MAUSAM, **74**, 1 (January, 2023), 119-128

MAUSAM

DOI : https://doi.org/10.54302/mausam.v74i1.3519
Homepage: https://mausamjournal.imd.gov.in/index.php/MAUSAM

UDC No. 551.577.38 : 551.553.21 (540.27)

Drought assessment and trend analysis using SPI and SPEI during southwest monsoon season over Bundelkhand region of Uttar Pradesh, India

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(*Received 27 October 2021, Accepted 17 August, 2022*)

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सार — जलवायु संबंधी विसंगति है जो अत्यधिक भिन्न जलवायु वाले सभी क्षेत्रों में हो सकती है। एक विस्तारित अवधि में वर्षा की लगातार कमी, आमतौर पर एक ऋतु या अधिक में ,होने के कारण जल का अभाव होता है जो आर्थिक, कृषि, पर्यावरण और सामाजिक पहलुओं पर महत्वपूर्ण प्रभाव डालता है। सूखे की स्थिति की प्रभावी निगरानी के लिएसूखा सूचकांक प्रमुख भूमिका निभाते हैं जो क्षेत्र विशिष्ट के होते हैं और विभिन्न जलवायविक परिस्थितियों में प्रयोज्यता की सीमा होती है। इसलिए, वर्तमान अध्ययन का उद्देश्य 48 वर्षों (1969-2016) की वर्षा और तापमान के आंकड़ों का उपयोग करके मध्य भारत का सबसे सूखा प्रवण क्षेत्र बुंदेलखंड क्षेत्र के लिए दो सूखा सूचकांकों अर्थात मानक वर्षा सूचकांक (SPI) और मानकीकृत वर्षा वाष्पीकरण सूचकांक (SPEI) द्वारा जलवायु विज्ञान और सूखे का विश्लेषण करना है। XLSTAT 2021 सॉफ्टवेयर की मदद से गैर पैरामीट्रिक मान-केंडल (MK) परीक्षण और सेन के ढलान एस्टिमेटर का उपयोग करके 5% के महत्वपूर्ण स्तर पर प्रवृत्ति विश्लेषण का प्रदर्शन किया गया है । एसपीआई और एसपीईआई की गणना R-स्टूडियो सॉफ्टवेयर में SPEI-R पैकेज के साथ की गई थी। अध्ययन से पता चला है कि (*i*) दक्षिण-पश्चिमी मॉनसून (जून से सितंबर) ने 29.9-39.5% के भिन्नता गुणांक (CV) के साथ कुल वार्षिक वर्षा में 88.8-91.8% का योगदान दिया। (*ii*) जुलाई, अगस्त और सितंबर के दौरान लगभग सभी जिलों में वर्षा में महत्वपूर्ण कमी की प्रवृत्ति देखी गई। हालांकि, हमीरपुर में जुलाई (4.03 मिमी वर्षा/वर्ष) और अगस्त (4.03 मिमी वर्षा/वर्ष) की वर्षा में एक महत्वपूर्ण (0.05 स्तर) और कमी की प्रवृत्ति देखी गई। (*iii*) मध्यम स्तर के सूखे की घटनाओं की आवृत्ति में वृद्धि के बाद गंभीर और अत्यधिक सूखा पड़ा। SPI-3 और SPEI-3 के घटते रुझान भी देखे गए जो दक्षिण-पश्चिमी मॉनसून के मौसम के दौरान और अधिक शुष्क दौर का संकेत देते हैं।

ABSTRACT. Drought is a climatic anomaly that can occur in all regions with vastly different climate. A persistent lack of precipitation over an extended period scaling usually a season or more results water stress that significantly impacts economic, agricultural, environmental and social aspects. For an effective monitoring of drought condition, drought indices play major role which are region specific and have limitation of applicability in different climatic condition. Hence, the present study aims to analyse the climatology and drought by two drought indices, *viz*., Standard Precipitation Index (SPI) and standardized precipitation evapotranspiration index (SPEI)) for Bundelkhand region, the most drought prone area of Central India by using 48 years (1969-2016) rainfall and temperature data. The trend analysis was performed at a significance level of 5% by using non parametric Mann-Kendall (MK) test and Sen's slope estimator with the help of XLSTAT 2021 software. The SPI and SPEI were calculated with the SPEI R package in R-Studio software. The study revealed that (*i*) the southwest monsoon (June to September) contributed 88.8-91.8% of total annual rainfall with coefficient of variation (CV) of 29.9-39.5%. (*ii*) Anon-significant decreasing trend in rainfall was noticed for almost all the districts during July, August and September. However, a significant (0.05 level) and decreasing trend was observed in July (4.03 mm rainfall/year) and August rainfall (4.03 mm rainfall/year) for Hamirpur. (*iii*) The frequency of moderate drought events increased followed by severe and extreme drought events. The decreasing trends of SPI-3 and SPEI-3 were also observed which indicates more dry spells during southwest monsoon season.

Key words – Rainfall Trends, Mann-Kendall (MK), Sen's Slope, drought, SPI and SPEI.

1. Introduction

Drought is an extreme event that is caused by prolonged deficiency in precipitation. Drought is the combined effect of meteorological (reduced rainfall) and hydrological (reduced available water supply) factors and the resulting agricultural drought (increased water stress in crops which can leads to reduction in biomass and crop yield). Drought occurrence and its severity were influenced by the trends associated with precipitation and air temperatures. At present scenario as the world is grappling against the climate change challenges, especially changes in temperature and precipitation, which are considered the most important variables in assessment of drought occurrence and its severity. Changing of these climate variables under global warming will cause changes in the severity and frequency of drought (Li *et al.*, 2009). Hence the long term trend analysis is the central process to assess the climatology of a region and to estimate the drought severity (Tarate and Kumar, 2021). Along with this, the information about the severity and duration of drought can be obtained through its real time monitoring and forecasting using drought indices which provide a quantitative information about the drought characteristics. The drought indices are very useful for helping planners to prioritize and communicate information to diverse users as drought indices allows comparisons on temporal and spatial scales (Wilhite *et al.*, 2007). Standard Precipitation Index (SPI) (McKee *et al*., 1993) and Standardised Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano *et al*., 2010) are the two most popular drought indices which can be used for drought assessment. The SPI and SPEI can be calculated at any timescale, but typically the 1-, 3-, 6-, 12- and 24- months are used (Chen *et al*., 2013). Drought at these time scales is relevant for agriculture (1-, 3- and 6-month) (Potop *et al*., 2014; Kamble *et al*., 2019).

For most of the year, the residents of Bundelkhand experience acute scarcity of water for agricultural and domestic use. Water sources are varied and often seasonal, ranging from ponds, tanks, lakes and streams to open wells, bore wells and irrigation canals radiating out from large-scale dams. Most agriculture is of the single-crop variety and rain fed, with supplementary water from open wells. Thus, a large number of farmers are highly dependent on the monsoon rains to recharge these wells. Based on this background information the present study was undertaken for Bundelkhand region of Uttar Pradesh, a drought prone region of central India which is highly vulnerable to drought and failure of cropping system. The specific objectives of the study are to study the climatology of rainfall and drought by two most widely used drought indices, the Standard Precipitation Index (SPI) and standardized precipitation evapotranspiration index (SPEI).

2. Data and methodology

2.1. *Study area*

The study area consists of six districts of Bundelkhand region of Uttar Pradesh (India) namely, Jhansi, Jalaun, Lalitpur, Hamirpur, Mahoba, Banda. It lies at the heart of India located at the latitude of 24.15° N to 26.42° N and longitude of 78.18° E to 81.02° E below the Indo-Gangetic plain to the north (Fig. 1).

2.2. *Data used*

In this study, the climatic parameters, *viz.*, maximum temperature, minimum temperature and rainfall of 48 years (1969-2016) pertaining to different districts of the study region were collected from India Meteorological Department (IMD) and India Water Portal website https://www.indiawaterportal.org/. Thereafter, data were statistically processed and then reduced to annual mean values for further analysis.

2.3. *Trend analysis*

The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. The analysis was carried out by using non parametric Mann-Kendall (MK) (Kendall, 1975) and Sen's slope estimator (Sen, 1968) and their statistical significance at a significance level of 5% with the help of XLSTAT 2021 software. The test was carried out on time series data of rainfall, SPI-3 and SPEI-3 for September month at 95% confidence level.

2.3.1. *The Mann-Kendall Test*

The mathematical equations for calculating Mann-Kendall Statistics S and (S) are as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j-i+1}^{n} \text{sig}\left(X_j - X_i\right) \qquad (1)$$

$$\text{sig}\left(X_j - X_i\right) = \begin{cases} +1 \text{ if } \left(X_j - X_i\right) > 0 \\ 0 \quad \text{if } \left(X_j - X_i\right) = 0 \\ -1 \text{ if } \left(X_j - X_i\right) < 0 \end{cases}$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \qquad (2)$$

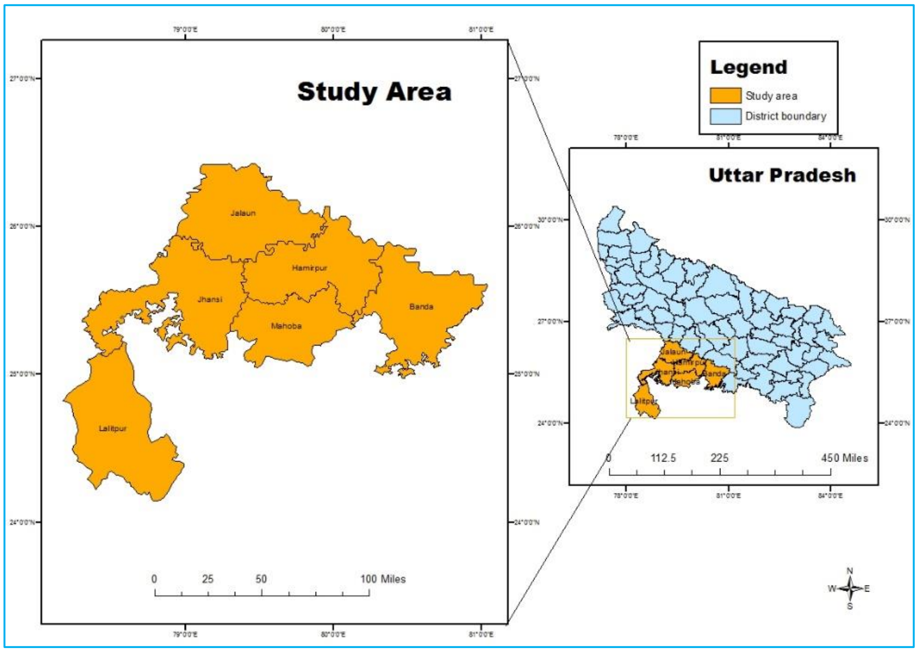


Fig. 1. Map of study area

2.3.2. *Sen's Slope Estimator*

Sen's nonparametric method (Sen, 1968) was used to estimate the magnitude of trends in the time series data. In this method the slope (Q_i) of all data pairs is first calculated using the following equation:

$$Q_i = \frac{x_j - x_k}{j - k} \quad i = 1, 2, 3, ..., N \tag{3}$$

In this equation, x_j and x_k represent data values at time j and k, ($j>k$) respectively. The median of these N values of Qi, *i.e.*, Sen's slope estimator (Q) is calculated as:

$$Q = \begin{cases} T_{(N+1)/2} & N \text{ is odd} \\ \frac{1}{2}\left[T_{N/2} + T_{(N+2)/2}\right] & N \text{ is even} \end{cases}$$

A positive value of Q indicates an increasing trend and a negative value indicates a decreasing trend in time series.

2.4. *Drought indices used*

Two meteorological drought indices namely the Standard Precipitation Index (SPI) and Standardised Precipitation Evapotranspiration Index (SPEI) were used for the drought study. The SPI uses long term rainfall/precipitation data and it is computed by fitting a gamma distribution to along-term rainfall series. The SPEI is a further development of the SPI which requires a series of the climate water balance (precipitation-potential evapotranspiration) as input. The parameters of the SPEI are a time-series of total monthly precipitation (P) and monthly potential evapotranspiration (PET). Here we applied the Thornthwaite equation (Thornthwaite, 1948), which employs the latitude and the monthly mean temperature in order to estimate the monthly PET. When calculating the SPEI, the log-logistic probability density function was used. For the purpose of this study, the SPEI and SPI were calculated with the SPEI R package (Beguería and Vicente Serrano, 2013) by using monthly rainfall and temperature data during years 1969-2016 (45 years). The shorter time scales (1, 3 and 6 months) accurately describe the meteorological drought conditions along with soil moisture deficit and reduction in crop yield

TABLE 1

Drought classification based on the SPI and SPEI

Drought Category	SPI, SPEI Values
Moderate drought	-1.00 to -1.49
Severe drought	-1.50 to -1.99
Extreme drought	≤−2.0

TABLE 2

District-wise statistics of monthly and seasonal rainfall during southwest monsoon season in the study region

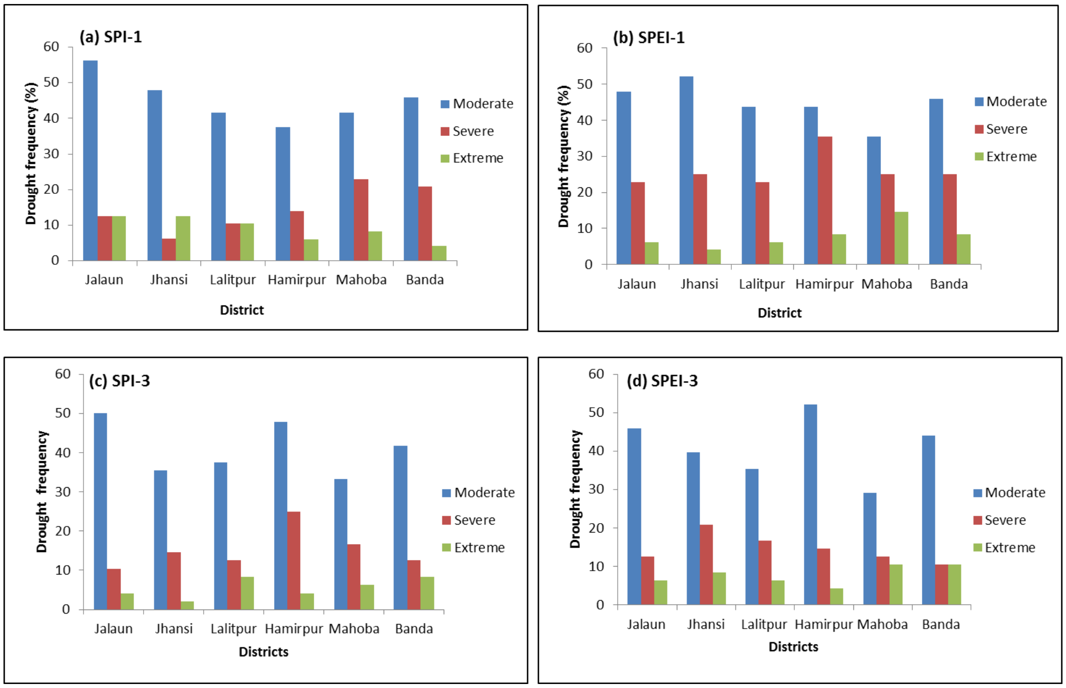
Months/season	Districts	Rainfall		
		Mean (mm)	Standard Deviation (SD)	Coefficient of Variation (CV) (%)
June	Jalaun	78.6	136.3	173.3
	Jhansi	95.7	111.7	116.6
	Lalitpur	105.3	128.8	122.3
	Hamirpur	91.6	72.6	79.2
	Mahoba	79.3	81.4	102.6
	Banda	100.9	91.6	90.7
July	Jalaun	220.7	107.7	48.8
	Jhansi	243.6	108.0	44.3
	Lalitpur	297.8	166.0	55.8
	Hamirpur	252.8	121.7	48.1
	Mahoba	247.5	111.5	45.0
	Banda	244.4	120.4	49.3
August	Jalaun	223.5	132.4	59.2
	Jhansi	254.6	121.3	47.6
	Lalitpur	304.5	183.0	60.1
	Hamirpur	287.9	114.3	39.7
	Mahoba	264.0	182.8	69.2
	Banda	274.6	144.2	52.5
September	Jalaun	131.4	102.8	78.3
	Jhansi	132.1	134.2	101.6
	Lalitpur	141.5	136.3	96.3
	Hamirpur	159.8	97.2	60.8
	Mahoba	155.0	131.8	85.0
	Banda	150.5	121.6	80.9
June-September	Jalaun	654.4	258.6	39.5
	Jhansi	726.1	241.3	33.2
	Lalitpur	849.1	307.6	36.2
	Hamirpur	792.1	262.1	33.1
	Mahoba	745.9	283.9	38.1
	Banda	770.3	230.5	29.9

(Ajaz *et al.*, 2019). The SPI/SPEI values at 1 month time scale for individual monsoon months (June to September) and the SPI/SPEI values at 3-month time scale (SPI-3 and SPEI-3) for September months were used for the drought analysis. The SPI/SPEI-3 for September was chosen because it represents the cumulative effects of three main monsoon months, *i.e.*, July, August and September. The SPEI follows the same classification criteria as SPI

TABLE 3

Mann-Kendall test results for monthly monsoonal rainfall for different districts of the study region

Districts	Kendall's tau	S Value	*p*-value (Two-tailed)	Sen's slope	Trend	Significant (S)/non-significant (NS)
			June			
Jalaun	-0.038	-38	0.719	-0.146	-	NS
Jhansi	0.023	23	0.830	0.111	+	NS
Lalitpur	0.042	42	0.690	0.235	+	NS
Hamirpur	-0.016	-16	0.884	-0.099	-	NS
Mahoba	0.125	124	0.229	0.802	+	NS
Banda	0.036	36	0.734	0.218	+	NS
			July			
Jalaun	-0.154	-152	0.140	-1.522	-	NS
Jhansi	0.004	4	0.977	0.009	+	NS
Lalitpur	0.048	48	0.648	0.774	+	NS
Hamirpur	-0.244	-242	0.018	-2.848	-	S
Mahoba	-0.093	-92	0.376	-1.262	-	NS
Banda	-0.063	-62	0.553	-0.761	-	NS
			August			
Jalaun	-0.046	-46	0.662	-0.776	-	NS
Jhansi	-0.121	-120	0.246	-1.728	-	NS
Lalitpur	-0.156	-154	0.135	-1.9	-	NS
Hamirpur	-0.358	-354	0.000	-4.032	-	S
Mahoba	-0.081	-80	0.442	-1.044	-	NS
Banda	0.008	8	0.946	0.14	+	NS
			September			
Jalaun	-0.073	-72	0.490	-0.624	-	NS
Jhansi	-0.063	-62	0.553	-0.504	-	NS
Lalitpur	-0.179	-177	0.085	-1.595	-	NS
Hamirpur	-0.099	-98	0.345	-0.957	-	NS
Mahoba	-0.030	-30	0.778	-0.415	-	NS
Banda	-0.006	-6	0.961	-0.083	-	NS
			June-September			
Jalaun	-0.127	-126	0.223	-2.938	-	NS
Jhansi	-0.006	-6	0.961	-0.218	-	NS
Lalitpur	-0.048	-48	0.648	-1.931	-	NS
Hamirpur	-0.265	-262	0.010	-8.035	-	S
Mahoba	-0.093	-92	0.376	-2.917	-	NS
Banda	0.044	44	0.676	0.985	+	NS
			Annual			
Jalaun	-0.133	-132	0.201	-3.75	-	NS
Jhansi	0.006	6	0.961	0.186	+	NS
Lalitpur	-0.085	-84	0.419	-3.161	-	NS
Hamirpur	-0.251	-248	0.015	-8.054	-	S
Mahoba	-0.079	-78	0.454	-2.538	-	NS
Banda	0.030	30	0.778	1.052	+	NS



Figs. 2(a-d). Frequency (%) of moderate, severe and extreme drought events in monsoon months (June-September) based on (a) SPI-1, (b) SPEI-1, (c) SPI-3 and (d) SPEI-3 during the period 1969-2016

(Table 1), because of the similarity in the calculation principles of SPEI and SPI (McKee *et al.*, 1993; Gocic and Trajkovic, 2013).

3. Results and discussion

3.1. *Climatology and variability in Rainfall*

District-wise statistics of monthly and seasonal rainfall during southwest monsoon season in the study region have been presented in Table 2. The results indicated that the study region receives its maximum rainfall in the month of August (224-305 mm) followed by July (220-298 mm), September (131-160 mm) and June (79-105 mm). The analysis also revealed that June months had highest rainfall variability with coefficient of variation (CV) of 79 to 173% among all the other monsoon months followed by September (CV of 61-102%), August (CV of 53-69%) and July (CV of 44-56%). The observed variability is lowest in Banda, while other districts showed relatively higher variability and the highest variability was noticed for Jalaun in the month of June. However, study further revealed that the monsoon seasonal rainfall as a whole (June-September) showed the less variability (CV of 30-40%) as compared to the individual months which clearly indicates that there will be large year-to-year variation in the monthly distribution of rainfall during the southwest monsoon as reported by the other researcher for southwest monsoon in India (Kumar *et al.*, 2017; Kharake *et al.*, 2021).

3.2. *Trend analysis of southwest monsoon rainfall: Mann-Kendall Test*

The results (Table 3) show that there is a slight but insignificant increasing trend in rainfall during June for the period 1969-2016. However, there is an insignificant and decreasing trend was observed for Jalaun and Hamirpur during the same period. The results show that there is a decreasing trend in July rainfall except for Jhansi and Lalitpur which showed slightly upward trend but it was not found significant. However, a significant (0.05 level)and decreasing trend of -2.85 mm/year were observed in July rainfall for Hamirpur. In consistent with this result Ahmed *et al.* (2019) also found a declining trend of 2.16 mm per year for Hamirpur district. All the districts except Banda showed a decreasing trend in rainfall but it was not significant during August. However, Hamirpur shows a significant (0.05 level) decreasing trend of 4.03 mm rainfall/year during this period. Even though statistically insignificant, almost all the districts noticed a decreasing trend in rainfall during September. Monsoon season as a whole (June to September) showed decreasing trend of rainfall for almost all the districts except Banda. But decreasing trend was found statistically significant

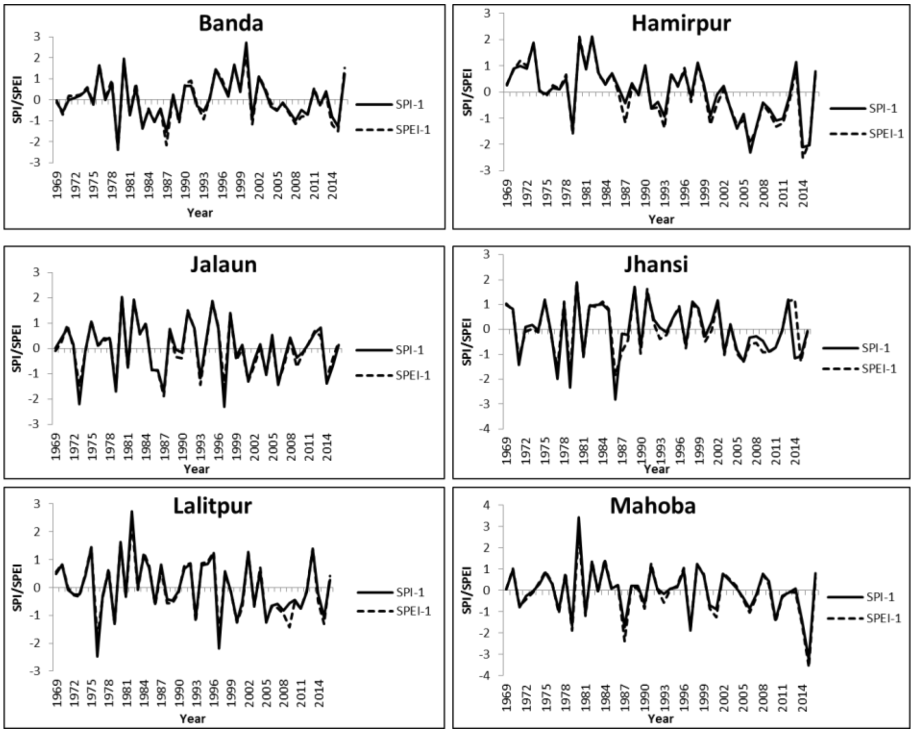


Fig. 3. Time series of SPI-1and SPEI-1(1969-2016) for the month of August in different districts

TABLE 4

Total drought events occurred during southwest monsoon based on SPI-1 and SPEI-1

District	Total drought events							
	June		July		August		September	
	SPI-1	SPEI-1	SPI-1	SPEI-1	SPI-1	SPEI-1	SPI-1	SPEI-1
Jalaun	6.0	6	8.0	9	11	10	14	12
Jhansi	6.0	7.0	9	12	8	9	9	11
Lalitpur	6	9	10	10	7	8	7	8
Hamirpur	10	12	9.0	8.0	10	12	9	10
Mahoba	8	9	10	10	8	9	9	8
Banda	9	8	9.0	11.0	8	10	8	9

only for Hamirpur district with Sen's slope value of -8.04 mm/year. The findings of the declining trend of rainfall in most of the districts of Bundelkhand region comply with the findings of most researchers (Thomas *et al*., 2014; Deo *et al*., 2015).

3.3. *Drought climatology*

3.3.1. *SPI-1 and SPEI-1*

Frequency analysis was performed for identifying a relationship between the magnitude or the severity of total drought events and their probability of occurrence during June to September based on SPI-1, SPEI-1 for the study period (1969-2016) [Figs. 2(a&b)]. The results of both SPI-1 and SPEI-1 indicated that, during June to September, the frequency of total moderate drought events had increased followed by severe and extreme drought events. The SPI-1 showed frequency of moderate, severe and extreme drought events varied from 38 to 56%, 6.3 to 23% and 4 to 13%, respectively in the study region. Similarly, based on SPEI-1, the frequency of moderate, severe and extreme drought events varied from 35 to 52%, 23 to 35% and 4 to 15%, respectively. Although

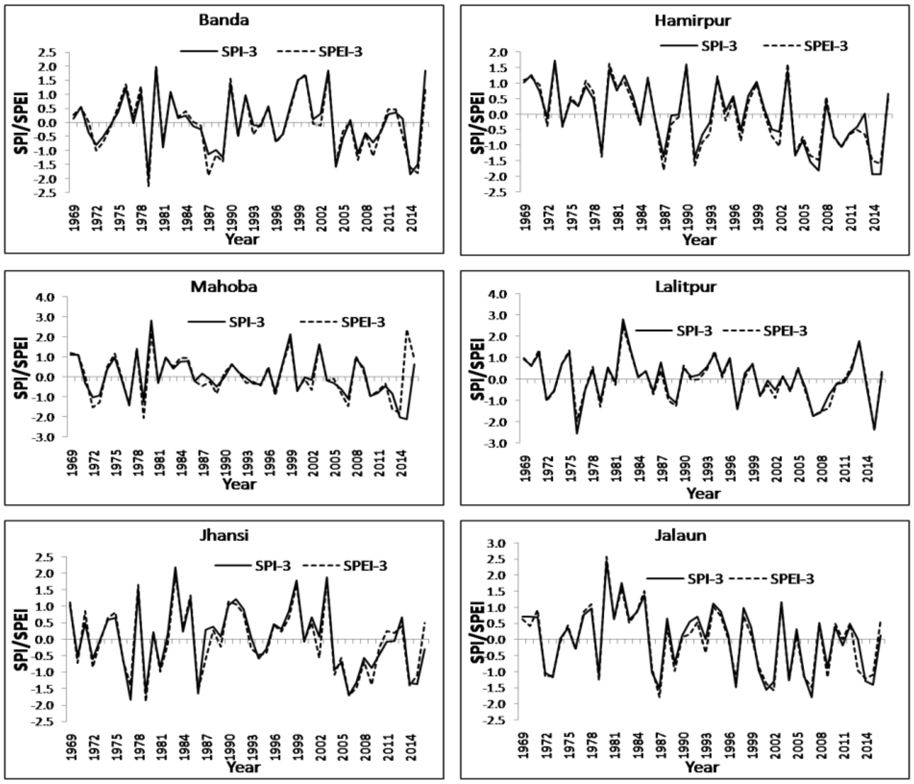


Fig. 4. Time series of SPI-3 and SPEI-3(1969-2016) for the month of September in different districts

TABLE 5

MK trend, S-statistics and Sen's Slope of SPI & SPEI at three-month scale (SPI-3& SPEI-3) for September (C.I. = 95%, p-value < 0.05)

Districts	Kendall's tau	S Value	p-value (Two-tailed)	Sen's slope	Trend	Significant (S)/non-significant (NS)
			SPI-3			
Banda	-0.042	-47	0.683	-0.006	-	NS
Hamirpur	-0.336	-379	0.001	-0.038	-	S
Mahoba	-0.221	-249	0.027	-0.023	-	S
Lalitpur	-0.159	-179	0.114	-0.018	-	NS
Jhansi	-0.144	-162	0.152	-0.016	-	NS
Jalaun	-0.212	-239	0.034	-0.017	-	S
			SPEI-3			
Banda	-0.094	-106	0.351	-0.011	-	NS
Hamirpur	-0.335	-378	0.001	-0.039	-	S
Mahoba	-0.144	-162	0.152	-0.020	-	NS
Lalitpur	-0.160	-180	0.112	-0.018	-	NS
Jhansi	-0.112	-126	0.267	-0.014	-	NS
Jalaun	-0.186	-210	0.063	-0.017	-	NS

there was a difference in frequency of magnitude of drought events observed between SPI-1 & SPEI, but the total drought events detected by both the indices were almost same (Table 4 and Fig. 3).

3.3.2. *SPI-3 and SPEI-3*

Frequency analysis based on SPI-3 and SPEI-3 [Figs. 2(c&d)] indicated that during the study period (1969-2016), the frequency of moderate drought events increased followed by severe and extreme drought events. The SPI-3 and SPEI-3 showed that the frequency of moderate drought varied from 33 to 56% and 29 to 52%, respectively in the study region. The frequency of severe drought detected by SPI-3 and SPEI-3 varied from 10 to 25% and 12 to 21%, respectively. While in case of extreme drought events it was varied from 2 to 8% (detected by SPI-3) and 4 to 9% (detected by SPEI-3). Time series of SPI-3 and SPEI-3 from 1969 to 2016 for the month of September which represents the cumulative effects of drought for the three months, *i.e.*, July, August and September have been presented in Fig. 4. The results of SPI-3 and SPEI-3 for the month of September showed 8 drought events (1979, 1987, 1988, 1989, 2004, 2007, 2014 and 2015) in Banda, 9 drought events (1979, 1987, 1991, 2004, 2006, 2007, 2010, 2014 and 2015) in Hamirpur, 7 drought events (1972, 1977, 1979, 2007, 2010, 2014 and 2015) in Mahoba, 8 drought events (1972, 1976, 1979, 1989, 1997, 2007, 2008 and 2015) in Lalitpur, 7 drought events (1977, 1979, 1986, 2006, 2007, 2014 and 2015) in Jhansi and 14 drought events (1972, 1973, 1979, 1986, 1987, 1997, 2000, 2001, 2002, 2004, 2006, 2007, 2014 and 2015) in Jalaun District. These findings are synchronized with Pandey *et al*. (2021).

3.4. *Trend Analysis of Drought: Mann-Kendall Test*

The district-wide trend analysis of SPI and SPEI at three-month scale (SPI-3& SPEI-3) for September month for the Bundelkhand region is shown in Table 5. The decreasing trends of SPI-3 and SPEI-3 were observed for all the districts which indicates more dry spells and thus the severity of meteorological drought in the study region. Similar result has been reported by Pandey *et al*. (2021). SPI-3 showed significant decreasing trend at a 95% confidence level for Hamirpur, Mahoba and Jalaun districts, while SPEI-3 showed decreasing trend at a 95% confidence level for Hamirpur district. However, there was not much difference was observed in the magnitude of decrease (Sen's slope) in SPI-3 and SPEI-3. The maximum value (-0.038-0.039) was observed for Hamirpur district by both the indices. The Sen's slope values of SPI-3 for Hamirpur, Mahoba and Jalaun districts were -0.038, -0.023 and 0.017, respectively. However, the decreasing trend of SPI-3 and SPEI-3 compel the increase of irrigation requirement which is major controlling factor for meteorological variables (precipitation, temperature, evapotranspiration) and also it highlights the concern of soil moisture deficit in identified regions (Saeed *et al*., 2009).

The shorter time scales of SPI and SPEI values are quite able to provide an accurate description of the early warning of meteorological drought as well as agricultural drought considering the soil moisture and crop yield deficit. The negative trend of SPI and SPEI indicates increasing trend of meteorological drought that could turn out in a soil moisture deficit and crop yield failure situation. It compels the requirement of efforts towards minimizing the soil moisture loss. To address this issue plethora of research study has been done before. Garg *et al*. (2020) reported about the meso-scale watershed monitoring scheme in rainfed area of Bundelkhand, UP region highlighting the renovation of traditional water harvesting structure, building of check dams and recharge of shallow ground water aquifer. Thomas *et al*. (2014) carried out supplemental irrigation requirement analysis for a dry spell, which underlines the selection of crop calendar and crop varieties for the contingency crop planning during imminent drought scenarios.

4. Conclusions

The exploratory results provide valuable observation of precipitation variability imprint on drought occurrence of Bundelkhand region. The falling trend indicates that, the increasing severity and frequency of meteorological drought in the region. In the face of climate change, it could be possible that drought severity hits stronger, which requires effective and contingency planning. The study concludes that all the seven districts of the Bundelkhand region experience recurrent drought events which highlights the importance of needful prescription of proper irrigation facilities during the crop growing periods, identification of the appropriate regions for water harvesting structure construction, suitable crop selection, etc. The outcomes of the present study have immense scope for improved water resource management and policy development in the Bundelkhand region and the adopted approach could be used as a reference to develop an economical drought-proofing system in alike regions and to communicate the drought risk to stakeholders and policy makers. Notably, the implication of both the indices is very effective in assessment of drought for the study region during the southwest monsoon.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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