Chapter 11
Monitoring Spatio-Temporal Pattern of Meteorological Drought Stress Using Standardized Precipitation Index (SPI) over Bundelkhand Region of Uttar Pradesh, India

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Introduction

Water is the most crucial element to maintain the life process on Earth. It is the surviving source for the biotic environment and all economic and non-economic activities of human beings. There is not a single substitute of water available on the face of Earth. Ensuring an adequate supply of water in the soil is a fundamental requirement for plant growth and agricultural sustainability. Conversely, water scarcity gives rise to a catastrophic phenomenon known as drought. On contrary of all human advancement in twenty-first century, whole world is suffering from water scarcity due to unchecked water pollution and scanty precipitation. Rainfall and glaciers are the only sources of freshwater, but alteration in long-term climate has severely impacted both the sources (Machiwal & Jha, 2012). Climate change can cause significant variation in hydro-meteorological parameters such as rainfall, temperature and humidity, but among all the parameters, rainfall is valued most relevant due to its role in the water cycle. Therefore, disasters such as flood and drought are highly associated with rainfall (Wang et al., 2017). Hydro-meteorological hazards caused due to variability in rainfall have severe effects on the environment, community, economy, health and agriculture. Millions of lives are impacted due to loss in biodiversity, economic loss, crop failure and mental disorder caused by these hazards (Miah et al., 2017). It is a well-established fact that the climate change has adversely affected the pattern of precipitation in most of the regions, which has worsened the situation of food security. Excess of anthropogenic interference in the natural environment has increased the frequency of extreme

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A. L. Singh et al. (eds.), *Climate Change, Vulnerabilities and Adaptation*,
https://doi.org/10.1007/978-3-031-49642-4_11

climatic events (floods and drought), which has depressed the crop yield and productivity (Fischer et al., 2005).

Drought is a natural hazard initiated due to lack of precipitation that leads to water scarcity, affecting the associated population at large. It is a natural reoccurring phenomenon that takes place due to long dry spells and inadequate rainfall. This event happens when evaporation and transpiration exceed the amount of rainfall for a long period of time at a specific location (Rahman & Lateh, 2016). On the basis of the affected areal extent, drought is ranked the second most severe natural disaster in the world (Nagarajan, 2009). In India, Approximately 68% of India's territory is plagued by recurring yearly droughts due to unpredictable monsoon patterns (Patel & Yadav, 2015). Drought is a complex disaster, which alters the whole system of a region wherever it occurs. Living organisms and the environment are more affected by drought than any other natural hazard. Drought has different categories based on the method of its measurement, i.e., meteorological drought, agricultural drought, hydrological drought and socio-economic drought. Meteorological drought can be defined as the intensity and duration of drought when precipitation falls below the normal level. It is usually considered when the amount of rainfall decreases by twenty-five percent. Then comes hydrological drought that shows the consequences of low precipitation in the form of a shortage in surface water and groundwater. Agriculture drought is also a consequence of meteorological and hydrological drought which can be seen in the form of low soil moisture to sustain the agriculture activity. Socio-economic drought is based on a shortage of goods due to a deficit of water supply and insufficient agricultural commodities (Ebi & Bowen, 2016).

Drought impact assessment is based on various parameters such as its frequency, time period, severity and area coverage. Drought assessment is a complex process, as every type of drought has its own identifying variables. To monitor the meteorological drought, various indices are used such as Standardized Precipitation Index (SPI) (McKee et al., 1993), Deciles Index (DI), Drought Area Index (DAI), Percent of Normal (PN), Palmer Drought Severity Index (PDSI) (Palmer, 1965), China-Z index (CZI), Effective Drought Index (EDI), Reconnaissance Drought Index (RDI) (Tsakiris et al., 2007) and, the most recently developed, Standardized Precipitation Evapotranspiration Index (SPEI). The calculation of these indices is performed using historical time series data of rainfall and temperature (Danandeh Mehr & Vaheddoost, 2020). Standardized Precipitation Index (SPI) is the most used and recognized drought index in the world. World Meteorological Organization (WMO) has widely accepted and suggested this method of drought monitoring due to its easy calculation and accuracy (WMO, 2012). In recent times, SPI (standardized precipitation index) is commonly employed by researchers in drought assessment due to its efficiency and simpleness. It has a specific feature in its evaluation that it can be computed at any time scale for any location and required only one parameter, which is rainfall (Komuscu 1999; Anctil et al., 2002; Lana et al., 2001; Min et al., 2003; Domonkos, 2003; Bonaccorso et al., 2003). This method has another peculiar advantage of standardization that it helps in identifying the frequency and intensity of extreme drought events at different time scales and locations. It also helps in studying the history of drought events if the values of SPI are plotted against time series (Rahman & Lateh, 2016).

Bundelkhand is one of the most drought-prone regions in the country having a background of reoccurring drought events. The region featured semi-arid and sub-humid climate, undulating topography and very few patches of forest. The major constraints of agriculture practice in this region are the soil with poor water holding capacity and lack of irrigation facility. Along with a long history of recurrent drought events and depleting water levels, this has created a threat to communities involved in agriculture (Kundu et al., 2021). The frequency of drought events has increased from one to three during the period of 1968–1992 (Singh et al., 2003). Recurrent events of drought have been recorded between 2004 and 2007 due to scanty rainfall, which has disturbed the crop planning in this region (Patel & Yadav, 2015).

The main objective of this study is to screen meteorological drought in the Bundelkhand region of Uttar Pradesh during the period of 1980 to 2020. To study the framed objective, a well-established meteorological drought index, i.e. SPI (Standardised Precipitation Index) has been employed. The monthly rainfall data from all seven districts of the study area have been used at different time scales of 3, 6 and 12 months. The values of SPI at different time scales have been categorized into four categories, i.e. normal, moderate, severe and extreme drought. Meteorological drought is basically insufficient rainfall over an area for a certain time period. Among all the indices used to detect meteorological drought, SPI remains the most sustainable due to its easy-to-calculate property. It simply uses monthly rainfall data to detect meteorological drought, and it also helps in exploring the spatial and temporal extent (Hayes et al., 1999; Heim, 2000; Ibrahim et al., 2009; Wilhite et al., 2000). Forty-six years of precipitation data from seven stations of Ankara Province, Turkey, was used to calculate SPI drought index at 3-, 6- and 12-month time scales. Drought events were determined in the province with respect to each time scale (Danandeh Mehr & Vaheddoost, 2020).

Study Area

Bundelkhand region of Uttar Pradesh is situated between the Indo-Gangetic plain in the north and Vindhyan Mountains to the north-west and south. It is spread over 29,400 sq. km of land in seven districts—Jhansi, Jalaun, Lalitpur, Hamirpur, Banda and Chitrakoot—accommodating around 97 lakh people (Census, 2011). This region has been characterized by a hot and semi-humid climate with hot and dry summers and equally cool winters. The annual precipitation varies from 60 cm to 100 cm, the majority of which is received from the south-west monsoons between the months of July and August (Planning Department, Govt. of U.P., 2020). The rainfall received is unpredictable and highly variable; as a result, the region experiences recurring situations of famine, droughts and limited agricultural production.

Material and Methods

Data Used

The monthly rainfall (mm) data of all seven districts has been used in this study. The required data has been downloaded from Climate Research Unit (CRU) at 0.5° × 0.5° spatial resolution from 1980 to 2020. For this study, time series gridded data available on the version CRU TS 4.04 (https://crudata.uea.ac.uk/), grid-box was used. Various research works have established close agreement between Indian Meteorology Department (IMD) and Climate Research Unit (CRU). CRU datasets have been used over IMD due to their finer resolution (Verma & Ghosh, 2019).

Method

Standardized Precipitation Index (SPI)

Over the time, climatologists and meteorologists had used different drought indices to monitor the drought intensity in a region. Many drought indices such as Palmer Drought Severity Index, precipitation percentiles, percentage of normal precipitation etc. were used for screening the drought severity. But meteorologists needed a simpler method that was convenient to calculate and statistically relevant and significant. It led American scientists McKee, Doesken and Kleist to create the Standardized Precipitation Index (SPI) in 1993 (World Meteorological Organization, 2012).

Standardized Precipitation Index (SPI) is a commonly used drought index based on normalization of precipitation probabilities. It studies the precipitation deficit and performs drought monitoring at different time scales. SPI is largely computed for monthly data, but it can also be used to evaluate daily and weekly precipitation data. Due to its simple handling, the World Meteorological Department has recommended the compulsory use of this index in every country monitoring meteorological drought (Danandeh Mehr and Vaheddoost, 2020).

McKee and others (1993) have developed the classification system for the values derived by SPI calculation. They defined that drought event occurs when SPI values remain continuously negative and reach an intensity of −0.1 or less, and it ends when values become positive. Therefore, each drought event has a duration given by the starting and ending points, and intensity for every month. Table 11.1 shows drought severity.

The major advantage of SPI is its statistical consistency and ability to detect both short- and long-term drought impacts with different time scales. Its intrinsic probability nature makes SPI suitable for drought risk analysis (Guttman, 1999). Hayes et al. (1999) in their paper found that SPI can be used for detecting the starting point of drought and its spatio-temporal progression. SPI is based on an equi-probability

Table 11.1 SPI values

2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
−0.99 to 0.99	Near normal
−1.0 to −1.49	Moderately dry
−1.5 to −1.99	Severely dry
−2 and less	Extremely dry

transformation of aggregated monthly precipitation into a standard normal variable. It is assumed that aggregated rainfall to be gamma distributed and maximum likelihood method is used to calculate the parameters of distribution (Thomas et al., 2015b). According to McKee et al. (1993), SPI is computed by fitting the gamma distribution function. It is then transformed into a standard normal distribution where the mean value is zero and the variance is one.

The gamma distribution is defined by the probability density function (p.d.f.) as follows:

$$g(x) = [1/\beta^{\alpha} \times \Gamma(\alpha)] \times x^{\alpha-1} \times e^{-x/\beta} \tag{11.1}$$

where $\alpha > 0$, α is sharp parameter; $\beta > 0$, β is scale parameter; $x > 0$, x is precipitation amount

$$(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} \mathrm{d}y, \ (\alpha) \text{ is a gamma function.}$$

The cumulative probability distribution function G(x) is obtained from integrating p.d.f. as follows:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\widehat{\beta}^{\widehat{\alpha}}\Gamma(\widehat{\alpha})} \int_0^x x^{\widehat{\alpha}-1} e^{-x/\widehat{\beta}} dx \tag{11.2}$$

where

$$\widehat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$$

$$\widehat{\beta} = \frac{\overline{x}}{\widehat{\alpha}}$$

$$A = \ln(\overline{x}) - \frac{\sum \ln(x)}{n}$$

n is the number of precipitation observations. Let $t = x/\beta$, putting it in G(x)

$$G(x) = \frac{1}{\Gamma(\widehat{\alpha})} \int_0^x t^{\widehat{\alpha}-1} e^{-t} dt \tag{11.3}$$

For $x = 0$, the gamma function is undefined; therefore, the cumulative probability becomes

$$H(x) = q + (1 - q)G(x) \tag{11.4}$$

Here q is the value when the probability at $x = 0$.

To find the SPI value, the cumulative probability function requires to change into a standard normal cumulative distribution function having a mean value of zero and variance of one. Then SPI is evaluated using the Abramowitz and Stegun's (1965) approximation as follows:

$$\mathrm{SPI} = -\left(t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t + d_3 t^3}\right) \text{ for } 0 < H(x) < 0.5 \tag{11.5}$$

$$\mathrm{SPI} = +\left(t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t + d_3 t^3}\right) \text{ for } 0.5 < H(x) < 1.0 \tag{11.6}$$

where

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \text{ for } 0 < H(x) < 0.5$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \text{ for } 0.5 < H(x) < 1.0$$

$$C_0 = 2.515517, C_1 = 0.802853, C_2 = 0.010328$$

$$d_1 = 1.432788, d_2 = 1.89269 \text{ and } d_3 = 0.001308$$

The sum of all SPI values within the drought duration is called magnitude of drought, and its division with duration of drought is called its intensity.

The SPI has been employed in this study at 3-, 6- and 12-month time scales by using the software RSTUDIO version 4.1.2. The graphs and tables are prepared using MS-EXCEL 2019.

Results and Discussion

The analysis has been carried out for all seven districts of the Bundelkhand region in Uttar Pradesh. Standardized Precipitation Index (SPI was calculated for all districts at three time scales of 3, 6 and 12 months to assess the intensity of meteorological drought. The values of SPI have been categorized into moderate, severe and extreme droughts. The spatio-temporal extension of drought in each district has been analysed. The calculated SPI values for all seven districts have been shown in Fig. 11.1.

The SPI values computed for each district of the Bundelkhand region of Uttar Pradesh at different time scales of 3, 6 and 12 months show variation in drought duration and occurrence. SPI3 values show a higher frequency of drought events, while SPI6 and SPI12 values show a less frequency of drought events. Although the length of SPI3 is much shorter compared to 6 and 12 months. The index exhibits a little delay in response as the time scale expands, suggesting a diminishing influence on precipitation with each successive month. Consequently, there will be a decrease in the occurrence of prolonged droughts.

Every time scale values depict different interpretations in reference to different water resources. SPI3 values show the soil moisture conditions as the monsoon period in Bundelkhand remains for 3 months (mid-June to mid-September). Water stress and soil moisture for cultivation can be accurately studied by using SPI3 values. However, stream flow and groundwater take more time to get impacted by a rainfall deficit, so SPI6 and SPI12 give a clearer picture of these conditions.

A three-month SPI was computed and shows frequent drought events in all seven districts. Jhansi shows the highest occurrence of drought, while Hamirpur has the least among all seven districts. On the other hand, Chitrakoot faces 81 months of total drought from 1980 to 2020, the highest average intensity. Table 11.2 shows the 3-month-based SPI characteristics.

Evaluation of drought characteristics, including drought intensity and duration, revealed that the highest frequency of drought with moderate to extreme intensity takes place in the period of June to September. There are an average of 25 events of drought in the monsoon period (June to September) in this region. The year 2010 has the longest duration (5 months) of a drought period after 1992–1993. Moderate intensity of droughts is more frequent in this region in comparison to severe and extreme intensity. The highest intensity (−3.19) of drought was faced by Hamirpur district in 2010.

Similar analysis was performed at 6- and 12-month time scales, and it was revealed that with increasing time scale, drought duration and severity have increased, while frequency has decreased (Table 11.3).

In the 6-month SPI calculation, it was revealed that there have been many drought events in the past 41 years. Some of the drought events last for a whole year. The drought events in 1987, 1992, 1993, 2001, 2009 and 2010 prevailed for a whole year. The average duration of the drought period is 5 months. Every district of Bundelkhand is found to be drought prone and has faced drought in similar years.

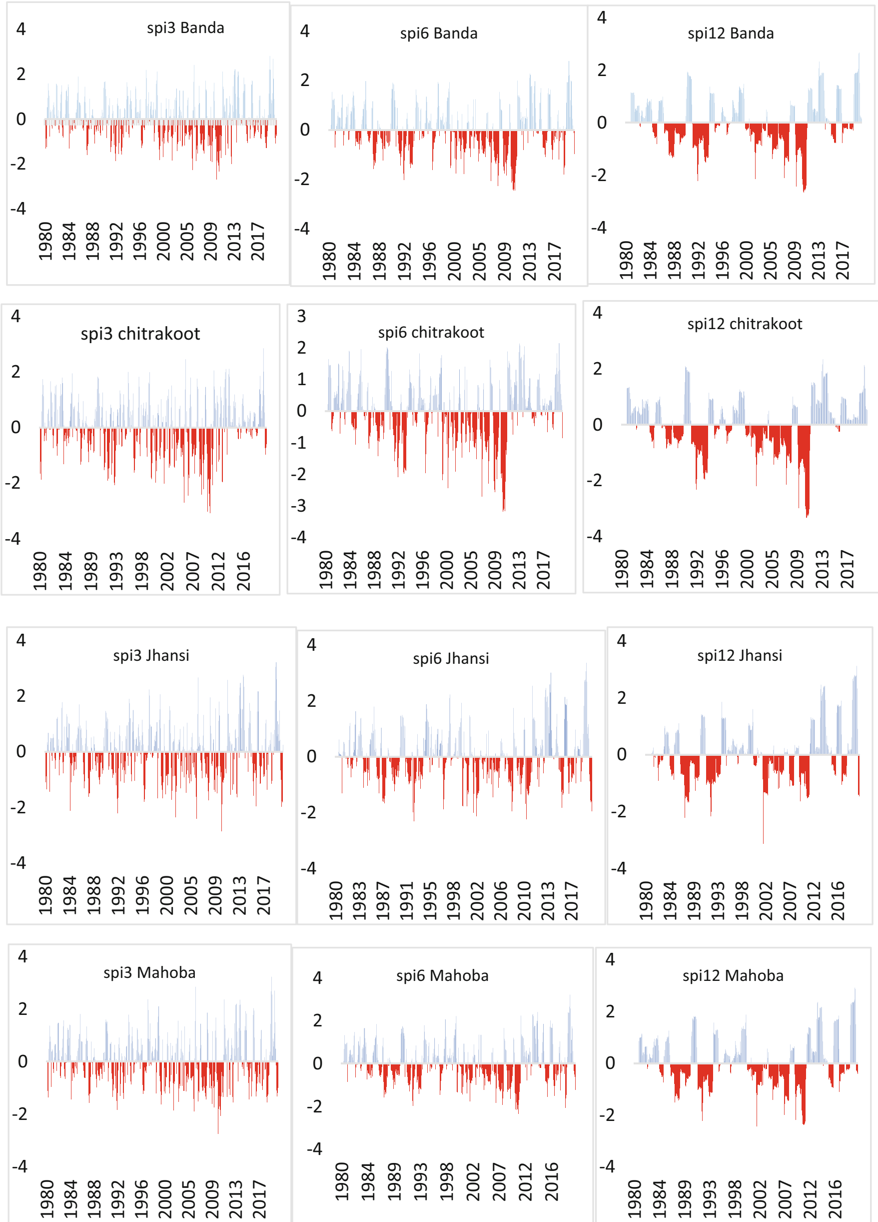

Fig. 11.1 Evaluation of 3-, 6- and 12-month SPI of seven districts of Bundelkhand, Uttar Pradesh, for the reference period (1980–2020)

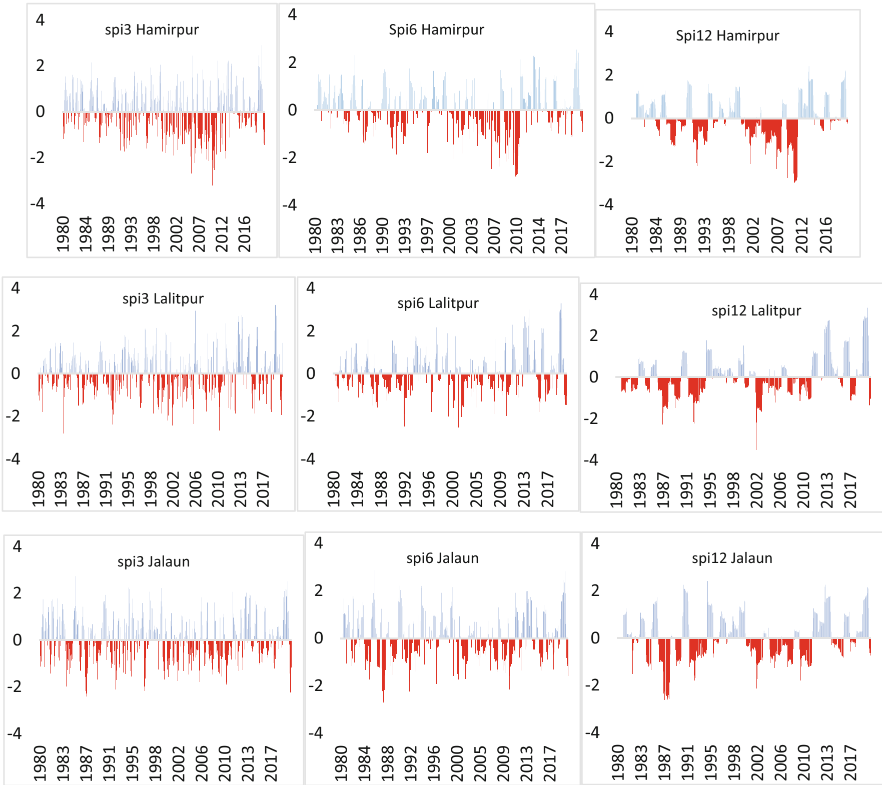

Fig. 11.1 (continued)

Table 11.2 Three-month-based SPI drought characteristics of all seven districts in the Bundelkhand region, Uttar Pradesh (1980–2020)

Districts	Number of drought events	Total duration of drought (months)	Average intensity
BANDA	24	77	−1.75
CHITRAKOOT	25	81	−1.81
MAHOBA	27	77	−1.75
JALAUN	29	72	−1.72
JHANSI	30	72	−1.76
HAMIRPUR	22	79	−1.75
LALITPUR	29	71	−1.79

The monsoon periods have more rain deficits, while the winter season also has low rainfall, which leads to drought conditions (Table 11.4).

Twelve-month SPI values also depict a similar pattern of drought conditions. The frequency of drought events drops significantly, while duration lasts for 9–-12 months. Moderate-intensity droughts are more prevalent for longer duration,

Table 11.3 Six-month-based SPI drought characteristics of all seven districts in the Bundelkhand region, Uttar Pradesh (1980–2020)

Districts	Number of drought events	Total duration of drought (months)	Average intensity
BANDA	21	68	−1.73
CHITRAKOOT	19	67	−1.84
MAHOBA	20	70	−1.7
JALAUN	25	64	−1.42
JHANSI	21	59	−1.47
HAMIRPUR	20	77	−1.49
LALITPUR	20	57	−1.45

Table 11.4 Twelve-month-based SPI drought characteristics of all seven districts in the Bundelkhand region, Uttar Pradesh (1980–2020)

Districts	Number of drought events	Total duration of drought (months)	Average intensity
BANDA	13	66	−1.77
CHITRAKOOT	12	72	−1.97
MAHOBA	13	58	−1.74
JALAUN	19	65	−1.75
JHANSI	16	60	−1.72
HAMIRPUR	14	78	−1.81
LALITPUR	14	59	−1.75

while extreme-intensity drought events last for 1 or 2 months. Chitrakoot and Hamirpur face most intense drought with a long duration, while Jalaun has the highest number of drought events. It shows that districts lying in the north part (Jalaun and Jhansi) have more drought events. Districts in the western part get a longer duration of drought with high intensity and severity.

Conclusion

The spatio-temporal analysis of drought events helps in studying variations in drought intensity, characteristics of drought, frequency, occurrence, its spatio-temporal extension and its beginning and withdrawal of the drought (Thomas et al., 2015a, b). The study presents a spatio-temporal pattern of drought in seven districts of the Bundelkhand region, Uttar Pradesh. Standardized Precipitation Index (SPI) has been employed to study the drought characteristics. Three different time scales—3-, 6- and 12-month SPI—have been used for the analysis of frequency, intensity and duration of drought events. Given that the research area experiences a three-month monsoon season, it is crucial to calculate the 3-month Standardised Precipitation Index (SPI) in order to evaluate soil moisture deficiency. The result shows a higher frequency of drought events among seven districts. Jhansi, Lalitpur and Jalaun have faced more frequent droughts, while Hamirpur has the least dry spells. The moderate- and severe-intensity drought are found more common. The evaluation of 6-month SPI examined the drought for every 6-month period, which depicts frequency decreases, while intensity and duration of drought events have increased. In this case, Jalaun, Lalitpur, Banda and Jhansi have more drought events with longer durations. Though every district faces drought in the same years, the intensity and duration vary. The analysis exposed that each district of Bundelkhand region, Uttar Pradesh, is drought prone with varying intensities. The rainfall in this region is erratic, which pushes it further on the edge of a drought problem. Agriculture is the main occupation in this region, mainly fed by rainfall, but the frequent occurrence of drought led to the economic crisis. The study of SPI helps in understanding the intensity and duration of drought, which further helps in better planning for ongoing drought events.

References

Anctil, F., Larouche, W., & Viau, A. A. (2002). Exploration of the standardized precipitation index with regional analysis. *Canadian Journal of Soil Science, 82*(1), 115–125.

Bonaccorso, B., Bordi, I., Cancelliere, A., Rossi, G., & Sutera, A. (2003). Spatial variability of drought: An analysis of the SPI in Sicily. *Water Resources Management, 17*, 273–296.

Census of India. (2011). "Population census." The Registrar General & Census Commissioner, Ministry of Home Affairs, Government of India, New Delhi, India. http://www.censusindia.gov.in

Danandeh Mehr, A., & Vaheddoost, B. (2020). Identification of the trends associated with the SPI and SPEI indices across Ankara, Turkey. *Theoretical and Applied Climatology, 139*(3), 1531–1542.

Domonkos, P. (2003). Recent precipitation trends in Hungary in the context of larger scale climatic changes. *Natural Hazards, 29*(2), 255.

Ebi, K. L., & Bowen, K. (2016). Extreme events as sources of health vulnerability: Drought as an example. *Weather and Climate Extremes, 11*, 95–102.

Fischer, G., Shah, M., Tubiello, N., & Van Velhuizen, H. (2005). Socio-economic and climate change impacts on agriculture: An integrated assessment, 1990–2080. *Philosophical Transactions of the Royal Society B: Biological Sciences, 360*(1463), 2067–2083.

Guttman, N. B. (1999). Accepting the standardized precipitation index: A calculation algorithm 1. *JAWRA Journal of the American Water Resources Association, 35*(2), 311–322.

Hayes, M. J., Svoboda, M. D., Wiihite, D. A., & Vanyarkho, O. V. (1999). Monitoring the 1996 drought using the standardized precipitation index. *Bulletin of the American Meteorological Society, 80*(3), 429–438.

Heim, R. R. (2000). Drought indices: A review. *Drought: a global assessment, 1*, 159–167.

Ibrahim, K., Zin, W. Z. W., & Jemain, A. A. (2009). Evaluating the dry conditions in peninsular Malaysia using bivariate copula. *ANZIAM Journal, 51*, C555–C569.

Kundu, A., Dutta, D., Patel, N. R., Denis, D. M., & Chattoraj, K. K. (2021). Evaluation of socio-economic drought risk over Bundelkhand region of India using analytic hierarchy process (AHP) and geo-spatial techniques. *Journal of the Indian Society of Remote Sensing, 49*(6), 1365–1377.

Lana, X., Serra, C., & Burgueño, A. (2001). Patterns of monthly rainfall shortage and excess in terms of the standardized precipitation index for Catalonia (NE Spain). *International Journal of Climatology: A Journal of the Royal Meteorological Society, 21*(13), 1669–1691.

Machiwal, D., Mishra, A., Jha, M. K., Sharma, A., & Sisodia, S. S. (2012). Modeling short-term spatial and temporal variability of groundwater level using geostatistics and GIS. *Natural Resources Research, 21*, 117–136.

McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. *Proceedings of the 8th Conference on Applied Climatology, 17*(22), 179–183.

Miah, M. G., Abdullah, H. M., & Jeong, C. (2017). Exploring standardized precipitation evapotranspiration index for drought assessment in Bangladesh. *Environmental Monitoring and Assessment, 189*, 1–16.

Min, S. K., Kwon, W. T., Park, E. H., & Choi, Y. (2003). Spatial and temporal comparisons of droughts over Korea with East Asia. *International Journal of Climatology: A Journal of the Royal Meteorological Society, 23*(2), 223–233.

Nagarajan, R. (2009). *Drought assessment*. Capital Publishing Company, Co-published by Springer.

Palmer, W. C. (1965). *Meteorological drought* (Vol. 30). US Department of Commerce, Weather Bureau.

Patel, N. R., & Yadav, K. (2015). Monitoring spatio-temporal pattern of drought stress using integrated drought index over Bundelkhand region, India. *Natural Hazards, 77*(2), 663–677.

Rahman, M. R., & Lateh, H. (2016). Meteorological drought in Bangladesh: Assessing, analysing and hazard mapping using SPI, GIS and monthly rainfall data. *Environmental Earth Sciences, 75*, 1–20.

Singh, R. P., Roy, S., & Kogan, F. (2003). Vegetation and temperature condition indices from NOAA AVHRR data for drought monitoring over India. *International Journal of Remote Sensing, 24*(22), 4393–4402.

Thomas, T., Jaiswal, R. K., Nayak, P. C., & Ghosh, N. C. (2015a). Comprehensive evaluation of the changing drought characteristics in Bundelkhand region of Central India. *Meteorology and Atmospheric Physics, 127*(2), 163–182.

Thomas, T., Nayak, P. C., & Ghosh, N. C. (2015b). Spatiotemporal analysis of drought characteristics in the Bundelkhand region of Central India using the standardized precipitation index. *Journal of Hydrologic Engineering, 20*(11), 05015004.

Tsakiris, G., Pangalou, D., & Vangelis, H. (2007). Regional drought assessment based on the reconnaissance drought index (RDI). *Water Resources Management, 21*, 821–833.

Umran Komuscu, A. (1999). Using the SPI to analyze spatial and temporal patterns of drought in Turkey. *Drought Network News, 1994–2001*, 49.

Verma, P., & Ghosh, S. K. (2019). Trend analysis of climatic research unit temperature dataset for Gangotri glacier, India. *Dynamics of Atmospheres and Oceans, 85*, 83–97.

Wang, R., Chen, J., Chen, X., & Wang, Y. (2017). Variability of precipitation extremes and dryness/wetness over the southeast coastal region of China, 1960–2014. *International Journal of Climatology, 37*(13), 4656–4669.

Wilhite, D. A., Hayes, M. J., & Svoboda, M. D. (2000). Drought monitoring and assessment: Status and trends in the United States. *Drought and drought mitigation in Europe*, 149–160.

World Meteorological Organization. (2012). *Standardized precipitation index user guide*. World Meteorological Organization, (1090).