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Districtwise Drought Climatology Of The Southwest Monsoon Season over India Based on Standardized Precipitation Index (SPI)

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Executive Summary

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16	Abstract	District-wise drought climatology over India for the southwest monsoon season has been examined first time using two simple drought indices; Percent of Normal (PN) and Standardized Precipitation Index (SPI). The drought indices were computed using long times series (1901-2003) of southwest monsoon season rainfall data of 458 districts over the country. Identification of drought incidences over the country as whole using both PN and SPI yielded nearly similar results. However, the district-wise climatology based on PN was biased by the aridity of the region. Whereas drought climatology based on SPI was not biased by aridity. Thus it was showed that SPI is better drought index for the district-wise drought monitoring. SPI is also suitable for examining break and active events in the monsoon rainfall. The trend analysis of district-wise SPI series showed significant negative trends over several districts from Chattisgarh, Bihar, Kerala, Jharkhand, Assam and Meghalaya, Uttaranchal, east Madhya Pradesh, Vidarbha etc., Whereas significant positive trends in the SPI series were observed over several districts from west Uttar Pradesh, west Madhya Pradesh, South & north Interior Karnataka, Konkan and Goa, Madhya Maharashtra, Tamil Nadu, East Uttar Pradesh, Punjab, Gujarat etc.
17	Key Words	Southwest Monsoon, Drought Climatology, Standardized Precipitation Index, Percent of Normal, Linear Trends.

1. Introduction

Drought is a normal, recurrent feature of climate and is observed in all the climatic zones. However, it has significantly different characteristics from one region to another. Drought differs from aridity. Aridity is a permanent feature of climate over regions where rainfall received is generally low. On the other hand, drought over a geographic area is a temporary condition caused by significantly less (deficient) rainfall for an extended period of time, usually during a season when substantial rainfall is normally expected over the area. For example, the primary rainy season for India is southwest monsoon season. However, in 2009, most parts of the north India experienced drought conditions due to lack of rainfall during major part of the southwest monsoon season. The deficiency in the rainfall is measured relative to the long-period average (LPA) of rainfall over the area. While considering the drought, it is also important to take into account the timing (i.e., principal season of occurrence, delays in the start of the rainy season) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. The severity of the drought can also be aggravated by other climatic factors such as high temperature, high wind and low humidity. However, there is no generally accepted classification scheme for drought (Wilhite and Glantz, 1985).

A drought index is typically a single number value used for indicating severity of a drought and it is far more useful than raw data to understand the drought conditions over an area. Due to multidisciplinary importance of droughts, several drought indices can be found in the literature (Bates 1935, Palmer 1965 & 1968, Gibbs and Maher 1967, Frere and Popov 1979, Bhalme and Mooley 1980, Petrasovits 1990, Rao et al. 1981, Sastri 1993, Heddinghaus 1991, Tate et al. 2000). Though rainfall is the primary factor that controls the generation and maintenance of drought conditions, evapotranspiration is also an important variable. However, due to the inherent difficulty in quantifying evapotranspiration rates, it is always advisable to use a drought index that use rainfall only for its computation. Drought indices like percent of normal (PN), deciles, standardized precipitation index (SPI), effective drought index (EDI), Bhalme- Mooley drought index (BMDI) etc. use only rainfall data for their computation. The indices based on only rainfall data are not only simple to compute, it has also been shown that these indices perform better compared to more complex hydrological indices (Oladipio, 1985). During the past few decades, several drought indices based on remote sensing data such as Normalized difference vegetation index (Jordan 1969, Tucker 1979), Enhanced vegetation index (Huete et al. 2002) Vegetation condition index & Temperature condition index (Kogan 1995 &1997) etc. have also been developed.

In India also there has been studies related to drought using drought indices based on the rainfall data only. These studies were mainly for the monsoon season (June to September) which contributes about 75-90% of the total annual rainfall over most parts of the country. Most of these studies were also based on the PN as the drought index. Using PN as the drought index and using subdivision wise areas and rainfall data, Banerji and Chabra (1964) considered severe drought conditions in the State of Andhra Pradesh, India to be coincident with seasonal rainfall of less than 50% of normal. Ramdas (1950) considered a drought to arrive when actual rainfall for a week is half of normal or less. Appa Rao (1991) classified the drought-prone areas and chronically drought-affected areas and found that most of the drought-prone areas were either in arid or in semiarid regions where droughts occur more frequently. Using long time series (1875-1987) of subdivision rainfall data over India, Chowdhury et al. (1989) examined various statistical features of all India drought incidences. For this, Chowdury et al. (1989) used standardized area affected by drought over the country as the drought index. Using subdivision wise rainfall and area data, Sen and Sinha Ray (1997) observed a decreasing trend in the area affected by drought in India, which are located over northwest India, parts of central Peninsula and southern parts of Indian Peninsula. Gore and Sinha Ray (2002) made a detailed study of the variability of drought incidence over districts of Maharashtra. Sinha Ray and Shewale (2001) have determined the probability of occurrence of drought on the basis of summer monsoon rainfall data for the period 1875-1999. Using district rainfall data of 424 districts over India, Guhathakurta (2003) studied the spatial variability of drought in the district scale and probability of drought conditions during 14 all India normal monsoon years 1988-2001. Gore et al. (2010) using PN examined the probability of drought incidence in the subdivision scale using rainfall data of 319 districts for the period of 1901-2000. Gore et al. (2010) also examined spatial variation of drought probability over India. However, so far there has not been any comprehensive drought study over India in the district level particularly using drought indices other than PN as long time series of district-wise data were not available. Now, rainfall data of 458 districts over India for long time period (1901-2003) prepared by Guhathakurta and Rajeevan, (2008) are readily available for research.

In this study, using PN and SPI, district-wise and all India drought climatology over India for the southwest monsoon season have been examined. A comparison of the drought climatology based on SPI has been made with that based on the PN to show that the SPI is a better index for monitoring drought conditions over smaller spatial scales like districts, subdivisions etc. The long term trends in the district-wise

SPI series over India were also studied to examine the regional variation in the trends in SPI over India. The sections 2 & 3 describe the data used and methodology employed for the study respectively. In section 4, the results of the study are discussed and section 5 presents the conclusions of the study.

2. Data Used

The basic data used in the study is the southwest monsoon season (June to September) rainfall data of 458 districts over India (Guhathakurta and Rajeevan, 2008) for the period 1901 – 2003. The data of geographical areas of all these 458 districts were also used. The districts used in this study are shown as shaded areas in the country map (Fig.1). The district-wise rainfall was calculated from 1476 stations (at least 2 stations from each district) that having maximum data availability during the data period and distributed all over the 36 meteorological subdivisions of India. The station data were obtained from archive of the National Data Center, India Meteorological Department. The district rainfall was computed as the simple arithmetic average of the rainfall of the stations in the district. However, for some of the districts, data were not available for the entire period. 450 of these districts have data for ≥70 years and 436 districts have data for ≥80 years during the data period. In order to test whether the district-wise rainfall follows a normal distribution, the Lilliefors test (Lilliefors 1967) for goodness of fit to a normal distribution was used. The Lilliefors test evaluates the hypothesis that X has a normal distribution with unspecified mean and variance, against the alternative that X does not have a normal distribution. This test compares the empirical distribution of X with a normal distribution having the same mean and variance as X. The districts for which the seasonal rainfall follows a normal distribution at the significant level of at least 5% are shown in the Fig.1 as grey shaded areas. As seen in the Fig.1, rainfall time series of most of the districts are following normal distribution. However, rainfall series of several districts in the country particularly from northwest India, southern parts of Peninsula, and subdivisions along the foot hills of Himalayas do not follow normal distribution.

The all India rainfall was computed as the area weighted average of the district rainfall data. The time series of district and all India rainfall used in this research work are different from commonly quoted rainfall time series of India Meteorological Department (IMD) which are computed from rainfall data of variable subset of about 3500 stations. The Lilliefors test on the all India seasonal rainfall series used in this study showed that the rainfall time series is normally distributed at significant level of 1%.

3. Methodology

Using the district-wise SW monsoon season (June to September) rainfall data for the period 1901-2003, the two drought indices; PN and SPI were computed for each of the districts and the country as a whole. The method of computation of PN and SPI is described in the next sections. Using each of these two basic drought indices data, climatology of percentage of drought incidences over all the districts was computed. By comparing climatology based on these two drought indices, it has been shown SPI is a better drought index than PN for monitoring drought conditions over smaller spatial scales (i.e. districts and subdivisions). Further, the percentage of areas of the country affected by drought based on PN were computed to examine the incidence of droughts of different intensities over the country as a whole and same was compared with the incidence of drought identified using SPI. Finally, the trends in the district-wise SPI time series was computed using data of districts that having data for at least 70 years. Simple linear regression technique was used to compute the trends and the 'Students t' test was used for significance testing the linear trends.

3.1. Percent of Normal (Percent of LPA)

The PN was calculated by dividing actual rainfall by its long period average (LPA) or normal rainfall and multiplying by 100%. In this study, for calculating the LPA of each district, all the available data during the entire period (1901-2003) was used. Fig.2 shows the district-wise LPA and coefficient of variation (C.V.) of the summer monsoon season rainfall. As seen in the Fig.2, during the southwest monsoon season, highest average rainfall of ≥2000mm is received by all the districts along the west coast from north Kerala to Maharashtra. Few isolated districts from northeast also receive average rainfall of ≥2000mm. Most of the other districts from northeast India receive average rainfall between 1000 and 2000mm. Another area that receive good average rainfall is the eastern region of central India which include east Madhya Pradesh, Chatisgargh, eastern part of Vidarbha, Jharkhand, Orissa and Gangetic west Bengal. Most of the districts over this area and many districts along the foothills of Himalaya also receive average rainfall between 1000 & 2000mm. For the country as whole, the long period average of rainfall during monsoon season computed in this study using all the data for the period 1901-2003 is around 877mm. The season rainfall over the country as a whole is termed as deficient (excess) when the rainfall is less than 90% (more than 110%) of its LPA. When the rainfall is between 90-110% of LPA, it is termed as normal. For about 70% of the years, the season rainfall over the country as a whole was normal. During a given SW monsoon season, the rainfall over the country as a whole may be normal, but various meteorological districts can have rainfall below or above LPA. The season rainfall over a district is classified as moderate meteorological drought, when the rainfall over the area is 50-74% of LPA and a severe meteorological drought when it is less than 50% of LPA. For the country as a whole, when the season rainfall is deficient (less than 90% of LPA) and 21 to 40% of the area of the country is under drought (moderate or severe), the situation is called "all India drought". When the seasonal rainfall over the country as a whole is deficient and >40% of the area of the country is under drought, the situation is called “all India severe drought”.

3.2. Standardized Precipitation Index (SPI)

The SPI is an index developed by McKee et al. (1993) based on the probability of rainfall for the time scale of interest and is relatively less complex to compute. The time scale reflects the impact of drought on the availability of the different water resources. Soil moisture conditions respond to rainfall anomalies on a relatively short scale. Groundwater, stream flow, and reservoir storage reflect the longer-term rainfall anomalies. For the calculation of SPI for any location long time series of rainfall for the desired period (monsoon season for this study) is used. This long time series of rainfall is fitted to a probability distribution, which is then transformed into a standardized normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median rainfall and negative values indicate less than median rainfall. The classification of the drought intensities based on the SPI value is as follows; It is called moderately dry/ moderate drought for SPI value from -1.0 to -1.49, severely dry/ severe drought for SPI value from -1.5 to -1.99 and extremely dry/ extreme drought for SPI value of -2 and less.

In this study, for the seasonal rainfall series was fitted to the gamma distribution. The gamma probability distribution function (pdf) is given as.

$$f(x) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-x/b}$$

for x >0, where a >0 & b >0 are the shape and scale parameters respectively, x>0 is the rainfall and Γ(a) is the gamma function.

The aim of fitting the distribution to the data is to estimate the parameters a & b. Integrating pdf with respect to x and inserting the estimated values of a & b, the gamma cumulative distribution function (cdf) is computed at each value of x. The cdf is then transformed into the standard normal distribution to yield SPI.

Fig.3 illustrates the computation of SPI for the seasonal rainfall over the country as a whole. Fig.3 shows the theoretical cdf of the gamma distribution fitted to the rainfall series and standard normal cdf derived using the data for the period 1901-2003. To compute SPI corresponding to a rainfall value (say 800mm), first mark 800 mm on the primary x- axis, from this point draw a line parallel to y-axis till it intersects with the theoretical gamma cdf line. Then from this point of intersection extend a line perpendicular to y-axis by maintaining equal cumulative probability till it intersects the standard normal cdf graph. Now, draw another line parallel to the y-axis from this point upwards to the secondary x-axis. The intersected x value (-1.1118) is the SPI value.

4. Results

4.1. Drought Climatology of the District Rainfall

Fig.4a shows the district-wise percentage of incidences (probability) of drought of moderate intensity during the monsoon season (June to September) based on PN. For the computation of the drought probability over each district, all the years for which data were available during the period 1901-2003 were used. Districts have been shaded into five categories (<5%, 5%≤ and <10%, 10%≤ and <15%, 15%≤ and <20%, ≥20%). Districts not used for this study have not been shaded. It is seen that majority of the districts in the northwest part of the country consisting of Rajasthan, Gujarat, Jammu & Kashmir, Punjab, Haryana have drought probabilities of ≥20%. The probabilities decrease as moving eastwards from northwest India to northeast India. Over northeast India, most of the districts have probabilities of less than 10%. Over the peninsula, many of the interior districts have probability of ≥20%. Districts along the west coast show less than 10% probability. The Fig.4b similarly shows the probability for severe drought based on PN. In the case of Fig.4b also highest probabilities are observed in the districts from northwest India. Some isolated districts over various other parts of the country shows probability for severe drought of more than 5%. If the Figures 4a & 4b are compared with district-wise distribution of mean (mm) and C.V (%) of rainfall shown in the Figures 2a & 2b, it can be seen that in general, the districts with highest probability for droughts based on PN have also lowest mean and highest C.V. Most of these districts as seen above are from the arid and semi arid regions of northwest India and south peninsula.

Figures 5a, 5b & 5c show the district-wise distribution of percentage of incidences (probability) of droughts of moderate, severe and extreme droughts computed based on the SPI. For the computation of probability over each district, all the years for which data available during the period 1901-2003 were used. Districts have been shaded into five categories of probability (<5%, 5%≤ and <10%, 10%≤ and <15%, 15%≤ and <20%, ≥20%). Districts not used for this study have not been shaded. A glance at Figures 5a, 5b & 5c show that the highest probabilities of drought of various intensities are not distributed only over the arid or semi-arid regions. Rather it can be seen that for all the districts, the probability for the moderate drought is more than 10% and over majority of the districts the probability of the severe drought is more than 5%. Further unlike the drought probability based on the PN, even in many districts in the west coast and northeast India, the probability for moderate drought is more than 15%. It is only in some districts in the south Telangana region of Andhra Pradesh that in both Fig.4a and Fig5a, the probability of moderate droughts show similar high values. In Fig5a, it is seen that districts with probabilities more than 15%, though spread in almost all parts of the country, are somewhat concentrated in northwestern part of the country (consisting of Gujarat, Rajasthan, Punjab, Haryana, Chandigargh, Delhi and Jammu & Kashmir) and eastern part of the Peninsula (that includes Gangetic West Bengal, Orissa, Vidarbha, Marathwada, Andhra Pradesh, Interior Karnataka and Tamil Nadu).

The major differences in the drought climatology over India prepared using PN and SPI seems to be mainly associated with the definition of drought categories using PN. The first is that the definition of various drought categories based on PN does not take into account the C.V. of the rainfall. As a result, over northwest India & southeast Peninsula, where the C.V. is relatively high, climatology based on PN indicates higher probability for drought incidences. Whereas over west coast and northeast India, where the C.V. is relatively low, the climatology based on PN indicates lesser probability for drought incidences. Further, the definition of PN assumes that the rainfall series is normally distributed (i.e. the mean and median of the district-wise season rainfall are equal). But as seen in the Fig.1, many districts over the country particularly from northwest India, southern part of Peninsula and subdivisions along the foothills of Himalayas are not normally distributed. However, SPI do not have both these drawbacks as it's a normalized drought index where the rainfall data are transformed into standardized normal distribution. Thus it can be concluded that the drought climatology based on the PN is biased by the aridity of the region rather than the occurrences of the incidences of droughts. However, drought climatology based on SPI is not biased by the aridity of the region and hence is a better index for drought monitoring.

4.2. Drought Climatology of the All India Rainfall

Fig.6 a & b shows the time series of all India SW Monsoon seasonal rainfall expressed in terms of PN and SPI respectively for the period 1901-2003. It is clearly seen that the year to year variation in both the plots are nearly same. In fact, the SPI values multiplied by 10 was nearly equal to the (PN -100). This is expected as the all India SW Monsoon seasonal rainfall series is normally distributed.

Using the criteria given in the section 3.1, all India drought and all India severe drought years were identified. For this purpose, the percentage of area of the country under drought (moderate and above) was calculated using PN and geographical area data of all the 458 districts. It is observed that during the period 1901-2003, there were 22 deficient monsoon years (with PN values less than 90%) and 28 years when the percentage area of the country under drought was more than 21%. From both these two information, 16 years (1901, 1904, 1905, 1907, 1913,1920, 1941, 1951, 1965, 1966, 1968, 1974, 1979, 1982, 1986 & 2002) were identified as the all India moderate drought years (with PN less than 90% and 21-40% of area of the country under drought) and 4 years (1911, 1918, 1972 & 1987) were all India severe drought years (with PN less than 90% and more than 40% of area of the country under drought).

Drought classification of all India rainfall time series based on SPI criteria (given in section 3.2) resulted 10 years (1901, 1904, 1907, 1913, 1920, 1941, 1966, 1968, 1974 &1986) under moderate drought category, 6 years (1905, 1911, 1951, 1965, 1982 & 2002) under severe drought category and 4 years (1918, 1972, 1979 & 1987) under extreme drought category. On comparing the drought years based on both the drought indices, it can be seen that in both the cases the list of 20 years is the same. Further it can be seen that 15 of the 16 moderate/severe drought years based on SPI is same as 15 of the 16 moderate drought years based on PN. The only exception is that in the drought years based on PN, 1979 comes under the moderate category and 1911 comes under severe category. On the other hand, in the case of SPI, 1979 comes under extreme drought category and 1911 comes under moderate/severe category.

4.3. Trends in the SPI Series over India

In order to examine the trend in the All India SPI series, a liner trend line was fitted. It is observed (figure not presented here) that though there is significant year to year variation in the SPI series, the fitted trend line was nearly flat indicating absence of any significant long term trend in the all India SPI series. Recently, Guhathakurta and Rajeevan (2008) examined the trends in the subdivision wise monthly and season rainfall series over India and observed significant long term trends over some of the subdivisions during southwest monsoon season. This clearly indicated regional variation in the monsoon rainfall trends over India. However, there have not been any studies that examined linear trends in the rainfall or related indices over the country at district level. Therefore, in order to examine the regional variation in the trends in the SPI series over India, linear trends in the district-wise SPI were computed and shown in the Fig. 7. In the Fig.7, districts have been divided into four categories; districts with positive trend, positive trend at significant level of 5% or more, negative trend and negative trend at significant level of 5% or more. In the Fig.7, each of these categories has been shown using distinct colours. It can be seen in the Fig.7 that maximum number of districts with negative trends are mainly distributed over eastern part of the country and northern and southern most meteorological subdivisions. Over other regions, most of the districts showed positive trends. The districts with negative trends at 5% or above significant level are mainly distributed over Chattisgarh, Bihar, Kerala, Jharkhand, Assam and Meghalaya, Gangetic West Bengal, Uttar Pradesh, Uttanranchal east Madhya Pradesh, Vidarbha, etc. On the other hand, districts with significant positive trends are mainly distributed over west Uttar Pradesh, west Madhya Pradesh, South & north Interior Karnataka, Konkan and Goa, Madhya Maharashtra, Tamil Nadu, East Uttar Pradesh, Punjab, Gujarat etc. Table-1a (Table-1b) shows the list of subdivisions that having at least 1 district with significant positive (negative) trend in the SPI series along with related district-wise statistics.

5. Conclusions

Drought climatology over India was examined both district-wise and all India wise using two drought indices, namely, Percent of Normal (PN) of rainfall and Standardized Precipitation Index (SPI). As the all India rainfall is significantly normally distributed, the years of all India drought (moderate and above) identified by both PN and SPI were nearly same. However, there were significant differences in the district-wise climatology based on these two drought indices. The district-wise drought climatology over India based on PN was found to be highly biased by the aridity of the region. Highest probability for droughts of moderate intensity was observed over many districts from northwest India and neighbouring central India and interior parts of south Peninsula. The lowest probability for droughts of moderate intensity was mainly observed over several districts along west coast of the north Peninsula and eastern and northeastern parts of the country. The highest probability of the severe droughts was also observed over the northwestern part of the country. On the other hand, district-wise climatology of the drought based on the SPI was not biased by aridity of the region. In almost all districts used for this study, the probability for moderate and above intensity drought was ≥10% and in majority of the districts, the probability for severe and above intensity drought was ≥5%. Therefore, SPI is a better drought index than the PN for monitoring the district-wise drought incidences over India.

Further as the SPI is a normalized index, it can be used to represent the excess rainfall or wet conditions in the same way as it is used to represent the drought/ dry conditions and wet periods can also be monitored using the SPI. As seen in the previous paragraph, whereas both PN and SPI are suitable for the seasonal drought monitoring in the all India scale, SPI is more suitable for district-wise drought monitoring. This is mainly because of the higher C.V. of district-wise rainfall than the all India rainfall. The C.V. also increases with decrease in the spatial and temporal scale for region of reference because of more frequent extreme events at these scales. Therefore, the SPI will also be a better index than PN in monitoring wet and dry incidences at intraseasonal scales such as break and active events over India. SPI is also more suitable as it allows drought severity at two or more locations to be compared with each other regardless of climatic differences between them. As the variability of the SPI is nearly same as that of the precipitation anomaly, prediction models can be developed for SPI and hence it is a suitable for drought prediction. Dynamical model forecasts of rainfall can be altered to produce spatial maps of SPI for drought prediction.

The trend analysis of district-wise SPI series showed significant decreasing trends over many districts in Uttanranchal, Kerala and in the subdivisions from east central India and such as east Madhya Pradesh, Vidarbha, Chattisgarh, Jharkhand, Bihar etc., and significant increasing trend was observed over several districts from

Konkan region, Karnataka, west Madhya Pradesh, Andhra Pradesh, Punjab and West Uttar Pradesh. Some districts from Kerala and Chattisgarh showed decreasing trends in SPI series and relatively high probability for drought occurrences of moderate and above intensity.

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Table – 1(a): List of subdivisions having at least one district showing significant positive trend in the SPI series. The second column shows the number of districts having positive trends in the SPI series along with number of districts with trends significant at 5% and above in the bracket. Total number of districts in each of these subdivisions is presented in the third column.

Subdivision name	**No. of districts with positive trend (No. of districts with significant positive trend)**	**Total number of districts used**
West Uttar Pradesh	25 **(12)**	27
West Madhya Pradesh	22 **(6)**	26
South Interior Karnataka	12 **(6)**	14
Konkan and Goa	6 **(4)**	6
Madhya Maharashtra	10 **(4)**	10
Tamilnadu	20 **(4)**	29
East Uttar Pradesh	23 **(3)**	39
Punjab	9 **(3)**	11
Gujarat	9 **(3)**	15
North Interior Karnataka	8 **(3)**	9
Assam and Meghalaya	7 **(2)**	18
Haryana	8 **(2)**	16
Jammu and Kashmir	5 **(2)**	10
Coastal Andhra Pradesh	9 **(2)**	9
Telangana	8 **(2)**	10
Nagaland, Manipur, Mizoram and Tripura	4 **(1)**	7
Gangetic West Bengal	6 **(1)**	9
Orissa	5 **(1)**	10
Saurashtra and Kutch	6 **(1)**	8
Vidarbha	5 **(1)**	11
Rayalaseema	4 **(1)**	4

Table – 1(b): List of subdivisions that having at least one district showing significant negative trend in the SPI series. The second column shows the number of districts that having negative trends in the SPI series along with number of districts with trends significant at 5% and above in the bracket. Total number of districts in each of these subdivisions is presented in the third column.

Subdivision name	**No. of districts with negative trend (No. of districts with significant -negative trend)**	**Total number of districts used**
Chattisgarh	12 **(7)**	13
Bihar	19 **(6)**	30
Kerala	13 **(6)**	14
Jharkhand	10 **(4)**	15
Assam and Meghalaya	11 **(2)**	18
Gangetic West Bengal	3 **(2)**	9
East Uttar Pradesh	16 **(2)**	39
West Uttar Pradesh	2 **(2)**	27
Uttaranchal	9 **(2)**	10
East Madhya Pradesh	9 **(2)**	16
Vidarbha	6 **(2)**	11
Orissa	5 **(1)**	10
Himachal Pradesh	4 **(1)**	7
Jammu and Kashmir	5 **(1)**	10
Telangana	2 **(1)**	10
Tamilnadu	9 **(1)**	29

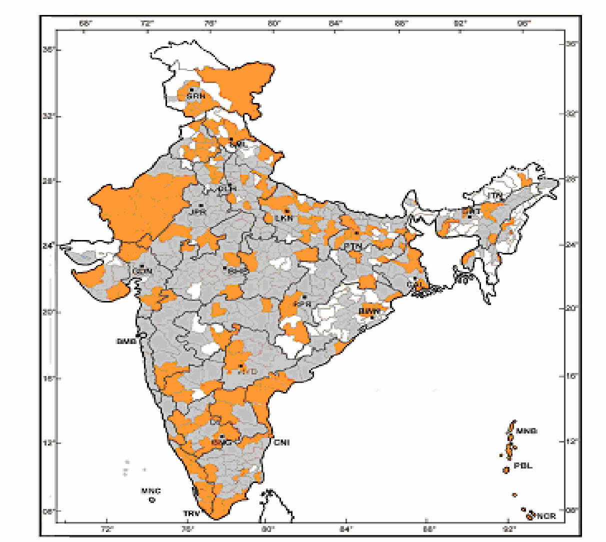

Fig.1. Map of India showing district boundaries. The 458 districts considered for this study are shown as shaded areas. The districts with monsoon season (June-September) rainfall series following normal distribution at ≥5% significant level are shaded grey and other districts are shaded orange. The boundaries of the 36 meteorological subdivisions in the country are also shown using thick black lines. Districts not used for this study have not been shaded.

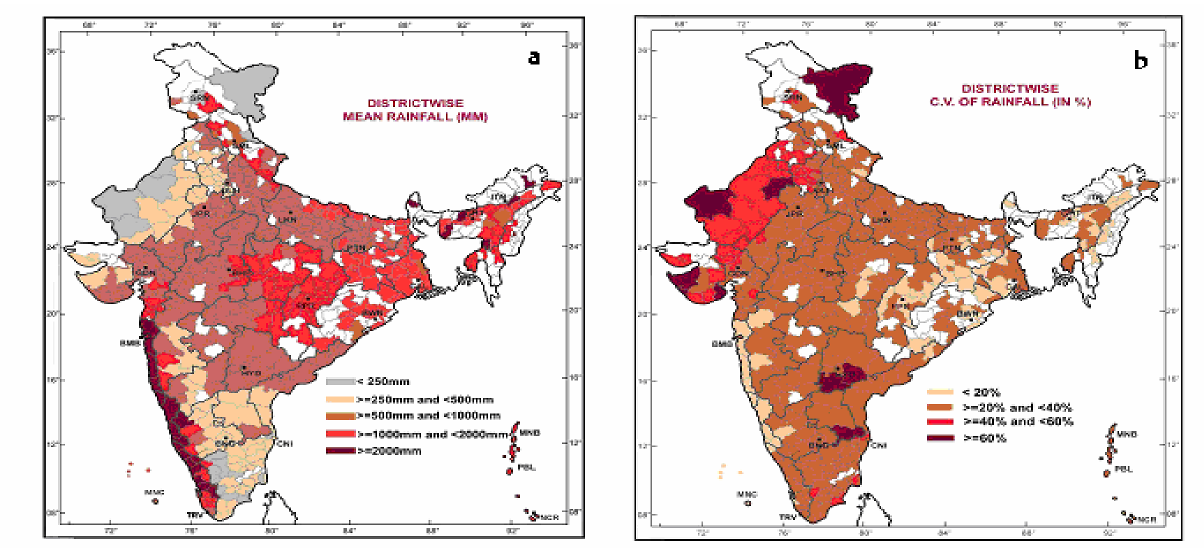

Fig.2. Map showing district-wise (**a**) mean (long period average) and (**b**) coefficient of Variation (C. V.) of southwest monsoon season (June to September) rainfall computed using all the data available during the period 1901-2003. Districts not used for this study are not shaded.

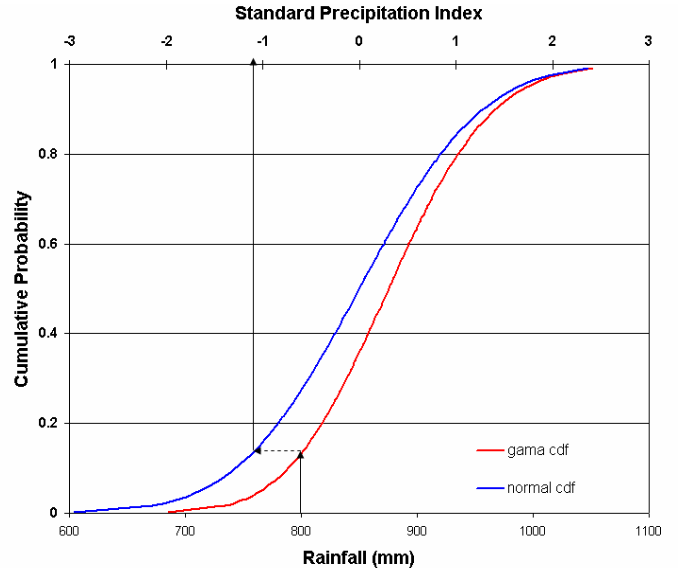

Fig.3. Illustration of computation of SPI for the seasonal rainfall over the country as a whole obtained through equiprobability transformation from fitted gama cumulative probability distribution to standard normal cumulative probability distribution. The southwest monsoon season rainfall over the country as a whole for the period 1901-2003 was used to fit the gama distribution. For a rainfall value of 800mm the transformation provides SPI value of -1.1118.

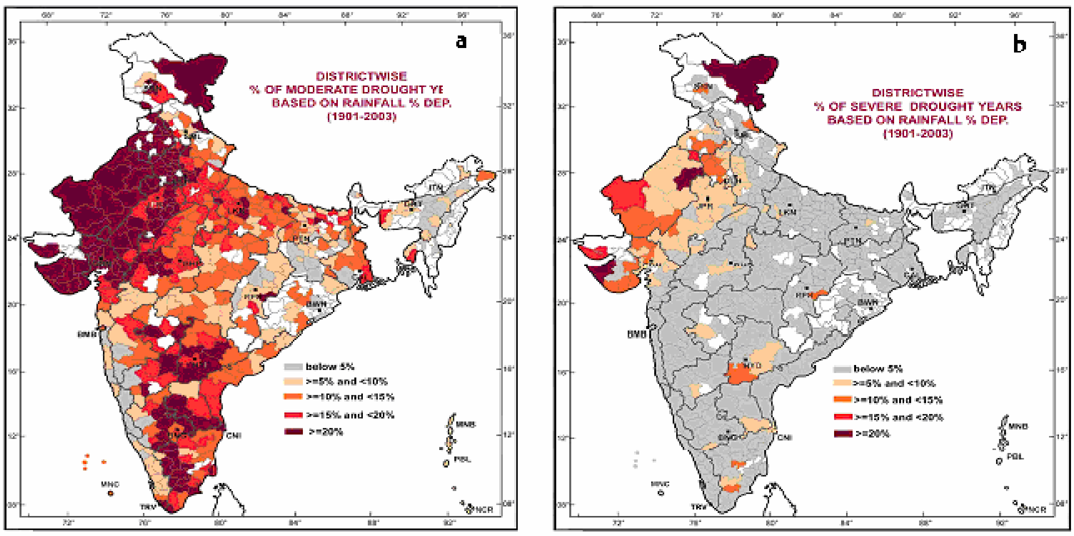

Fig.4. Map showing district-wise percentage of incidences (probability) of drought of (**a**) moderate intensity and (**b**) severe intensity during the southwest monsoon season (June to September). Percentage of Normal (PN) of rainfall was used to identify the drought incidences of various intensities. All the data available during the period 1901-2003 were used for the computation. Districts not used for this study are not shaded.

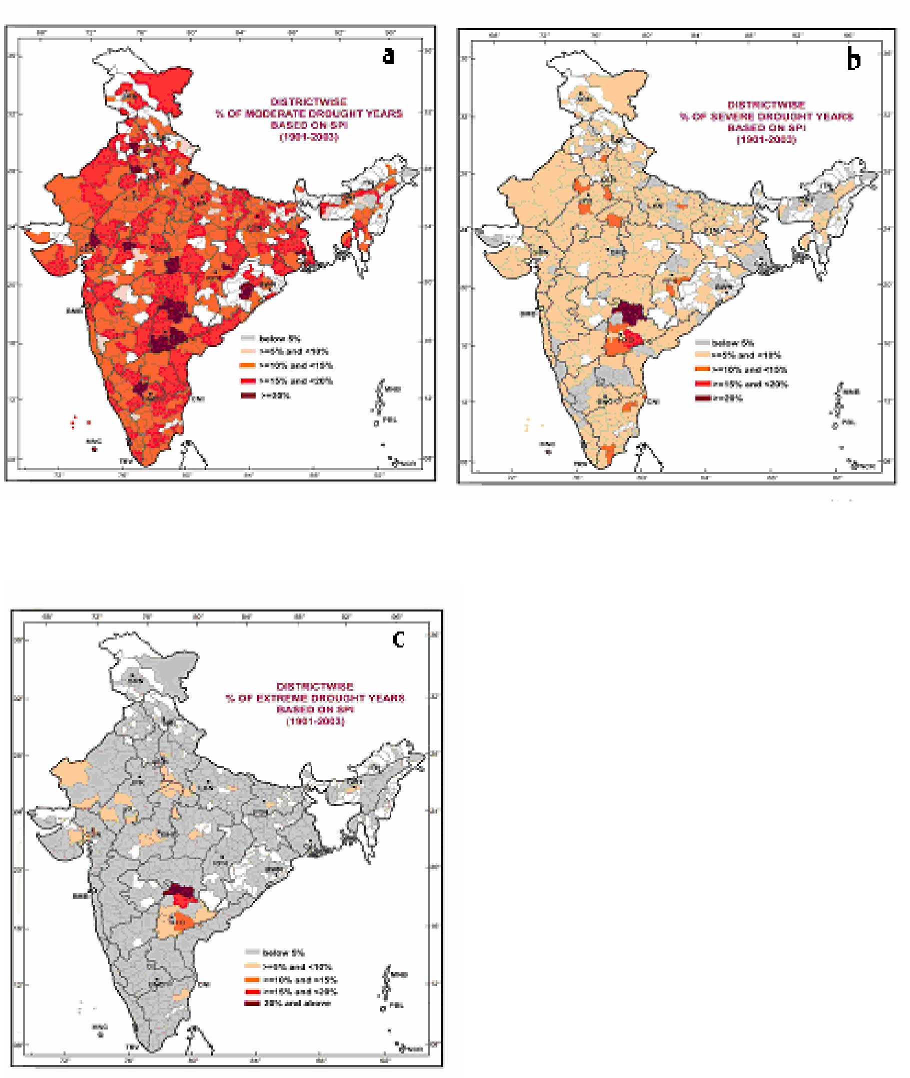

Fig.5. Map showing district-wise percentage of incidences (probability) of drought of (**a**) moderate and above intensity, (**b**) severe and above intensity, and (**c**) extreme intensity during the southwest monsoon season (June to September). Standardized Precipitation Index (SPI) was used to identify the drought incidences of various intensities. All the data available during the period 1901-2003 were used for the computation. Districts not used for this study are not shaded.

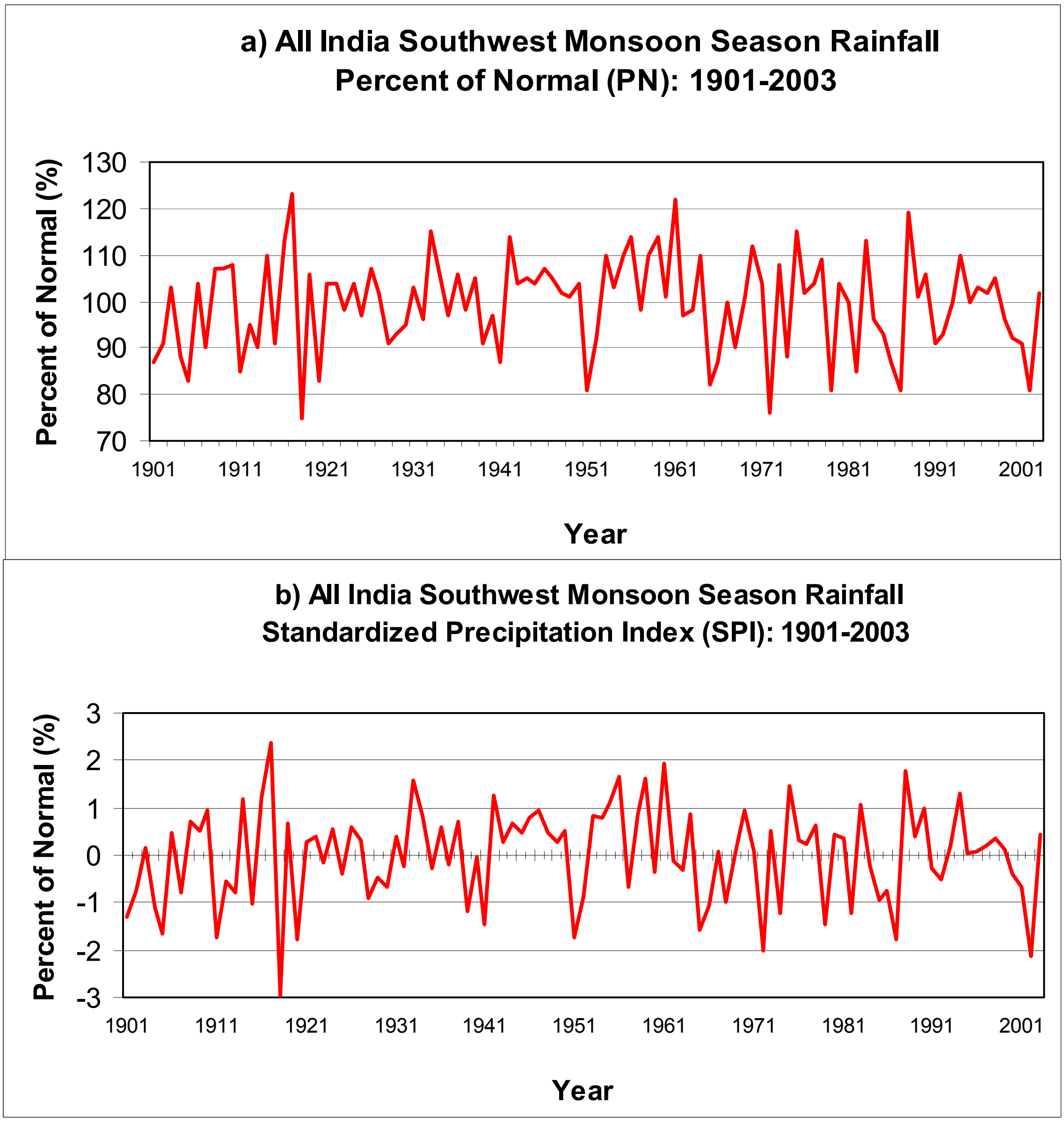

Fig.6. Time series of (**a**) Percent of Normal (PN) and (**b**) Standardized Precipitation Index (SPI) derived from All India southwest monsoon season (June to September) rainfall for the period 1901-2003.

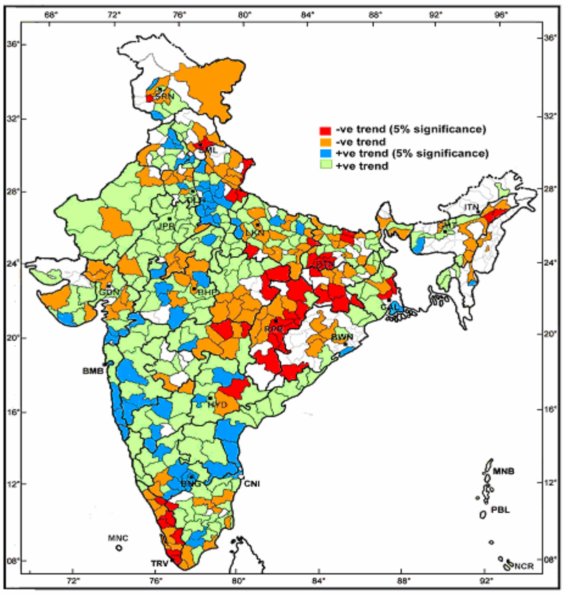

Fig.7. Map showing long term linear trends in the district-wise Standardized Precipitation Index (SPI) series. To compute the linear trends, all the data available during the period 1901-2003 were used. Districts are categorized into (i) those with negative trends significant at ≥5% level, (ii) those with negative trends (not significant), (iii) those with positive trends (not significant) and (iv) those with positive trends significant at ≥5% level. Districts under each category are shaded using distinct colours. Districts not used for this study are not shaded.

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⇨ 2) Trends in the rainfall pattern over India, P. Guhathakurta and M. Rajeevan, May 2006.

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⇨ 6) Active and Break Spells of the Indian Summer Monsoon, M. Rajeevan, Sulochana Gadgil and Jyoti Bhate, March 2008.

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⇨ 12) Mapping of Drought Areas over India, P.G. Gore, Thakur Prasad and H.R. Hatwar, January 2010.

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