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Research Article

COMPUTATION OF THE STANDARDIZED PRECIPITATION INDEX (SPI) FOR ASSESSING DROUGHTS OVER INDIA

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ABSTRACT

Droughts are extreme meteorological/hydrological events affecting many cultural, social, agricultural and thereby economics of the region affected and the country as well. Analysis of monthly rainfall data for 34 meteorological sub-divisions in India for 1951 to 2015 has been carried out to assess the droughts by computing Standardized Precipitation Index. The SPI values were also analyzed with actual rainfall as well as rainfall deviations from normal for different seasons and on annual scale. The analysis revealed that of the 34 met sub-divisions, 16 sub-divisions during monsoon season and annual are drought prone showing high negative SPI values. The extreme eastern sub-divisions of Arunachal Pradesh and Nagaland, Manipur, Mizoram, Tripura did not record severe droughts while North and South Interior Karnataka sub-divisions in the Peninsular India recorded six severe drought years. There was a relation between SPI and negative rainfall deviations, but the magnitude of SPI values did not indicate the severity of drought situation. The results of the study will be useful to drought monitors, water resources planners, and too agriculturists.

INTRODUCTION

Drought with its negative effect is one of the serious disasters resulting due to less or no rainfall over the region. India is mostly an agricultural country depending upon rainfall during the four monsoon months. Any adverse change in this rainfall receipt leads to drought which not only affects water storage, agriculture but country's economy also. Depending upon duration, magnitude, intensity, severity and geographical extent, the Indian National Commission on Agriculture (INCA, 1978) has categorized drought into three types:

1. Meteorological drought - dominance of dry weather condition over a large area for longer duration.
2. Hydrological drought - less water availability especially in streams, reservoirs, and groundwater levels, usually after meteorological drought for long period.
3. Agricultural drought – occurrence of short period rainfall or without rainfall for a longer duration resulting in prolonged period of dryness causing damage to crop yield and vegetation cover.

To characterize meteorological drought at different time scales, therefore, it is necessary to evaluate the performance of Standardized Precipitation Index (SPI) to mitigate the drought condition in the region using past drought events. Besides, deviation in rainfall from its long term means (Normal) is the most commonly used indicator for meteorological drought monitoring.

As stated by Zarger *et al* (2011) drought indices are quantitative measures that characterize drought levels by assimilating data from one or several variables (indicators) such as precipitation and evapo-transpiration into a single numerical value. There are several drought indices that measure on how much precipitation for a given period of time has deviated from its long period normal. The following are the most widely used drought indices–

Standardized Precipitation Index (SPI): (McKee *et al*. (1993)) has introduced this most popularly used Index for meteorological drought using only precipitation data for evaluation. This gives an indication of wet and dry years/periods also depending upon monthly precipitation values.

Palmer Drought Severity Index (PDSI): This is another most popularly used meteorological drought index in US as given by Palmer (1965). In PDSI, emphasis is mostly on abnormalities in moisture deficiency (such as evapotranspiration, runoff, soil recharge, and soil moisture) rather than weather anomalies (Guttman 1999).

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US Drought Monitor (USDM) Index: Using SPI, PDSI along with the vegetation cover and hydrologic condition of the region, Svoboda *et al*. (2002) evaluated this index.

Normalized Difference Vegetation Index (NDVI): Based on remote sense data that measures vegetation condition over a region Rouse *et al*. (1974) introduced this index with the formula

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}}$$

Where NIR stand for the spectral reflectance measurements acquired in the near-infrared regions (NIR) and visible (red), respectively.

In this index as mentioned, an advanced very high resolution radiometer (AVHRR) reflected red and near-infrared channels are used to calculate the vegetation cover over the region i.e. healthy, unhealthy or sparse showing as suffering from drought or infested by insects. In healthy vegetation cover, chlorophyll in plants absorbs light and less R is reflected whereas in unhealthy condition plants reflect higher R and hence low NDVI values.

Considering the recent climate change scenario, number of studies on SPI has been carried out world wide. Using NCEP/NCAR precipitation gridded data for 45 raingauge stations in the entire Marche region of Italy for 1948-1981, Bordi *et al* (2001) analysed large scale drought in Italy based on the December 1981 SPI values. They also considered the effect of orography on the regional scale rainfall. Wu *et al* (2007) in their study revealed the effects of arid climates and dry seasons on SPI values on short time scale across the contiguous United States to investigate whether these values represent flood and drought events in a similar way. Wenhong Li *et al* (2008) used monthly precipitation data to derive SPI values for the period 1970 to 1999 in the Amazon using 23 climate models.

Trend analysis of SPI carried out for four weather stations of the State of São Paulo, Brazil by Blain (2011) showed that Pearson type III distribution of monthly SPI series was closer to assumed normality. The Mann-Kendall and the Pettitt testes indicated temporal variability in the index. Mernoi *et al* (2016) tested performance of SPI for the gridded rainfall over the Sahel region for 1 to 6 month time scale. Their result showed that on an average 40% of the variance of the Z-score of the cumulative value of the Fraction of Absorbed Photosynthetically Active Radiation over the growing season (zCFAPAR) assisted in identification of earlier drought condition.

In India, very few studies on drought computing SPI values are available. Sharma *et al* (2001) for Karnataka State, Kumar *et al* (2009) for Andhra Pradesh, Rachchh and Bhatt (2014) over Rajkot, Gujarat, for Surat district, Gujarat by Shah *et al* (2015), etc are the studies mostly carried out on regional scale. Therefore, in monitoring droughts on regional scale, SPI are highly in use by many researchers. WMO (Report No.872) also recommended using SPI to characterize the meteorological droughts by all National Meteorological and Hydrological organizations in the world. In view of this, in the present study authors have computed the SPI values for 34 meteorological subdivisions in the Indian region for 1951 to 2015 period which will be useful in drought monitoring of the country.

MATERIAL AND METHODOLOGY

As stated earlier, in the present paper, WMO (2012) recommended method for the evaluation of SPI is used to determine the drought properties of the Indian region. Monthly rainfall data for 65 years period (1951-2015) of 34 meteorological sub-divisions (Fig.1) in the Indian region are used in the computation of SPI values for different time scales of seasons viz. Jan-Feb, Mar-May, Jun-Sept, Oct-Dec and for annual.

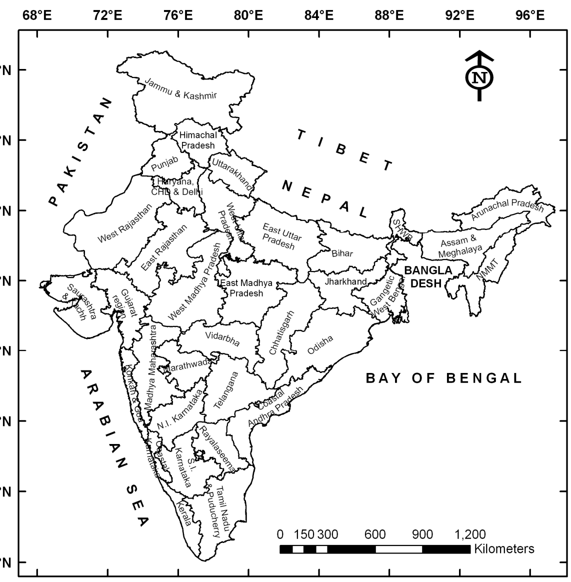


Fig 1 Map of India showing Meteorological sub-divisions

METHODOLOGY

Standardized Precipitation Index (SPI) – The SPI is a probability index developed by McKee *et al*., (1993) that expresses the observed cumulative precipitation for a given time scale of 3, 6, 12, 24, and 48 months. These values are used as drought time scales and have effects on five water usable sources such as soil moisture, stream flow, groundwater, snow cover and water in reservoirs. The SPI is found to be an efficient drought indicating tool as it expresses the actual rainfall as standardized departure from rainfall probability distribution function. SPI gives more better results in drought assessment against the normal method of rainfall deviation from the long term average rainfall in the assessment of drought over a region (Kumar *et al*, 2009).

Computation of the SPI involves fitting of a two parameter gamma probability density function to a given time series of precipitation (Thom, 1966) and this is performed individually for each time scale. In this procedure, for a given series of rainfall, average rainfall values are adjusted to zero; standard deviations and skewness are adjusted to one and zero respectively.

$$\mathrm{g}\,(\mathrm{X},\alpha,\beta) = \frac{1}{\beta^{\alpha} * \Gamma(\alpha)} X^{\alpha - 1} * e^{\frac{-X}{\beta}} \quad \text{..... (1)}$$

Where β is a Scale parameter, α is a shape parameter and Γ (α) is the ordinary Gamma function of α.

The rainfall values are converted to log normal and statistics U using the following formulae

$$\log \text{ mean } = \bar{X}\ln = \ln(\bar{X}) \qquad \text{..... (2)}$$

Parameters of Gamma Probability Density function are estimated as

$$U = \bar{X}_{\ln} - \frac{\sum \ln(X)}{N} \qquad \text{..... (3)}$$

$$\text{Shape parameter } (\alpha) = \frac{\bar{X}}{\beta}$$

where $\text{Scale parameter } (\beta) = \dfrac{1+\sqrt{1+\dfrac{4U}{3}}}{4U}$ ..... (4)

Integrating the two parameter Gamma probability distribution function, the cumulative probability of an observed rainfall is calculated as

$$G(X) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} dx}{\beta^{\alpha}\Gamma(\alpha)} \qquad \text{..... (5)}$$

Since rainfall series may contain zero, the Gamma function is undefined for x = 0. Therefore, the Cumulative Probability is given as

$$H(x) = q + (1 - q)\, G(X) \qquad \text{..... (6)}$$

Where q = probability of a zero = m/n; here m is the number of zeros in a rainfall time series n.

Edwards and McKee (1997), transformed this H(x) to the standard normal random variable Z having mean zero and variance as one to get the value of SPI as

$$Z = SPI = -\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right]$$

$$t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right)} \quad \text{when } 0 < H(x) \le 0.5 \qquad \text{..... (7)}$$

and

$$Z = SPI = +\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right]$$

$$t = \sqrt{\ln\left(\frac{1}{(1-H(x))^2}\right)} \quad \text{when } 0.5 < H(x) \le 1.0 \qquad \text{..... (8)}$$

Here, $c_0 = 2.515517$, $c_1 = 0.802583$, $c_2 = 0.010328$ and $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$

(Ref: Abramowitz and Stegun, 1965)

The negative and positive SPI values are computed by the equations (7) and (8) respectively with the same t under the two conditions mentioned in equations. This gives balanced negative and positive values. On computing the SPI values as mentioned above, the drought is classified as given in Table 1.

Table 1 Standardized Precipitation Index and corresponding moisture category

(Ref: Edward and McKee, 1997).

SPI Range	Drought Type
≥ 2.0	Extremely Wet
1.5 to 1.9	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.9	Severely Dry
≤ -2.0	Extremely Dry

RESULTS OF THE ANALYSIS

Rainfall variability over the Indian region

It is well-known that most of the rainfall in India, being a tropical country, occurs during June-July-August-September (JJAS) monsoon months. Average annual rainfall over the country varied from 920.8 mm to 1403.0 mm and Jun-Sept rainfall varied from 679.5 mm to 1066.1 mm during 1951 to 2015 (Fig.2). It is said that the southwest monsoon season is the principle rainy season and about 80% of the rainfall is received during this season. But annual and monsoon rainfall distribution over the country during 1951 to 2015 showed that about 75% of rainfall is received during the monsoon months indicating reduction in rainfall over the country during the monsoon season. Therefore annual rainfall is more subjected to seasonal rainfall. This may have an impact on the agriculture activities of a region. Percentage variation of monsoon rainfall with reference to El-Nino/La-Nina years and Drought/Flood years (Fig.3) also showed that numbers of drought years are more in 1951 to 2015 period than 1901-1950 period.

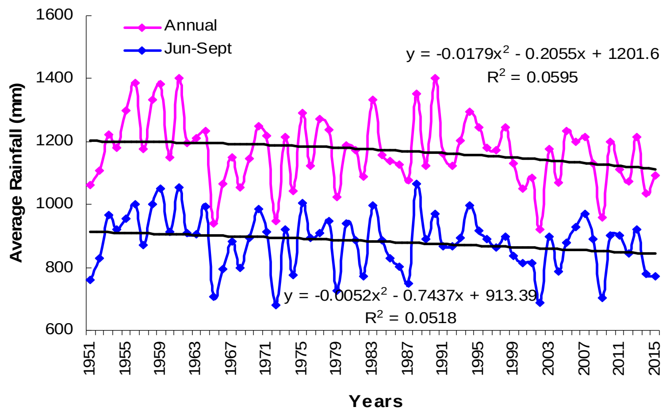


Fig 2 Average annual and seasonal rainfall during 1951 to 2015 over the Indian region

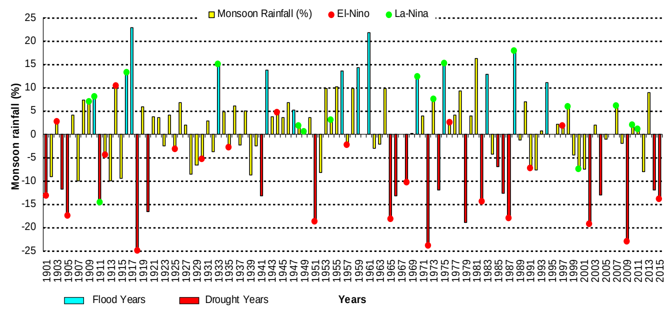
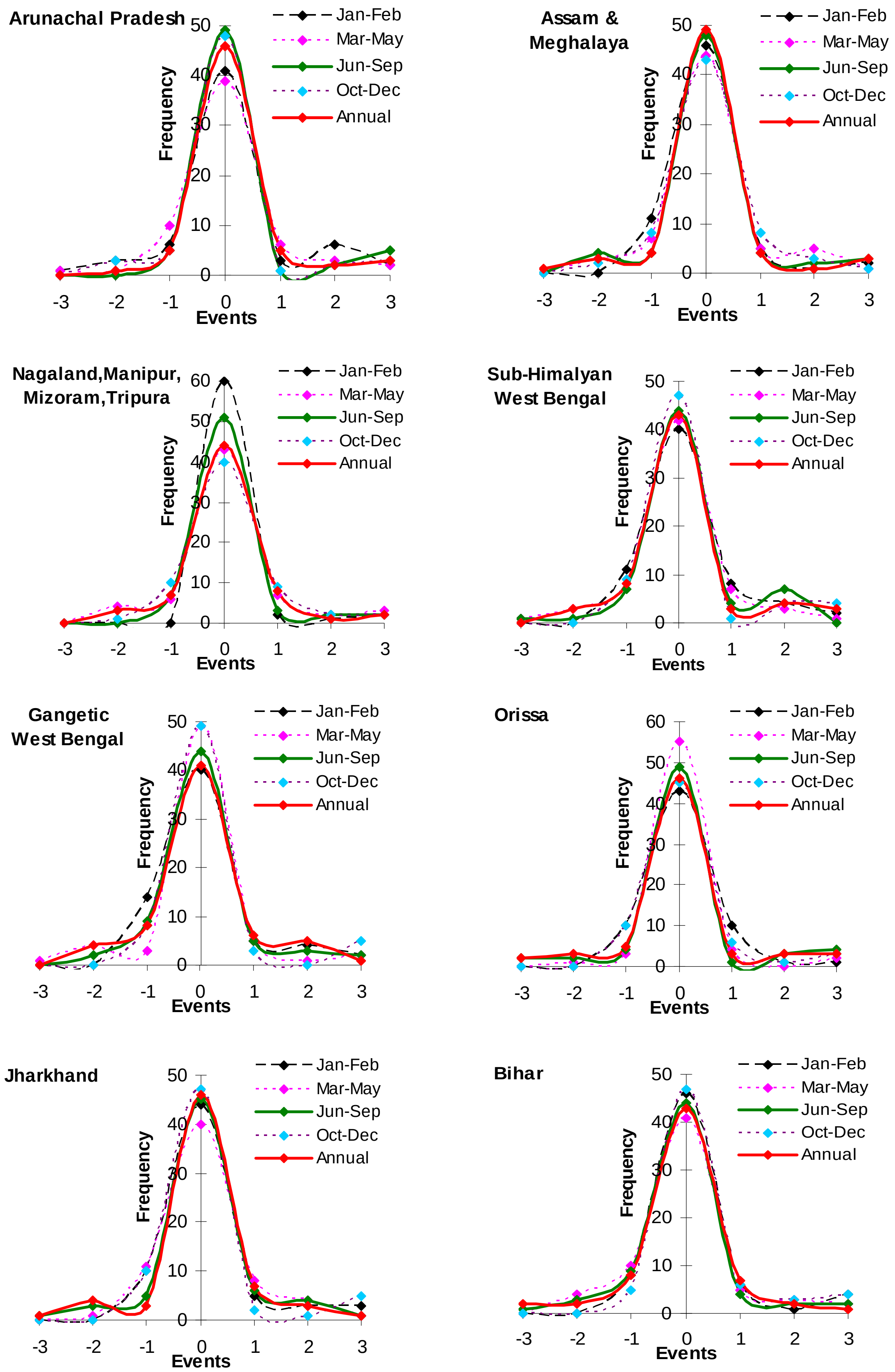
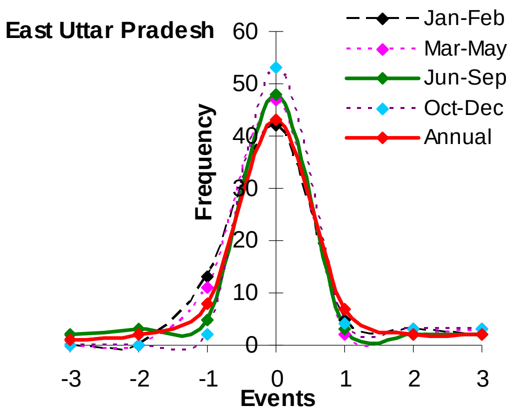
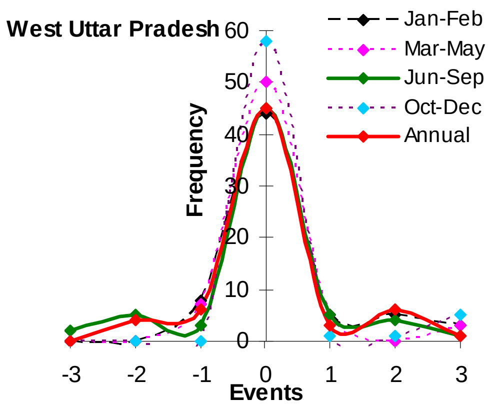


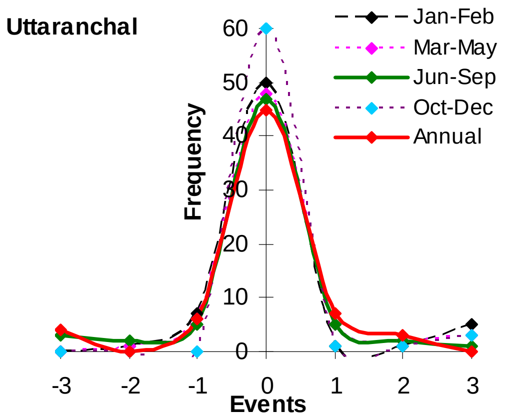
Fig 3 Monsoon rainfall (%) along with El-Nino/La-Nina years and flood/drought years

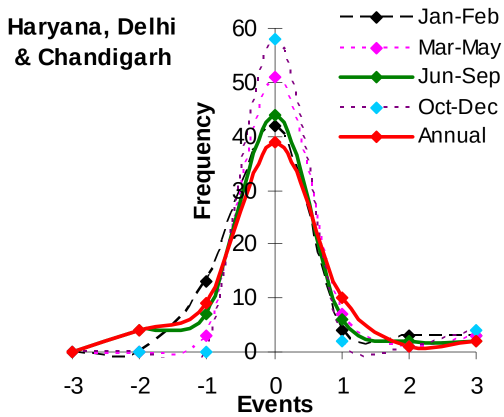
Fig 4 Frequency distribution of dry and wet events with respect to SPI values

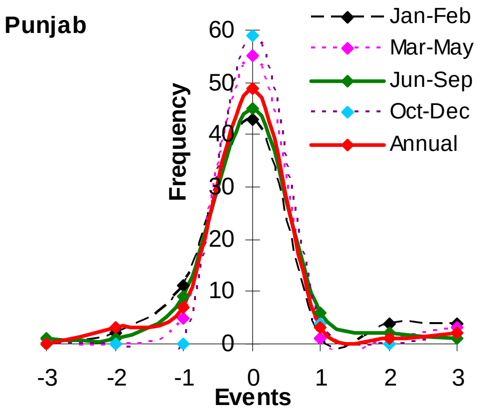


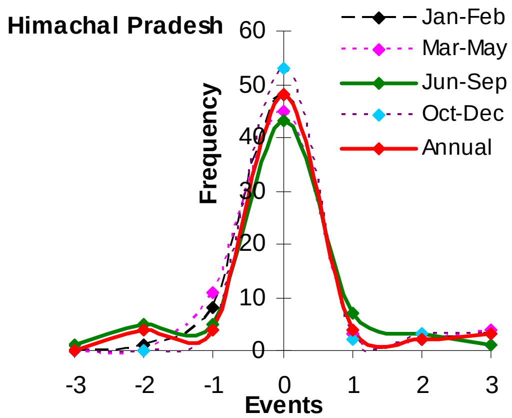

East Uttar Pradesh
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events

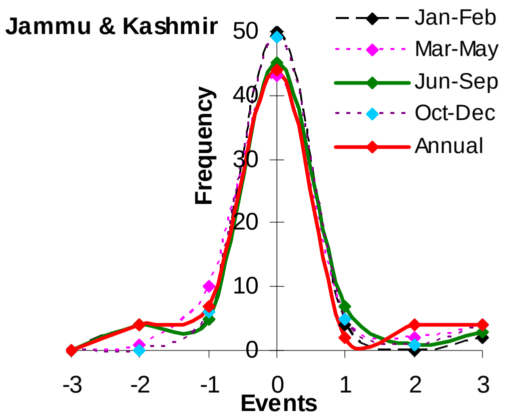

West Uttar Pradesh
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events

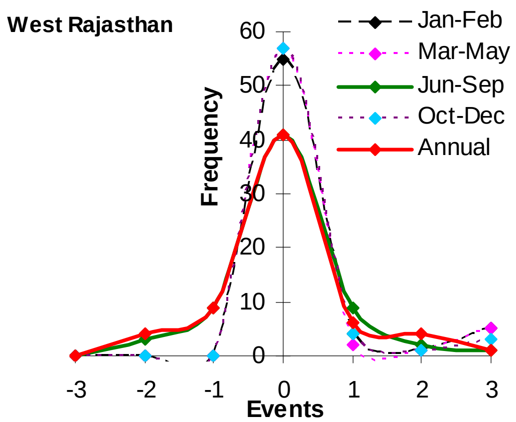

Uttaranchal
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events

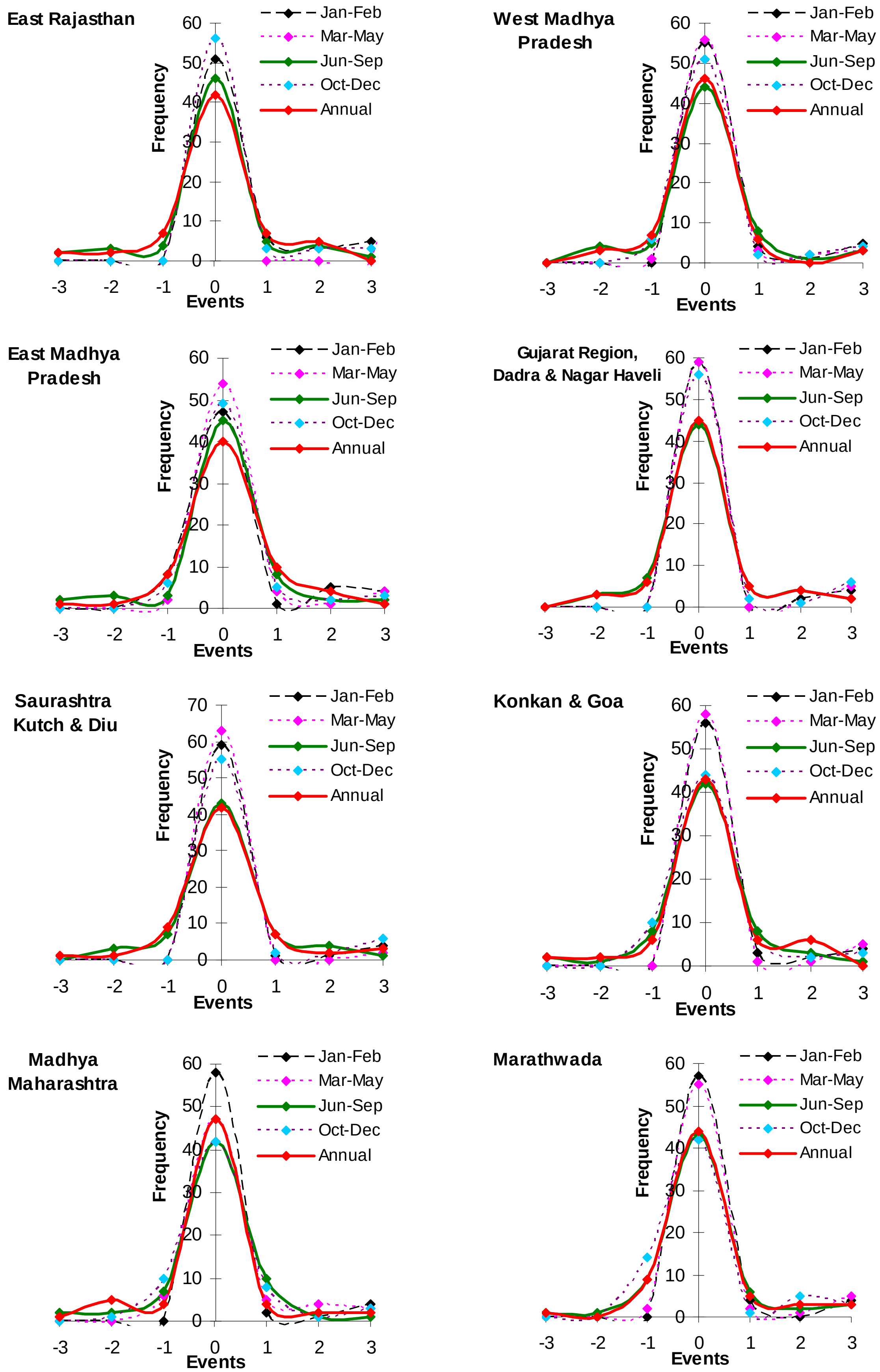

Haryana, Delhi
& Chandigarh
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events

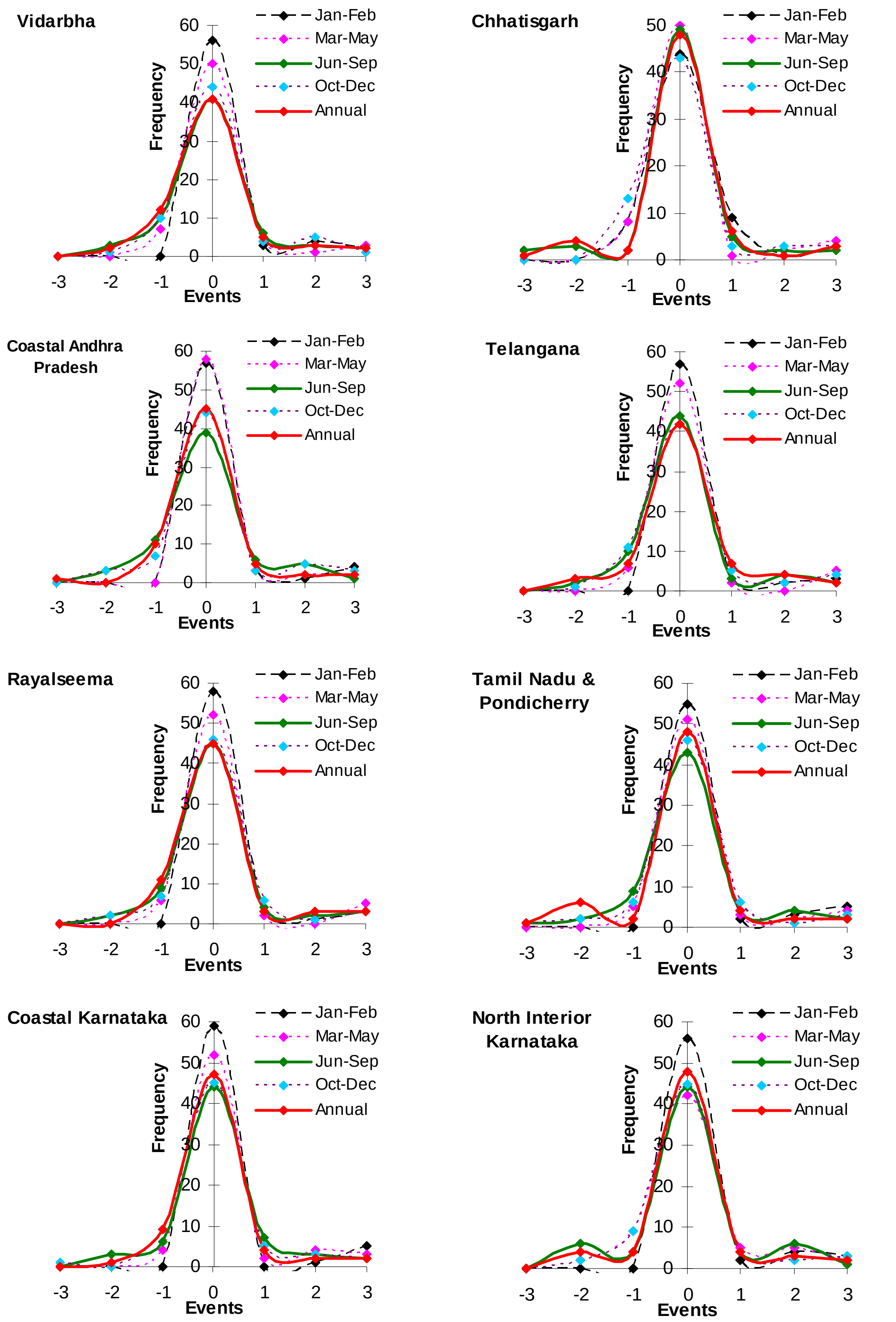

Punjab
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events

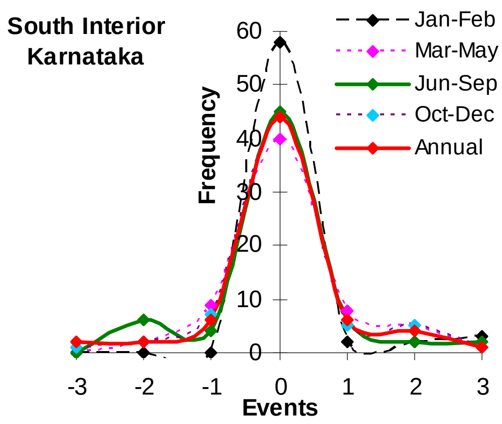

Himachal Pradesh
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events

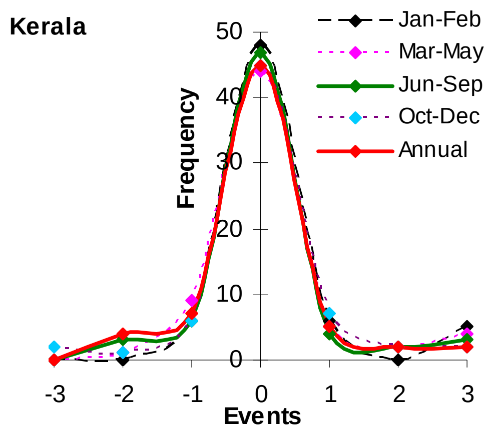

Jammu & Kashmir
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events


West Rajasthan
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events


East Rajasthan
West Madhya Pradesh
East Madhya Pradesh
Gujarat Region, Dadra & Nagar Haveli
Saurashtra Kutch & Diu
Konkan & Goa
Madhya Maharashtra
Marathwada
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events


Vidarbha
Chhatisgarh
Coastal Andhra Pradesh
Telangana
Rayalseema
Tamil Nadu & Pondicherry
Coastal Karnataka
North Interior Karnataka
Jan-Feb
Mar-May
Jun-Sep
Oct-Dec
Annual
Frequency
Events





Frequency distribution of dry and wet years

The frequency distribution of dry and wet categories of different seasons viz. Jan-Feb (Winter Season), Mar-May (Pre monsoon season), Jun-Sept (Monsoon season), Oct-Dec (Post monsoon season) and annual SPI values are shown in Fig.4. Here X-axis suggests the intensity of SPI values in seven categories i.e. from extremely dry (SPI ≤ -2.0); severely dry ($-1.5 > \text{SPI} > -1.99$); moderately dry ($-1.0 > \text{SPI} > -1.49$); near normal ($-0.99 < \text{SPI} < 0.99$); moderately wet ($1.0 < \text{SPI} < 1.49$); very wet ($1.5 < \text{SPI} < 1.99$); and extremely wet (SPI ≥ 2.0) against the frequencies of dry and wet events on Y-axis (McKee *et al.* 1993).

As it is seen from the Fig.4 that in different sub-division, some of the distributions especially for shorter time scales viz. Jan-Feb have values only up to -1 i.e. lower limit. Some of the distributions for monsoon (Jun-Sept) and post monsoon (Oct-Dec) season do not have values less than -2. These are mostly observed in extreme eastern sub-divisions of Arunachal Pradesh; Nagaland, Manipur, Mizoram,Tripura; Gangetic West Bengal and north –northwestern sub-divisions of West Uttar Pradesh; Jammu and Kashmir; Gujarat Region, Dadra & Nagar Haveli and peninsular sub-divisions of Vidarbha, Telangana; Rayalseema; Tamil Nadu & Pondicherry; North Interior Karnataka.

Yearly variation of SPI values

Annual and seasonal time series for each of the sub-divisions showed more number of negative SPI values than positive SPI values indicating numbers of dry years are more than wet years (see Table 2). It is important to note that even during the monsoon months of Jun to Sept, except Uttaranchal sub-division, all other sub-divisions recorded more than 30 dry years. Number of years recording negative SPI values is more (40 years of total 65 years period) in Nagaland, Manipur, Mizoram,Tripura; Marathwada and Kerala sub-divisions. This is an alarming situation for water management authorities.

The years which are identified as extremely dry, Severe dry and Extremely wet, Very wet are tabulated (see Table 3) for all the 34 meteorological sub-divisions. It is seen from this Table that except Arunachal Pradesh and Nagaland, Manipur, Mizoram, Tripura sub-divisions, rest of the sub-divisions experienced 1 to 6 severe dry years. North Interior Karnataka and South Interior Karnataka sub-divisions experienced six severe dry years.

Next to this, West Uttar Pradesh and Himachal Pradesh sub-divisions experienced 5 severe dry years, Assam & Meghalaya; Haryana, Delhi & Chandigadh; Jammu & Kashmir sub-divisions experienced 4 severe dry years. It is also seen that Uttaranchal sub-division has experienced consecutive three extremely dry years i.e. 1997, 1998 and 1999 with SPI values -2.93, -2.61 and -2.10 respectively. Sixteen sub-divisions experienced extremely dry years during 1951, 1965, 1972, 1974, 1979, 1986, 1987, 1994, 1997, 1998, 1999, 2002, 2009, 2010, 2014, 2015. All the sub-divisions experienced 1-3 or more very wet years.

Table 2 Frequency of positive and negative SPI years in each sub-division during 1951-2015

No.	Sub-divisions	No. of years showing			
		Annual		Jun-Sept	
		+ve SPI	-ve SPI	+ve SPI	-ve SPI
1	Arunachal Pradesh	24	38	22	39
2	Assam & Meghalaya	31	34	30	35
3	Nagaland, Manipur, Mizoram,Tripura	29	36	25	40
4	Sub-Himalayan W Bengal & Sikkim	28	37	29	36
5	Gangetic West Bengal	32	33	31	34
6	Orissa	31	34	32	33
7	Jharkhand	31	34	33	32
8	Bihar	34	31	34	31
9	East Uttar Pradesh	29	36	33	32
10	West Uttar Pradesh	29	36	33	32
11	Uttaranchal	37	28	38	27
12	Haryana, Delhi & Chandigarh	29	36	34	31
13	Punjab	31	34	34	31
14	Himachal Pradesh	28	37	34	31
15	Jammu & Kashmir	29	36	33	32
16	West Rajasthan	32	33	30	35
17	East Rajasthan	30	35	33	32
18	West Madhya Pradesh	29	36	28	37
19	East Madhya Pradesh	29	36	27	38
20	Gujarat Region, Dadra & Nagar Haveli	32	33	32	33
21	Saurashtra Kutch & Diu	31	34	30	35
22	Kokan & Goa	32	33	30	35
23	Madhya Maharashtra	35	30	32	33
24	Maratwada	28	37	25	40
25	Vidarbha	32	33	30	35
26	Chattisgarh	31	34	27	38
27	Costal Andhra Pradesh	29	36	31	34
28	Telengana	29	36	32	33
29	Rayalseema	29	36	27	38
30	Tamil Nadu & Pondicherry	32	33	33	32
31	Coastal Karnataka	29	36	30	35
32	North Interior Karnataka	28	37	31	34
33	South Interior Karnataka	30	35	32	33
34	Kerala	30	35	25	40

Table 3 Types of dry and wet years experienced by sub-divisions during 1951-2015

No.	Sub-divisions	Extreme dry years	Severe dry years	Extreme wet years	Very wet years
1	Arunachal Pradesh			1958, 1960, 1962, 1963,1964	1957, 1959
2	Assam & Meghalaya		1961, 2006, 2011, 2013	1974, 1984, 1995	1987, 1988
3	Nagaland, Manipur, Mizoram,Tripura			1969, 1970	1963, 1971
4	Sub-Himalayan W Bengal & Sikkim	1994	2009		1954, 1955, 1964, 1968, 1980, 1990, 1998
5	Gangetic West Bengal		1982, 2010	1984, 2007	1971, 1978, 1999
6	Orissa	1974, 1986	1979, 2000	1956, 1961, 1994, 2006	2001, 2007, 2008
7	Jharkhand	2010	1966, 1979, 2005	1971	1953, 1984, 1994, 1999
8	Bihar	1972	1966, 1992, 2013	1987, 2007	1953, 1984
9	East Uttar Pradesh	1997, 2015	1972, 2009, 2014	1955, 1980	1953, 1975
10	West Uttar Pradesh	1987, 2014	1979, 1997, 2006, 2009, 2015	1978	1958, 1967, 1983, 2003
11	Uttaranchal	1997, 1998, 1999	1987, 1996	2010	1978, 2007
12	Haryana, Delhi & Chandigarh		1951, 1979, 1987, 2014	1988, 1995	1964, 1967
13	Punjab	1987	2014	1988	1958, 1995
14	Himachal Pradesh	1987	1965, 1972, 1979, 1982, 2004	1988	1954, 1958, 1995
15	Jammu & Kashmir		1957, 1963, 1965, 1991	1959, 1988, 1996	1994
16	West Rajasthan		1969, 1987, 2002	1975	1973, 2010
17	East Rajasthan	1951, 2002	1965, 1979, 1987	1973	1961, 1975, 1977, 2011
18	West Madhya Pradesh		1951, 1965, 1979, 2000	1961, 1973, 2013	1994
19	East Madhya Pradesh	1965, 1979	2009, 2014, 2015	1961, 1994	1999, 2003
20	Gujarat Region, Dadra & Nagar Haveli		1951, 1974, 1987	1976, 1994	1959, 1970, 2005, 2006
21	Saurashtra Kutch & Diu		1974, 1987, 1999	2010	1959, 1979, 1994, 2007
22	Kokan & Goa	1972, 2015	1986	1958	1954, 1983, 2011
23	Madhya Maharashtra	1972, 2015	1985, 2012	2006	2005
24	Maratwada	1972	2014	1955, 1983, 1988	1989, 1998
25	Vidarbha		1974, 1987, 2009	1959, 2013	1961, 1990, 1994
26	Chattisgarh	1979, 2009	1965, 1974, 2000	1961, 1994	1959, 2003
27	Costal Andhra Pradesh		1952, 1968, 1987	2010	1983, 1988, 1989, 2007, 2015
28	Telengana		1971, 1972	1983, 1988	1959, 1978, 1989, 2010
29	Rayalseema		1952, 1994	1988, 1996, 2007	1964, 1983
30	Tamil Nadu & Pondicherry	2002	1952, 1982	1981, 1985	1966, 1975, 1983, 1996
31	Coastal Karnataka		1966, 1987, 2002	1961, 1994	1959, 1975, 1982
32	North Interior Karnataka		1952, 1972, 1985, 2002, 2003, 2012	1981	1955, 1964, 1979, 1983, 1988, 2007
33	South Interior Karnataka		1952, 1976, 1990, 2002, 2003, 2012	1959, 1961	1975, 2007
34	Kerala		1976, 1987, 2002	1959, 1961, 2007	1968, 2013

Seasonal variation of SPI values

The analysis also showed that maximum SPI value during Jan-Feb winter months are recorded by Arunachal Pradesh (-2.05, 1957) sub-division, and during pre-monsoon months of Mar-May it was recorded by Arunachal Pradesh (-3.40, 1957), Sub-Himalayan West Bengal & Sikkim (-2.35, 1957), Gangetic West Bengal (-2.04, 1957) sub-divisions. During post-monsoon months of Oct-Dec maximum SPI values are recorded by Tamil Nadu & Pondicherry (-2.26, 1974), Coastal Karnataka (-2.05, 1971), South Interior Karnataka (-2.14, 1988) and Kerala (-2.42, 1988) sub-divisions.

The negative SPI peak values during monsoon months are recorded by the sub-divisions of Uttaranchal (-2.93, 1997), Rayalseema (-2.62, 2002), East Rajasthan (-2.57, 2002), Bihar (-2.33, 1972), Sub-Himalayan West Bengal (-2.33, 1994), Orissa (-2.09, 1974), Jharkhand (-2.27, 2010), East Uttar Pradesh (-2.21, 1997), West Uttar Pradesh (-2.14, 2014), Punjab (-2.00, 1987), Himachal Pradesh (-2.04, 1987), East Rajasthan (-2.57, 2002), East Madhya Pradesh (-2.09, 1979), Konkan & Goa (-2.29, 1972), Madhya Maharashtra (-2.26, 1972), Marathwada (-2.08, 1972), Chhatisgarh (-2.03, 2009), and Tamil Nadu & Pondicherry (-2.62, 2002) indicating extreme drought conditions during the monsoon season. All the remaining sub-divisions, except Arunachal Pradesh sub-division, showed SPI values between -1.5 to -2 representing severe dryness during the monsoon season of 1951 to 2015.

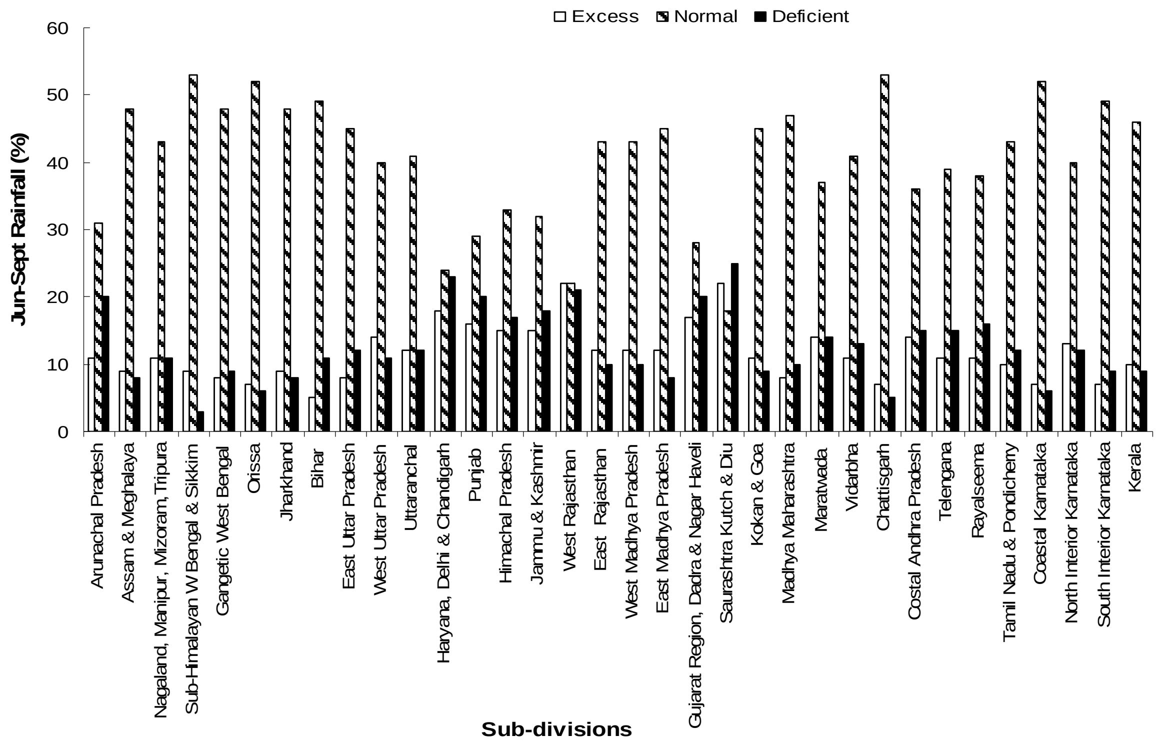


Fig 5 Frequency distribution of excess, normal and deficient rainfall over the sub-divisions

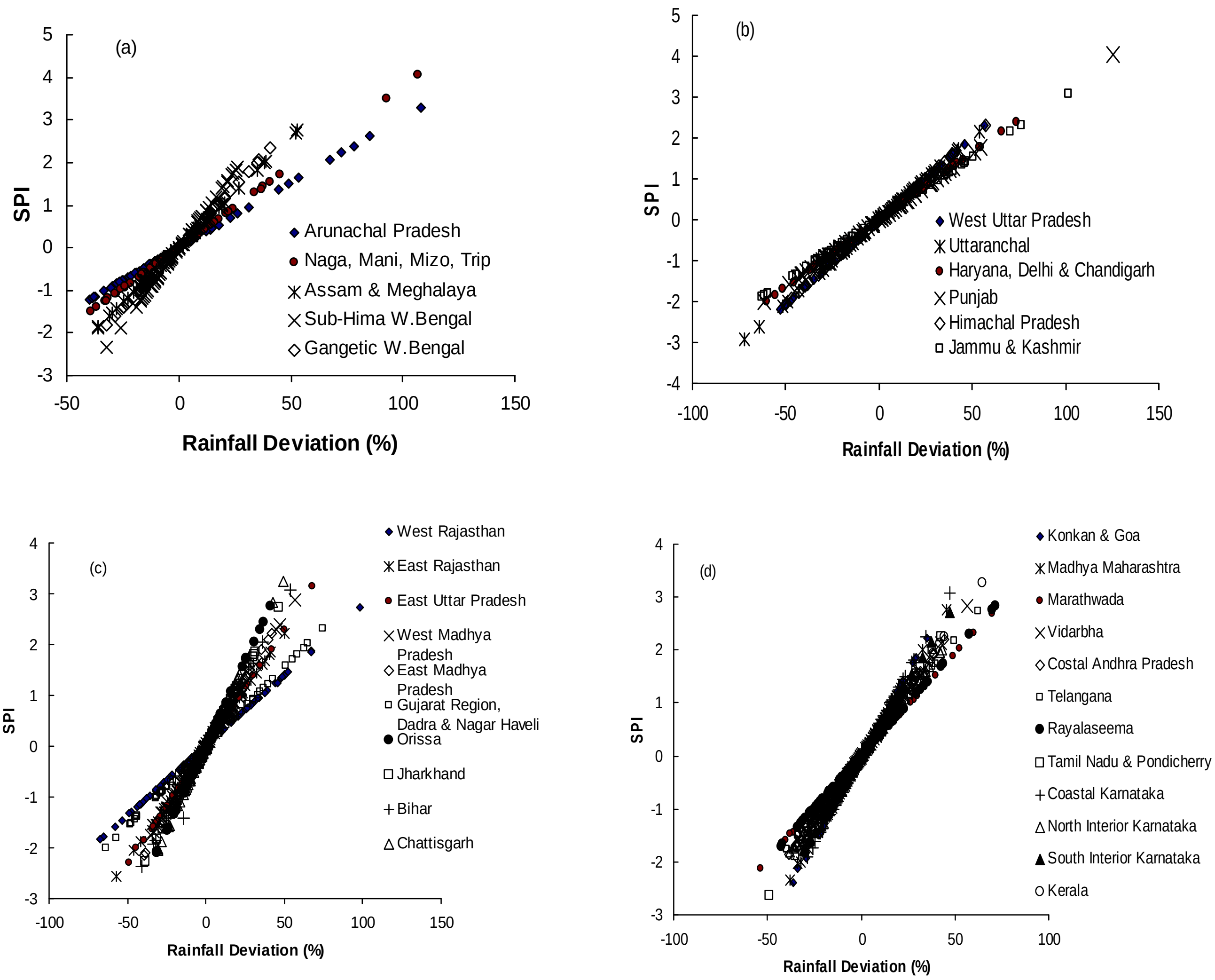


Fig 6 Plot showing association between rainfall deviation and SPI values

The positive SPI peak values are recorded by the sub-divisions of Punjab (4.07, 1988), Arunachal Pradesh (3.32, 1964), Kerala (3.29, 1961) and Chhatisgarh (3.27, 1961) during the monsoon months.

The annual maximum SPI values are recorded by the sub-divisions of Assam and Meghalaya (-2.15, 2013), Orissa (-2.08, 1974), Jharkhand (-2.15, 2010), Bihar (-2.28, 1972), East Uttar Pradesh (-2.37, 1997), Uttaranchal (-2.93, 1997), East Rajasthan (-2.51, 2002), East Madhya Pradesh (-2.21, 1965), Saurashtra Kutch and Diu (-2.06, 1987), Konkan & Goa (-2.46, 1972), Madhya Maharashtra (-2.73, 1972), Marathwada (-2.40, 1972), Chhatisgarh (-2.14, 2009), Coastal Andhra Pradesh (-2.08, 2013), Tamil Nadu & Pondicherry (-3.36, 2013) and South Interior Karnataka (-2.26, 1965) indicating extreme dryness over these sub-divisions during their respective years. All the remaining sub-divisions, except Rayalaseema sub-division, have SPI values between -1.5 to -2 indicating severe drought conditions over these sub-divisions during 1951 to 2015.

The sub-divisionwise detailed analysis showed that moderate to severe drought is observed at different time scale. During the 65 years moderate droughts have been observed only 2 times (in Chattisgarh) to 11 times (in Coastal Andhra Pradesh).

Rainfall deviation and SPI values

Based on rainfall, there are number of methods used in the assessment of drought over a region. Deviation of rainfall from long term mean (i.e.normal rainfall), is most commonly used indicator for drought monitoring (Kumar *et al*, 2009). On the basis of season total rainfall deviation against the long term mean rainfall, India Meteorological Department (IMD) has classified the rainfall over the region as a) ≥ 20% - Excess, b) +19% to -19% - Normal, c) -20% to -59% - Deficient and d) > -60% - scanty. Fig.5 shows the frequency of excess, normal and deficient rainfall years experienced by 34 meteorological sub-divisions during 1951-2015.

Scatter plots between SPI and rainfall deviation were drawn for Jun-Sept monsoon season dividing the 34 meteorological sub-divisions into four groups (Fig.6 a-d) i.e.

1. North east Indian sub-divisions
2. North Indian or Hilly sub-divisions
3. Central Indian sub-divisions and
4. Peninsular Indian sub-divisions

The plot includes comparison of negative/positive rainfall deviation with negative/positive SPI values.

It is seen from Fig.6(a)& (b) that rainfall over these sub-divisions is highly influenced by the Himalayan ranges. In Fig.6 (a), sub-divisions with high rainfall deviations (> -40%) have low rainfall events with SPI values between -1 to -2 indicating moderate dryness/drought. In fact, such a severe dryness should indicate SPI < -2. Similarly, negative deviations between -40 to -30 have comparatively high rainfall events but very high negative SPI values between -2 to -3 indicating severe drought condition. Positive rainfall deviations were found to be associated with positive SPI values. The extreme north Indian hilly sub-divisions (Fig.6 b) having high rainfall deviations (-40% to -80%) showed low rainfall values and higher SPI values (> -1.5) indicating severe dryness but with increasing positive rainfall deviation, there is increase in positive SPI values. Thus, sub-divisions having heavy rainfall showed wider range in both negative and positive SPI values.

It is seen from Fig.6 (c) that many of these sub-divisions located in central India showed high negative rainfall deviation (-50% to -70%). Here also high rainfall deviation between -60% to -70% showed negative SPI values between -1 to -2 indicating moderate to severe dryness and rainfall deviation between -50% to -60% showed SPI values <-2 indicating very severe drought conditions. Increase in positive SPI values are seen with increasing rainfall deviation, but the extent of positive rainfall deviation and SPI values have not shown the same degree of wetness. This can be illustrated as East Uttar Pradesh sub-division with positive rainfall deviation of 68% showed SPI values greater than 3 whereas, West Rajasthan with 98% positive rainfall deviation showed only 2.73 SPI value.

The relationship between rainfall deviation and SPI over sub-divisions of peninsular India (Fig.6 d) showed that high rainfall deviation (-50% to -55%) showed SPI values range between -1.5 to -2.1 and rainfall deviation between -40% to -50% showed high negative SPI values greater than -2. In these sub-divisions also increase in positive SPI values are seen with increasing rainfall deviation, but the extent of positive rainfall deviation and SPI values have not shown the same degree of wetness. Thus, there was a relation between SPI and negative rainfall deviations, but the magnitude of SPI values did not indicate the severity of drought situation.

Discussion

India, being located in a tropical region, every year face monsoon vagaries. Excess rainfall cause severe floods in one part whereas very little or no rain result into severe droughts in other parts. This has tremendous burden on the country's economy. The country has faced three consecutive drought years in the recent past. The average monsoon rainfall over the country was to the negative side against the normal. During 2001 to 2015, eleven years have recorded below normal rainfall of which 2002, 2004, 2009, 2012, 1014 and 2015 are the severe droughts years.

Being an agricultural country, an accurate estimation of precipitation is a challenging task for the assessment of crop yield, droughts and floods monitoring as well as water resources management every year. Excess rainfall cause severe flooding, loss of lives and damage to properties, while prolonged or absence of rainfall lead to droughts which results in reduction in crop yields and power generation, water consumption, etc. Therefore, rainfall is the main index of monsoon activity over the Indian subcontinent. However, rainfall variability is observed on both temporal and spatial scale. Temporal variation can be studied on the basis of rainfall data of raingauge stations.

In view of the above, in the present paper variability in drought with special reference to dry and wet years is computed on the basis of 65 years rainfall data of the 34 meteorological sub-divisions. For this purpose, widely accepted Standardized Precipitation Index (SPI) is used because standardization allow to understand the causes of drought events in the past and probable precipitation necessary to end the drought in the region (McKee *et al*., 1993, 1995). The analysis revealed that of the 34 met sub-divisions, 16 sub-divisions during monsoon season and annual are drought prone showing high negative

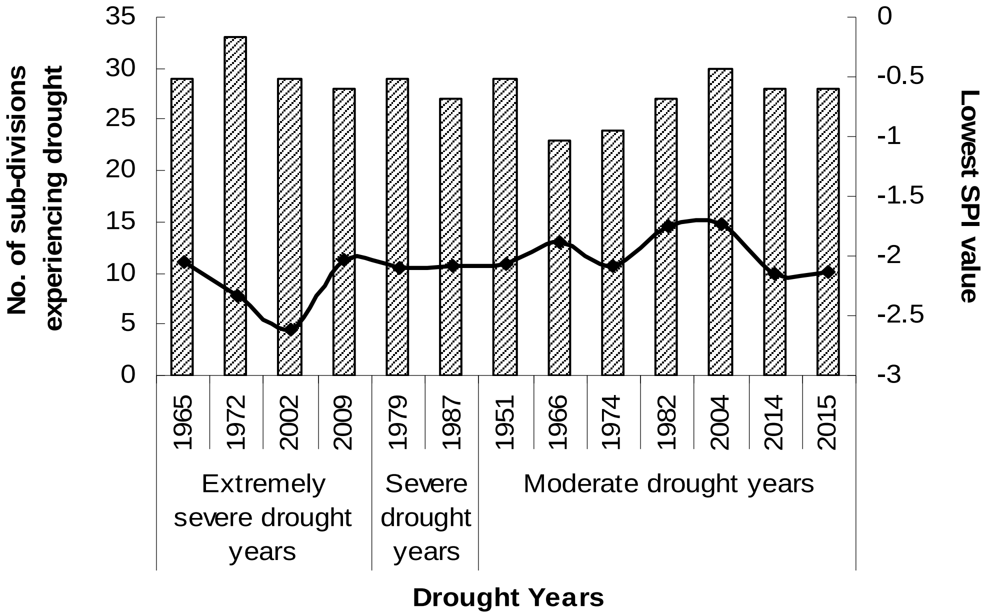


Fig 7 Sub-divisional performance during moderate to extreme drought years

SPI values. It is also seen that for high rainfall deviation with low rainfall events, SPI values are over estimated on the contrary low negative rainfall deviation with high rainfall events showed high negative SPI values. In the heavy rainfall sub-divisions, there is wide extension in SPI values both on negative and positive sides than that of sub-divisions receiving less rainfall during the monsoon season. This information may be useful to drought monitors, water resources planners, and so also agriculturists.

Guhatakurta (2015) analyzed SPI values over India for 1901-2015. His analysis reported four extremely severe drought years viz. 1965, 1972, 2002 and 2009; two severe drought years viz. 1979 and 1987, and 7 moderate drought years, viz. 1951, 1966, 1974, 1982, 2004, 2014, 2015 during 1951 to 2015. The sub-divisional performance for these drought categories are shown in Fig.7. The present study also agrees the severeness of drought in meteorological sub-divisions in different drought categories.

CONCLUSION

In the present study Standardized Precipitation Index (SPI) is used as a drought monitoring index to assess the type and intensity of drought experienced by 34 met. Sub-divisions of the Indian region during 1951 to 2015 as the index values are compared on time and space scales. The SPI values were analysed with actual rainfall as well as rainfall deviations from normal for different seasons and annual.

It is to be kept in mind that although SPI is world wide used to determine the drought over a region, but it is just a statistical product of input data given and therefore, has limitations where orography/ topography play major role in distribution of rainfall. Although, 2-parameter gamma distribution is used in estimating SPI to normalize it in time and at location, in arid region having very little or no rainfall, the SPI index may lead to conflict (Wu *et al*, 2007) due to small sample size or more zero data. Similarly, although assessment of drought on rainfall deviation from long term mean is a simple method, in a country like India, where topography plays important role in the distribution of high or low rainfall over a region, there will not be uniform distribution of rainfall deviation and hence it will be difficult to predict drought over a region.

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