense droughts than that in sub-humid climatic regions (NIH, Report No. CS(AR) – 13/1998-99). Also, a better correlation is obtained between average drought return period and ratio of mean annual deficit to mean annual precipitation {(E_p -

$P_a)/P_a\}$ (*See* Fig. 6.0). It can be stated (from Fig. 4.0, 5.0 and 6.0) that the average drought return period has non-linear relationship with (E_p / P_a), (E_p - P_a) and $\{(E_p - P_a)/P_a\}$.

The drought duration is seen to vary between 1 and 5 years in the different climatic regions. Relatively a greater number of persistent drought events are observed in the districts of Rajasthan followed by Gujrat, Karnataka and Andhra Pradesh. It is also observed that the longest persistent droughts of 5 years duration occurred repeatedly in semiarid and arid climatic regions with E_p/P_a ratio > 3.0. Few persistent drought events of 5 years duration are also observed in regions with E_p/P_a ratio around 2.0. This broadly supports to the statement made by Rasool (1984) that "In semiarid , the drought duration can approach as long as 4-5 yrs due to greater interannual precipitation variability". Also, Laird et al. (1996) have documented the evidences of greater drought persistence in the Great Plains of central North America than in any other part of the United States.

The median value of longest drought persistence among the different climatic regions is observed as 2 yrs. However no relationship could be established between drought duration and E_p/P_a ratio.

Thus the above comparison of relationships between drought characteristics and regional climatic parameters (i.e., E_p/P_a ratio), with drought data and experiences documented throughout the world indicate that the results are reasonably acceptable. These relationships can be used as a base for further critical analysis of drought and for planning of drought management strategies for given areas. The work's strength is its climatic basis, i.e., its ability to depict regional variability.

8.0 Conclusions

Drought frequency and intensity as a function of dimensionless climatic parameter derived as the ratio of mean annual potential evapotranspiration to mean annual precipitation (E_p/P_a). The study revealed that the frequency and intensity of meteorological droughts have significant relationship with the E_p/P_a ratio. Average drought frequency (i.e. yr^{-1}) is seen to decrease gradually from dry to wet regions, from once in two-to-three years in the arid regions ($12 > E_p/P_a \geq 5$) to three-to-five years in the semiarid regions ($5 > E_p/P_a \geq 2$). Also, similar relationship is obtained between the average drought return period and the mean annual deficit (E_p-P_a), and between average drought return period and ratio of mean annual deficit to mean annual precipitation $\{(E_p - P_a)/P_a\}$.

The relationships between the E_p/P_a ratio and the percentage probability of occurrence of moderate, severe and extreme intensity droughts clearly show that the probability of occurrence of a severe or extreme intensity drought increases gradually from the semi arid to the arid regions, however, it is reverse in the case of moderate intensity drought. Thus it is concluded that the areas located in arid regions are prone to suffer from relatively more intense meteorological droughts than the areas in semiarid climatic region. The occurrence of severe droughts are quite less in the regions with E_p/P_a ratio less than 2.0. This again confirms that the climatic region with lesser mean annual deficit are less susceptible to intense droughts.

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

The relationships presented in this report can be used as a useful tool for the prediction of regional drought characteristics and planning of appropriate drought management strategies for arid and semi arid climatic regions in India.

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Notations

Av. = Average;

C = drought susceptibility index;

CWC = Central Water Commission

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;

IMD = India Meteorological Department

Mx. = Maximum

mo = month

P = annual precipitation;

P_a = mean annual precipitation;

PDSI= Palmer Drought Severity Index;

P_g = global terrestrial mean annual precipitation; and

S = drought severity;

Yrs. = Years;

Study Conducted by	**:**	**R. P. Pandey**
		Scientist C
Assisted by	**:**	**Y. K. Dhama**
		Research Assistant