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Drought assessment using standardized precipitation index for Akola District, Maharashtra

Gaurav Sharma[1]*, Ankit Kumar[1] and Chandra Kishor Kumar[2]

[1]Regional Centre, National Institute of Hydrology, Bhopal 462 016, Madhya Pradesh, India
[2]Department of Farm Engineering, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, Uttar Pradesh, India

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ABSTRACT

Drought is mostly the result of a decrease in precipitation in comparison with the mean value and it affects the quantities of soil moisture and water resources. The standardized precipitation index (SPI) has been used to monitor the Spatio-temporal variability of dryness and wetness on multiple time scales, which is based only on long-term monthly rainfall data. In the present study, the spatio temporal variations of the drought scenario over Akola district have been studied using the standardized precipitation index (SPI) for the time scales of 3, 6, 12 months. For different time scale drought characterization has been carried out based on severity, intensity and drought magnitude. Based on analysis drought preparedness and mitigation strategy can be formulated which will help to render the impact of drought and its hazardous effects.

Keywords: *Drought intensity, Standard Precipitation Index, Variability*

Introduction

A comprehensive analysis of the spatial and temporal extension of droughts help to develop drought-monitoring signals based on relevant drought indices (Chiew *et al.*, 1998; Moreira *et al.*, 2006; Rossi 2003; Sivakumar and Wilhite 2002). Nowadays the most commonly used drought indices are standardized precipitation index (SPI) which only uses long term rainfall data to provide real-time monitoring of the intensity and spatial extension of droughts, at different time scales of 3, 6, 12, and 24 months. The SPI is a probability-based indicator that depicts the degree to which the accumulative precipitation of a specific period departs from the average state. The SPI is space-independent and has a sound performance when representing precipitation anomaly, (Mckee *et al.*, 1993) compared with other indices and methods based on physical processes like the Palmer drought severity index (PDSI). The comparison of SPI with other indexes established the strength of SPI in drought analysis based on six weighted evaluation performance criteria viz., robustness, tractability, transparency, sophistication, extendibility, and dimensionality (Keyantash and Dracup 2002). Drought evolvement characteristics has being studied based on Standardized Precipitation Index (SPI) in the Huaihe river basin and found that the intensity of drought increases while the areas under drought get decreased (Li *et al.*, 2012). The spatio-temporal variability of the drought characteristics over the Bundelkhand region in central India using the Standardized Precipitation Index (SPI) for the time scales of 3, 6 and 12 months was studied at which the drought occurs and also developed relationship among time scale of SPI, drought duration and its severity (Thomas *et al.*, 2015). The meteorological drought characteristics was studied including onset, departure, duration, severity, intensity as well as inter relationship among the drought duration, number of drought events, drought severity and time scale have been developed for Dhasan basin using SPI index (Kar *et al*., 2018). The purpose of this study is to examine the spatio-temporal variation of drought at different time scales.

Materials and Methods

Description of study area

Akola district situated in Vidarbha region of Maharashtra state of central India and lies between latitudes 20°162 and 21°172 N and longitudes 76°382 and 77°382 E with at an altitude of 287 m to 316 m above mean sea level. The total geographical area of the district is 5417 square km and covers the parts of Survey of India degree sheets 55 C, 55 D, 55 G, and 55 H. The climate of the district is characterized by a hot summer and general dryness throughout the year except during the south-west monsoon season. The average minimum temperature is 12.6°C and average maximum temperature is 42.4 °C. The Normal annual rainfall over the district varies from about 740 mm to 860 mm with more than 80 % rainfall occurs in monsoon season (June to September) and a considerable amount of rainfall occurs in December to February months. The soils of the study area classified mainly medium black soil and deep black soil. The location of the study area is shown in Fig. 1.

Data Availability

The rainfall data is obtained from IMD, Pune and Regional Meteorological Department, Mumbai from 1973-2008 for 35 years.

SPI- based Meteorological Drought Evaluation

The drought characteristics are generally evaluated

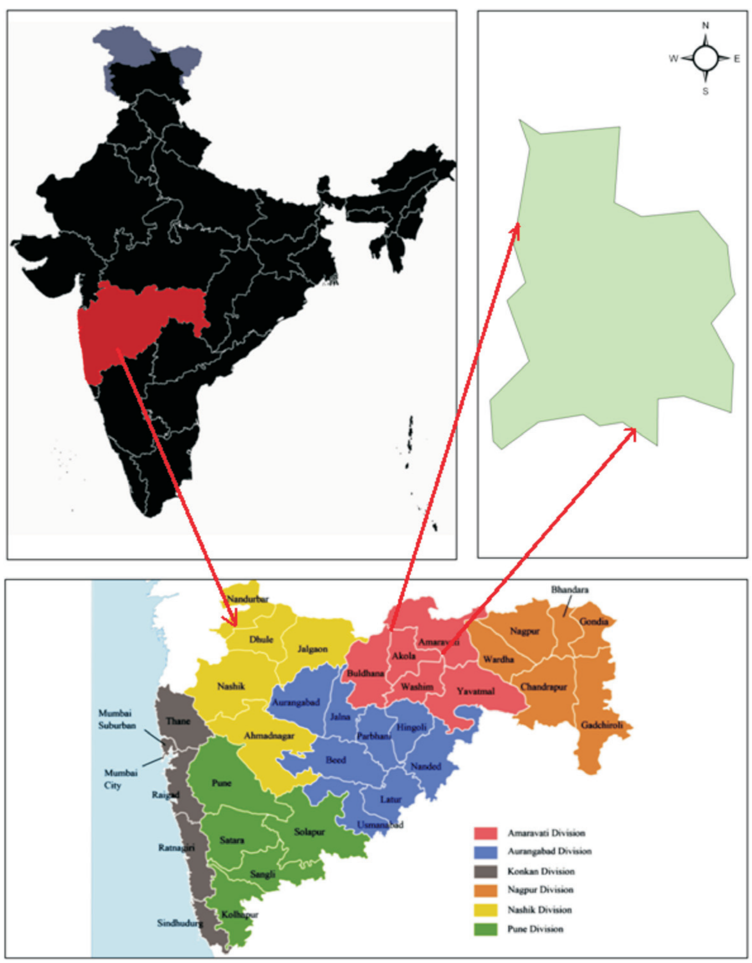

Fig. 1. Location of study area

based on drought indices developed for various types of droughts. Among the several proposed indices, SPI has found a widespread application (McKee *et al.*, 1993; Wilhite *et al.*, 2000). The SPI has advantages of statistical consistency and ability to describe both short-term and long-term drought impacts through the different time scales. Also, due to its intrinsic probabilistic nature, the SPI is best suited for drought risk analysis (Guttman, 1999). The SPI is able to take into account different time scales at which drought occurs and, due to its standardization, is particularly suited to compare drought conditions among regions with different climatic conditions and different time periods (Bonaccorso *et al.*, 2003). McKee *et al.*, (1993) assumed the aggregated precipitation to be gamma distributed and used a maximum likelihood method to estimate the parameters of the distribution. The computation of the SPI involves, (a) calculation of mean of the normalized precipitation of the lognormal (ln) rainfall series; (b) fitting a two-parameter gamma probability density function to a given frequency distribution of the precipitation and computation of shape and scale parameters b and a, for each time scale of shape and scale parameters b and a, for each time scale of interest (1, 3, 6 and 12 months) respectively, as given by the following equations 1 to 11.

$$\bar{X}in = \sum \frac{ln\bar{X}}{N} \quad .. (1)$$

$$\beta = \frac{1}{4\,U}\left[1 + \sqrt{\frac{4U}{3}}\right] \quad .. (2)$$

$$\beta = \frac{\bar{x}}{\beta} \quad .. (3)$$

Where,
U is the constant given by

$$U = \log_e(\bar{X}) - \log_e(\bar{X}\,in) \quad .. (4)$$

The resulting distribution parameters which have been estimated by the maximum likelihood approach are then used to find the cumulative probability of an observed precipitation event for the given month and time scale, for a particular station. The cumulative probability as given by gamma distribution is

$$G(x) = \frac{1}{\alpha^{\beta}\Gamma_{\beta}}\int_0^x x^{\beta-1} e^{\frac{x}{\alpha}}\,dx \quad .. (5)$$

Letting $t = \frac{-x}{\alpha}$, this equation becomes the incomplete gamma function

$$G(x) = \frac{1}{\Gamma_{\beta}}\int_0^{t\alpha} t^{\beta-1}\,e^{-t}dt \quad .. (6)$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zero, the cumulative probability becomes

$$H(x) = q + (1 - q)G(x) \quad .. (7)$$

Where,
'q' is the probability of a zero.

However, the three parameter gamma distribution is considered to produce more robust values of SPI. If m is the number of zeros in a precipitation time series, states that q can be estimated by m/N and used tables of incomplete gamma function to determine cumulative probability H(x). The cumulative probability is then transformed to the standard normal random variable Z with mean zero and variance one, which is the value of the SPI. The Z or SPI values are more easily obtained computationally using an approximation provided by Abramowitz and Stegun, (1972) that converts cumulative probability to the standard normal random variable Z.

$$Z = SPI = -\left[t - \frac{c_o + c_2 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right] \quad .. (8)$$

For $0 < H(x) \leq 0.5$

$$Z = SPI = +\left[t - \frac{c_o + c_2 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right] \quad .. (9)$$

For $0.5 < H(x) \leq 1.0$

Here,

$$t = \sqrt{\log_e\left\{\frac{1}{\left(H(x)\right)^2}\right\}} \quad .. (10)$$

For $0 < H(x) \leq 5.0$

$$t = \sqrt{\log_e\left\{\frac{1}{\left(1 - H(x)\right)^2}\right\}} \quad .. (11)$$

For $0.5 < H(x) \leq 1.0$

c_0 = 2.515517, c_1 = 0.802853 and c_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269 and d_3 = 0.001308.

Classification of SPI

A drought event occurs during the period when SPI is continuously negative and reaches an intensity of -1.0 or less and ends when the SPI become positive. The frequency, duration and intensity of drought can be calculated with SPI. The positive sum of the SPI for all the months within a drought event is termed as drought magnitude. The division of the drought magnitude by its duration results in drought intensity. The drought severity has been evaluated using the classification of Hayes *et al.*, (1999) given in Table 1.

Table 1. Standard Range of SPI values and their classification

S. No.	SPI range	Classification
1	≥ 2.0	Extremely wet
2	1.5 to 1.99	Very wet
3	1.0 to 1.49	Moderately wet
4	0.0 to 0.99	Mild wet
5	0.0 to -0.99	Mild Drought
6	-1.0 to -1.49	Moderate Drought
7	-1.5 to -1.99	Severe Drought
8	≤ -2.0	Extreme Drought

A 3-month SPI has been used as a short-term or seasonal drought index, 6-month SPI for intermediate-term drought index, 12-month as long-term drought index.

The SPI for a month/year in the period of record is dependent upon the timescale. The SPI can be used for all stations having more than 30 year rainfall data (Hayes *et al.*, 1999).

Results and Discussion

SPI-Based Evaluation of Drought Characteristics

The meteorological and hydrological drought characteristics have been evaluated based on the Standardized Precipitation Index (SPI). The 1-month and 3-month SPI indicates the soil moisture deficit, 6-month SPI indicates the surface water deficit and 12-month SPI indicates the groundwater deficit. In this study, the 1- month and 3-month SPI is used as a seasonal drought index to represent short-term drought, the 6-month SPI is used for intermediate-term drought, and the 12-month SPI is used for long-term drought. As the monsoon season is principally three months (July, August, and September), the 1-month and 3-month SPI is considered to reflect the deficit and surplus in the soil moisture availability. The temporal variation of the 1-month and 3-month SPI is depicted in Fig. 2 and 3.

The analysis of the 1-month SPI indicates the highest drought intensity (-1.54) with the maximum occurrence of extreme drought event (SPI>-2) only in 1 occasion followed by 8 severe drought event from 1973 to 2008. However, the total number of drought events considering different classes as one is 22. Most of the rainfall occurred in August and September but in the years 1995 for September, there is a substantial decrease in rainfall which resulting in acute soil moisture deficit.

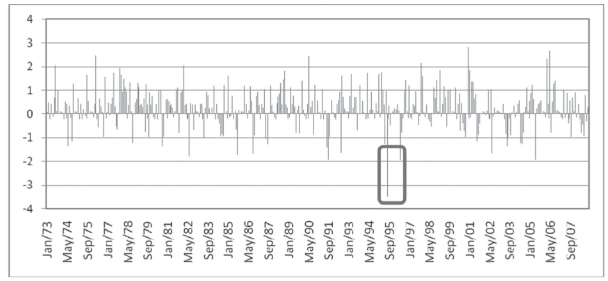

Fig. 2. 1-month SPI for Akola District of Maharashtra

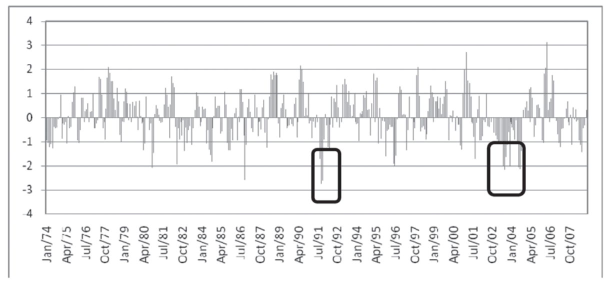

Fig. 3. 3-month SPI for Akola District of Maharashtra

The analysis of the 3-month SPI indicates the highest drought intensity (-1.46). Increase in moderate drought events indicates rainfall deficit which resulting in inadequate soil moisture that causes a decrease in crop production. Table 2 shows the classification of different drought event at different time scales. In July 1991 and from October 2002 to January 2004 there is soil moisture deficit in the region which results in a decrease in crop yield. From the table 2, it is cleared that drought events increase with an increase in time scales.

With the increase in time scale (eg., 6-month SPI), it is observed that there is a further increase in drought duration and severity. Agricultural drought occurred due to deficiency of soil moisture for a longer period resulting in water stress like situation and thus affecting the entire region. 6-month SPI uses to indicate the agricultural drought. Fig. 4. show the 6-month SPI for Akola district of Maharashtra.

Table 2. Drought characteristics based on different time scale

Time Scale	Extreme Drought	Severe Drought	Moderate Drought	Total	Drought Intensity
1-Month	1	8	13	22	-1.54
3-Month	10	11	42	63	-1.46
6-Month	17	17	29	63	-1.66
12-Month	16	17	33	66	-1.69

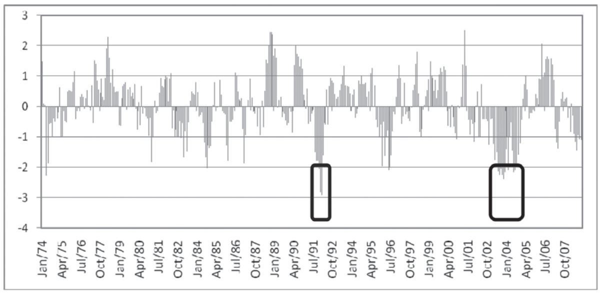

Fig. 4. 6-month SPI for Akola District of Maharashtra

Drought intensity (-1.66) has increased with increase in time scale. The occurrence of extreme drought event has been increased (17) followed by severe drought event (17). Thus, indicating drought-like situation and inadequate water resource to meet the agricultural demand. From the figure above it is visible that the magnitude and intensity of drought increases. For July 1991 to October 1992 and from October 2002 to January 2004 intense agricultural drought occurred in that region and is responsible for the complete failure of the crop. Such event occurred successively in that region but its magnitude is not as much extreme which will fail crops. 12-month SPI is used for assessment of Hydrological drought dealing with groundwater storage. Fig. 5. shows the 12-month SPI for Akola district of Maharashtra.

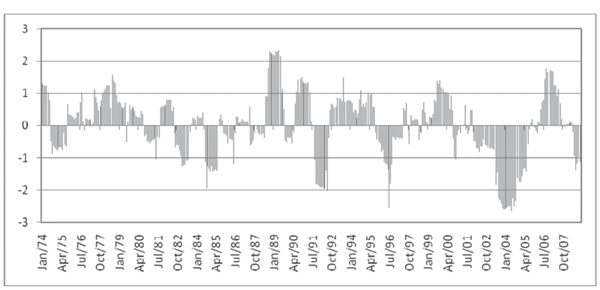

Fig. 5. 12-month SPI for Akola District of Maharashtra

It is interesting to note that the number of Moderate drought events has increased substantially indicated least groundwater storage with the increase in duration and severity. Total drought events have been increased to 66 events with an increased intensity of -1.66. Thus indicating very less groundwater recharges and demonstrates that an increase in duration leads to an increase in severity. With the increase in time scale drought duration also increases which results in a decrease in runoff from the river due to inadequate recharge from groundwater. From the above figure, it is visible that there is decrement of groundwater availability in most of the period and it is extreme from October 2002 to January 2004.

Conclusion

The monsoon pattern in India is varied every year and under such circumstances, spatiotemporal variations of the drought analysis can help increase understanding of drought signature and characteristics, including severity, duration, aerial extent, progression, and withdrawal, which can encourage the development of a mechanism to address drought-related issues effectively. The SPI analysis indicates that drought predominantly occurs with different magnitude and intensity. Hence it is important to have an area-specific solution to deals under such condition. Based on assessment it is evidenced that the region is under extreme drought condition from 1991 to October 1992 and from October 2002 to January 2004. During these periods the region is affected not only by agricultural drought but also by hydrological drought and under such condition different mitigation strategy is developed to render the effect of drought. Based on SPI analysis drought effects to groundwater storage can also be accessed and based on that different scientific methods can be adopted to enhance groundwater recharge in that region. In present scenario climate change further escalating drought-like situation and making the poorer section of the society more vulnerable hence there should be a proper channel like early warning system based on real-time monitoring to cope under such situation.

References

Abramowitz, M. and Stegun, I. A. 1965. *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables* (Vol. 55). *Courier Corporation.*

Bonaccorso, B., Bordi, I., Cancelliere, A., Rossi, G. and Sutera, A. 2003. Spatial variability of drought: an analysis of the SPI in Sicily. *Water Resources Management.* 17 (4) : 273-296.

Chiew, F. H., Piechota, T. C., Dracup, J. A. and McMahon, T. A. 1998. El Nino/Southern Oscillation and Australian rainfall, streamflow and drought: Links and potential for forecasting. *Journal of Hydrology*. 204(1-4) : 138-149.

Gaurav Sharma, Chandra Kishor Kumar and Ankit Kumar. 2020. Assessment of Meteorological Drought characteristics using Standardized precipitation Index for Ajmer district, Rajasthan, India. *Int. J. Curr. Microbiol. App. Sci.* 9(02): 1343-1354.

Guttman, N. B. 1999. Accepting the standardized precipitation index. *Journal of the American Water Resources Association*. 35(2) : 311-322.

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

Kar, S. K., Singh, R. M. and Thomas, T. 2018. Spatio-temporal evaluation of drought characteristics in the Dhasan basin. *Mausam.* 69(4) : 589-598.

Keyantash, J. and Dracup, J. A. 2002. The quantification of drought: an evaluation of drought indices. *Bulletin of the American Meteorological Society.* 83(8) : 1167-1180.

Li, Y. J., Zheng, X. D., Lu, F. and Ma, J. 2012. Analysis of drought evolvement characteristics based on standardized precipitation index in the Huaihe River Basin. In *Procedia Engineering*. 28 : 434-437.

McKee, T. B., Doesken, N. J. and Kleist, J. 1993. The relationship of drought frequency and duration to time scales. *8th Conference on Applied Climatalogy, Anaheim,* CA, 179-184.

Moreira, E. E., Paulo, A. A., Pereira, L. S. and Mexia, J. T. 2006. Analysis of SPI drought class transitions using log-linear models. *Journal of Hydrology*. 331(1-2) : 349-359.

Rossi, G. 2003. Requisites for a drought watch system. In *Tools for Drought Mitigation in Mediterranean Regions* (pp. 147-157). Springer, Dordrecht.

Sivakumar, M. V. K. and Wilhite, D. A. 2002. Drought preparedness and drought management. Drought mitigation and prevention of land desertification (*Proc., Int. Conf., Bled, Slovenia*), UNESCO, Slovenia.

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

Wilhite, D. A. 2000. Drought as a natural hazard: Concepts and definitions. Drought: A Global Assessment, 3-18.