# Evaluation of drought conditions in six districts within the Bundelkhand region, covering the Ken River basin, India

**Abstract**

The present study analyses the response of various Standardized Precipitation Index (SPI) values to drought situation vis-à-vis comparison of SPI with Rainfall Departure (RD) in the districts of drought prone Ken basin. Precipitation data from 1990 to 2020 for the region were used to compute SPI and RD values. The computation of SPI series was done for 3-monthly and 6-monthly scales. The drought severity and frequency were estimated. Based on the analysis of RD, the droughts ocuured in all the districts of Ken basin region during the years 2006, 2015 and 2017. The intensity of these droughts was found to be moderate severe to extreme. The comparative analysis of RD and SPI exhibited a good correlation with 3- monthly and 6-monthly SPI values.

Keywords: Standardized Precipitation Index; Rainfall Departure; Drought; Ken Basin; Bundelkhand

## • Introduction

In the field of atmospheric sciences research, droughts stand out as a significant environmental challenge, captivating the interest of experts across various fields such as hydrology, ecology, environmental science, geology, meteorology, and agriculture (Warde et al., 2018). The concept of drought carries diverse connotations depending on one's disciplinary perspective (Garcia and Escudero, 1981). What may constitute a drought in the eyes of an agriculturist may not necessarily align with the viewpoints of a meteorologist or hydrologist. Consequently, the definition of drought varies among different scientific disciplines. Droughts, observed in various global climatic zones, are often linked to prolonged decreases in precipitation (Kogan, 1997; Dai, 2011; Mishra and Singh, 2010; Orimoloye et al., 2022). These events, spanning seasons or years, are influenced by factors such as temperatures, wind speeds, relative humidity, and rainfall characteristics. Drought is characterized by prolonged precipitation deficits, causing water scarcity and adverse effects on vegetation, animals, and people. Broadly defined as a severe water shortage associated with reduced rainfall and agricultural production, drought lacks a universal definition. However, experts commonly agree on this characterization. Drought is distinct from aridity, a constant feature in low precipitation areas like deserts. A widely used drought indicator is the rainfall deviation from the mean (Elbeltagi et al., 2023). However, its simplicity is constrained by a significant limitation—dependency on the mean. This approach becomes less effective in monitoring drought in regions with variable mean rainfall, where areas with differing rainfall levels can show similar deviations. Hence, careful consideration is essential when interpreting rainfall deviations across diverse spatial and temporal contexts.

The Standardized Precipitation Index (SPI) serves as an indicator for actual precipitation, standardized by its departure from the probability distribution function of rainfall (Attri and Tyagi, 2010; Harishnaika et al., 2022; Elbeltagi et al., 2023). In recent years, SPI has gained prominence as a valuable drought indicator facilitating spatial and temporal comparisons. Calculating SPI involves utilizing long-term precipitation data to establish the probability distribution function (PDF), which is then transformed into a normal distribution with a mean of zero and a standard deviation of one. SPI values, expressed in standard deviations, indicate deviations from the median—positive values signify above-median precipitation, while negative values denote below-median precipitation (Edwards and McKee, 1997). As SPI values adhere to a typical normal distribution, approximately 68% fall within one standard deviation (σ), 95% within 2σ, and 98% within 3σ (Wu et al., 2006). Recently, SPI has seen increased use for assessing drought intensity in various countries (Vicente-Serrano et al., 2004; Vijendra et al., 2005; Giddings et al., 2005; Joshi et al., 2016; Bhunia et al., 2020; Chandrasekara et al., 2021; Faye, 2022; Berhail et al., 2023). The efficacy of interpreting drought at different time scales using the Standardized Precipitation Index (SPI) has been demonstrated to surpass that of the Palmer Drought Index (Guttman, 1998; Goodrich and Ellis, 2006; Mahmoudi et al., 2019; Silva et al., 2022). The SPI, introduced by McKee et al. (1993, 1995), proves to be a potent and adaptable index, requiring only precipitation as an input parameter. Its simplicity extends to being equally proficient in analyzing both wet and dry periods or cycles. Classification of SPI drought severity involves consistent negativity indicating drought presence, commencement when SPI reaches zero, and cessation when severity values turn positive (McKee et al., 1993). In the Ken River, a non-snowfed waterway, floods swell during the rainy season and recede to a few cusecs in the dry summer months, necessitating water storage to avert famine-like conditions. This study investigates the responsiveness of various SPI values to drought scenarios, comparing SPI with rainfall departure in the Ken River Basin of the Bundelkhand region.

## 1.2 **Study area**

In this investigation, we focus on a region susceptible to drought situated in the Bundelkhand Region of Central India. Bundelkhand, located south of the Yamuna River, spans the fertile

Gangetic plain in northern Uttar Pradesh (UP) and the elevated terrains of central Madhya Pradesh (MP). Encompassing six districts in northern MP and seven in southern UP, this semi-arid plateau holds historical significance, witnessing the rise and fall of Indian and Mughal dynasties, followed by British colonial rule until independence in 1947. Bundelkhand, known for its temples, forts, and palaces, is flanked by the Yamuna River to the north, Sindh to the west, and Narmada to the south. Despite this, the region's economic sustenance is not directly dependent on these rivers. The study focuses on the Ken River Basin, a vital economic factor for Bundelkhand, geographically spanning latitudes 23°07' to 25°54' north and longitudes 78°30' to 80°40' east. Predominantly covering districts in MP and UP, the basin is surrounded by the Vindhyan range to the south, the Betwa basin to the west, the free catchment area of the Yamuna River to the east, and the Yamuna River itself to the north. Major area of the basin lies under Sagar, Damoh, Panna and Chattarpur districts of M.P. and Hamirpur and Banda districts of U.P. Encompassing 28,692 sq. km, the Ken River basin comprises 24,768 sq. km in MP and 3,924 sq. km in UP, as illustrated in Figure 1.

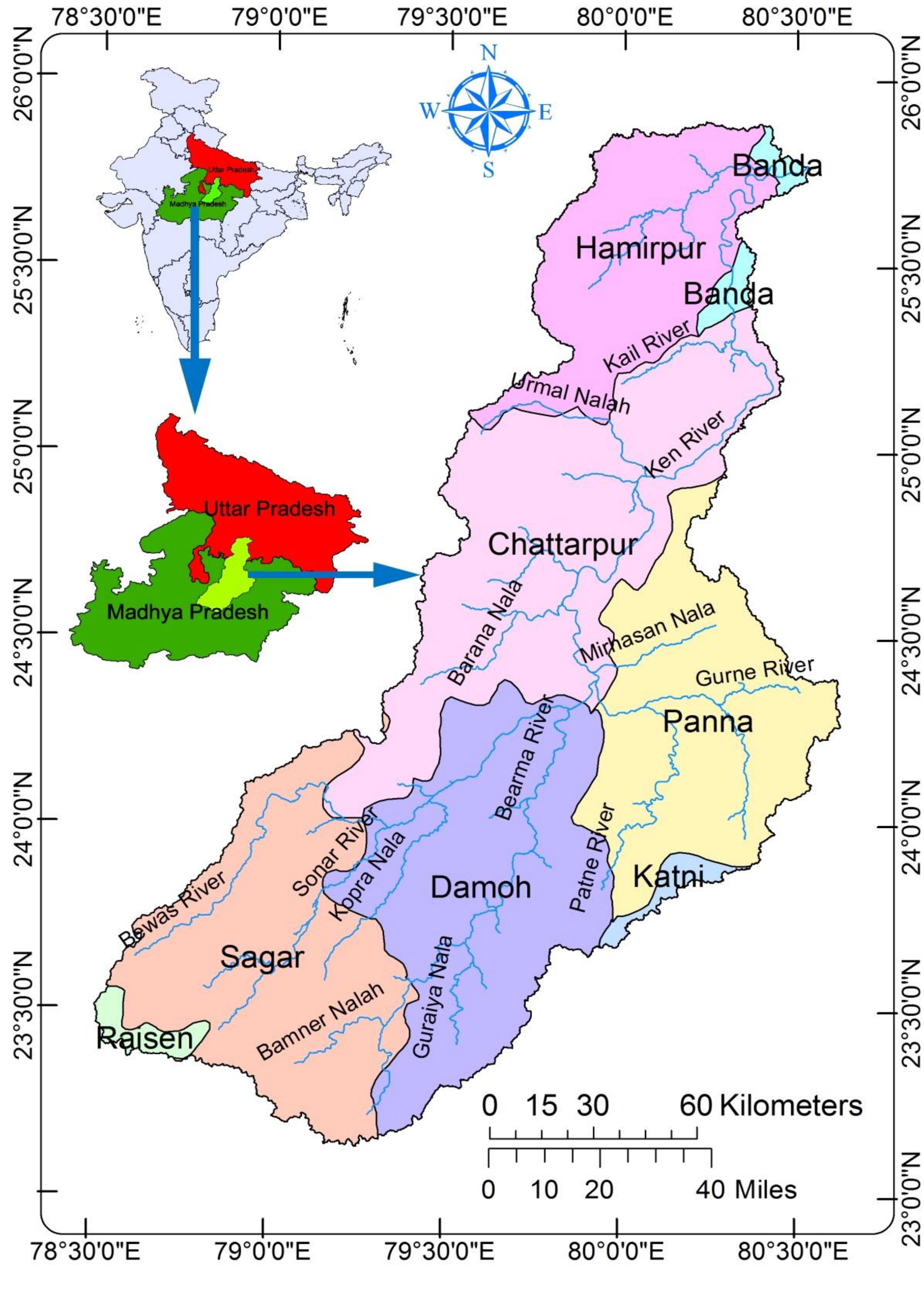


**Figure 1. Location Map of Ken River Basin**

## 3.0 Materials and Methods

Rainfall data for the period 1990 to 2020 in six districts covering most of the Ken River basin were collected from two reliable sources: Indian Meteorological Department (IMD) website (http://www.imd.gov.in/section/hydro/distrainfall/districtrain.html) and India Water Portal (http://www.indiawaterportal.org/metdata). The data from these websites are average rainfall values from different stations within each district. It's important to note that the data series is complete, eliminating the need for any additional gap-filling procedures.

### 3.1 Rainfall Departure Analysis

Rainfall departure (RD) is a good indicator of dry/wet conditions for a given time over specified areas and to understand the climatological regime of the basin (Pandey et al., 2010). Rainfall departure provides a quick estimate of the water deficiency associated with all forms of water and can be computed using Eq. (1)

$$RD(\%) = \frac{\left(x_i - \overline{x_i}\right)}{\overline{x_i}} X100 \tag{1}$$

Where, $x_i$ represent the rainfall for a given month, a season or a year 'i', and represent the long term average of the corresponding duration.

The Rainfall Departure (RD) functions as a direct indicator, with negative values indicating a deficit and positive values signifying excess rainfall relative to the corresponding average. This metric offers a straightforward measure of how rainfall deviates from its long-term mean, median, or a specified percentage based on regional weather conditions. It proves practical for assessing local weather conditions, especially for brief periods of rainfall deficiencies, commonly utilized in weather broadcasting.

In the Indian context, the India Meteorological Department (IMD) designates an area as experiencing drought if it receives less than 75% of its normal seasonal rainfall. Similarly, South Africa defines droughts as periods with less than 70% of normal precipitation (Samkhtin and Hughes, 2004). Notably, Banerjee and Raman (1976) propose a straightforward approach to identify good or bad monsoon years, classifying a year as a bad monsoon year for a specific area if seasonal rainfall is deficient in more than two-thirds of the meteorological stations in that region. RD is further classified into dry/wet categories based on the percentage departure (deficit/excess) of rainfall over a specified period compared to its corresponding long-term average. For this study, the IMD's criteria for defining drought across various severity categories, as presented in Table 1, have been applied, providing a nuanced perspective on the severity and impact of rainfall variations in the study area.

**Table 1. Criterion adopted by IMD to classify a year from wet to drought affected**

| Sr. No. | Rainfall Received in any year | Category |
|---|---|---|
| 1. | > 125% of Mean | Wet |
| 2. | 110% - 125% of Mean | Mild Wet |
| 3. | 90% - 110% of Mean | Average |
| 4. | 90% - 75% of Mean | Mild Dry |
| 5. | < 75% of Mean | Drought |

that an event is from the mean.

**Table 2. SPI Values with their corresponding drought categories**

| SPI Values | Drought Category |
|---|---|
| 2.00 + | extremely wet |
| 1.50 to 1.99 | very wet |
| 1.00 to 1.49 | moderately wet |
| - 0.99 to 0.99 | near normal |
| -1.00 to -1.49 | moderate drought |
| -1.50 to -1.99 | severe drought |
| - 2.00 and less | extreme drought |

### 3.2 Standardized Precipitation Index (SPI)

The computation of the Standardized Precipitation Index (SPI) at a given location relies on an extensive precipitation dataset spanning the desired timeframe. This dataset undergoes a fitting process with the gamma probability distribution, aligning the data with its statistical properties. Following this, the fitted distribution is transformed into a normal distribution, ensuring that the mean SPI for the specified location and period is standardized to zero, as per the methodology introduced by McKee et al. (1993). The resulting transformed probability becomes the SPI value, constrained within the range of +2.0 to -2.0. Instances of extremes beyond this range are rare, occurring only 5% of the time, as indicated by Edwards and McKee (1997). For interpretation, drought severity categories are established based on SPI values, with defined thresholds outlining severity levels, as presented in Table 2. This categorization framework enhances the applicability of SPI by offering a clear and standardized evaluation of drought severity for informed decision-making and resource management. Thom (1966) noted that the gamma distribution fits climatological time series effectively. The gamma probability density function to a given frequency distribution of precipitation totals for the station of interest is fitted as

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad \text{for } x>0 \qquad (2)$$

Where, x is the precipitation amount (x > 0) and α is a shape parameter (α > 0), β is a scale parameter (β > 0). $\Gamma(\alpha)$ is the gamma function. α and β are estimated as

$$\alpha = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right) \quad \text{and} \quad \beta = \frac{\bar{x}}{\alpha} \qquad (3)$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \qquad (4)$$

Where, represents the rainfall average over the time scales of interest, and n is the number of precipitation records. Integrating the probability density function with respect to x and inserting the estimates of α and β yields an expression for the cumulative probability G(x) of an observed amount of precipitation occurring for a given month and time step. The cumulative probability function is derived as

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

Since the gamma distribution is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes as follows

$$H(x) = q + (1-q)G(x) \tag{6}$$

Where q is the probability of a zero (P(x=0) >0). Thom (1966) states that q can be estimated as m/n, where m is the number of zeros in a precipitation time series having 'n' data values. He used tables of the incomplete gamma function to determine the cumulative probability G(x). McKee et al. (1993) used an analytic method alongwith suggested software code from Press et al. (1988) to determine the cumulative probability.

An equiprobability transformation is made from the cumulative probability to the standard normal random variable Z with mean equal to zero and variance of one, where the SPI takes on the value of Z. The value of SPI can also be obtained using an approximation provided by Abramowitz and Stegun (1965) that converts cumulative probability to the standard normal random variable Z

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{For } 0 < H(x) \leq 0.5 \tag{7}$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{For } 0.5 < H(x) \leq 1.0 \tag{8}$$

Where,

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \quad \text{For } 0 < H(x) \leq 0.5 \tag{9}$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \quad \text{For } 0.5 < H(x) \leq 1.0 \tag{10}$$

and

$$\begin{Bmatrix} c_0 = 2.515517 \\ c_1 = 0.802853 \\ c_2 = 0.010328 \\ d_1 = 1.432788 \\ d_2 = 0.189269 \\ d_3 = 0.001308 \end{Bmatrix} \tag{11}$$

Conceptually, the SPI represents a z-score or the number of standard deviations above or below

## 4.0 Results and Discussion

The analysis of the present study was focused on agreement of the SPI to actual rainfall departures and the behaviour of SPI in drought and normal years.

### 4.1 Rainfall Departure analysis

To identify drought years and assess the extent of annual rainfall deficit in the Ken River basin in the Bundelkhand region, an analysis of annual rainfall departure was conducted. Figure 2 illustrates the percentage annual rainfall departures across six districts in the region. Upon analysis, it is evident that in Banda district, the years 2007, 2009, 2010, 2015, and 2017 are categorized as moderate drought years, with only the years 1997 and 2012 identified as severe drought years. Similarly, for Mahoba district, the years 2000, 2004, 2006, 2007, 2012, 2014, 2015, and 2018 are considered moderate drought years, with only the year 1997 identified as a severe drought year. In Chattarpur district, the years 1991, 1995, 2006, 2007, 2014, 2015, and 2017 are classified as moderate drought years, with only the years 2005 and 2017 identified as severe drought years. For Panna district, the years 2000, 2006, 2010, 2015, and 2017 are designated as moderate drought years, with only the year 2007 identified as a severe drought year. Similarly, in Sagar district, the years 1992, 2008, 2009, 2015, 2017, and 2020 are considered moderate drought years, with only the year 2010 identified as a severe drought year. In Damoh district, the years 2002, 2006, 2007, 2014, 2015, and 2017 are categorized as moderate drought years, with only the year 2005 identified as a severe drought year. At the basin scale, the years 2006, 2007, 2010, 2015, and 2017 are considered moderate drought years, with no year identified as a severe drought year. The likelihood of drought occurrence every 10 years ranges from 0.1 (years 1991-1993) to 1 (year 2020) for all districts and at the basin scale.

Figure 2. Percentage annual rainfall departures across six districts in the region and of Ken basin

## 4.2 Analysis of 1- monthly Standardized Precipitation Index

The Standardized Precipitation Index (SPI) was computed for the Ken River basin, covering the districts of Banda, Mahoba, Chattarpur, Panna, Sagar, and Damoh, spanning the period from 1990 to 2020. This analysis aimed to illustrate the frequency of dry and wet conditions, with a particular focus on 1- monthly, 3- monthly, 6-monthly, 9-monthly and 12-monthly SPI values. The temporal patterns of 1- monthly SPI values are presented in Figure 3.

**Figure 3.** Temporal patterns of 1- monthly SPI values of six districts and of Ken basin

For Banda district, the years 1990-2020 witnessed 12 moderate drought events (3.23% of total events), 09 severe drought events (2.42% of total events), and no extreme drought events. In Mahoba district, the same period saw 14 moderate drought events (3.76% of total events), 07 severe drought events (1.88% of total events), and no extreme drought events. Chattarpur district experienced 05 moderate drought events (1.34% of total events), 07 severe drought events (1.88% of total events), and 03 extreme drought events (0.81% of total events) during 1990-2020. Similarly, for Panna district, there were 13 moderate drought events (3.49% of total events), 05 severe drought events (1.34% of total events), and 03 extreme drought events (0.81% of total events) during the same period. Sagar district observed 12 moderate drought events (3.23% of total events), 08 severe drought events (2.15% of total events), and 02 extreme drought events (0.54% of total events) from 1990 to 2020. In Damoh district, 06 moderate drought events (1.61% of total events), 05 severe drought events (1.34% of total events), and 02 extreme drought events (0.54% of total events) were recorded during the specified years. At the basin scale, there were 16 moderate drought events (4.3% of total events), 02 severe drought events (0.54% of total events), and 02 extreme drought events (0.54% of total events) during the years 1990-2020.

### 4.3 Analysis of 3- monthly Standardized Precipitation Index

The temporal patterns of 3- monthly SPI values are presented in Figure 4. For Banda district, the years 1990-2020 witnessed 25 moderate drought events (6.72% of total events), 10 severe drought events (2.69% of total events), and 03 extreme drought events (0.81% of total events).

**Figure 4.** Temporal patterns of 3- monthly SPI values of six districts and of Ken basin

| | |
|---|---|
| | |
| | |
| | |

In Mahoba district, the same period saw 14 moderate drought events (3.76% of total events), 10 severe drought events (2.69% of total events), and 02 extreme drought events (0.54% of total events). Chattarpur district experienced 15 moderate drought events (4.03% of total events), 07 severe drought events (1.88% of total events), and 05 extreme drought events (1.34% of total events) during 1990-2020. Similarly, for Panna district, there were 29 moderate drought events (7.80% of total events), 08 severe drought events (2.15% of total events), and 04 extreme drought events (1.08% of total events) during the same period. Sagar district observed 12 moderate drought events (3.23% of total events), 08 severe drought events (2.15% of total events), and 08 extreme drought events (2.15% of total events) from 1990 to 2020. In Damoh district, 30 moderate drought events (8.06% of total events), 07 severe drought events (1.88% of total events), and 01 extreme drought events (0.27% of total events) were recorded during the specified years. At the basin scale, there were 41 moderate drought events (11.02% of total events), 02 severe drought events (0.54% of total events), and 02 extreme drought events (0.54% of total events) during the years 1990-2020.

### 4.4 Analysis of 6- monthly Standardized Precipitation Index

The temporal patterns of 6- monthly SPI values are presented in Figure 5. For Banda district, the years 1990-2020 witnessed 27 moderate drought events (7.26% of total events), 22 severe drought events (5.91% of total events), and 06 extreme drought events (1.61% of total events).

**Figure 5.** Temporal patterns of 6- monthly SPI values of six districts and of Ken basin

| | |
|---|---|
| | |
| | |
| | |
| | |

In Mahoba district, the same period saw 36 moderate drought events (9.68% of total events), 16 severe drought events (4.30% of total events), and 03 extreme drought events (0.81% of total events). Chattarpur district experienced 34 moderate drought events (9.14% of total events), 13 severe drought events (3.49% of total events), and 06 extreme drought events (1.61% of total events) during 1990-2020. Similarly, for Panna district, there were 41 moderate drought events (11.02% of total events), 16 severe drought events (4.30 % of total events), and 07 extreme drought events (1.88% of total events) during the same period. Sagar district observed 31 moderate drought events (8.33% of total events), 10 severe drought events (2.69% of total events), and 10 extreme drought events (2.69% of total events) from 1990 to 2020. In Damoh district, 49 moderate drought events (13.17% of total events), 17 severe drought events (4.57% of total events), and Zero extreme drought events (0% of total events) were recorded during the specified years. At the basin scale, there were 36 moderate drought events (9.68% of total events), 19 severe drought events (5.11% of total events), and 04 extreme drought events (1.08% of total events) during the years 1990-2020.

### 4.5 Analysis of 9- monthly Standardized Precipitation Index

The temporal patterns of 9- monthly SPI values are presented in Figure 6. For Banda district, the years 1990-2020 witnessed 23 moderate drought events (6.18% of total events), 20 severe drought events (5.38% of total events), and 09 extreme drought events (2.42% of total events).

**Figure 6.** Temporal patterns of 9- monthly SPI values of six districts and of Ken basin

| | |
|---|---|
| | |
| | |
| | |
| | |

In Mahoba district, the same period saw 38 moderate drought events (10.22% of total events), 10 severe drought events (2.69% of total events), and 06 extreme drought events (1.61% of total events). Chattarpur district experienced 41 moderate drought events (11.02% of total events), 16 severe drought events (4.30% of total events), and 10 extreme drought events (2.69% of total events) during 1990-2020. Similarly, for Panna district, there were 48 moderate drought events (12.9% of total events), 10 severe drought events (2.69 % of total events), and 10 extreme drought events (2.69% of total events) during the same period. Sagar district observed 34 moderate drought events (9.14% of total events), 10 severe drought events (2.69% of total events), and 11 extreme drought events (2.96% of total events) from 1990 to 2020. In Damoh district, 46 moderate drought events (12.37% of total events), 15 severe drought events (4.03% of total events), and 03 extreme drought events (0.81% of total events) were recorded during the specified years. At the basin scale, there were 40 moderate drought events (10.75% of total events), 24 severe drought events (6.45% of total events), and 02 extreme drought events (0.54% of total events) during the years 1990-2020.

### 4.6 Analysis of 12- monthly Standardized Precipitation Index

The temporal patterns of SPI values are presented in Figure 7. For Banda district, the years 1990-2020 witnessed 22 moderate drought events (5.91% of total events), 18 severe drought events (4.84% of total events), and 13 extreme drought events (3.49% of total events).

**Figure 7.** Temporal patterns of 12- monthly SPI values of six districts and of Ken basin

| | |
|---|---|
| | |
| | |
| | |

In Mahoba district, the same period saw 49 moderate drought events (13.17% of total events), 05 severe drought events (1.34% of total events), and 08 extreme drought events (2.15% of total events). Chattarpur district experienced 33 moderate drought events (8.87% of total events), 25 severe drought events (6.72% of total events), and 12 extreme drought events (3.23% of total events) during 1990-2020. Similarly, for Panna district, there were 46 moderate drought events (12.37% of total events), 08 severe drought events (2.15 % of total events), and 11 extreme drought events (2.96% of total events) during the same period. Sagar district observed 44 moderate drought events (11.83% of total events), 05 severe drought events (1.34% of total events), and 09 extreme drought events (2.42% of total events) from 1990 to 2020. In Damoh district, 35 moderate drought events (9.41% of total events), 09 severe drought events (2.42% of total events), and 08 extreme drought events (2.15% of total events) were recorded during the specified years. At the basin scale, there were 30 moderate drought events (8.06% of total events), 23 severe drought events (6.18% of total events), and 05 extreme drought events (1.34% of total events) during the years 1990-2020.

### 4.7 Correlation between RD and SPI

In order to better understand the drought assessment methods a correlation between the RD and 1- monthly, 3- monthly, 6-monthly, 9-monthly and 12-monthly SPI values were calculated.

**Figure 8:** Correlation between RD and 3- monthly SPI values

The correlation coefficient between RD and the 1- monthly, 3- monthly, 6-monthly, 9-monthly and 12-monthly SPI is found to be 0.0082, 0.2128, 0.1924, 0.1094, 0.1668 respectively. From the result of correlation between RD and SPI values, 3- monthly SPI exhibited a better correlation with RD (figure 8).

## 5.0 Conclusion

The primary objective of this investigation was to assess drought conditions in six districts situated in the Bundelkhand region, encompassing the Ken River basin in India. The assessment utilized the Standardized Precipitation Index (SPI) and Rainfall Departure criterion. Analysis of temporal drought patterns yielded noteworthy findings regarding the variability in drought occurrence in the region. Mahoba experienced the highest number of moderate drought events on the 1-monthly and 12-monthly timescales, while Damoh faced the most of the moderate drought events on the 3-monthly and 6-monthly scales. Panna encountered the majority of moderate drought events on the 9-monthly scale. Severe drought events were prominent in Banda district on the 1-monthly, 6-monthly, and 9-monthly scales. Panna and Sagar districts experienced severe droughts on the 3-monthly scale, while Chattarpur district faced severe droughts on the 12-monthly scale. Chattarpur and Panna districts exhibited extreme drought events on the 1-monthly and 9-monthly scales, and Sagar district on the 3-monthly and 6-monthly scales, with Banda district exhibiting extreme drought events on the 12-monthly scale.

## References

Attri, S.D. and Tyagi, A., 2010. Climate profile of India. Environment Monitoring and Research Center, India Meteorology Department: New Delhi, India.

Berhail S, Katipoğlu OM. Comparison of the SPI and SPEI as drought assessment tools in a semi-arid region: Case of the Wadi Mekerra basin (northwest of Algeria). Theoretical and Applied Climatology. 2023 Nov;154(3):1373-93.

Bhunia P, Das P, Maiti R. Meteorological drought study through SPI in three drought prone districts of West Bengal, India. Earth Systems and Environment. 2020 Mar;4(1):43-55.

Chandrasekara SS, Kwon HH, Vithanage M, Obeysekera J, Kim TW. Drought in South Asia: A review of drought assessment and prediction in South Asian countries. Atmosphere. 2021 Mar 11;12(3):369.

Dai, A., 2011. Drought under global warming: a review. Wiley Interdisciplinary Reviews: Climate Change, 2(1), pp.45-65.

Elbeltagi A, Pande CB, Kumar M, Tolche AD, Singh SK, Kumar A, Vishwakarma DK. Prediction of meteorological drought and standardized precipitation index based on the random forest (RF), random tree (RT), and Gaussian process regression (GPR) models. Environmental Science and Pollution Research. 2023 Mar;30(15):43183-202.

Elbeltagi, A., Kumar, M., Kushwaha, N.L., Pande, C.B., Ditthakit, P., Vishwakarma, D.K. and Subeesh, A., 2023. Drought indicator analysis and forecasting using data driven models: Case study in Jaisalmer, India. Stochastic Environmental Research and Risk Assessment, 37(1), pp.113-131.

Faye, C., 2022. Comparative analysis of meteorological drought based on the SPI and SPEI indices.

Garcia, R.V. and Escudero, J., 1981. Drought and man. Oxford and New York: Pergamon Press.

Harishnaika N, Ahmed SA, Kumar S, Arpitha M. Computation of the spatio-temporal extent of rainfall and long-term meteorological drought assessment using standardized precipitation index over Kolar and Chikkaballapura districts, Karnataka during 1951-2019. Remote Sensing Applications: Society and Environment. 2022 Aug 1;27:100768.

Joshi N, Gupta D, Suryavanshi S, Adamowski J, Madramootoo CA. Analysis of trends and dominant periodicities in drought variables in India: a wavelet transform based approach. Atmospheric Research. 2016 Dec 15;182:200-20.

Kogan, F.N., 1997. Global drought watch from space. Bulletin of the American Meteorological Society, 78(4), pp.621-636.

Mahmoudi P, Rigi A, Miri Kamak M. A comparative study of precipitation-based drought indices with the aim of selecting the best index for drought monitoring in Iran. Theoretical and Applied Climatology. 2019 Aug 1;137:3123-38.

Mishra, A.K. and Singh, V.P., 2010. A review of drought concepts. Journal of hydrology, 391(1-2), pp.202-216.

Orimoloye, I.R., Belle, J.A., Orimoloye, Y.M., Olusola, A.O. and Ololade, O.O., 2022. Drought: A common environmental disaster. Atmosphere, 13(1), p.111.

Silva T, Pires V, Cota T, Silva Á. Detection of drought events in setúbal district: comparison between drought indices. Atmosphere. 2022 Mar 28;13(4):536.

Warde, P., Robin, L. and Sörlin, S., 2018. The environment: A history of the idea. JHU Press.