Influence of Morphological Factors on Meteorological Drought Characteristics

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ABSTRACT

Drought characteristics over different climatic regions in India have been related with the ratio of mean annual potential evapotranspiration to mean annual precipitation (E_p/P_a), distance from mountains and sea coast. The study revealed that the average drought frequency can be described using E_p/P_a ratio. It was found that the frequency duration and intensity of meteorological droughts have significantly relationship with the E_p/P_a ratio. Average drought frequency (i.e. yr^{-1}) decreases exponentially with increase in wetness. The probability of occurrence of a severe or extreme intensity drought increases gradually from wet to dry regions, the case is however reverse for moderate intensity droughts. Study revealed that the areas located in arid and semiarid climatic regions are prone to suffer from relatively more. intense meteorological droughts than areas in the sub-humid climatic region. Study further substantiated that the occurrences of severe & extreme droughts events are much rare in the regions with E_p/P_a ratio less than 1.2. Study indicates that the drought duration varies between 1 and 5 years in different climatic regions. Persistent drought events have more chances to occur in arid and semi-arid climatic regions. Presence of mountains and ocean in close vicinity influence the drought characteristics in the regions with P_a˜E_p. The study revealed that the stations which are located at relatively shorter distance from sea and have P_a˜E_p rarely face persistent droughts of 2 or more consecutive years. Regions with Ep/Pa<1.2, d_s<100 km, and d_h<100 km hardly ever faced persistent droughts or the drought events of severe and extreme intensity. The stations which are within 100 to 150 km from ocean (100<d_s<150) and have close distance (d_h< 100 km) from mountain/major hill hardly faced the drought events of severe and extreme intensity, and also the occurrence of persistent droughts events had been very rare. The results were compared with drought experiences in other countries and were found to be in conformity with them.

INTRODUCTION

Droughts characteristics refer to duration, intensity, and frequency. Mean annual precipitation and potential evapotranspiration over a given regions are the key climatic parameters governing these drought characteristics drought in different climatic regions

(Dracup *et al.*, 1980a; Gregory, 1989; Ponce *et al.*, 2000; Pandey & Ramasastri, 2001& 2002) and may provide an appropriate framework for the systematic analysis of droughts and in the planning of management strategies for coping with drought catastrophe in a given region. Precipitation has been considered as principal indicator in most of the studies for analyzing drought characteristics (Herbst et al., 1966; Mohan & Rangacharya, 1991; Bogardi *et al.*, 1994; Sharma, 1997a; Wilhite, 2000; Ponce *et al.*, 2000, Pandey & Ramasastri 2001a &2002). Dracup *et al.* (1980a) indicated that if one is interested in determining causes or characteristics of drought, the attention should be focused on the meteorological (precipitation) droughts. However, if one is interested in determining the effect or impact of drought, attention should be focused on streamflow and agricultural drought.

The most popular perception of drought is as a "meteorological phenomenon", characterized by lack of rainfall compared to the expected amount over a given period of time. A drought exists when rainfall is below 75% of the long-term mean (Glantz, 1994), while others might consider it to occur at or below 60 or 50% of normal. In this study a definition suggested by the India Meteorological Department (IMD) has been used, i.e. "for a given time period (seasonal/yearly), if a meteorological station/division receives total rainfall less than 75 percent of its normal, it is considered as a drought" (National Commission on Agriculture, 1976)

The objective of study presented in this chapter is to explain the influence of morphological factors on average drought frequency, intensity and duration in arid, semiarid and sub humid climatic regions of India. The morphological factors which are considered in this study include distance from sea and presence of orographic barrier.

DEFINITION OF DROUGHT CHARACTERISTICS

Drought frequency (*F*) pertains to the number of years that it would take a drought of a certain intensity to recur; for instance, once in 10 years. The reciprocal of the frequency is the return period or recurrence interval (Ponce et.al. 2000). In common usage, however, frequency and return period are often used interchangeably, for instance, a frequency of 10 years. Since dry periods are generally followed by corresponding wet periods, it follows that the recurrence interval of drought is always greater than the drought duration. Drought duration (D) may be defined as the period of time when there is a deficiency of precipitation, preceded and followed by periods when there is no deficiency (Ponce et.al. 2000). Drought intensity (I) ascribes to the magnitude to which actual precipitation is lesser than the mean or a predefined threshold value. Drought intensity may be considered independent of the duration (Dracup et al., 1980b; Sharma, 1997a&b).

Drought severity (S) refers to the accumulated deficit over the period of drought duration. It may be depicted using simple law of multiplication of duration and intensity (i e. $S=I \times D$) (Bonaci, 1993; Dracup et al., 1980 a&b; Sharma, 1997b). 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. Also, there are several other methods to define drought intensity and severity (WMO, 1989). For example, Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI), Effective Drought Index (EDI), etc. The PDSI (Palmer, 1965) is one of the popular methods in the United States, which is strictly applicable to mid-latitudinal regions (Gregory et al., 1997). The PDSI classifies drought intensity into six classes (Alley, 1984): Near normal ($0 \geq PDSI > 0.5$), Incipient ($-0.5 \geq PDSI > 1$), Mild ($-1 \geq PDSI > -2$), Moderate ($-2 \geq PDSI > -3$), Severe ($-3 \geq PDSI > -4$) and Extreme ($PDSI \geq -4$). However, the Palmer Index has its own limitations (Alley 1984). PDSI values may lag emerging droughts by several months and this limits its application in areas of frequent climatic extremes, like southwest Asia, where large areas are dominated by monsoon climate (Kogan, 1995; Smakhtin and Hughes, 2004). McKee et al. (1993) suggested that the PDSI was designed for agricultural drought only. McKee et al. (1993) developed Standardized Precipitation Index (SPI) to quantify the precipitation deficit for multiple time scales and to define drought intensities resulting from SPI. Byun and Wilhite (1999) developed the Effective Drought Index (EDI) for quantification of drought severity. Unlike many other drought indices, the EDI in its original form is based on time dependent reduction factor and it is calculated with a daily time step. EDI is a function of precipitation needed for a return to normal conditions (PRN). PRN is precipitation, which is necessary for recovery from the accumulated deficit since the beginning of drought. PRN, in turn, effectively stems from daily effective precipitation (EP) and its deviation from the mean for each day. Similar to SPI, EDI values are standardized, which allows comparison of drought severities (at two or more locations) with each other regardless of climatic differences between them. EDI varies in the range from -2 indicating extremely dry to 2 extremely wet conditions. The details of calculation procedures for SPI and EDI are available in McKee et al. (1993) and Byun and Wilhite (1999), respectively.

DESCRIPTION OF APPROACH AND ANALYSIS

A drought year is one with less than average annual precipitation. A drought event is a series of one or more consecutive drought years. The climatic parameters used in this study refer to mean annual precipitation and mean annual potential evapotranspiration. Since the time unit is a year, the minimum duration of a meteorological drought is one year and the minimum drought return period may be two years.

In the present study, the annual rainfall series for 35–106 years for each of the given stations was analysed using percentage annual rainfall departure from normal (PARD) to identify the drought years and the drought events. Using the definition given by IMD, a meteorological drought year is marked as PARD = -25%. Plots of percentage annual rainfall departure from mean were prepared for identification of drought years and the drought events. The sample plots of PARD for Damoh station in Madhya Pradesh and Bijapur in Karnataka are shown in Fig. 1 & 2.

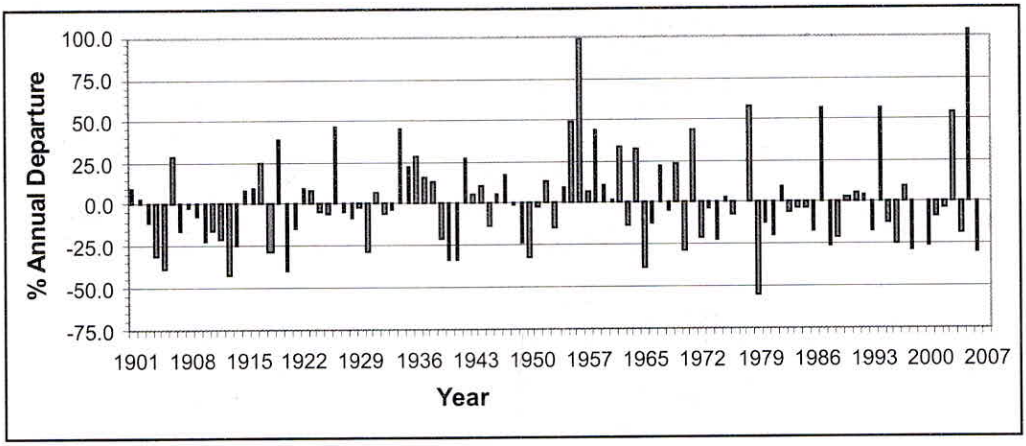

Fig. 1: Plot of percentage annual rainfall departure from mean for Damoh, Madhya Pradesh

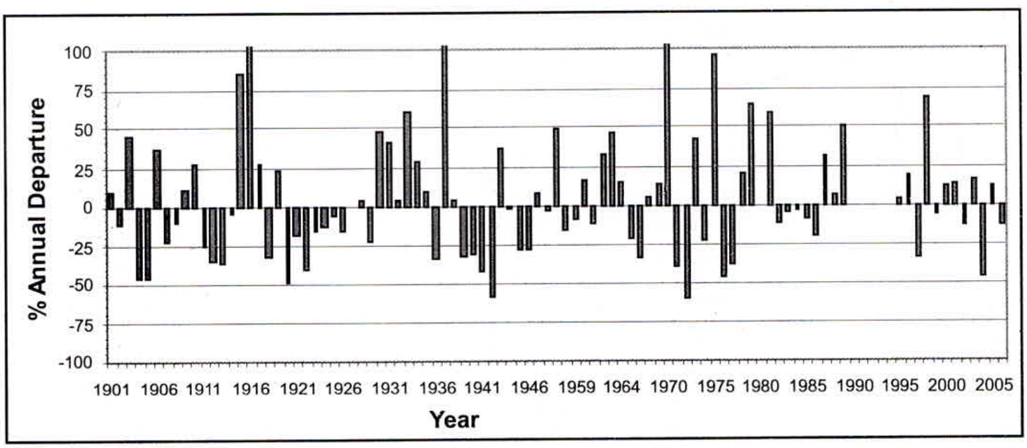

Fig. 2 : Plot of percentage annual rainfall departure from mean for Bijapur, Karnataka

The average drought return period (T) has been obtained as numbers of years of rainfall records analyzed divided by the number of meteorological drought years. The years for which rainfall records were missing at a given station, were not accounted in the analysis while estimating total number of years of records analyzed for a given station.

In this study, drought intensity (I), for a given place during a drought year with actual rainfall, P_{id}, and with mean annual rainfall, P_a, has been obtained as follows:

Equation

The precipitation P_{id} in a drought year is always less than P_a at a given place (i.e. $P_{id} < P_a$), and therefore, equation 1 estimates the negative values of drought intensity (I). Depending on the magnitude of deficits, Banerji and Chhabra (1963) categorized meteorological drought intensity index, I, in to three classes; Moderate I_m; Severe I_s; and Extreme I_e. They defined a moderate intensity as $-0.25 \geq I > -0.50$, a severe intensity as $-0.5 \geq I > -0.75$, and an extreme intensity as $I \leq -0.75$. However, it was subsequently realized that this classification of 'I' was very crude and the perception needed further rationalization (National Institute of Hydrology, 1990). While studying the applicability of various drought indices in India, Dash (2006) proposed a new classification for I as Mild (CI_{ml}) = $-0.25 \geq I > -0.35$; Moderate (CI_m) = $-0.35 \geq I >$ to -0.45, Severe (CI_s) = $-0.45 \geq I > -0.60$, and Extreme (CI_e) I-0.60. This classification of I has been utilized for further analysis of drought intensity in this study. Out of the total estimated drought events at a given station, over the period of record analyzed, the percent probabilities of occurrence of drought events of different intensity classes were estimated. For the purpose of simplicity in presentation, CI_{ml} and CI_m were combined into a single class, and percent probabilities of occurrence of three major categories (i.e. CI_{ml}-CI_m, CI_s, and CI_e) were computed.

A meteorological drought can have a duration (D) of one or more years. Using the plots of percent annual departure from mean, the number of drought events of different durations (1-, 2-, 3-, 4-, and 5-years) were identified over the period of records analysed for each station. The percent probabilities of occurrence of drought events of different duration out of total events at each station were estimated. The relations of percent probabilities of occurrence of drought events of different duration were thus derived with E_p/P_a ratio and ratio of mean annual deficit to mean annual precipitation $\{(E_p - P_a)/P_a\}$.

Using annual rainfall records for 110 stations located in different climatic regions of India, Pandey and Ramasastri, (2002) developed relationship between drought characteristics (viz. frequency, intensity and duration) and climatic parameters. Also, the inferences drawn from above relationship for drought frequency (F), drought intensity (I) and drought duration (D) were compared with the documented experiences in various countries.

The annual rainfall records for 110 stations located in different climatic regions of India have been used for establishing relationships between drought characteristics (viz. frequency, intensity and duration) and climatic parameters. Details of long-term annual rainfall records for various stations are given in Appendix I. To estimate potential evapotranspiration rates, 35 years of daily meteorological data (1965-2002) from various stations were used. Potential evapotranspiration (PET) was estimated using the Penman (1963) method and the results were compared with the data published by the India Meteorological Department (IMD) (Rao *et al.*, 1971) to assess trustworthiness of the estimates.

Among the 110 selected stations of the country (India), the mean annual rainfall (*Pa*) ranges from 190 mm at Jaisalmer in Rajasthan to 1628 mm at Madurai in Tamilnadu and the potential evapotranspiration varies from 874 mm in Doda (in J&K) to 2144.6 mm at Jafrabad (in Gujarat). Here, the mid-climatic regions of India are defined as arid, semiarid and subhumid climatic regions. These regions are categorized as the areas which receive mean annual rainfall between 200–400, 400–800 and 800–1600 mm, respectively, and have mean annual potential evapotranspiration/ precipitation ratio (E_p/P_a) as: $5 = E_p/P_a < 12$, $2 = E_p/P_a < 5$ and $0.75 = E_p/P_a < 2$, respectively. These climatic regions have a wet season length of approximately two, three and four months, respectively.

RESULTS AND DISCUSSION

Percentage annual rainfall departures from normal were estimated from long-term annual rainfall series for each of the given stations to identify the drought years and the drought events. The average drought return period for each station was thus computed from the number of years of rainfall records at a given station divided by number of meteorological drought years (i.e. the number of years for which annual rainfall was less than 75% of its mean value).

RELATING E_p/P_A RATIO WITH AVERAGE DROUGHT FREQUENCY

Drought frequency (F) refers to reciprocal of return period (T) (i.e. F=1/T). Since the ratio of mean annual potential evapotranspiration to mean annual precipitation (E_p/P_a) may never be zero, both power and exponential regression models were applied to relate the E_p/P_a ratio with the average drought frequency (i.e. in terms of return period) (Fig. 3). The power type regression showed better correlation ($R^2 = 0.68$) than did the logarithmic or exponential type regression. Figure 3 shows that the frequency of meteorological droughts has a significant relationship with the Ep/Pa ratio. Average drought frequency (expressed in terms of return period) varies from 2 to 3 years in arid regions (with $12 > E_p/P_a = 5$), 3 to 5 years in semiarid regions (with $5 > E_p/P_a = 2$), and 5 to 9 years in subhumid regions (with $2 > E_p/P_a = 3/4$).

Also, Fig.3 shows that the areas which receive mean annual rainfall nearly equal to their mean annual potential evapotranspiration (i.e. $E_p/P_a \sim 1$) experience drought every 8 years. Further, if the area belongs to the further wet side of the climatic spectrum,

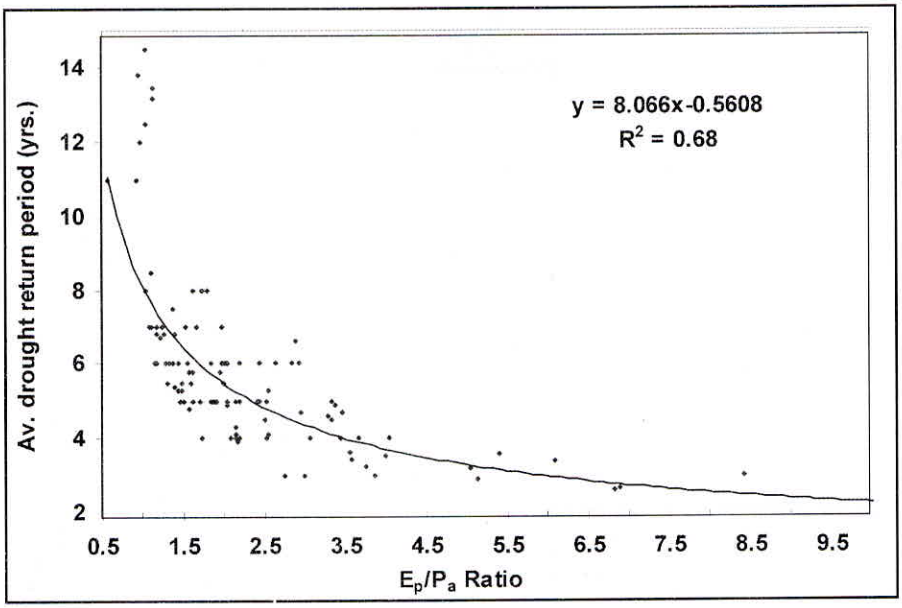

Fig. 3 : Relationship of average drought return period with E_p/P_a ratio

(i.e. $0.5 = E_p/P_a < 1$), the drought frequency is of the order of once in 9–11 years. However, it can also be seen from analysis (Fig. 3) that a few stations in subhumid regions, namely, Midnapur and Bankura in West Bengal, Phulbani in Orissa and Belgaum in Karnataka State, whose mean annual rainfall nearly equals the local mean annual potential evapotranspiration, experienced less frequent droughts. The average frequency of drought at these stations was once in every 14, 13, 12 and 11 years, respectively. This typically indicated the possibility of some influence of other physical/ regional/morphological factors particularly in respect of presence of orograpgraphic barrier (distance of station from mountains/ major-hills, h_s) and distance from sea (d_s).

A comparison of the above inferences with drought data and experiences elsewhere (Table 1) indicates that the results are rationally comparable. For instance, in Brazil, in Sarido, which belongs to an arid region with $E_p/P_a \sim 5.8$, and in semiarid Caatinga and Saritao, where the E_p/P_a ratio varies from 2.2 to 4.8 (Ponce, 1995a), droughts recur approximately once in every 3 and 5 years, respectively.

However, in subhumid Agreste and Mata, where the Ep/Pa ratio varies between 1.3 and 2.0 and between 0.7 and 1.1, respectively, the drought conditions occur every 8–12 years on an average (Ponce, 1995a; Magalhaes & Magee, 1994). For subhumid climatic regions in the upper midwest United States with mean annual precipitation of about 1500 mm (NOAA, 1980), the average return period of drought is reported as approximately 10 years (Klugman, 1978). French (1987) analysed long-term series of annual rainfall for Georgetown in 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 years. Swearingen (1994) reported that Morocco, which belongs to the semiarid climatic region (Pa = 400–500 mm), experienced approximately 25 years of drought during the period from 1901 to 1994, i.e. an average drought frequency of once in 3.5 years. Thus, the relationships proposed broadly follow the drought frequency behaviour in similar climatic regions in other parts of the world. It is hoped that these relations may be useful for further critical analysis of drought in different climatic regions.

Table 1: Summary of some documented drought experiences on drought frequency

Climatic Region	Place or Location	E_p/P_a	Drought frequency
Arid	1. Kazakhstan in Russia	5.4-6.2 *(Zonn et al. 1994)*	35 severe drought in last 100 yrs. *(Kogan, 1997)*
	2. Sarido in Brazil	5.8 *(Ponce 1995a)*	Once in 3 yrs *(Magalhaes and Magee, 1994)*
Semi-Arid	1. Ukraine in Russia	2.8 *(Zonn et al. 1994)*	Once in 4-5 yrs *(Kogan 1997)*
	2. Caasinga & Saritao in Brazil	3.2-4.8 *(Ponce, 1995a)*	Once in 5 yrs *(Magalhaes and Magee, 1994)*
	3. Georgetown, in Australia	*3.9* *(French, 1987)*	Once in 5 years *(French 1987)*
	4. Morocco, Algeria & Tunisia in Africa (NW)	3.8-4.4	Once in 3.5 yrs *(Swearingen, 1994)*
Sub-humid	1. Agreste & Mata in Brazil	1.3-2.0 & 0.7-1.1 *(Ponce, 1995a)*	Once in 8-12 yrs *(Magalhaes and Magee, 1994; Ponce, 1995a)*
	1. Upper midwest in USA	0.7 -1.2 *(NOAA, 1980)*	Once in 10 yrs. *(Klugman, 1978)*

RELATING E_P/P_A RATIO WITH DROUGHTS INTENSITY

For given drought years, the magnitudes of annual deficits were computed using equation 1 to get the intensity of drought in the respective years. Being a percentage, it is purely qualitative and descriptive in nature which is used to express the magnitude (i e. intensity) and severity of drought in terms of rainfall deficiency. Based on the extent of deficit, the droughts of mild, moderate, severe and extreme intensity were identified and their percent probabilities of occurrence estimated. Regressions were applied to exhibit the relationships between the E_p/P_a ratio and probabilities of occurrence of mild-&-moderate, severe and extreme intensity droughts (Fig. 4). The power type regression showed relatively better correlation (R^2 = 0.57) than the logarithmic or exponential type regression indicating that the intensities of meteorological droughts are evidently related with the E_p/P_a ratio.

Fig. 4 shows that the probability of occurrence of severe and extreme intensity droughts increases progressively from the sub-humid to arid regions, it however, decreases in the case of mild-moderate intensity drought. For example, an area with E_p/P_a ratio equal to 1.5 has percent probabilities of occurrence of mild-moderate, severe and extreme intensity droughts as 80%, 18% and 2%, respectively, and for the area with E_p/P_a ratio as 4.0 these values are 64%, 28% and 7%, respectively. In case of a place in arid region where E_p/P_a ratio is 7.0 the values are 55%, 35% and 10%, respectively. Thus, the areas located in arid and semiarid climatic regions are likely to suffer relatively more frequent severe and extreme meteorological drought conditions than the areas in sub-humid climatic region. The probability of occurrence of severe droughts is below 18% in the regions with E_p/P_a ratio less than 1.5. The relationships, shown in Fig. 4, indicate that the extreme drought events are almost none in the regions with E_p/P_a ratio less than 1.25. This categorically substantiates that the regions which receive mean annual precipitation in the order of more than 80% of their local mean annual potential evapotranpiration (i.e., $E_p/P_a < 1.25$) are nearly free from the risk of occurrence of extreme drought events.

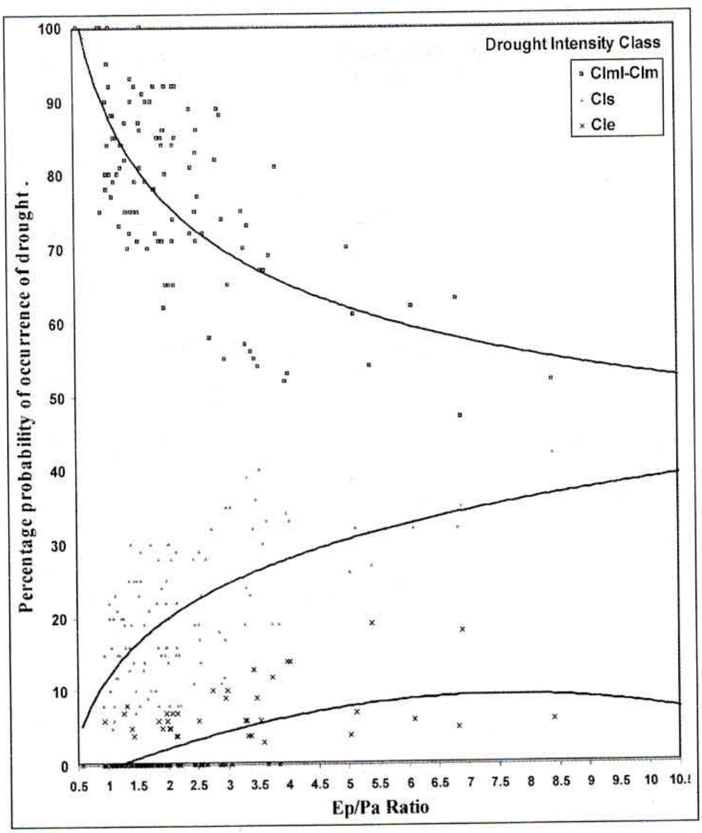

Fig. 4: Relationship of (E_p/P_a) ratio with percent probability of occurrence of droughts of different intensity

Further, it is also clear from Fig. 4 that the regions where amount of mean annual rainfall is more than local mean annual potential evapotranpiration (i.e. E_p/P_a <1) the prevalence of severe drought events is rare or negligible. Above discussed pattern of probability of occurrence exhibits that the climatic regions with lesser E_p/P_a ratio are less vulnerable for intense meteorological droughts. In other words, the climatic regions with less mean annual deficit (E_p-P_a) face less intense droughts, consistent with the works of Lugo and Morris (1982), Gol'tsberg (1972), Gregory (1989) etc. For instance, Magalhaes and Magee (1994) and Ponce (1995a) found Agreste (sub-humid) to be affected by drought but not as severely as the Sertao (semiarid) in Brazillian Northeast. Also, the Australian experience shows the droughts to be most serious (i.e., intense) where rainfall ranges between 250 and 750 mm, i.e., in arid and semiarid regions (Kendrew, 1961), further supporting the results.

Relating E_p/P_a Ratio with Drought Duration

Duration of drought is one of the important characteristics, which forms a basis in the planning of strategies to cope with drought for a given region. Drought conditions may continue to prevail for one or more consecutive years. The tendency of drought conditions to prolong for more than one year is termed as drought persistence. For example, an event of drought with duration of two or more years is a persistent drought event. The experiences (reported in literature) show that the droughts have a tendency to last longer in those climatic regions which have greater inter-annual precipitation variability (WMO, 1975; Karl, 1983; Johnson and Kohne, 1993; Rasool, 1984).

In this study, an attempt has been made to relate drought persistence with climatic parameters in the arid, semiarid, and sub-humid climatic regions in India. The drought duration is seen to vary between 1 and 5 years in the different climatic regions. Identified drought events yielded the median duration of a persistent drought as 2 years and maximum duration of persistent droughts has been 5 years. 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 persistent drought events (= 3 yrs. duration) are very few in sub-humid regions.

From the data-spread sheet, it was found that the drought events of 4- and 5- years duration are a few only. Therefore, plots of percent probability of occurrence of droughts for 2- and 3-years duration with E_p/P_a ratio were prepared and presented in Fig 5. The depicted relationships could not lead to significant interpretation as the plots are quite scattered with low values of correlation coefficient. However, it can be expressed that the chances of occurrence of meteorological droughts of more than one year duration are relatively more in arid and semiarid regions.

On examining the spread-sheet of data analyses, it was found that the stations located in the sub humid climatic regions indicate different pattern in respect of drought persistence. However, it was seen that the stations (particularly with E_p/P_a ratio < 2.0)

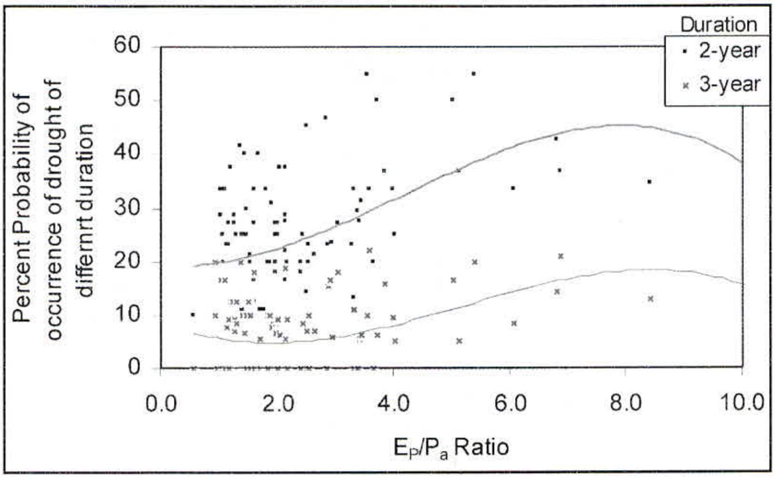

Fig. 5: Relationship of E_p/P_a ratio with percent probability of occurrence of droughts of 2- and 3- years duration

which are either located close to sea coast (distance < 100 Km from coast) or close to mountain (distance < 100 Km) rarely face persistence drought events of 2 or more than 2-years duration.

Relatively a greater number of persistent drought events are observed in many parts of Rajasthan followed by Gujarat, 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 sub-humid climatic regions with E_p/P_a ratio between 1.20 and 2.0. This broadly supports to the conclusion of Rasool (1984) that "in semiarid and sub-humid regions, the drought duration can approach as long as 4-5 yrs due to greater inter-annual 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.

Thus, the above comparison of relationships between drought characteristics and regional climatic parameters (i.e., E_p/P_a ratio and $(E_p-P_a)/P_a$ ratio), derived using 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 basically lies in its climatic basis, i.e., its ability to depict regional variability.

INFLUENCE OF MORPHOLOGICAL FACTORS ON DROUGHT CHARACTERISTICS

According to Lana & Burgueno (1998), besides morphological factors orography affects the drought characteristics significantly. In view of this, an attempt was made to assess relevance of drought characteristics with the distance of major orographic barriers (d_h), distance from sea coast (d_s) and elevation of the place from mean sea level (m.s.l.). Multiple regressions were applied to determine significance of these factors in description of frequency, duration, and intensity of meteorological droughts using long-term data for 110 stations. Some influences of elevation could be observed in drought intensity and of distance from sea coast on drought persistence (i.e. duration). However, no specific pattern could be established among them. From the spreadsheet analysis of long-term meteorological drought, it was seen that the stations which are close to sea, and are situated near some mountain/major hill did not face drought events of severe and extreme intensity (Table 2).

It was found from the data that stations which are located at relatively shorter distance from sea and have $P_a \sim E_p$ did not faced persistent droughts of 2 or more consecutive years. Regions with Ep/Pa<1.2, d_s<100 km, and d_h<100 km hardly ever faced persistent droughts or the drought events of severe and extreme intensity. For example, Madurai and Kanyakumai in Tamilnadu (Ep/Pa<1.2, ds<100 km and d_h<100) have respectively

Table 2: List of stations which never faced drought events of severe & extreme intensity

Sl. No.	Station	Ep/Pa	Data length, years	Total No. of drought events	No. of events with duration > 1 yr	No. of events with Cl_s & Cl_e intensity	Approx. Altitude (w.r.t. msl), m	Distance from sea coast km	Distance from major hill/mountain km
1	Tumkur Karnataka	1.84	77	12	0	0	300	252	150
2	Bangalore Karnataka	1.66	80	11	0	0	1200	280	95
3	Mandya Karnataka	2.0	79	14	0	0	800	195	90
4	Hassan Karnataka	1.62	76	8	1	0	1000	135	50
5	Tirunelveli Tamilnadu	1.96	76	13	1	0	40	52	40
6	Salem Tamilnadu	1.8	78	9	1	0	300	178	12
7	Madurai Tamilnadu	1.03	78	6	0	0	100	98	45
8	Agastheswara Kanyakumari Tamilnadu	1.19	76	9	0	0	30	10	15
9	Belgaum Karnataka	1.10	77	6	1	0	700	90	40
10	Hulsi Maharashtra	0.9	77	9	1	0	1200	114	On hills

experienced 7 and 9 drought events during 1901- 2001, but none of them persisted for two or more consecutive years. Further, the stations which are within 100 to 150 km from ocean ($100<d_s<150$) and have close distance ($d_h<$ 100 km) from mountain/ major hill seldom faced the drought events of severe and extreme intensity, and also the occurrences of persistent droughts events were very few. Thus, beside the climatic parameters, drought characteristics at a given location are influence by distance from sea coast and mountain barrier.

SUMMARY AND CONCLUSIONS

Average drought frequency can be described using dimensionless climatic parameters 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 notable 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 ($12> E_p/P_a \geq 5$), three to five years in the semiarid regions ($5>E_p/P_a \geq 2$) and five to nine years in the sub-humid regions ($2>E_p/P_a \geq 3/4$). In semiarid to sub-humid regions with Ep/Pa ratios between 3.5 and 0.5, the drought frequency decreases exponentially with increase in wetness. Identical relationship is obtained between the average drought frequency (F) and the ratio of mean annual deficit to mean annual precipitation [$(E_p-P_a)/P_a$].

The probability of occurrence of a severe or extreme intensity drought increases gradually from wet to dry regions, the case is however reverse for moderate intensity droughts. Thus, it can be concluded that the areas located in arid and semiarid climatic regions are prone to suffer from relatively more intense meteorological droughts than areas in the sub-humid climatic region. The occurrences of severe droughts are much rare in the regions with E_p/P_a ratio less than 1.2. The extreme drought events are almost unnoticed in the regions with E_p/P_a ratio less than 1.20. This again confirms that the climatic region with lesser mean annual deficit is less susceptible for intense droughts.

The drought duration is seen to vary between 1 and 5 years in different climatic regions. The median value of longest drought persistence among different climatic regions is 2 years. However, the persistent drought events have more chances to occur in arid and semi-arid climatic regions. Presence of mountains and ocean in close vicinity influence the drought characteristics in the regions with $P_a \tilde{} E_p$. the study revealed that the stations which are located at relatively shorter distance from sea and have $P_a \tilde{} E_p$ rarely face persistent droughts of 2 or more consecutive years. Regions with $Ep/Pa<1.2$, $d_s<100$ km, and $d_h<100$ km hardly ever faced persistent droughts or the drought events of severe and extreme intensity. The stations which are within 100 to 150 km from ocean ($100<d_s<150$) and have close distance ($d_h<$ 100 km) from mountain/major hill hardly faced the drought events of severe and extreme intensity, and also the occurrences of persistent droughts events were very few.

The results were compared with drought experiences in other countries and were found to be in conformity with them. The relations presented in this paper can be used as a sensible tool for prediction of regional drought characteristics and planning of appropriate drought management strategies for different climatic regions in India.

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