

## Spatiotemporal analysis of meteorological drought variability in the Indian region using standardized precipitation index

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**ABSTRACT:** Grid (1° latitude × 1° longitude) level daily rainfall data over India from June to September for the years 1951–2007, generated by the India Meteorological Department, were analysed to build monthly time series of Standardized Precipitation Index (SPI). Analysis of SPI was done to study the spatial and temporal patterns of drought occurrence in the country. Geographic spread of SPI-derived Area under Dryness (AUD) in different years revealed the uniqueness of the 2002 drought, with widespread dryness in July. Mann–Kendall trend analysis and moving average based trends performed on the AUD indicated an increasing trend in July. The area under moderate drought frequency has increased in the most recent decade. Ranking of years based on Drought Persistency Score (DPS) indicated that 1987 was the most severe drought year in the country. The results of the study have revealed various aspects of drought climatology in India. A similar analysis with the SPI of finer spatial resolution and relating it to crop production would be useful in quantifying the impact of drought in economic terms. Copyright © 2011 Royal Meteorological Society

**KEY WORDS** meteorological drought; standardized precipitation index; Pearson III; drought intensity; drought persistence; trends; climate change; change point; area under dryness

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### 1. Introduction

The southwest summer monsoon, spreading from June to September, is a major period of rainfall in India as monsoonal torrents supply about 80% of India's annual rainfall (Chang, 1967; Bagla, 2006). The monsoon reaches south India, generally by the end of May or first week of June, and progresses to northern parts by the end of June or first week of July. The withdrawal of the monsoon starts at the end of September. Rainfall during this season plays a vital role in economic development, disaster management and hydrological planning in the country.

Time series rainfall data analysis of a region helps in better understanding its drought climatology. In addition to detection of changes in intensity, magnitude and duration of droughts, identification of frequently drought affected regions also plays an important role in drought management. Further, past performances provide indications of future scenarios. Information on spatial and temporal dimensions of drought occurrence and its spread enables design of more focussed management tasks. Therefore, systematic understanding of drought climatology is indispensable for evolving efficient drought management strategies, particularly in tropical regions such as India. A number of studies have been reported on the analysis of time series of rainfall data for characterizing drought events in terms of periodicity and magnitude. Such long term rainfall data analysis would also result in an assessment of drought vulnerability. The dominant rainfall patterns for all of India were evolved through time series analysis of rainfall data from 1871 to 1990, using map-to-map correlation, fuzzy c-means clustering and empirical orthogonal functions (Kulkarni

and Kriplani, 1998; Kulkarni *et al.*, 1992). It was observed that the rainfall from monsoons over all India has no relation to its spatial distribution.

There are many indices to measure meteorological dryness, such as simple rainfall deviation from historic norms, Palmer Drought Severity Index (PDSI) and Standardized Precipitation Index (SPI). Among these indices, SPI has been widely used in recent years because of its computational simplicity and reliable interpretation. For representing dryness, a simple measure is better than using complex hydrological indices (Oladipio, 1985). SPI is a simple and more effective method for studying drought climatology (Lloyd-Hughes and Saunders, 2002). Both SPI and PDSI indicated temporal changes in the proportion of area experiencing drought in Europe (Lloyd-Hughes and Saunders, 2002). Pai *et al.* (2010) evaluated district-wise drought climatology in India using SPI and Briffa *et al.* (1994) characterized drought across Europe using PDSI derived from time series rainfall data from 1892 to 1991 at a spatial resolution of 0.5°. Analysis of time series PDSI in Hungary revealed occurrences of more droughts at the end of the time series (Szinell *et al.*, 1998). Bordi *et al.* (2001) computed SPI with time series rainfall data from 1948 to 1981 and analysed regional drought patterns in the Mediterranean. Rodriguez-Pubela *et al.* (1998) analysed annual precipitation observations through empirical orthogonal functions and derived four regional precipitation regimes. Sirdas and Sen (2003) used a kriging technique to generate spatial maps of rainfall and SPI to characterize drought intensity and magnitude in Trakya region, Turkey. Vicente-Serrano *et al.* (2004) analysed drought patterns in Spain using SPI and observed significant increase in the area under drought from mid to northern areas. The spatial patterns of drought were found to be very complex in the rest of the areas. Iran's precipitation climate was regionalized based on rainfall data analysis using factor analysis and clustering (Dinpashoh *et al.*, 2004).

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The objective of the current study is to build a long-term monthly SPI time series from the rainfall data and to analyse the SPI derived Area under Dryness (AUD) for drought spread, drought frequency and drought persistence. The emphasis is on highlighting the spatial and temporal variations in the occurrence of meteorological dryness. Although several studies of drought analysis based on rainfall data were reported in India (Chowdhury *et al.*, 1989; Sen and Sinha Ray, 1997; Sinha Ray and Shewale, 2001; Guhathakurta, 2003; Pai *et al.*, 2010), the present study is relevant due to its larger coverage, long term data analysis and adoption of robust indicators such as SPI. Further, since the southwest monsoon is a key determinant of the performance of the kharif agricultural season, the results of the study become more relevant and significant, particularly for drought management. Section 2 of the paper describes the methodology for computing SPI using regional probability functions and trend analysis using Mann–Kendall trend coefficient. In Section 3, results and discussion are presented covering the analysis pertaining to drought spread, inter-annual variability of AUD, trends in AUD, spatial drought frequency and drought persistence. Conclusions of the study are presented in Section 4.

## 2. Methodology

Daily rainfall data from June to September for 57 years (from 1951 to 2007) generated by the India Meteorological Department (IMD) at a grid size of  $1^\circ$  latitude  $\times$   $1^\circ$  longitude were the input data in this study. The details of gridded rainfall data generation are available in Rajeevan *et al.* (2006). Monthly Standardized Precipitation Index (SPI) was computed using Pearson III distribution for different years.

There are three important steps in the computation of SPI: (1) development of regional probability functions based on regional rainfall patterns, i.e. regionalization approach particularly while using the data over larger geographic areas representing diverse rainfall patterns, (2) selection of suitable probability distribution, and, (3) estimation of parameters of the selected distribution. The regionalization approach was adopted, with Pearson III distribution, by deriving the distribution parameters through the L-moments method following Guttman *et al.* (1993) and Guttman (1999).

Regional probability functions are developed after identifying homogeneous rainfall regions (Hosking and Wallis, 1997). For example, the National Climatic Data Centre (NCDC) prepared the National Drought Atlas for the U.S. Department of Energy using monthly precipitation and temperature data for 1219 stations by adopting hierarchical clustering techniques (<http://www.iwr.usace.army.mil/iwr/atlas>). IMD categorized the country in to 36 meteorological sub-divisions based on rainfall patterns. Parthasarathy *et al.* (1995) grouped India into five homogeneous regions based on spatial contiguity, actual seasonal rainfall and global circulation parameters. Since the generation of rainfall homogeneous zones is not the main task of the current study, five broad zones based on the average rainfall are considered: Region 1 with  $<500$  mm of rainfall, Region 2 with 501–750 mm, Region 3 with 751–1000 mm, Region 4 with 1001–1500 mm and Region 5 with  $>1500$  mm of rainfall, with due consideration of the spatial contiguity of these regions. The rainfall intervals of these regions are generally in agreement with the standard rainfall variability in India. According to the reports of the Ministry of Agriculture, Government of India, the low rainfall region receiving less than

750 mm of rainfall represents 33% of cropped area and rainfall of 750–1125 mm represents 35% of cropped area. Similarly, rainfall of 1125–2000 mm represents 24% of the cropped area and  $>2000$  mm represents 8% of sown area. The purpose of rainfall zoning in this study is to develop regional probability functions to evolve a robust SPI.

### 2.1. Estimation of the parameters of Pearson III distribution using L-moments

L-moments are the estimates of moments using linear order statistics, for relating a probability distribution to the observation of the physical process. The L-moment estimates are more robust compared to the conventional moments in the presence of outliers (Royston, 1992; Sankarasubramanian and Srinivasan, 1999; Ulrych *et al.*, 2000). The L-moments are less sensitive to the effects of sampling variability and are used to characterize a wider range of distributions than the conventional moments. Practically, they are less subject to bias in estimation and they approximate their asymptotic normal distribution more closely. The parameters estimated through L-moments are more accurate than the maximum likelihood and least square estimates. This property of L-moments has been extensively used in the regionalization processes (Hosking and Wallis, 1989; Guttman, 1993; Adamowski, 2000; Storch and Zwiers, 1999).

The L-moments of the regions were computed using a MATLAB subroutine. The parameters of the Pearson III distribution were computed using the FORTRAN subroutines of Hosking (1990), invoked through an interface developed in MATLAB.

### 2.2. SPI-based drought classes

The ranges of SPI values and the corresponding drought intensity levels proposed by McKee *et al.* (1993) were adopted in this study. Two drought classes, moderate drought, with SPI ranging from  $-1$  to  $-1.5$ , and severe–extreme drought, with  $\text{SPI} < -1.5$ , were used to represent dryness. Summation of moderate drought and severe–extreme drought classes was done to represent the total AUD. That means that all the grid cells having an SPI value less than or equal to  $-1.0$  in a given month constitute the AUD.

### 2.3. Methods for smoothing time series data and trend detection

The SPI-derived AUD time series data were first analysed for the presence of autocorrelations. The Durbin–Watson  $d$  test was performed for each month separately. The computed  $d$  value and the corresponding  $d_L$  and  $d_U$  were applied to the decision rules (Gujarati, 1988) and it was found that the autocorrelations were not statistically significant in any month. The Mann–Kendall trend test based on Sen's method (Sen, 1968) was selected as it is well suited for analysing trends in data over time (Gilbert, 1987; Gregory *et al.*, 2004; Picarreta *et al.*, 2004) and it does not require any assumptions as to the statistical distribution of the data (e.g. normal, lognormal). To remove noise and bring out significant trends in the time series data, local weighted scatter plot smoothing (LOWESS), a non-parametric technique based on local polynomial fits (Cleveland, 1979), was implemented before subjecting the data to the Mann–Kendall Trend test. LOWESS is a widely used smoothing technique for detecting trends in time series data (Crick and Sparks, 1999; Abaurrea *et al.*, 2001; Wang *et al.*, 2003). A smoothness parameter  $f = 0.06$  (Kaunda-Arara

*et al.*, 2003) was selected as it was found to smooth the data adequately without distorting the main temporal patterns.

The Mann–Kendall Statistic,  $S$ , was computed after arranging the data in rank order and correcting for ties. Significance of trend was checked at the 95 percentile to reject the null hypothesis  $H_0$  that there is no trend in the different dryness classes in the region. The trend is increasing ( $I$ ) if  $S > 0$  and confidence in trend is greater than 95%. The trend is decreasing ( $D$ ) if  $S < 0$  and confidence in trend is greater than 95%.

### 3. Results and discussion

The results of the study are discussed under four sub-topics: (1) drought spread in the time series with emphasis on geographic spread of drought in major drought years, (2) inter-annual variability of AUD, regional trends and trend reversals in the AUD, (3) drought frequency, and, (4) drought persistence.

#### 3.1. Drought spread in different years

The main agricultural season, the kharif season, extends from June to October/November and depends largely on the rainfall

from the southwest monsoon. July represents the peak sowing period, August represents the active growing period of crops and September represents the maximum vegetative phase or early reproductive phase of rain fed crops. Harvesting of rain fed crops is mostly done in October or November in different parts of the country. Keeping in view the crop phenology and crop calendar, rainfall during July, August and September plays a vital role in dry land agriculture. Rainfall in June is essential in triggering sowings in the country. AUD during July to September has direct bearing on the agricultural situation in the country. Although sowing starts in June, the larger proportion of the agricultural area is sown during July. Therefore, rainfall during July is critical for timely completion of crop sowings as well as for the sustenance of early sown crops. Similarly, dryness in August and September strongly influences crop growth and performance. Consequently, drought spread analysis was carried out for each month separately.

The spatial extent of dryness in different months in some of the prominent drought years of the country is depicted in Figure 1. During June (Figure1(a)), the AUD was mostly confined to central and northern parts of the country. Also, the dryness in June occurred mostly in the earlier years of the time series. In recent years the geographic spread of dryness in

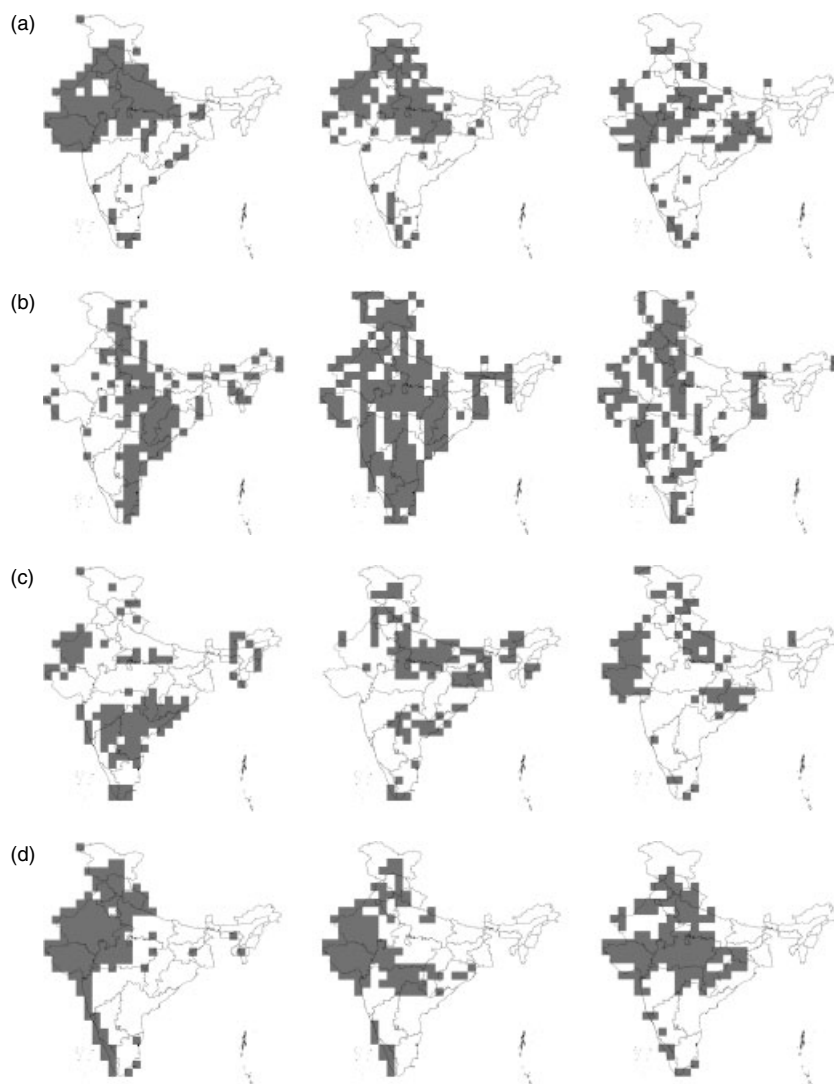


Figure 1. Spatial extent of dryness of (a) June for the years 1965, 1969, 1974. (b) July for the years 2006, 2002, 1987. (c) August for the years 1968, 1979, 1987. (d) September for the years 1952, 1987, 2001.

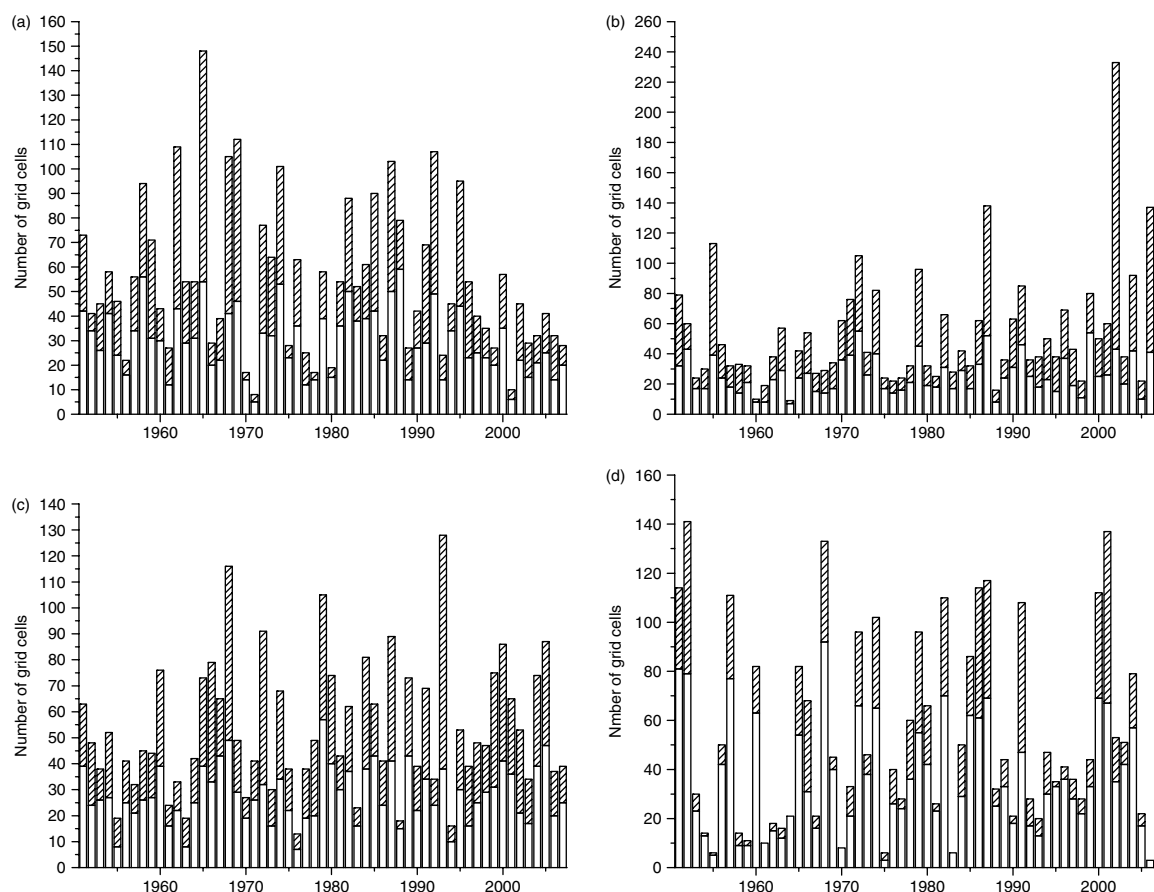


Figure 2. AUD in (a) June, (b) July, (c) August, (d) September during 1951–2007. Blank bars: moderate dryness; hatched bars: severe–extreme dryness.

the month was to a lesser extent. In July (Figure 1(b)), the year 2002 stands unique with a large number of dry grids covering many parts of the country, compared to any other year in the time series. The drought spread in 1987 and 2006 showed contrasting patterns with a symmetrical shift in the dry grids in vertical mode, i.e. east and west side. During August (Figure 1(c)), the dryness of 1968 was concentrated in the southern half and in the western parts of the country. In 1979, dryness was located mostly in the northern part of the country. The most prominent drought year of 1987 has dryness located as distinct clusters in north, east and west sides. The September dryness (Figure 1(d)) was mostly concentrated to the north western part of the country, synchronous with the receding pattern of the southwest monsoon. Thus, the prominent drought years showed spatial uniqueness in the geographic spread of dryness.

The AUD categorized under (1) moderate and (2) severe-extreme drought classes during 1951–2007 for June, July, August and September separately are depicted in Figures 2(a)–(d). The significance of inter-annual variability of AUD in all 4 months is evident from a visual examination of these figures. The coefficient of variation (CV) of AUD which reflects the average rate of change over the time series indicated larger variations to an extent greater than 70% in July and September. July represents the most active phase of the monsoon and September represents the receding phase of the monsoon. From an agriculture point of view, July is more critical because of its influence on crop sowings. Dryness in

September, if not preceded by dryness in August, has less bearing on the crops. Thus, the uncertainty in AUD vis-à-vis rainfall during July is more when compared to other months. The CV was found to be less during June (which is the beginning of the season) and August (which is the active crop growing phase), when compared to other months. In absolute terms, the CV values of June and August were at slightly less than 50%, which signifies considerable variability and uncertainty in the occurrence of dryness. The dryness in June affects the crop sowings to some extent, particularly the early sown crops. The dryness and its variability in August, which represents the active crop growing period, has a more deleterious effect on the performance of crops.

The year-wise comparison of June AUD shows the years 1962, 1965, 1968, 1969, 1974, 1987 and 1992 with more dryness (>100) grids in each year. Similarly, the lower AUD was observed in the years 1956, 1961, 1970, 1971, 1977, 1978, 1980, 1993 and 2001. The AUD in these years was less than 30 grids in each year. The AUD in June was widespread in the decade of the 1960s, whereas it is interesting to note that in the recent decade (1997–2007), it was significantly less, indicating reduced dryness in the month.

The year 2002 has a greater number of grids under dryness in July compared to rest of the years in the time series, followed by 1987. Even though 1987 was the second most widespread drought year, the number of dry grids in the year is approximately half that of 2002. Further, the proportion of area under severe–extreme dryness was very large in 2002. Therefore, July dryness during 2002 is geographically widespread and more

intensive and hence remains as an unprecedented drought event. The drought of 2002 in India is unique due to acute rainfall deficiency in 18 out of 26 states, as a result of which crops could not be sown (<http://www.imd.gov.in>, <http://www.agricoop.nic.in>). The normal practice of declaring drought at the end of the season in October after observing the performance of crops was not practiced in 2002, as most of the states adopted the unusual approach of declaring drought by the end of July or 1st week of August (Samra, 2004; Rathore, 2005).

The other years having extensive dry areas in July include 1955, 1972, 1979, 1987, 2004 and 2006. Among these years, 1972, 1979 and 1987, were reported to be widespread drought years in the country (DFID, 2008). In the other 3 years dryness was confined to July alone and hence they could not be considered as drought years.

The AUD in July was very low in the years 1960, 1961, 1964, 1976 and 1988. In general, more area under July dryness was observed only during recent years. As compared to earlier decades, the number grids with dryness in July is higher in the recent decades.

Larger areas under dryness were detected in August of 1968, 1972, 1979, 1987, 1993, 2000 and 2005. Of these years, in 1968, 1972, 1987 and 1993 the proportion of area under severe-extreme dryness was significant. The prominent drought years in the country are 1987, 1972, 1979 and 1968 (<http://www.agricoop.nic.in>).

The AUD in September was mostly under the moderate category. The years with more area include 1952, 1968, 1974, 1986, 1987 and 2001 and the years with less area under dryness include 1955, 1975, 1983 and 2006. The years with more dry areas, such as 1987, 1974 and 1968 happened to be the drought years in the country.

### 3.2. Trends in AUD

Areas under (1) moderate dryness, (2) severe–extreme dryness and (3) total dryness derived from SPI thresholds were subjected to the LOWESS algorithm for smoothing (Figure 3). Mann–Kendall trend coefficient was computed for each of the 4 months.

Decreasing trend in the total area under dryness (moderate + severe-extreme classes) was evident in June, with severe-extreme dryness showing no trend and moderate dryness showing decreasing trend. That means rainfall tends to be closer to normal in the initial month of the monsoon. The areas under all three classes of dryness showed increasing trends in July. Therefore, increasing uncertainty in the rainfall of July, a critical month for the agricultural season, was evident. During August, the AUD reveals no significant trend, although the area under severe–extreme dryness shows an increasing trend. Since the area under this class is less this does not signify serious implications. There was no significant trend in any dryness category in September. Significant inter-annual fluctuations in the withdrawal pattern of monsoon in the month could cause no significant trend in the dryness.

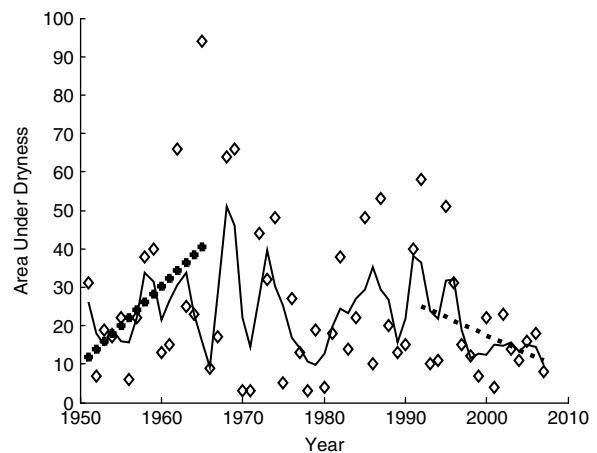


Figure 3. Country wide AUD for June month (a) diamond actual AUD (b) Line indicates AUD smoothed using LOWESS (c) starred line indicates increasing trend (d) dotted line indicates decreasing trend.

Thus, to summarize, the area under dryness was decreasing during June and increasing during July, followed by no significant trend in the other 2 months. Mooley and Parthasarathy (1984) found that all India rainfall was without any trend and random in nature. Trends in rainfall at different spatial scales were also observed by Parthasarathy (1984) and Rupa Kumar *et al.* (1992).

Change point analysis was performed to detect the differential trends in the AUD within the time series. Significant trend reversals were detected in three cases: (1) the area under severe-extreme dryness in June showing no trend in the total time series, increasing trend during 1951–1965 and decreasing trend during 1992–2007, (2) the area under severe–extreme dryness in September showing no significant trend in the overall analysis period but increasing trend during 1954–1986, and, (3) the area under total dryness (moderate + severe-extreme) showing no significant trend in the overall period but increasing trend during 1954–1986.

#### 3.2.1. Trends with moving averages

Trend analysis of time series AUD was also performed with moving average technique. Five- and seven-year moving averages were computed and trend lines were fitted for the AUD of each month separately. The details of trend equations are presented in Table 1. Among the trend lines of 4 months, only that of July was statistically significant. The trend line of July showed increasing trend in the AUD. The trend coefficient of June is unique since it assumed a negative value indicating decreasing trend in the AUD in contrast to the rest of the months. The trend lines of August and September were almost flat with very small increases from year to year, as indicated by smaller trend coefficients.

Table 1. Trend equations with moving averages.

	Five-year moving average	Seven-year moving average
June	$-0.362x + 64.94, R^2 = 0.175$	$-0.377x + 65.55, R^2 = 0.230$
July	$0.662x + 34, R^2 = 0.333$	$0.68x + 33.31, R^2 = 0.463$
August	$0.312x + 45.15, R^2 = 0.228$	$0.309x + 45.78, R^2 = 0.328$
September	$0.308x + 44.57, R^2 = 0.099$	$0.336x + 44.58, R^2 = 0.164$

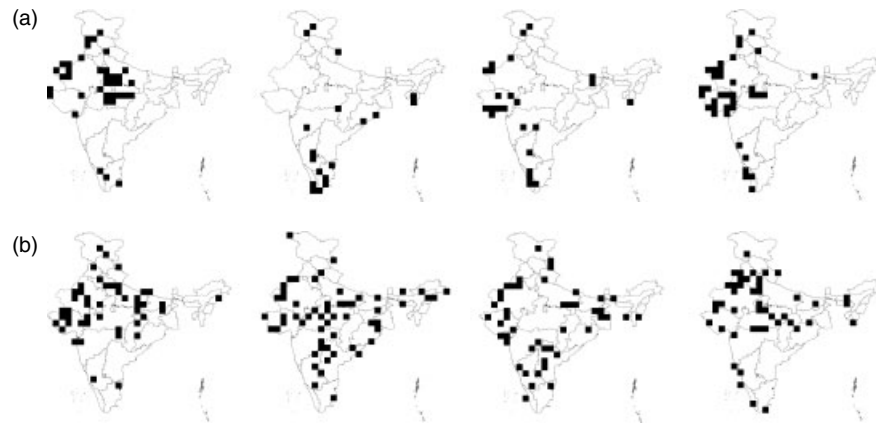


Figure 4. Drought frequency of (a) 2–3 years and (b) 4–5 years for grids from June to September.

### 3.3. Drought frequency

Drought frequency, in this study, was measured by the number of years a grid cell experienced dryness ( $SPI < -1.0$ ) in the total time series of 57 years. Grid cells which experienced dryness in 19–29 years out of 57 years, i.e. drought frequency of 2–3 years, and the grids under dryness in 10–14 years out of 57 years, i.e. drought frequency of 4–5, were identified and mapped. The month-wise drought frequency maps thus developed reveal a significant number of grids belonging to high frequency (2–3 years) in the months of June and September (Figure 4(a)). Such grids were mostly distributed in central India. During July and August such high frequency grids were fewer in number, showing isolated distribution.

Moderate drought frequency (drought occurring once in 4–5 years), was observed in a significant number of grid cells, particularly in June and July (Figure 4(b)). In June, such grids were mostly distributed in Central and North India, which could be due to fluctuations in the arrival time of the monsoon and variations in the quantity of rainfall. The moderate drought frequency grids in July were greater in number compared to those of the other 3 months and were well distributed throughout the country. This shows the growing uncertainty in July rainfall. During August, the drought frequency grids were mostly located in southern and northern India. In September, such frequent drought grids were mostly located in north and central India.

Decade-wise analysis of drought frequency was performed to bring out the variations within the time series. The interval of a decade is selected for convenience and easy perception of interpreted results. Kiem and Franks (2004) and Gregory *et al.* (2004) have identified changes in the climate occurring on decadal to multi-decadal time-scales. The decadal analysis facilitates identification of decades with significant changes. The time series data in this study was divided in to five decades – the decades ending 1967, 1977, 1987, 1997 and 2007.

In each decade, the grid cells under dryness, i.e.  $SPI < -1.0$ , were identified. Drought frequency indicating the number of years under dryness was represented in three categories: (1) low frequency with less than 2 years of dryness in 10 years, (2) moderate frequency with 3–4 years of dryness, and, (3) high frequency with more than 4 years experiencing dryness in a decade, indicating drought in almost every year or alternate year. The area under each frequency class in terms of the number of grid cells was computed for each decade. The decade-wise areas under the three drought frequency classes

for June, July, August and September months were shown (Figure 5(a)–(d)).

In June, low frequency area was significantly higher in the decade ending 2007 compared to all other decades. In all the other decades such area was more or less equal. The area under moderate frequency and high frequency categories was significantly less in the decade of 2007 compared to the rest. In the remaining four decades, the area with moderate and high frequency droughts do not show significant differences. Thus, the area with low frequency dryness was more and the area with high frequency dryness was less during June in the recent decade. This unique feature of the recent decade compared to the rest of the time series indicates less varying rainfall in June in recent years.

During July, the area under low frequency drought was decreasing from the 1960s with a larger reduction during the recent decade of 1996–2007. Similarly, the area under moderate drought frequency was on a constant rise from the past with significant increase in the recent decade. There was slight increase in the area with high frequency drought. There was significant increase in the area under moderate frequency drought in the month.

The area under different categories of drought frequencies has shown insignificant variations during August in different decades. Most of the area in different decades was under low frequency drought. None of the five decades exhibited any uniqueness or discernable pattern in any drought frequency class.

Drought frequency during September revealed mixed trends. The area with less frequent drought was higher in the decades ending 1967 and 1997. In the remaining three decades it was slightly less. The decade ending 1977 was characterized by more area under high frequency drought.

### 3.4. Drought persistence

The magnitude of drought is determined by geographic spread of dryness as well as persistency of drought conditions in the time domain. Continued dryness over longer periods of time is called persistent drought. Unsustained drought conditions, i.e. dryness that exists for shorter time periods, are called non-persistent or intermittent droughts. While assessing the magnitude of drought, one has to account for the area under persistent and non-persistent drought. Persistent dryness results in more deleterious effects on agriculture, surface water and ground water. Therefore, drought persistence assumes greater importance in drought management.

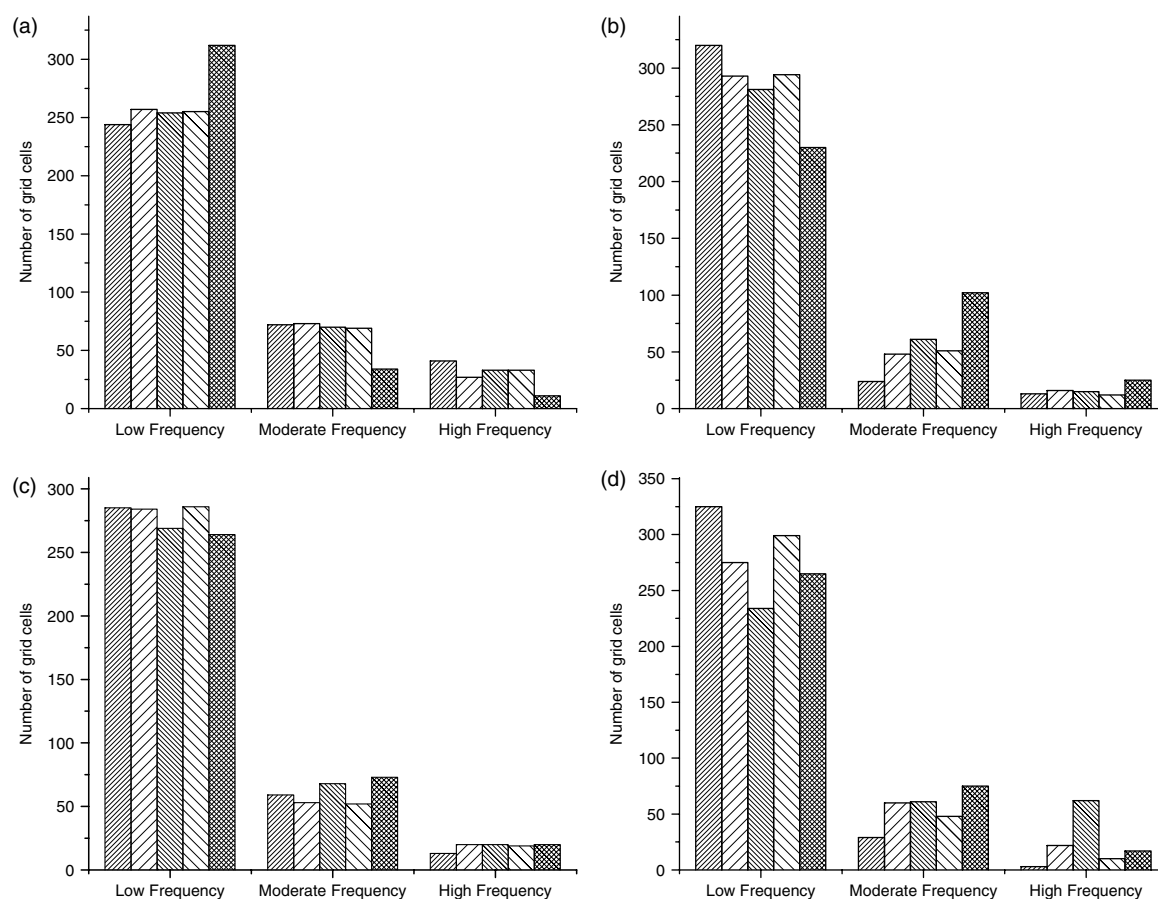


Figure 5. Decadal drought frequency (a) June, (b) July, (c) August, (d) September. Dense line from left to right for decade ending in 1967; sparse lines left to right for decade ending in 1977; dense lines from right to left for decade ending in 1987; sparse lines right to left for decade ending in 1997; dense cross lines for decade ending in 2007.

During the 4 months of the southwest monsoon season (June to September), the drought conditions occur and persist in different ways on a monthly time scale: (1) 4 months drought, persisting over all the 4 months, (2) 3 months drought, occurring in two possible combinations, June–August and July–September, (3) 2 months drought occurring in three possible ways, June + July, July + August, August + September, and, (4) 1 month drought (i.e. non-persistent drought occurring in any one of the 4 months). The 4 months drought has maximum impact, whereas a single month or intermittent droughts have relatively less impact.

A Drought Persistency Score (DPS) was developed in this study by assigning linear weights to the areas under each persistency class. The weighing factor for 4 month drought is 4, for 3 month drought is 3, and so on. Thus, the DPS is a direct indicator of magnitude and intensity of drought for the season as a whole. In each year, the number of grids under different combinations of persistent and non-persistent dryness during June to September were identified and the DPS was computed.

The DPS for different years, arranged in ascending order, is presented in Figure 6. The highest values of DPS in 1972, 1974, 1987 and 2002 indicate more intensive drought in those years. The 1987 monsoon season stands unique with very high values of DPS. Another uniqueness of 1987 was its very high proportion of persistent drought score in the total score, clearly signifying the highest magnitude of drought conditions. The drought of 1987 was one of the worst Indian droughts, with a rainfall deficiency of 19% (DFID, 2008, [www.agricoop.nic.in](http://www.agricoop.nic.in)).

The drought affected 60% of crop area. As *per* the reports of the Ministry of Agriculture, monsoon rainfall was less than normal by 24% in 1972, 12% in 1974 and 19% in 2002. In these years, also, the proportion of persistent drought score was considerably high reflecting the drought intensity. The 2002 drought ranks fifth in terms of magnitude in the country (DFID, 2008). The second set of years with higher values of DPS include 1968, 1979 and 1991. The rainfall deficiency in the 1979 drought was 19%, which has resulted in the reduction in the production of food grains by 19% (DFID, 2008 and [www.agricoop.nic.in](http://www.agricoop.nic.in)). The lowest values of DPS could be observed in 1961, 1964, 1975, 1977, 1981 and 1983, which indicates less magnitude compared to the rest of the years in the time series. In this set of years the proportion of persistent score in the total score was also less, signifying the very low magnitude of drought. On the basis of the DPS, the time series 1951–2007 can be grouped in to different classes as shown in Table 2. It is evident that there were many years with moderate magnitude in the recent decade. Most of the years in the 1950s and 1960s recorded lower DPS scores, indicating lower magnitude of drought.

#### 4. Conclusion

A regionalized Pearson III distribution with L-moments based parameter estimation was adopted to compute SPI from the all India  $1^\circ$  latitude  $\times$   $1^\circ$  longitude gridded rainfall data of 57 years (1951–2007). The grid-wise rainfall data were provided by the

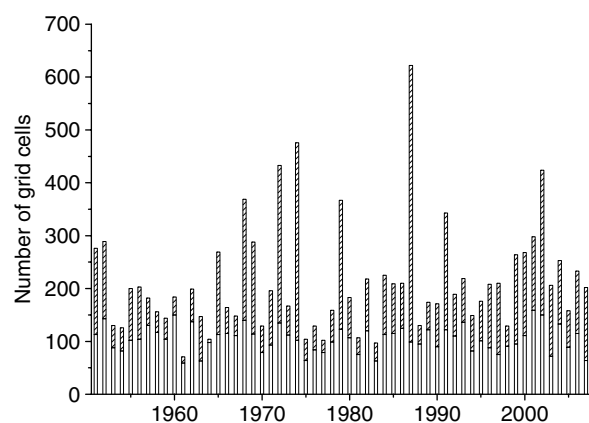


Figure 6. Drought Persistence Score (DPS) of different years. Blank bars: non-persistent drought; crossed bars: persistent drought.

Table 2. Grouping of years on the basis of drought persistency.

Category	Years in the category
<100 (very low drought intensity)	1961, 1964, 1975, 1977, 1981, 1983
100–199 (low drought intensity)	1953, 1954, 1955, 1956, 1957, 1958, 1959, 1960, 1962, 1963, 1966, 1967, 1970, 1971, 1973, 1976, 1978, 1980, 1985, 1986, 1988, 1989, 1990, 1992, 1994, 1995, 1996, 1997, 1998, 2003, 2005, 2007
200–299 (moderate drought intensity)	1951, 1952, 1965, 1969, 1982, 1984, 1993, 1999, 2000, 2001, 2004, 2006
300–399 (high drought intensity)	1968, 1979, 1991
400–499 (very high drought intensity)	1972, 1974, 2002
>500 (extremely high drought intensity)	1987

Indian Meteorological Department. This study examined the drought patterns across space and time using time series standardized precipitation index (SPI). Despite its coarse resolution, the SPI has revealed many interesting results on the variability in the occurrence of meteorological drought in India. A decreasing trend in the area under dryness in June and increasing trend in July has many implications on the management of agriculture towards minimizing the impact of early season drought on crop planting. Comparison of drought frequency in different decades and ranking years based on drought persistence are extremely useful for understanding historic drought patterns and assessment of future risk. Increased drought frequency in the recent decade observed in the study facilitates better preparedness and coping mechanisms. The SPI-based drought patterns can be integrated with agricultural and hydrological parameters for quantifying drought risk. The results of the study are also relevant to climate change studies to understand the historic patterns and build future scenarios of drought.

Further research should include the SPI of higher spatial resolution and relating dryness patterns with cropping pattern and crop production. Such an endeavour enables quantification of drought impact in economic terms.

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