MAUSAM, **69**, 4 (October 2018), 589-598

551.577.38 (540.49)

Spatio-temporal evaluation of drought characteristics in the Dhasan basin

SASWAT KUMAR KAR, R. M. SINGH* and T. THOMAS**

ICAR-IISWC, Kaulagarh Road, Dehradun – 248 195, U. K., India

**Deptt. of Farm Engg., Institute of Agricultural Sciences, Banaras Hindu University, Varanasi – 221 005, U. P., India*

***Ganga Plains South Regional Centre, National Institute of Hydrology, Bhopal – 462 016, M. P., India*

(*Received 17 February 2017, Accepted 7 August 2018*)

e mail : saswatkumarkar@gmail.com

सार – मौसम वैज्ञानिक अनावृष्टि की विशिष्टताएँ जैसेः- आरंभ, प्रस्थान, अवधि, भीषणता के साथ ही साथ तीव्रता का मूल्यांकन मुख्यत ढांसा बेसिन में स्थित तीन वर्षा मापी स्टेशनों पर मानसून वर्षा ऋतु के लिए किया गया। अनावृष्टि भीषणता पर बहुसमय श्रृंखला (1, 3, 6, 12 और 24 महीने) को समझने और परिमाणात्मकता के लिए मानक वर्षण सूचकांक (SPI) का प्रयोग किया गया। तीन महीने के मानक वर्षण सूचकांक के आधार पर अनावृष्टि का स्थानिक कालिक विश्लेषण भी अनावृष्टि वाले वर्षों और अध्ययन वाले इलाकों के क्षेत्रों जहां अनावृष्टि की परिघटनाएँ लगातार घटती है का पता लगाने के लिए किया गया। तीन महीनों के मानक वर्षण सूचकांक के आधार पर मुख्य अनावृष्टि वाली परिघटनाओं का पता लगाया गया है। 11.17 की अनावृष्टि की अधिकतम भीषणता नवम्बर 1991 से अगस्त 1992 के दौरान रही जो सागर वर्षा मापी स्टेशन के अन्तर्गत 10 महीनों की अवधि वाला सबसे लंबी अवधि का समय था। इस बेसिन में होने वाली अनावृष्टि की घटनाओं का आरंभ खरीफ के मौसम के आरंभ में सबसे अधिक रहा हो और अगस्त या सितम्बर के अतः तक समाप्त हुआ। स्थानिक परिवर्तनशीलता से यह पता चला है कि जून 2002 के दौरान लगभग 55.74% का बेसिन क्षेत्र ने भीषण अनावृष्टि की स्थितियों का सामना किया। इसके बाद 35.29% क्षेत्र सामान्य अनावृष्टि की स्थितियाँ और सिर्फ 8.97% क्षेत्र ने कम अनावृष्टि की स्थितियों का सामना किया। अनावृष्टि अवधि, अनावृष्टि की घटनाओं की संख्या, अनावृष्टि की भीषणता और समय श्रृंखला का अध्ययन किया गया।

ABSTRACT. The meteorological drought characteristics including onset, departure, duration, severity as well as intensity have been evaluated mainly for monsoon season at all the three rain gauge stations located in Dhasan basin. The Standardized Precipitation Index (SPI) has been applied to understand and quantify the drought severity on multiple time scale (1, 3, 6, 12 and 24 months). The spatiotemporal analysis of drought based on 3-month SPI has also carried out to identify drought years and the regions of the study area which is under the grip of continuous drought events. Based on the 3-month SPI, major drought events have been identified. The maximum drought severity of -11.17 occurred during November 1991 to August 1992 having the longest duration of 10 months, in the area under Sagar rain gauging station. The onset of most of the drought events in the basin take place during the beginning of *Kharif* season and terminate by the end of August or September, so affect the agricultural crops severely. The spatial variation indicates that during June 2002, about 55.74% of basin area was experiencing severe drought conditions, followed by 35.29% area under moderate drought condition and only 8.97% area faced mild drought conditions. The inter-relationship among the drought duration, number of drought events, drought severity and time scale have been studied.

Key words – Standardized precipitation index, Drought characteristics, Time scales.

1. Introduction

Drought is a natural hazard and is one of the major threats among all the natural hazards to livelihood and socio-economic development thereby affecting more people than any other natural hazards. It can be defined as the inadequate availability of water for a long and sustained period due to erratic rainfall distribution, resulting in deficient soil moisture content (Dracup *et al.*, 1980a and Redmond, 2002). The parameters indicating drought impacts include soil moisture depletion, reduction in stream flow, reservoir storage, lake levels and groundwater level (Dracup *et al.*, 1980b). It is a complex process which can be characterized by various spatially and temporally varying factors like areal extent, severity and duration, among them drought severity is the most important parameter for assessing drought characteristics. Various drought indices are generally used to address drought severity in an area (Tigkas *et al.*, 2014). Drought severity is assessed by drought indices, which are indicator based and useful for identifying and monitoring drought events and acts as an early warning system (Tigkas *et al.*, 2013). McKee *et al.* (1993) developed the Standardized Precipitation Index (SPI) which is widely used for assessing drought severity and it has the advantages of statistical consistency. Thomas *et al.* (2014)

TABLE 1

Location details of the raingauge stations

Rain gauge stations name	Latitude	Longitude	75% dependable rainfall (mm)	Data availability
Sagar	23° 50′ 00′′	78° 43′ 00′′	896.80	1970 to 2014
Khurai	24° 03′ 00′′	78° 19′ 40′′	1011.17	1970 to 2014
Banda	24° 03′ 00′′	78° 57′ 40′′	741.80	1980 to 2014

evaluated the drought characteristics based on the drought indices for various types of droughts occurring regularly in the Bearma basin in Bundelkhand *viz*., SPI, Surface water Drought Index (SDI), Groundwater Drought Index (GDI) and dry spell analysis and the various aspects of meteorological, hydrological and agricultural drought characteristics have been analysed. Pandey *et al.* (2008) studied various indices for drought characterization in KBK (Koraput, Balangir and Kalahandi) districts of Orissa (India). Thomas *et al.* (2015) studied the spatiotemporal 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 at which the drought occurs and also developed relationship among time scale of SPI, drought duration and its severity. Kar *et al.* (2016) have also assessed the meteorological drought characteristics for Bundelkhand region using effective drought index (EDI) and groundwater drought index (GDI). During 20th century Bundelkhand region was facing drought-like situation having once in sixteen years but presently the scenario has been changed and the frequency has been increased to once in three years. The drought vulnerability assessment for Dhasan basin of Bundelkhand region carried out by Kar *et al.* (2018) indicated that, most of the study area is highly drought vulnerable. As it is under frequent occurrence of droughts since decades due to irregularity in rainfall, lack of sufficient water in reservoirs and wells which leads to crop failure and ultimately affect livelihoods of local population. This study has been carried out to understand and quantify the scenario of the meteorological drought characteristics in Dhasan basin of Bundelkhand region (Madhya Pradesh). In the present study, meteorological drought characteristics were evaluated by using Standardised Precipitation Index (SPI) and the drought characteristics including onset, departure, duration, severity as well as intensity have been evaluated for all the three rain gauge stations in Dhasan basin.

2. Data and methodology

2.1. *Study area*

River Dhasan originates from the Jashrathi hill (MSL of 714 m) near the Bhaisa village (23°26′00″ N latitude to 78°33′00″ E longitude) located at the north-east part of Raisen district (Madhya Pradesh) and subsequently joins River Betwa which is a tributary of the Yamuna river system. It is bounded by Sonar-Ken basin in the east, Bina-Betwa basin in the west, Narmada river basin in the south and Yamuna river in the north and is located at the southern eastern edge of Malwa Plateau. For the purpose of analysis, the monthly rainfall data of Sagar and Khurai from 1970 to 2014 and for Banda from 1980 to 2014 were collected from water resources department, Madhya Pradesh and the location details of the rain gauge stations are presented in Table 1. The study area has been limited to Dhasan basin in Madhya Pradesh up to Patan village, with a catchment area of 2054.39 sq. km. The index map showing the study area is given in Fig. 1.

TABLE 2

SPI based severity classification

Drought severity classes	SPI ranges
Mild drought	0.00 to -0.99
Moderate drought	-1.00 to -1.49
Severe drought	-1.50 to -1.99
Extreme drought	≤ -2.00

TABLE 3

3-m SPI based drought events in Dhasan basin

Station name	Extreme	Severe	Moderate	Mild	Total
Sagar	3	10	25	123	161
Khurai	4	11	25	70	110
Banda	2	7	21	87	117

2.2. *Climate*

The average maximum, minimum and mean monthly temperatures for Dhasan river basin are 42.01 °C during May and 8.39 °C during January respectively (Pareta, 2004). Generally, the monsoon commences between 15th and 30th June and the monsoon season lasts for 3 to 4

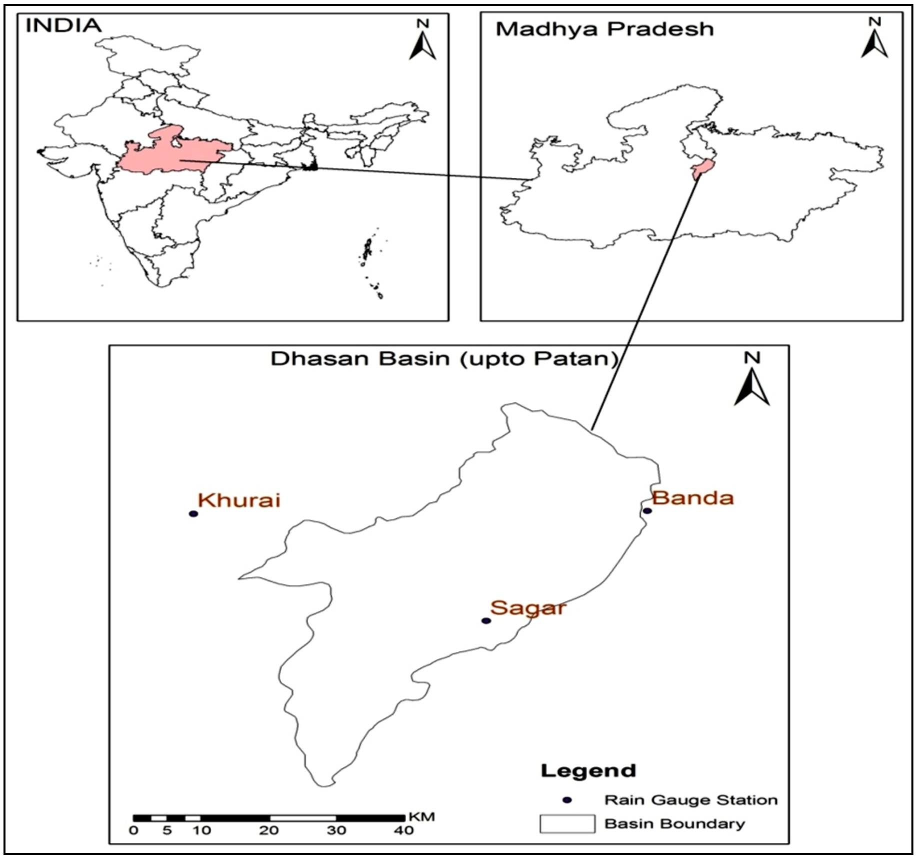

Fig. 1. Index map of Dhasan basin up to Patan

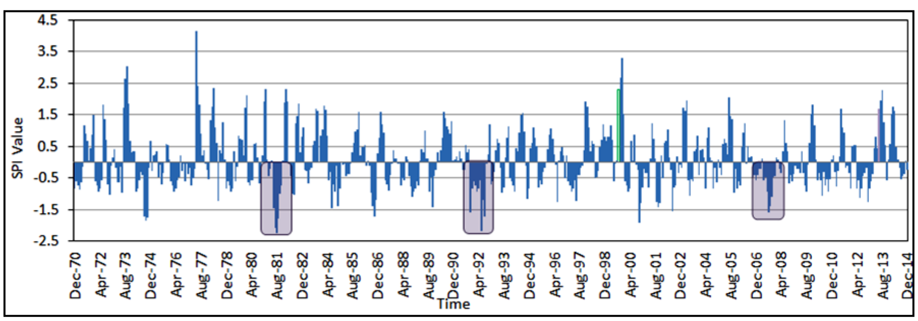

Fig. 2. 3-month SPI for the area under Sagar rain gauging station

consecutive months. The maximum rainfall is obtained during the month of August followed by July. More than 90% of the annual rainfall is provided by the southwest monsoon during the months of June to September and the rest during winter and summer seasons. The average annual rainfall of Dhasan basin is around 1117.2 mm and seasonal rainfall is about 1020.2 mm.

2.3. *Soil type and geology*

Eight soil groups have been identified in the study area namely, deep clayey soils, deep calcareous clayey soils, moderately deep calcareous clayey soils, slightly deep clayey soils, very shallow clayey-skeletal soils, deep loamy soils, slightly deep loamy soils and very shallow loamy soils. Most of the area is covered by deep calcareous clayey type soils having an area of 41.54%. The area is covered mostly by Deccan traps, which is basaltic lava flow and also some portions with alluvial and Vindhyan rocks.

2.4. *Evaluation of drought characteristics using SPI*

The Standardised Precipitation Index (SPI) developed by McKee *et al.* (1993) is used for drought evaluation which serves as an ideal tool for drought

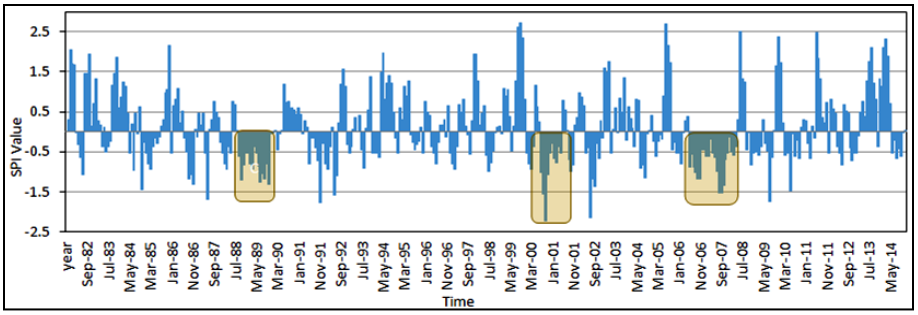

Fig. 3. 3-month SPI for the area under Banda rain gauging station

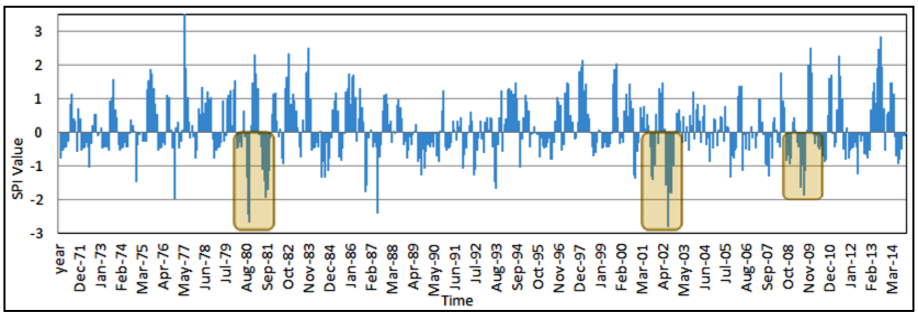

Fig. 4. 3-month SPI for the area under Khurai rain gauging station

monitoring and analysis. The SPI has been computed for five-time scales, *viz.*, 1-month time scale (1m-SPI), 3-month time scale (3m-SPI), 6-month time scale (6m-SPI), 12-month time scale (12m-SPI) and 24-month time scale (24m-SPI) for which a program was compiled using Fortran 90. The computation of SPI requires continuous long-term data of monthly precipitation for at least 30 years. The computation of the SPI involves following steps as given by Equations 1 to 11.

(*i*) Calculation of mean of the normalized precipitation of the log normal (ln) rainfall series.

(*ii*) Fitting a two-parameter gamma probability density function to a given frequency distribution of the precipitation.

(*iii*) Computation of shape and scale parameters β and α respectively for each time scale of interest (1, 3, 6, 12 and 24 months).

$$\text{Log mean}\left(\overline{\mathrm{X}}_{\ln}\right) = \frac{\sum \ln \mathrm{X}}{\mathrm{N}} \tag{1}$$

$$\text{Shape parameter}(\beta) = \frac{1}{4U}\left[1 + \sqrt{\frac{4U}{3}}\right] \tag{2}$$

$$\text{Scale parameter}(\alpha) = \frac{\overline{\mathrm{x}}}{\beta} \tag{3}$$

where, U is the constant given by

$$\mathrm{U} = \ln(\overline{\mathrm{X}}) - \overline{\mathrm{X}_{\ln}} \tag{4}$$

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 the rain gauge station. The cumulative probability as given by gamma distribution is given below:

$$G(x) = \frac{1}{\alpha^{\beta}\Gamma\beta} * \int_0^x x^{\beta-1}\, e^{-x/a}\, dx \tag{5}$$

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

$$G(x) = \frac{1}{\Gamma\beta} * \int_0^{t\alpha} t^{\beta-1}\, e^{-t}\, dt \tag{6}$$

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

$$H(x) = q + (1-q)G(x) \tag{7}$$

Here 'q' is having probability of zero and it can be estimated by m/N, where m is the number of zeros in a precipitation time series, then cumulative probability $H(x)$

TABLE 4

3-month SPI based drought characteristics of Dhasan basin in Madhya Pradesh

Rain gauge stations name	Onset	Termination	Duration (months)	Severity	Intensity
Sagar	December 1970	April 1971	5	-3.69	-0.74
	January 1972	May 1972	5	-3.67	-0.73
	March 1974	May 1974	3	-2.32	-0.77
	August 1974	October 1974	3	-5.31	-1.77
	January 1976	May 1976	5	-3.67	-0.73
	December 1978	April 1979	5	-3.95	-0.79
	February 1980	May 1980	4	-2.54	-0.64
	June 1981	November 1981	6	-9.29	-1.55
	July 1984	September 1984	3	-3.09	-1.03
	August 1986	November 1986	4	-5.27	-1.32
	May 1987	July 1987	3	-2.16	-0.72
	March 1988	May 1988	3	-1.81	-0.60
	September 1988	February 1989	6	-5.01	-0.84
	November 1991	August 1992	10	-11.17	-1.12
	December 1993	March 1994	4	-2.78	-0.70
	June 1995	August 1995	3	-2.09	-0.70
	January 1997	June 1997	6	-4.89	-0.82
	January 2000	April 2000	4	-3.11	-0.78
	October 2000	December 2000	3	-4.03	-1.34
	September 2001	November 2001	3	-4.00	-1.33
	July 2002	September 2002	3	-3.11	-1.04
	May 2003	August 2003	4	-2.78	-0.70
	December 2005	February 2006	3	-2.19	-0.73
	July 2007	October 2007	4	-5.04	-1.26
	August 2010	November 2010	4	-2.79	-0.70
	April 2012	July 2012	4	-3.39	-0.85
	November 2012	January 2013	3	-2.69	-0.90
Banda	January 1985	March 1985	3	-2.25	-0.75
	September 1986	November 1986	3	-3.56	-1.19
	January 1988	March 1988	3	-2.25	-0.75
	September 1988	March 1989	7	-5.46	-0.78
	May 1989	November 1989	7	-6.99	-1.00
	December 1993	March 1994	4	-2.24	-0.56
	January 1997	March 1997	3	-2.25	-0.75
	June 1998	August 1998	3	-2.37	-0.79
	January 2000	March 2000	3	-2.25	-0.75
	August 2000	December 2000	5	-6.42	-1.28
	September 2001	November 2001	3	-2.51	-0.84
	July 2002	September 2002	3	-4.67	-1.56
	July 2004	September 2004	3	-2.91	-0.97
	December 2005	February 2006	3	-1.86	-0.62
	June 2006	November 2006	6	-5.7	-0.95
	May 2007	December 2007	8	-7.78	-0.97
	November 2012	January 2013	3	-1.78	-0.59
Khurai	August 1980	October 1980	3	-6.39	-2.13
	June 1981	October 1981	5	-7.3	-1.46
	July 1984	September 1984	3	-3.52	-1.17
	July 1989	December 1989	6	-4.99	-0.83
	June 1992	August 1992	3	-2.91	-0.97
	October 2000	December 2000	3	-3.21	-1.07
	September 2001	November 2001	3	-3.68	-1.23
	June 2002	September 2002	4	-7.93	-1.98
	October 2005	January 2006	4	-3.31	-0.83
	August 2007	October 2007	3	-3.21	-1.07
	September 2008	December 2008	4	-3.2	-0.80
	June 2009	September 2009	4	-5.57	-1.39
	August 2010	October 2010	3	-2.34	-0.78
	October 2012	January 2013	4	-2.62	-0.66
	June 2014	September 2014	4	-2.93	-0.73

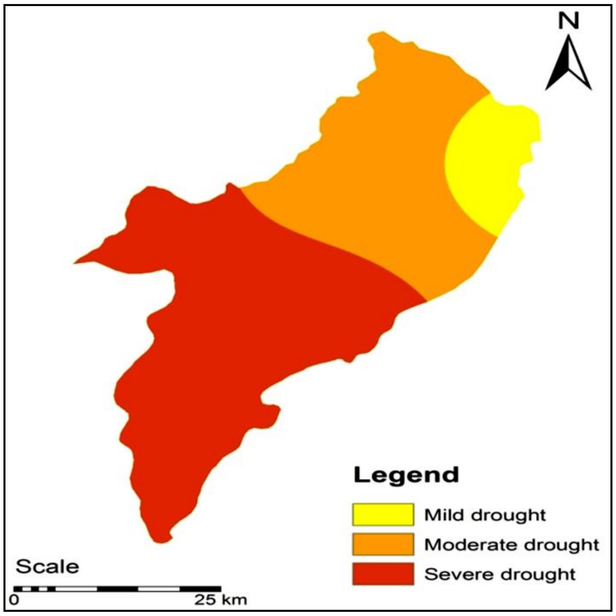

Fig. 5. The spatial variation of drought for June 2002

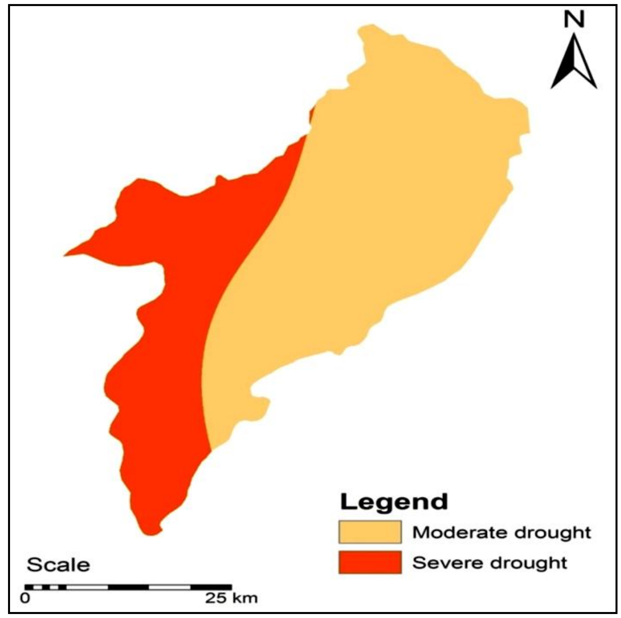

Fig. 7. The spatial variation of drought for August 2002

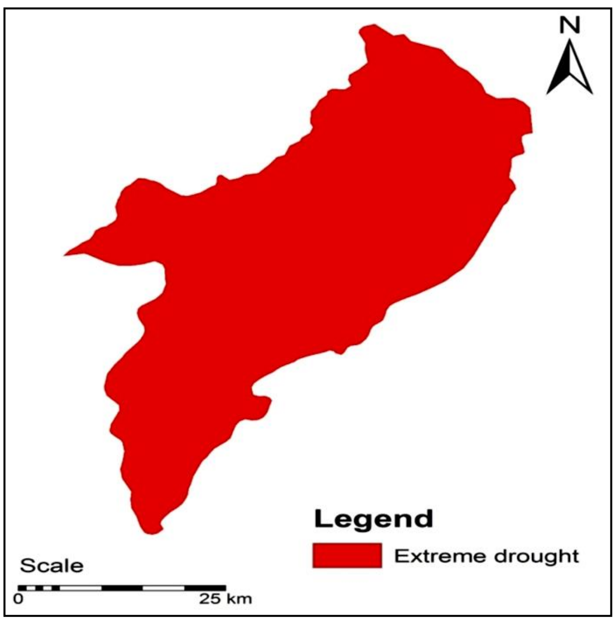

Fig. 6. The spatial variation of drought for July 2002

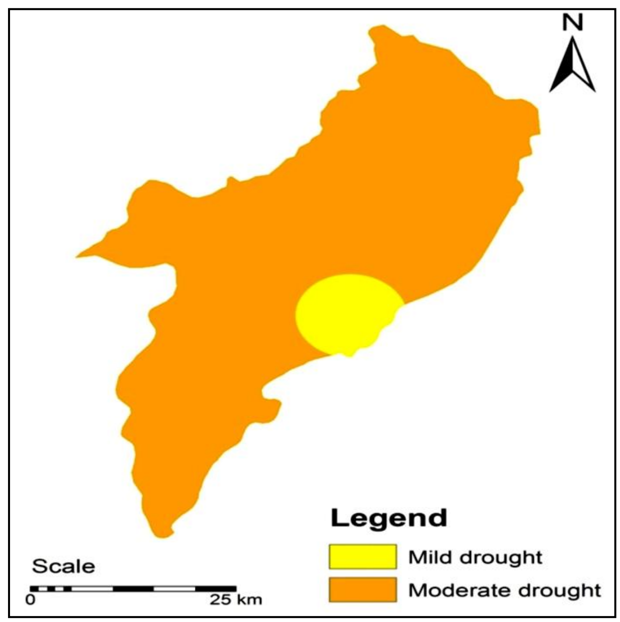

Fig. 8. The spatial variation of drought for September 2002

is determined as stated by Thom (1966). The cumulative probability was then transformed to the standard normal random variable *Z* with a mean of zero and variance of 1, which is the value of the SPI. Abramowitz and Stegun (1965) suggested an approximation for determination of the *Z* or SPI values that converts cumulative probability to the standard normal random variable *Z*.

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

$$Z = SPI = -\left[t - \frac{C_0 + C_1\,t + C_2\,t^2}{1 + d_1 t + d_2\,t^2 + d_3\,t^3}\right] \tag{8}$$

$$\text{where, } t = \sqrt{\ln\left\{\frac{1}{(H(x))^2}\right\}} \tag{9}$$

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

$$Z = SPI = +\left[t - \frac{C_0 + C_1\,t + C_2\,t^2}{1 + d_1 t + d_2\,t^2 + d_3\,t^3}\right] \tag{10}$$

TABLE 5

Spatial and temporal variation of drought during 2002 based on 3-month SPI

Drought severity	Area (sq. km.) under various drought severity classes during monsoon months			
	June	July	August	September
Extreme	-	2054.39(100%)	-	-
Severe	1145.09 (55.74%)	-	713.61 (34.74%)	-
Moderate	725.11 (35.29%)	-	1340.78(65.26%)	1921.15(93.51%)
Mild	184.19 (8.97%)	-	-	133.24 (6.49%)

TABLE 6

Variation in several drought characteristics based on the SPI time scale for Sagar station

Time scale (Months)	Drought duration (Month)	No of drought events	Average drought intensity	Maximum drought severity	Number of drought events under various severity classes			
					Extreme	Severe	Moderate	Mild
1	55	43	-1.08	-3.01	4	7	14	28
3	158	66	-0.90	-2.24	3	10	25	118
6	156	50	-1.04	-2.71	7	18	42	89
12	167	27	-1.05	-2.29	5	30	34	97
24	183	14	-1.05	-2.11	2	15	70	95

where, $$t = \sqrt{\ln\left\{\frac{1}{(1-H(x))^2}\right\}} \tag{11}$$

where, C_0= 2.515517, C_1 = 0.802853, C_2 = 0.010328, d_0 = 1.432788, d_1= 0.189269 and d_2 = 0.001308

The frequency, duration and intensity of drought have been calculated using SPI. The positive sum of the SPI for all the months within a drought event is termed as drought magnitude which represents the severity of drought and the division of the drought magnitude by its duration results in drought intensity (Thomas *et al*., 2014). The values of SPI are expressed in standard deviations, positive SPI (*i.e*., greater than normal precipitation) indicating the intensity of wet conditions and negative SPI values (*i.e*., less than normal precipitation) indicating the intensity of drought conditions. So a drought event occurs during the period when the SPI is continuously negative (with intensity less than -0.5). The classification of the drought severity is given in Table 2.

2.5. *Spatial and temporal assessment of drought characteristics*

The soil moisture is another important factor responsible for drought in agricultural areas and its decrease in the region of the plant root zone indicates the water stress for crop growth and agricultural drought in a region. The monsoon season in the study area ranges for 3 months between mid-June and mid-September so the occurrence of agricultural drought in the study area is more sensitive to a 3-month SPI (Thomas *et al.*, 2015). The spatial and temporal variation of soil moisture and thereby the agricultural drought can be evaluated using the 3-m SPI which is considered as a suitable indicator to represent the soil moisture variation (Sims *et al.*, 2002 and Thomas *et al*., 2016). A point map of 3-m SPI values has been created for each of the monsoon months for the drought years using Integrated Land and Water Information System (ILWIS) 3.0 software and spatially interpolated using moving average algorithm to obtain the variation of the drought severity in the basin. The interpolated map was reclassified on the basis of the modified drought severity classes. The final map showing the variation of drought severity within the basin was prepared by the raster operation cross.

3. Results and discussion

3.1. *Temporal variation of drought characteristics*

The application of the SPI-based drought analysis pertaining to time scales of 3-months has been used for evaluating the soil moisture drought characteristics in the

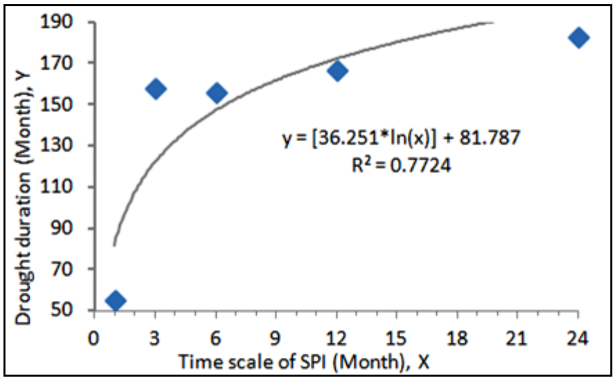

Fig. 9. Relationship between drought duration and time scale of SPI

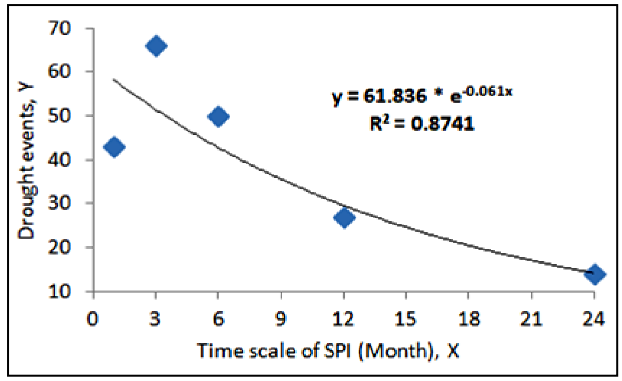

Fig. 10. Relationship between number of drought events and time scale of SPI

region. The temporal variation of drought on the basis of 3-m SPI at Sagar, Banda and Khurai are depicted in Figs. (2-4). The temporal variation of drought characteristics at various time scales including its onset, termination, duration as well as its severity can be easily identified from these graphs. Based on the SPI values, major drought events observed have been highlighted in the Figs. (2-4).

The drought events faced at all the three rain gauge stations have been analysed and the results given in Table 3. It has been observed that the number of extreme drought events occurred at Sagar, Khurai and Banda are 3, 4 and 2 respectively during the period of 1970-2014. A maximum of 11 severe drought events and 25 moderate drought events occurred at Khurai whereas maximum numbers of mild drought events (123) occurred at Sagar. However, the total number of drought events has been distributed in the basin, varying between 110 events at Khurai to 161 events at Sagar.

3.2. *Drought characteristics assessment based on 3-m SPI*

The drought characteristics, including onset, termination, duration, severity and intensity based on the 3-month SPI have been evaluated for the Sagar, Banda and Khurai rain gauge station. The drought severity assessment based on the 3-month SPI time series indicates that the maximum drought severity of -11.17 occurred between November 1991 to August 1992 having the longest duration of 10 months, indicating failure of monsoon rainfall in the area under Sagar rain gauging station. The next most severe drought occurred from June 2002 to September 2002, with a severity of -7.93 and it was of 4 months' duration drought in the area under Khurai rain gauge station. The onset of most of the drought events take place during the beginning of *Kharif* season (June and July) and its termination occurs by the end of August or September, thereby affecting the agricultural crops severely. Highest drought intensity of -2.13 was observed in Khurai during August to October 1980. The drought characteristics including the onset, termination, duration, severity and intensity are given in Table 4.

3.3. *Temporal variation of drought characteristics*

The spatio-temporal progression and subsequent withdrawal of the drought phenomena in the region for the monsoon months during the drought of 2002 is presented in Figs. (5-8). In June 2002 due to the late arrival of monsoon, the drought-like situation raised in the basin area with about 55.74% area was experiencing severe drought conditions, followed by 35.29% area under moderate drought condition and only 8.97% area faced mild drought conditions. During this period the south part of the basin was under severe drought events whereas the extreme north and few portion of north-east was under moderate drought. Due to the slow progression of monsoon and lack of adequate rainfall, the drought situation got worsened considerably in July 2002, with the almost entire area (2054.39 sq. km.) experiencing extreme drought conditions. During August 2002 which is one of the principal monsoon months, the drought situation in the basin area was reduced, with 34.74% of the area under severe drought and 65.26% under moderate drought. Mostly the southwest part of the basin was under severe drought condition whereas the northeast part of the basin was under moderate drought condition. Towards the end of monsoon season, during September, the drought severity further decreased with an area of 93.51% reeling under moderate drought and only 6.49% of the area was experiencing mild drought conditions. The area under moderate drought further spread to entire basin area except few patches falling in southeast near the centre of the basin which was experiencing mild drought condition. The study indicates that the south-west part of the basin is

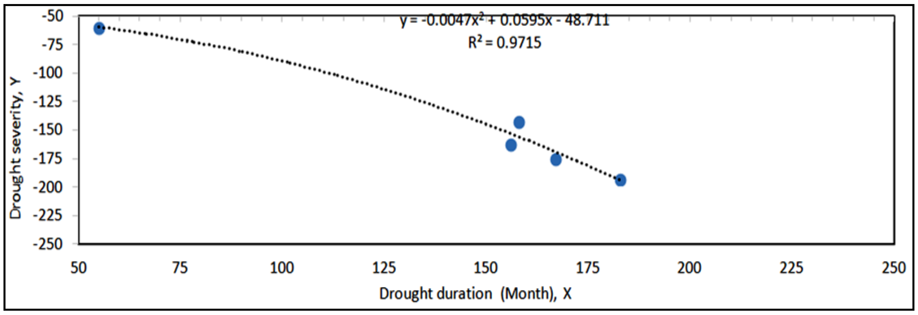

Fig. 11. Relationship between number of drought severity and drought duration

drought prone for most of the time during drought. Similar analysis has been carried out for the remaining drought years during which extensive droughts were observed in the region. The variation of drought severity and area under various drought severity classes during drought period of June to September 2002 is analysed in Table 5. This analysis helps to identify the areas and regions in Dhasan basin where drought is dominant in terms of severity and the pattern of areal expansion and withdrawal of drought in the subsequent months.

3.4. *Influence of time scale on drought characteristic*

The SPI values have been estimated for all the rain gauging stations of Dhasan basin for time scales of 1, 3, 6, 12 and 24 months. The variation in several drought characteristics based on the SPI time scale for Sagar station is presented in Table 6. For 1-m time scale drought duration is 55 months with a number of drought events 43, with further increase in the time scale to 3-month the drought duration increases to 158 and the number of drought events to 66. But with increases in the time scale to 6 or 12-month SPI, the number of drought events decrease but the average drought intensity increases. In case of 24-month time scale, the drought duration and average drought intensity increases but the number of drought events decrease. It can be obtained from the comparison of the 1, 3, 6, 12 and 24-month SPI that there are changes in drought duration and number of drought events as the time scales change. The relationship between drought duration and SPI time scale is shown in Fig. 9, which shows that the drought duration increases with the increase time scale SPI. Similarly, Fig. 10 represents the relationship between a number of drought events and time scale of SPI, which indicates that an increase in the time scale of SPI tends to decrease the number of drought events. Fig. 11 signifies that the drought severity increases with an increase in drought duration. The empirical relationships are also developed between (*i*) drought duration and SPI time scale (*ii*) number of drought events and time scale of SPI (*iii*) drought severity and duration.

4. Conclusions

The spatiotemporal analysis of drought based on 3-m SPI is helpful to identify the progression and withdrawal of drought and the areas prone to drought and further the pattern of expansion drought in the subsequent months. Spatial analysis of drought based on meteorological drought indicates that the North-Eastern part of Dhasan basin is drought prone for most of the time. The highest number of droughts (161) have been observed in Sagar followed by 117 drought events in Banda and 110 drought events in Khurai. The onset of most of the drought events in the basin take place during the beginning of *Kharif* season (June and July) and its termination occurs by the end of August or September, so affect the agricultural crops severely. Thereby, it necessitates the need to develop water harvesting structures or to adopt water conservation practices to provide life-saving irrigation during critical periods. The influence of drought time scale on various drought characteristics indicates that an increase in the time scale of SPI tends to decrease the number of drought events but it increases drought duration. This information will help the decision makers in better decision making for drought mitigation and further management planning.

Disclaimer

The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Abramowitz, M. and Stegun, I. A., 1965, "Handbook of mathematical functions with formulas, graphs and mathematical tables", *National bureau of standards*, USA, Applied mathematics series-55.

Dracup, J. A., Lee, K. S. and Paulson, E. G., 1980a, "On the statistical characteristics of drought events", *Water Resources Research*, **16**, 2, 289-296.

Dracup, J. A., Lee, K. S. and Paulson, E. G., 1980b, “On the definition of droughts”, *Water Resources Research*, **16**, 2, 297-302.

Kar, S. K., Thomas, T. and Singh, R. M., 2016, “Assessment of drought characteristics for Dhasan basin in Bundelkhand region”, *International Journal of Agriculture, Environment and Biotechnology*, **9**, 5, 897-902.

Kar, S. K., Thomas, T., Singh, R. M. and Patel, L., 2018, “Integrated assessment of drought vulnerability using indicators for Dhasan basin in Bundelkhand region, Madhya Pradesh, India”, *Current Science*, **115**, 2, 338-346.

McKee, T. B. N., Doesken, J. and Kleist, J., 1993, “The relationship of drought frequency and duration to time scales”, *Eight Conference on Applied Climatology. Amer. Meteor. Soc.*, 179-184.

Pandey, R. P., Dash, B. B., Mishra, S. K. and Singh, R., 2008, “Study of indices for drought characterization in KBK districts in Orissa”, *Hydrological Processes*, **22**, 12, 1895-1907.

Pareta, K., 2004, “Geomorphological and hydrogeological study of Dhasan basin, India using remote sensing techniques”, Thesis Ph.D., Faculty of science, Department of general and applied geography, Dr. Harisingh Gour University, Sagar (MP), India.

Redmond, K. T., 2002, “The depiction of drought”, *Bull. Amer. Meteor. Soc.*, **83**, 1143-1147.

Sims, A. P., Niyogi, D. S. and Raman, S., 2002, “Adopting drought indices for estimating soil moisture: A North Carolina case study”, *Geophysical Research Letter*, **29**, 8, 241-244.

Thom, H. C. S., 1966, “Some methods of climatological analysis”, World Meteorological Organization Technical Note, Number 81, WMO, Geneva.

Thomas, T., Jaiswal, R. K., Nayak, P. C. and Ghosh, N. C., 2014, “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. and Ghosh, N. C., 2015, “Spatiotemporal analysis of drought characteristics in the Bundelkhand region of central India using the Standardized Precipitation Index” *Journal of Hydrologic Engineering*, **20,** 11, 05015004.

Thomas, T., Jaiswal, R. K., Galkate, R., Nayak, P. C. and Ghosh, N. C., 2016, “Drought indicators-based integrated assessment of drought vulnerability: a case study of Bundelkhand droughts in central India”, *Natural Hazards*, **81**, 3, 1627–1652.

Tigkas, D., Vangelis, H. and Tsakiris, G., 2013, “Water resources management in an interdisciplinary and changing context” Proceedings of 8th International Conference of EWRA, Porto, Portugal.

Tigkas, D., Harris, V. and George, T., 2014, “DrinC: a software for drought analysis based on drought indices”, *Earth Science Informatics*, **8**, 3, 697-709.