ORIGINAL ARTICLE

Meteorological Drought Study Through SPI in Three Drought Prone Districts of West Bengal, India

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Abstract

Deficiency in rainfall introduces drought phenomena with temporal and spatial variability in terms of intensity and magnitude. Study of drought in different scales is necessary for successful planning in a country such as India, where agricultural sector contributes highest in economy. Drought indices (DI) have a tool to quantify the drought nature and express a single digit which is helpful to recognise a drought character. Standardized Precipitation Index (SPI) is a tool to quantify the drought characteristics, widely used for its simplicity and variable approaches to dignify a drought. Therefore, the present study deals with SPI to analyse drought phenomena in pre-monsoon, monsoon, post-monsoon and monthly time steps in three relatively drought prone districts (Purulia, Bankura, Midnapore) of West Bengal in India of rainfall data of 117 years (1901–2017). From SPI values, drought frequency is analysed using Gumbel's type 1 distribution and trend is calculated using Mann–Kendal test (M–K test). Occurrence of drought with negative SPI values is frequent in these districts with increasing dry events and decreasing wet and normal event. More intensive study in hydrological and agricultural drought is necessary to implement any plan with this increasing aggravation of drought.

1 Introduction

Drought is one of the most creeping climatic hazards without any proper universal definition; any fixed universal parameter to measure its severity; exact beginning or ending date for mitigating its long period impact on the hydrology, environment, economy, socio-cultural aspects, etc. In general sense, drought is a natural phenomenon of less water availability in a particular period and over a particular area (Beran and Rodier 1985). In general, the phenomenon is classified into four categories viz., meteorological, hydrological, agricultural, and socioeconomic drought based on its nature. Among them, meteorological drought is the introducer of the other three types as drought impact is seen step by step, first as a shortage of soil moisture, then as a decrease in stream flow which results into a shortage of water storage in reservoir, depletion of groundwater table and lastly a negative impact is shown upon human economy and society (Tsakiris 2017). Shortage of rainfall (less than 75% to the average annual precipitation in India by the Indian Meteorological Department) is the main cause of beginning of a meteorological drought, but the intensity can be increased by temperature increase. In this aspect of climate change, temperature will rise by 2.7–4.3 °C over India by the 2018s (Shah et al. 2015). A detailed study is thus necessary to identify drought occurrence at the regional level and its probable return period analysis in this variable climatic context for the water planners and policy makers before ensuring any water resources management plan with an assumption of similar climatic condition for near future.

Drought index is a tool for monitoring drought condition and can be explained as a single value, which express the

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dryness or wet ness scenario. Surface Water Supply Index (SWSI) developed in Colorado (Shafer and Dezman 1982), Palmer Drought Severity Index (PDSI) (Palmer 1965), Crop Moisture Index (CMI) (Palmer 1968), Standardized Precipitation Index (SPI) (McKee et al. 1993a, b), Effective Drought Index (EDI) (Byun and Wilhite 1999), and Reclamation Drought Index (RDI) are some of the popular drought indices used as operational definition of drought. Among these, there is a wide application of SPI because of its simplicity and ability to interpret rainfall data in different time scales (1, 2, 3 … 12, 24 months) to assess drought duration, intensity, severity, magnitude, and frequency (Khadr et al. 2009). This paper also deals with standardized Precipitation Index (SPI) proposed by McKee et al. (1993a, b) in different time steps in three relatively drought prone districts (Purulia, Bankura and Midnapore) of West Bengal in India, as regional drought may not be highlighted in a countrywise or statewise study and long-term rainfall study may not be helpful in capturing the actual drought scenario. Despite their climatic dry condition, the other main similarity between these three districts lies in their demographic structure with a high concentration of tribal population and economic backwardness, in 2006, Ministry of Panchayat Raj classified these three districts among the most backward districts in India under Backward Regions Grand Fund (BRGF) scheme. Therefore, the objectives of the study are to evaluate the nature, tendency and probability of meteorological drought in different temporal (1, 2, 3 … 12 month) scale, where distribution of weather station is limited and data recording is irregular in country such as India with an rainfed agrarian base economy. Based on the SPI data, Gumbel's Distribution method was applied to predict the return period of moderate, severe, and extreme drought and Mann–Kendall (M–K) test was employed to detect the trend of dryness for several time steps (monthly, seasonal, and annual).

2 About Study Area

Present study area lies in the Midnapore administrative division in the western part (22°40′ N–23°33′ N and 85°75′ E–87°38′ E) of West Bengal in India, covering an area of 22,486 km^2 as a whole and bounded by West Barddhaman, Hoogly district in the North, Hoogly, Howrah and East Midnapore district in East, state of Jharkhand in South and West (Fig. 1). It is typically a fringe area of Chhotonagpur plateau in West and Gangetic plain in East. These three districts cover 25% of the total area of West Bengal, and 15% of the total population. All the blocks (20) of Purulia, seven from Bankura and Midnapore are listed under Drought Prone Areas Programme (DPAP) by Department of Land Reforms, Ministry of Rural Development (GoI) (Table 2).

Most of the Purulia and West of Bankura district are covered by the Chhotonagpur Gneissic complex of Archaean age, where aquifer is shallow and unconfined [yield is 500–7000 L per hour (lph)] and is developed at the capping of weathered residuals, fissures, cracks etc. In the southern portion of Purulia district Singbhum group of rocks (phyllite and mica schist, quartzite) predominates which is separated from the Chhotonagpur Gneissic complex by a tectonically disturbed shear zone named 'South Purulia Shear Zone' with a WNW–ESE trend. Gondwana group of sediments with coal seams along North–East part of Purulia yields about 8000–10,000 lph groundwater. Shallow aquifer with 5000–7000 lph yield is found along the narrow riverine tract. Deep aquifer is rarely found in entire Purulia district, therefore, dependence on surface water relatively greater than the other parts of the study area. Surface water is highly susceptible to drought occurrence, demands more attention from the policyholders. In Western Bankura weathered residuum and fractures of granite and are the main source of ground water with a depth of 30–60 m below ground level; around 30–95 m below ground level (mbgl) ground water is found along older alluvium sediments of central Southern and Eastern part and along the recent alluvium of Eastern Bankura ground water is found along 30–270 mbgl. In North–West Midnapore ground water is available along the weathered and fractured hard crystalline rocks within depth of 85 mbgl which yields 5–7 lps. However, in the Eastern part of Midnapore very significant water bearing formation occurs along the quarternary alluvium (40 mbgl to 50 mbgl yields 15–25 m^3/h). A very strong relation is noticed in between the distribution of soil and the occurrence of drought events. In Midnapore and Bankura, most of the drought affected blocks are covered with lateritic soils, whereas rocky soils cover the entire Purulia district. The general gradient is from West to East direction encouraging all the rivers like Damodar, Kangsabati, Kumari, Silabati, Dwarakeswar, Subarnarekha, Betai, Kubai, Parong, Dulung etc. to flow from western highlands to eastern lowlands causes Alfisol soils with poor water holding capacity in west and alluvial soils in east. Greater slope, rocky, poorly weathered, and shallow top soil is unable to tap surface flow for a long time; therefore, the western part of the study area is physically considered as a dry region. The area is dominated by hot and dry sub-tropical monsoon climate, characterises by annual rainfall between 1100 and 1500 mm in Purulia, 1400 mm in Bankura and 1550 mm in Paschim Midnapore (Table 1) and 75% of the total precipitation receives during the monsoon period from June to September. However, these four months do not receive same intensity of rains throughout the period, rather, a concentrated nature is noticed. According to IMD, the region receives 75% of monsoon rainfall in just less than

Fig. 1 Location map of the study area. The entire region is lies within the tropical region. Considering coast, Purulia is farthest from the Bay Bengal and received precipitation less than the Midnapore. Amount of rainfall is decreasing far from the coast
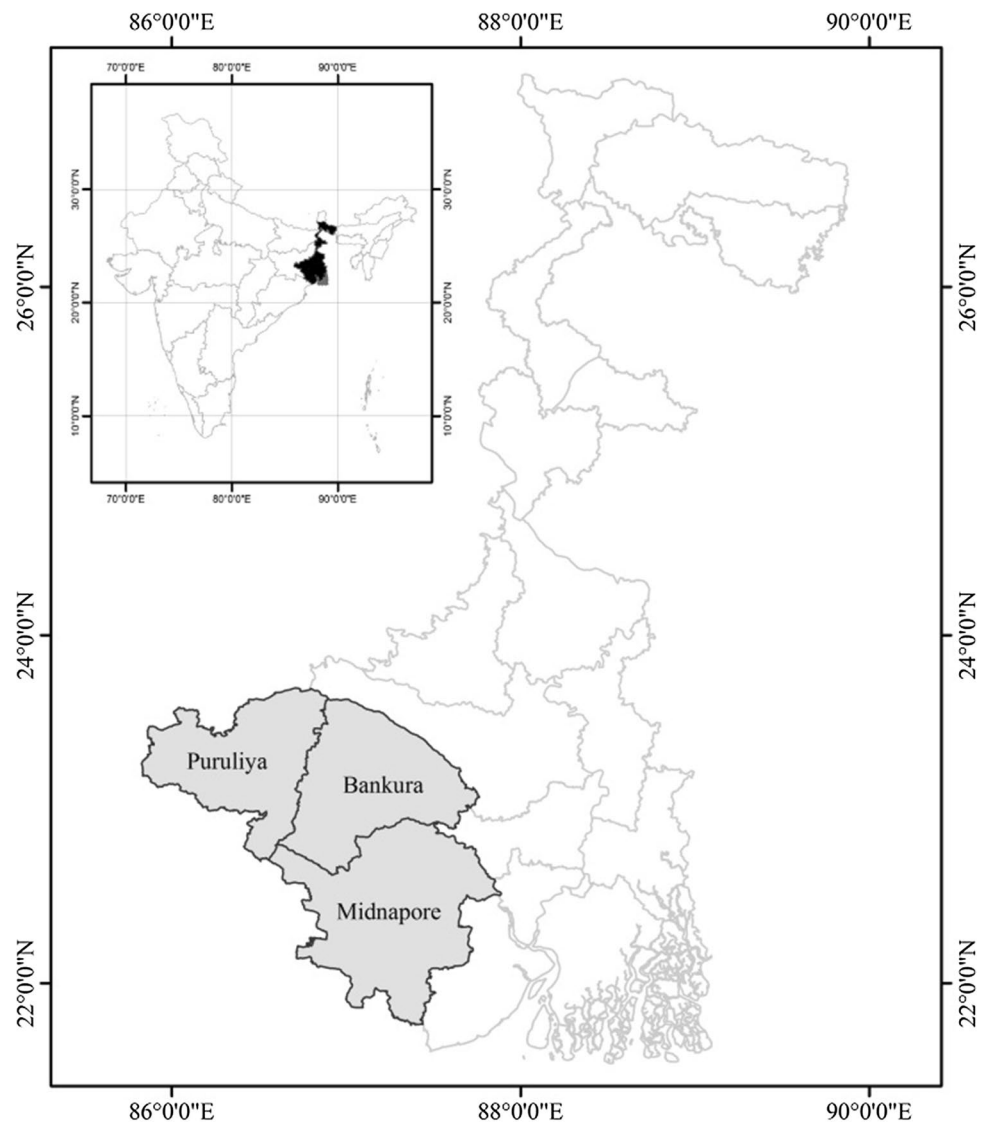
Table 1 Statistical characteristics of studied rain gauge stations *Source:* Indian Meteorological Department (IMD), Pune

Rain gauge stations	Elevation (m) (a.m.s.l.)	Geographic coordinates		Statistical properties of annual rainfall series (1901–2017)					
		Latitude	Longitude	Mean (mm)	Max (mm)	Min (mm)	Standard deviation	Skewness	Kartosis
Purulia	240	23°24′ N	86°49′ E	1327.4	2152.0 (2017)	820.4 (1966)	217.8	0.82	2.08
Bankura	78	23°23′ N	87°08′ E	1421.4	2230.2 (1971)	901.3 (1966)	231.7	0.81	1.32
Midnapur	10	22°15′ N	87°39′ E	1572.1	2298.0 (1971)	1019.0 (1935)	240.7	0.52	0.22

100 h. This results regular flood in the lower reach (eastern part) of Damodar, Silabati, Dwarakeswar River, and dry condition on the upper reach of these rivers (western part) as the water is rolling back quickly to the down and is triggering by greater slope and immature soil conditions. Relative humidity during monsoon (June to September) is nearly 80% but it lowers down only to 25% during the dry period (March to May) (Fig. 2). Average temperature in Purulia ranges from 2.8 °C in winter to 52 °C in summer causes high rate of evaporation which is not favourable for the growth of vegetation and different crops. Station data from three districts, viz. Purulia, Bankura, and Midnapore are collected from Indian Meteorological Department (IMD) for the period of 1901–2017 (Table 2).

3 Methodology

3.1 Standardized Precipitation Index (SPI)

Standardized Precipitation Index (McKee et al. 1993a, b) is calculated for a continuous monthly rainfall data set of at least 30 years in different time steps. Each of the data sets which are determined from the data of previous months fitted to Gamma function to define the relationship of probability to precipitation from where the probability of any observed data point is obtained and precipitation deviation is calculated for a normally distributed probability density with a mean of zero and standard deviation of unity.

'Drought event' occurs when SPI reaches an intensity of -1.0 or less and the normal situation occurs when this value becomes positive or greater than -1.0 (Table 3). Agnew (2000) proposed a new classification of drought intensity based on SPI from which he wanted to highlight that McKee's classification on SPI pointed drought event more frequent indicating towards a 'persistent drought' condition may be confused with a permanent aridity or desiccation (Table 3). Not only the dry events but wet intensity can also be accounted through SPI (Costa 2011) (Table 4).
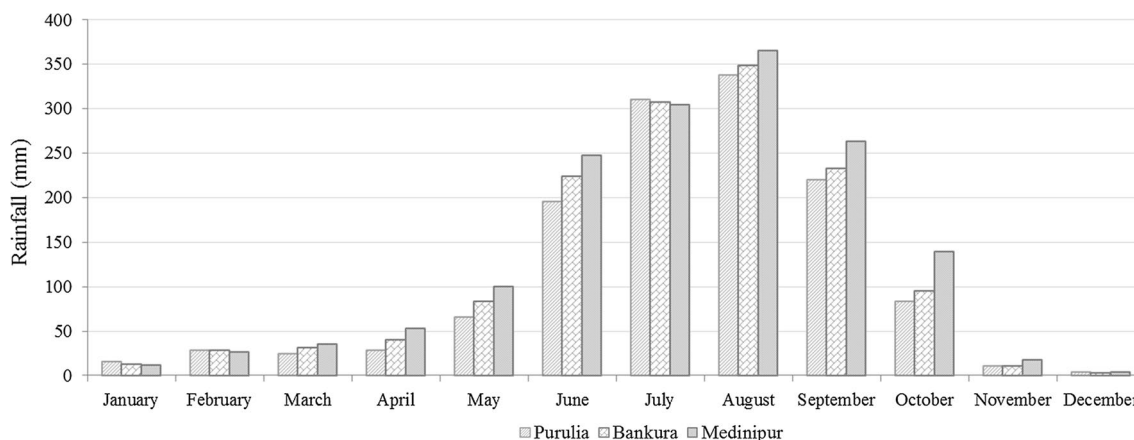

Fig. 2 Monthly distribution of rainfall over the studying stations

Table 2 Drought prone district profile. *Source*: Department of Land Resources, Ministry of Rural Development (GoI)

Districts	Drought affected blocks	Population (2011 census)
Purulia	Jaipur, Purulia-I and II, Para, Raghunathpur-I and II, Neturia, Santuri, Kashipur, Hura, Puncha, Arsha, Jhalda I and II, Baghmundi, Balarampur, Barabazar, Manbazar I and II, Bundwan	28, 63,296
Bankura	Saltore, mejhia, Gangajalghanti, Chhatna, Indpur, Khatra, Ranibundh	11,07,139
Medinipur	Binpur-I, Jhargram, Jambani, Gopiballavpur-I and II, Nayagram, Sankrail	10,10,963
Total	34 blocks (area-11,197 km^2)	49,81,398

Table 3 Comparative dry period calculation according to SPI index

SPI values	Probabilities of occurrence (ΔP)	McKee et al. (1993a, b) Drought classification	Proposed new drought classes by Agnew (2000)	Recurrence and Severity of drought
Less than -2.00	0.023	Extreme drought		1 in 50 years
Less than -1.65	0.050		Extreme drought	
Less than -1.50	0.067	Severe drought		1 in 20 years
Less than -1.28	0.100		Severe drought	
Less than -1.00	0.159	Moderate drought		1 in 10 years
Less than -0.84	0.201		Moderate drought	
Less than -0.50	0.309		No drought	
Less than 0.00	0.500	Mild drought	No drought	1 in 3 years

Table 4 Wet period according to SPI (McKee et al. (1993a, b)

Index value	Class	Probability
SPI ≥ 2.00	Extremely wet	0.977–1.000
1.50 ≤ SPI < 2.00	Very wet	0.933–0.977
1.00 ≤ SPI < 1.50	Moderately wet	0.841–0.933
−1.00 ≤ SPI < 1.00	Near wet	0.159–0.841

The advantages of SPI are—calculation of SPI is based on rainfall data alone, so that drought assessment is possible even if other hydro-meteorological measurements (temperature, humidity, evapotranspiration etc.) are not available; the SPI is also not adversely affected by topography, the SPI is defined over various timescales (1, 2, 3 … 12, 24 months); this allows it to describe drought conditions more rapidly than other indices like PDSI (Palmer Drought Severity Index proposed by Palmer 1965) over a range of meteorological, hydrological and agricultural applications; the standardization of SPI ensures that the frequencies of extreme events at any location and on any time scale are consistent (Hayes et al. 1999; Mishra and Desai 2005). Using this technique, a drought condition can be compared among different climatic region also because of its standardization (Bonaccorso et al. 2003a, b). Drought risk can also be analysed by SPI because of its congenital probabilistic nature (Guttman 1999). Different aspects of hydrological cycle such as soil moisture condition, stream flow and ground water reservoir storage can be analysed by applying SPI in short (2–3 months), medium (2–6 months) and long-term precipitation analysis (Lloyd-Hughes and Saunders 2002). Primarily the purpose of constructing such an index was to propose an indicator which could serve as a versatile tool in drought monitoring and analysis (McKee et al. 1993a, b).

SPI is a worldwide useful drought indices and has been applied to understanding different aspects of drought and wet conditions, for example, changes in precipitation by applying SPI in precipitation data of drier part of southern Portugal for 1940–1999 on a regional scale (Costa 2011); correlation between shifting of precipitation and SPI values in Portugal (Paulo et al. 2015).

In India several attempts were made to estimate the dryness scenario by applying SPI such as Mishra and Desai (2005) tried to apply linear stochastic models known as ARIMA and multiplicative Seasonal Autoregressive Integrated Moving Average (SARIMA) models to forecast drought using SPI in Kangsabati river basin in India. District wise SPI and PN was computed to study the drought climatology during southwest monsoon and trend was analysed by simple linear regression technique and the 'Students t' test was used for significance testing the linear trends which showed a positive trend in several parts and negative trend in several districts in the country (Pai et al. 2011). Kar et al. (2012) finds that during pre-monsoon period rainfall variability is high in Purulia and during post-monsoon it is high in all of the three districts of present study by computing Coefficient of variation and by SPI computation reported that during pre-monsoon Purulia and Bankura; during monsoon Midnapore experienced higher number of droughts. An analysis to assess the efficiency of remote sensing and GIS based techniques such as NDVI, VCI etc. to examine the spatio-temporal extent of agricultural drought compared by meteorological drought indicator such as SPI, RAI shows a good agreement in Rajasthan, the driest part of India (Dutta et al. 2015). Shah et al. (2015) applied SPI on 40 years of rainfall data of Surat district of Gujarat, a drier region of western India, to observe drought in 12-month time scale and to compare it with actual drought scenario. Drought duration, severity and interval was analysed from the rainfall data using SPI by Hangshing and Dabral in their work on multivariate frequency analysis of drought for Agartala, India (2018).

In this study, annual rainfall series was fitted to the gamma distribution. The gamma Probability Distribution Function (pdf) is given as

$$G(X) = \frac{1}{b^a \Gamma(a)} \int_0^X X^{a-1} e^{-x/\beta} \, dx, \tag{1}$$

where $G(x)$ is the cumulative probability, β is the scale parameter, α is the shape parameter, x is the random variable (monthly precipitation), and $\Gamma(a)$ is the Gamma function

Parameters α and β are estimated by

$$\alpha = \frac{1}{4A}\left(1 + 1 + \frac{4A}{3}\right). \tag{2}$$

In addition

Table 5 Seasonal share of precipitation (in %). *Source:* Indian Meteorological Department (IMD), Pune

District	Pre-monsoon			Monsoon			Post-monsoon		
	Average	Highest	Lowest	Average	Highest	Lowest	Average	Highest	Lowest
Purulia	11.08	22.87 (1907)	2.56 (1966)	80.26	92.44 (1922)	55.25 (2013)	8.66	24.44 (2013)	0.85 (1918)
Bankura	12.94	25.63 (1981)	3.01 (1966)	78.47	92.33 (1922)	60.52 (1998)	8.59	23.01 (1998)	0.96 (1976)
Medinipur	13.82	27.49 (1905)	3.03 (1966)	75.18	91.74 (1922)	53.60 (2017)	11.00	29.75 (2003)	1.24 (1918)

$$\beta = \frac{\overline{X}}{\alpha}, \tag{3}$$

where

$$A = \text{In}(x) - \frac{\sum (\text{In}(x))}{n}. \tag{4}$$

Being 'n' is the number of observations.

The aim of fitting the distribution of the data is to estimate the parameters α and β. Integrating pdf with respect to x and inserting the estimated values of α and β, 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.

In case of positive SPI the classes and probabilities are:

3.2 Gumbel's Return Period

It is hard to estimate the exact time when a drought event starts and when it ends. So, it seems to be harder to analysis drought frequency for future prediction. Many literary articles have been published to highlight the best technique to calculate the return period of drought based on any historic data set. Such as Poisson process (Zelenhastic and Salvai 1987); bivariate and multivariate techniques with copula function (Cancelliere et al. 2003; Salas et al. 2005; Shiau 2006; Mishra et al. 2009; Reddy
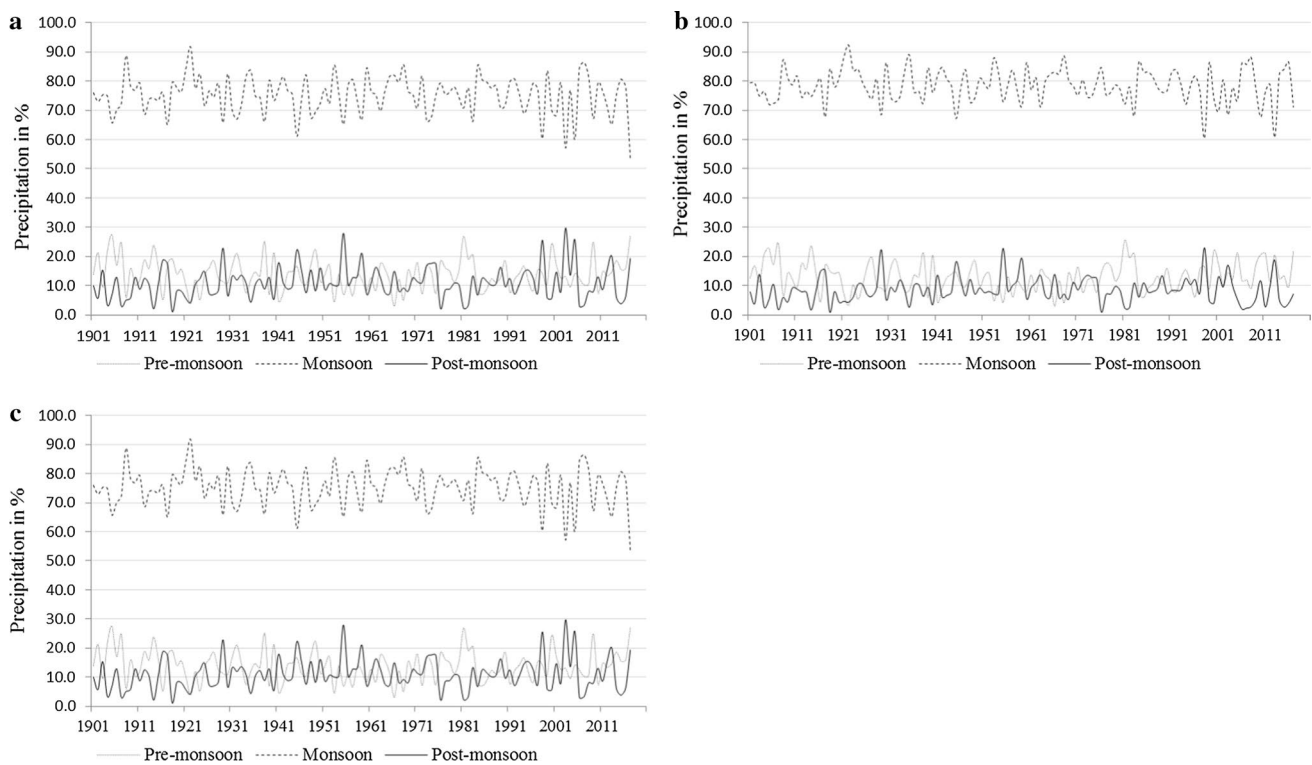
Fig. 3 Seasonal share of precipitation at **a** Purulia, **b** Bankura, and **c** Midnapore. Monsoonal rainfall accounted almost 75–80% of the total annual precipitation and remaining are distributed in pre- and post-monsoonal seasons with little or no precipitation. As an agrarian society, such spell of dryness is hard to cope

Table 6 Yearly SPI values for 117 years are categorise and estimation of drought frequency

Drought categories	Purulia		Bankura		Midnapur	
	No. of years	DF (%)	No. of years	DF (%)	No. of years	DF (%)
Mild	46	39.3	47	40.2	46	39.3
Moderate	8	6.8	9	7.7	10	8.5
Severe	4	3.4	6	5.1	5	4.3
Extreme	3	2.6	2	1.7	2	1.7
No drought	56	47.9	53	45.3	54	46.2

DF drought frequency

and Ganguli 2012; Kwak et al. 2016); probability distribution of stochastic hydrological series (Bonaccorso et al. 2003a, b; Salas et al. 2005). But edification of the probabilistic nature of drought beginning, drought intensity or severity is still acting as a hurdle to cross for the water managers. In this paper drought frequency is analysed using Gumbel's type 1 distribution, because it deals with the extreme value (here maximum) and long period data of stochastic nature is available.

Gumble extreme value distribution is based on the arrangement that distribution of an extreme event is unlimited and hence the most suitable distribution for fitting to the extreme value data is of the 'double exponential type'. Hence, the probability of occurrence of a peak discharge, x equal to or larger than value, x_0 is given by

$$f\left(x \geq x_0 = 1 - p' = 1 - e^{-e^{-y}}\right) \tag{5}$$

In which e is the base of normal logarithm and y is a dimensionless reduced variate given by

$$y = \frac{1}{0.78\delta}\left(x_T - \bar{X}\right) + 0.577, \tag{6}$$

where x_T = the event (or, magnitude of the discharge with probability of occurrence) in T-year return period. T is calculated as

$$T = \frac{1}{1 - e^{-e^{-y}}}. \tag{7}$$

Reduced variate y is calculate as

$$y = -\text{in}\left[-\text{in}\left(1 - \frac{1}{T}\right)\right]. \tag{8}$$

Since the event x of T-year return period is x_T then from equation (Eq. 5) we can compute x_T as

$$x_T = \bar{X} + \delta(0.78y - 0.45), \tag{9}$$

in which the frequency factor k is $(0.78y - 0.45)$.

Table 7 The strong drought years during 1901–2017

Drought category	Purulia	Bankura	Midnapur
Moderate	1902, 1907, 1912, 1954, 1955, 1957, 1979, 2014	1907, 1912, 1935, 1938, 1954, 1957, 1982, 2001, 2015	1903, 1907, 1911, 1924, 1927, 1938, 1953, 1982, 2009, 2012
Severe	1903, 1962, 2000, 2001	1962, 1979, 1992, 2000, 2010, 2014	1954, 1957, 1962, 1979, 2014
Extreme	1966, 1992, 2010	1903, 1966	1935, 1966

Table 8 Yearly return period of different drought categories

Drought categories	Purulia		Bankura		Medinipur	
	Frequency	Return period (years)	Frequency	Return period (years)	Frequency	Return period (years)
Moderate	7	7–12	9	6–10	10	7–11
Severe	5	12–20	7	12–19	5	12–18
Extreme	3	28–57	1	50	2	25–51

Table 9 Seasonal SPI values for 117 years are categorise and estimation of drought frequency (DF)

Drought categories	Pre-monsoon (February–May)						Monsoon (June–September)						Post-monsoon (October–January)					
	P	DF	B	DF	M	DF	P	DF	B	DF	M	DF	P	DF	B	DF	M	DF
Mild	41	35.0	37	31.6	30	25.6	40	34.2	46	39.3	41	35.0	42	35.9	41	35.0	38	32.5
Moderate	7	6.0	8	6.8	14	12.0	11	9.4	9	7.7	14	12.0	5	4.3	5	4.3	8	6.8
Severe	7	6.0	7	6.0	5	4.3	5	4.3	7	6.0	6	5.1	4	3.4	3	2.6	5	4.3
Extreme	3	2.6	3	2.6	4	3.4	3	2.6	2	1.7	0	0.0	6	5.1	7	6.0	5	4.3
No drought	59	50.4	62	53.0	64	54.7	58	49.6	53	45.3	56	47.9	60	51.3	61	52.1	61	52.1

P Purulia, *B* Bankura, *M* Midnapore

Fig. 4 Drought category distribution in **a** pre-monsoon, **b** monsoon, and **c** post-monsoon period. Purulia has the maximum number of drought events during pre and post monsoon period, whereas Bankura at monsoonal period

4.2 Yearly Rainfall

Using the formula of drought frequency of yearly value of SPI reveals that dry situation occurs in these three districts having a frequency of more than 50% (Table 6) which is calculated by dividing the number of drought years by the total number of observed years and multiplying it with 100%. The frequency of mild drought condition (SPI 0 to − 1) is 40% for the three observation stations. Moderate drought is more frequent in Paschim Midnapore (8.5%), severe drought in Bankura (5.1%) and extreme drought in Purulia (2.6%) (Table 6). Purulia district experienced maximum number of extreme drought in the year of 1966, 1992 and 2010. 1966 is a famous drought year and was declared as a drought year by Indian Meteorological Department (IMD). Similarly 2010 is the another well-known drought year, hits almost all over the India and the Purulia and Bankura pass through a very strong drought condition (Table 7) in 2010. Successive dry event hits Purulia for several times, i.e., 1902–1903,

1954–1955, and 2000–2001 (Table 7) and makes the drought situation different from the other districts. In general the extreme drought event having a recurrence interval of 1 in every 50 years for the all studying districts and second half of the twentieth century experienced maximum meteorological drought events indicates an abrupt changes in the normal climatic cycle.

4.2.1 Return Period

The calculation of return period of extreme event like drought is important as it helps to estimate the water budget for the lean period. Water retention structures, like dam, pond etc., and strategy should follow it in such a rational way so that supply of water maintains continuity and follow sustainability throughout the year. The maximum capacity of water storages and management policies should be prepared to accommodate a given severity of drought corresponding to maximum risk.

Drought severity for extreme drought is maximum in Purulia, three extreme drought events hit the district during 117 years of study with a recurrence interval of 28–57 years, followed by Midnapore (25–51 years), and Bankura (50 years) (Table 8). The return period of severe and moderate drought is maximum in Bankura, followed by Midnapore and Purulia district.

4.3 Seasonal Rainfall

In the next step SPI values were calculated for 4 months, i.e., pre-monsoon (February–May), monsoon (June–September) and post-monsoon (October to January) season. For pre-monsoonal period, Purulia ranks top in terms of

Table 11 Trend detection of seasonal SPI by M–K Test

Time series	Test Z	Significance
Purulia_pre-monsoon	0.14	Less than 0.1
Bankura_pre-monsoon	0.40	
Midnapore_pre-monsoon	0.20	
Purulia_ monsoon	− 1.35	
Bankura_monsoon	− 0.58	
Midnapore_monsoon	0.08	
Purulia_post-monsoon	0.67	
Bankura_post-monsoon	0.00	
Midnapore_post-monsoon	1.02	
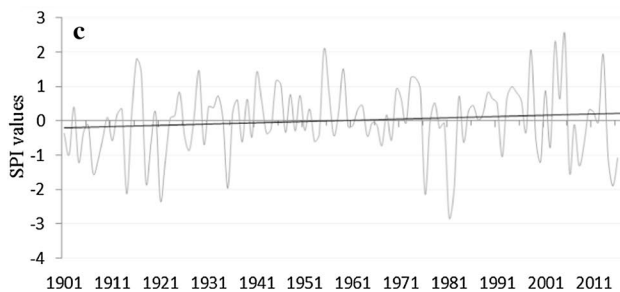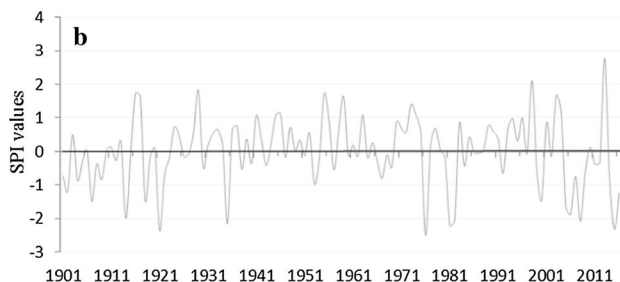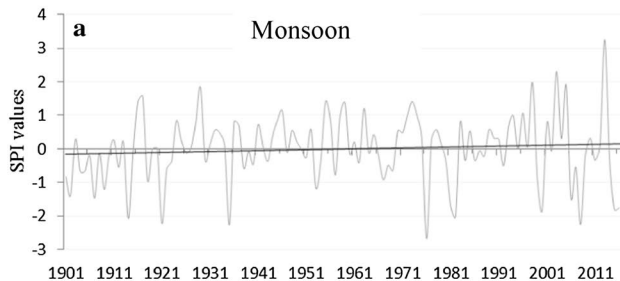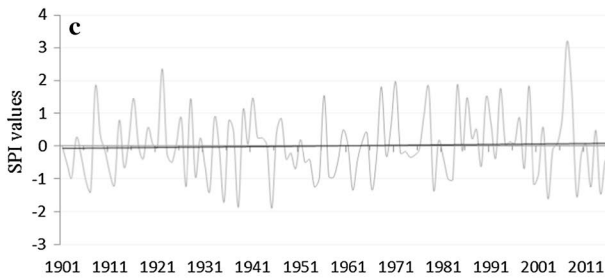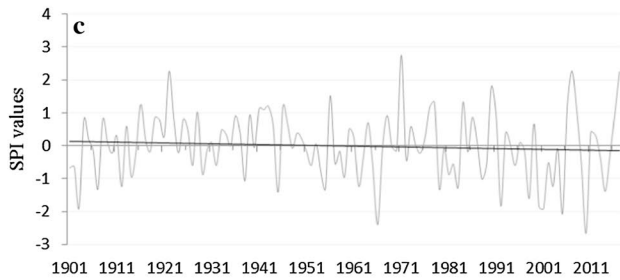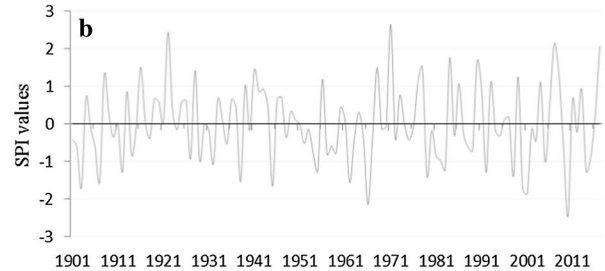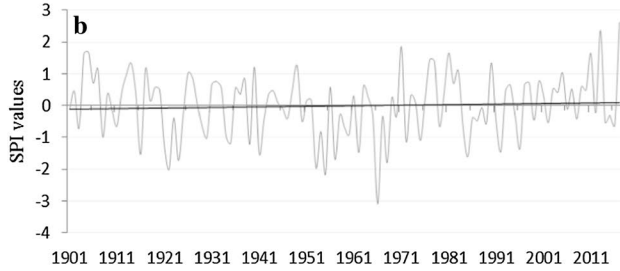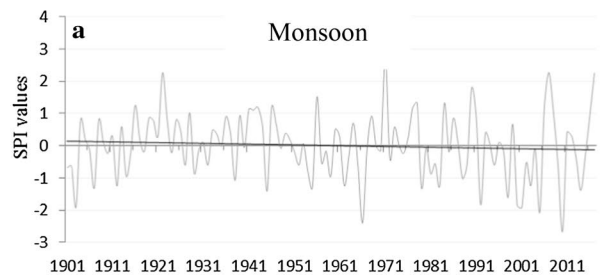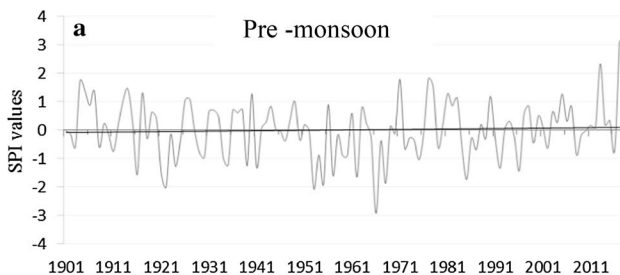
negative SPI value. 49% of total no of years have a negative SPI but in terms of extreme drought condition having less than −2 SPI, Paschim Midnapore tops as 1922, 1924, 1953 and 1966 show low SPI values (Table 9). After 1966, no extreme drought occurred during this pre-monsoon period in these three drier districts of West Bengal. Severe drought during this period occurred 7 times both in Purulia and Bankura before 1985 and there is a similarity of drought occurrence in 1922, 1953, 1957, 1966, 1968 and 1985 for the all districts. Considering the drought nature, much similarity was found in between the Purulia and adjoining Bankura district; both districts were experienced the severe to extreme droughts in 1916, 1922, 1953, 1955, 1957, 1966, 1968, and 1985 (Table 10) together.

Computation of monsoonal rainfall data indicates that Purulia suffers worst by high magnitude drought (SPI > -2.0) events in this period from June to September as in 1966, 2005 and 2010. Bankura also experienced negative SPI with highest frequency (54%) followed by Midnapore (52%) and Purulia (50%). In case of Paschim Midnapore the scenario is quiet relaxing as there is not any extreme drought event during these 117 years in monsoon time. There was no extreme or severe drought event after 2010 in any of the districts except Midnapore in 2017. As stated earlier, similarity on drought nature again matched in between Purulia and Bankura; severe to extreme dry events hit the both districts during 1903, 1966, 2000, 2001, and 2010.

Post-monsoon data of rainfall shows an interesting result as most of the extreme droughts occurred during this period with a frequency of 6.0% (7), 5.1% (6) and 4.3% (5) in the district of Bankura, Purulia and Paschim Midnapore, respectively (Table 9, Fig. 4). Among the 10 severe and extreme drought events, similarities match for 7, i.e., in 1914, 1921, 1935, 1976, 1981, 1982, and 2015 for the three districts (Table 10) and, therefore, concluded that the nature of dryness during post-monsoonal period almost similar in the drought prone districts of West Bengal.

4.3.1 Seasonal SPI Trend

The Mann–Kendall test was employed to detect the temporal trends of SPI at the three stations seasonally. The 4-month SPI (SPI-4) at May, September and January were used in the seasonal trend analysis for summer (pre-monsoon), rainy (monsoon), and winter (post-monsoon), respectively. Seasonally, the SPI values (SPI-4) exhibited an increasing trend for pre-monsoonal and post-monsoonal period at three districts and decreasing trend for monsoonal period at Purulia and Bankura district. No trend is observed for post-monsoonal period at Bankura station. Monsoonal trend

is increasing at Midnapore but none of the increasing or decreasing trend is significant (Table 11, Fig. 5).

The seasonal SPI-4 values exhibited patterns of change during the three seasons. In general, a largely dominating drying tendency could be observed in summer and winter, and the opposite in rainy. In rainy season, the SPI-4 trend is decreasing, indicating more concentration of rainfall within this short span. Such huge concentration of rainfall is really unmanageable and causes flood situation at the lower reach of Damodar, Kanshabati, Dwarakeswar and Shilabati river, mainly in Midnapore district. Some pockets of these rivers at Midnapore district are famous for frequent flood events. SPI-4 is increasing in pre-monsoonal period at every district. This is more harmful as the season is generally dry by climatic factor and the season is just following by another dry period, post-monsoonal period, ranges from October to January. The dry situation of these two successive seasons are increasing and would become the future intolerable as the prolong dry situation longing up to 8-months from October to May, with little or no precipitation.

4.4 Monthly Rainfall

Considering the single month SPI-1, all the districts received low rainfall in a similar tendency. Drought frequency in different seasons varies from 32 to 34% in every districts (Table 12) but almost 49% of the total months received lower rainfall having negative SPI (Table 13), whereas normal rainfall occurs only in 35% of the total months (Table 13). In terms of occurrence of severe and extreme drought events, Bankura comes first after Purulia and Midnapore (Table 13). By this 1 month time period analysis, a drought event may be detected which may not be always detected by longer time period.

4.4.1 Monthly Trend Analysis

The M–K test once again employed to detect the trend of change in dryness or wetness by considering the monthly SPI-1 values (Table 14). SPI values of dry months exhibited an increasing trend for the all districts and decreasing trend for wet or normal situation, but either increasing or decreasing trend is significant. For Purulia and Midnapore, the dry trend is close enough to significant level. The decreasing wet trend in Purulia, and decreasing normal trend in Midnapore are also very close to significant level.

From the monthly SPI-1 results, it is clear that these three districts suffer from shortage of rainfall very often. As most of the rainfall occurs during monsoon season in this area, it is necessary to interpret the data into three different time gaps like monsoon, pre-monsoon, post-monsoon period. Occurrence of extreme or severe drought during monsoon gives a message that here is a need to manage water seriously. Besides, pre- and post-monsoon drought is also

Table 12 Monthly and seasonal drought frequency

Districts	Pre-monsoon					Monsoon					Post-monsoon					Total
	Feb	Mar	Apr	May	In %	Jun	Jul	Aug	Sep	In %	Oct	Nov	Dec	Jan	In %	
Purulia	57	56	55	58	32.8	63	61	56	59	34.7	58	56	55	54	32.5	688
Bankura	56	55	53	54	32.4	59	58	56	58	34.3	58	57	56	54	33.3	674
Medinipur	53	61	52	52	32.1	61	57	52	58	33.5	57	58	66	53	34.4	680

Table 13 Number of months and nature of dryness and wetness

Districts	Dryness						Normal		Wetness				
	Extreme	Severe	Moderate	Mild	Total	In %	Months	In %	Extreme	Severe	Moderate	Total	In %
Purulia	30	59	100	502	688	49.0	486	34.8	23	66	141	230	16.2
Bankura	32	60	94	485	674	48.0	500	35.6	23	66	142	230	16.4
Midnapur	23	60	140	457	680	48.4	498	35.5	23	65	138	226	16.1

Table 14 Trend detection of monthly SPI by M–K Test

Time series	Test Z	Significance
Purulia_dry	1.38	Less than 0.1
Purulia_wet	−1.45	
Purulia_normal	−0.90	
Bankura_dry	0.69	
Bankura_wet	−0.92	
Bankura_normal	−0.85	
Midnapore_dry	1.13	
Midnapore_wet	−0.09	
Midnapore_normal	−1.52	

mention-worthy as these three districts belong to an agrarian society mainly. If continuation of agriculture throughout the year is prior to this society despite of dry condition in non-monsoon season there is a need for proper irrigation which is also dependent upon availability of both surface and sub-surface water. So, water management in a systematic way has no option in these three districts of West Bengal.

5 Conclusion

Drought is not a sudden event rather a creeping climatic phenomena, and is difficult to predict its occurrence, magnitude, intensity, and return period. Forecasting drought is of highest importance in the dry parts of West Bengal for planning of water and rational utilization of irrigated water as agriculture is the main economic activity and highly depends on rainfall. The study area is the home of nearly 5 millions of people and more than 90% are from rural areas, where water distribution system is already inadequate. The present study was highlighted on quantification of drought,

forecasting drought using SPI. The seasonal M–K test developed for different SPI series (seasonal) to detect the trend of drought events and Gumbel's Return period employed to estimate the probable recurrence interval of several drought types. Results show a greater temporal variability of rainfall, a strong indication of drought event. Return period of drought with moderate intensity is just 6–12 years, increase of dry event and decrease of wet and normal events enlighten the causes of water scarcity.

Further study of other varieties of drought, i.e., agricultural or hydrological drought is required as this region suffers from lower amount of surface water due to steeper slopes and crop failure or lower agricultural production due to change in rainfall pattern. Not only detailed drought investigation but also new techniques of surface water conservation and safe ground water recharge should be studied in a regional basis also to cope up with the variable climate and growing water demand.

References

Agnew CT (2000) Using the SPI to identify drought. drought network news (1994–2001) 12(1): 6–12. DIALOG. http://digitalcommons.unl.edu/droughtnetnews/1. Accessed 13 Dec 2016

Beran M, Rodier JA (1985) Hydrological aspects of drought. Studies and reports in hydrology 39, Unesco-WMO, Paris

Bonaccorso B, Bordi I, Cancelliere A, Rossi G, Sutera A (2003a) Spatial variability of drought: an analysis of SPI in Sicily. Water Resour Manag 17:273–296

Bonaccorso B, Cancelliere A, Rossi G (2003b) An analytical formulation of return period of drought severity. Stoch Env Res Risk Assess 17(3):157–174

Byun HR, Wilhite DA (1999) Objective quantification of drought severity and duration. J Clim 12:2747–2756

Cancelliere A et al (2003) On the probabilistic characterization of drought events. Hydrol Days 33–44

Costa AC (2011) Local patterns and trends of the Standard Precipitation Index in southern Portugal (1940–1999). Adv Geosci 30:11–16

Dutta D et al (2015) Assessment of agricultural drought in Rajasthan (India) using remote sensing derived Vegetation Condition Index (VCI) and Standardized Precipitation Index (SPI). Egypt J Remote Sensing Space Sci. https://doi.org/10.1016/j.ejrs.2015.03.006

Guttman NB (1999) Accepting the standardized precipitation index: a calculation algorithm. J Amer Water Resour Assoc 35(2):311–322

Hangshing L, Dabral PP (2018) Multivariate frequency analysis of meteorological drought using copula. Water Resour Manag 32(5):1741–1758. https://doi.org/10.1007/s11269-018-1901-0

Hayes MJ, Svoboda MD, Wilhite DA, Vanyarkho OV (1999) Monitoring the 1996 drought using the standardized precipitation index. Bull Am Meterol Soc 80:429–438. https://doi.org/10.1175/1520-0477(1999)080%3c0429:MTDUTS%3e2.0.CO;2

Kar B, Saha J, Saha JD (2012) Analysis of meteorological drought: the scenario of West Bengal. Indian J Spat Sci 3(2):1–11

Khadr M, Morgenschweis G, Schlenkhoff A (2009) Analysis of meteorological drought in the ruhr basin by using the standardized precipitation index. World Acad Sci Eng Technol 57:607–616

Kwak J, Kim S, Kim G, Singh VP, Park J, Kim HS (2016) Bivariate drought analysis using streamfow reconstruction with tree ring indices in the Sacramento Basin, California, USA. Water 8(4):122. https://doi.org/10.3390/w8040122

Lloyd-Hughes B, Saunders MA (2002) A drought climatology for Europe. Int J Climatol 22(13):1571–1592

McKee TB, Doesken NJ, Kleist J (1993a) The relationship of drought frequency and duration to time scales. In: 8th conference on applied climatology, Am Meteor Soc, Boston, pp 179–184

McKee TB, Doesken NJ, Kleist J (1993b) The relationship of drought frequency and duration to time scales. In: Proceedings of the 8th Conference on Applied Climatology. American Meteorological Society, Boston 17(22):179–183

Mishra AK, Desai VR (2005) Drought forecasting using stochastic models. Stoch Env Res Risk Assess 19(5):326–339

Mishra AK, Singh VP, Desai VR (2009) Drought characterization: a probabilistic approach. Stoch Env Res Risk Assess 23(1):41–55

Pai DS, Sridhar L, Guhathakurata P, Hatwar HR (2011) District-wise drought climatology of the southwest monsoon season over india based on standardized precipitation index (SPI). Nat Hazards 59(3):1797–1813

Palmer WC (1965) Meteorological drought. Research Paper No. 45. US Weather Bureau. NOAA Library and Information Services Division, Washington, DC

Palmer WC (1968) Keeping track of crop moisture conditions, nationwide: the new crop moisture index. Weatherwise 21(4):156–161

Paulo A, Martins D, Pereira LS (2015) Influence of precipitation changes on the SPI and related drought severity: an analysis using long-term data series. Water Resour Manag 30(15):5737–5757

Reddy MJ, Ganguli P (2012) Bivariate food frequency analysis of upper Godavari river flows using Archimedean copulas. Water Resour Manag 26(14):3995–4018

Salas J, Fu C, Cancelliere A, Dustin D, Bode D, Pineda A, Vincent E (2005) Characterizing the severity and risk of droughts of the Poudre River, Colorado. J Water Resour Plan Manag 131(5):383–393

Shafer BA, Dezman LE (1982) Development of a surface water supply index (SWSI) to assess the severity of drought conditions in snowpack runoff areas. In: Proceedings of the Western Snow Conference. Fort Collins. Colorado State University, pp 164–175

Shah R, Bharadiya N, Manekar V (2015) Drought index computation using standardized precipitation index (SPI) method for Surat District, Gujarat. Aquatic Proc 4:1243–1249

Shiau JT (2006) Fitting drought duration and severity with two-dimensional copulas. Water Resour Manag 20(5):795–815

Tsakiris G (2017) Drought risk assessment and management. Water Resour Manag 31(10):3083–3095

Zelenhastic E, Salvai A (1987) A method of streamflow drought analysis. Water Resour Res 23(1):156–168