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Spatio-Temporal Variation of Drought Characteristics in Bearma Basin of Bundelkhand Region in Madhya Pradesh

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ABSTRACT: Long-term drought forecasts can provide valuable information to help in mitigation of the consequences of drought. The study has been carried out for Bearma basin of Bundelkhand region in Madhya Pradesh which is regularly suffered from frequent droughts due to large variation of rainfall. Rainfall data of 5 stations located in Bearma basin over the period of 1976-2005 were used. Efforts have been made to identify the drought characteristics through the modern technique using the Standardized Precipitation Index (SPI). The drought severities as well as the drought intensity have been evaluated for all the rain gauge stations in Bearma basin. The result showed that Damoh faced drought of 5 months in 1979 with the highest drought severity of -11.95 and intensity of -2.39 whereas a drought of severity -11.12 occurred during June to November 1979 at Jabera for a period of 6 months. It is also indicated that the maximum intensity of -5.50 was observed between onset and termination of drought of 1984 at Hatta. The drought of 4 months duration was recorded at Deori during June-September 1992 and at Rehli during August-November 1986. The spatial and temporal variations of drought and its progression into more areas in subsequent months and its withdrawal after the initiation of sufficient rainfall has been studied in detail for drought year 2002 as well as normal year 2004. The analysis indicated that each drought had unique phenomenon and area under its influence varied from one drought event to the other. In July 2002, 100% of the basin was reeling under extreme and severe drought whereas by October 2002, over 71% of the basin area was back to normal condition due to favourable rainfall scenario. During 2004, the drought situation varied rapidly between successive months. About 86% of the area was affected with moderate drought in June 2004 but in July and August, the situation was near normal in the entire basin.

Key words: Drought characteristics, standardized precipitation index (SPI)

A drought is a prolonged period of water deficit, and usually occurs when an area does not receive significant precipitation for a sustained period of time, say several months (Chen *et al.,* 2009*;* Linsely *et al.,* 1959*)*. Droughts can be classified into four categories as meteorological, hydrological, agricultural and socio-economic *(*American Meteorological Society*,* 1997*;* Palmer, 1965*;* White and Walcott*,* 2009*)*. Drought is a normal part of climate and occurs in all regions of the world. Drought is a regional phenomenon and its characteristics will vary from one climate regime to another (Iglesias *et al.,* 2009). Drought is often perceived as a creeping hazard as it develops slowly and has a prolonged duration (Smith, 2000). Drought has become more common and can last for many years which can have disturbing effects on the socioeconomic, agricultural, and environmental conditions that may be resulted from one or more of the water-scarcity factors of insufficient precipitation, high evapotranspiration, and over-exploitation of water resources (Bhuiyan *et al.* 2006; Wilhite 2000; Yurekli and Kurunc 2004). The preparedness and planning for a drought depend on the information about its areal extent, severity and duration (Mishra and Singh, 2011). Akinremi *et al*. (1996) state that the spatial and temporal dimensions of drought create problems in generating a drought index because not only an anomaly must be normalized with respect to location, but the anomaly must also be normalized in time if it is produce a meaningful estimate of drought. The SPI accomplishes both. Drought occurrences are depending on various interactions of hydrological phenomena such as precipitation, runoff, evaporation, infiltration, and surface and groundwater storages. McKee *et al*. (1993) developed the standardized precipitation index (SPI) to understand whether a deficit of precipitation has different impacts on the groundwater, reservoir storage, soil moisture and stream flow. The index offers the capability to monitor climatic conditions over a wide spectrum of time scales; it permits to compare dry and wet periods on different locations. SPI was designed to quantify the precipitation deficit for multiple time scales, which reflect the impact of drought on the availability of different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short time scale, while groundwater, stream flow, and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee *et al*. (1993) originally calculated the SPI for 3, 6, 12, 24, and 48 month moving average time scales for the monitoring of drought. The SPI has been calculated for shorter period of 3 months as the 3-m SPI is suitable representation of short and medium term moisture conditions and offers a seasonal estimation of precipitation deficit or surplus that is particularly useful in agricultural activities whereas 12 month SPI avoids intra annual frequency variations and allows the identification of the main hydrological drought and dry/wet periods (Vicenta-Serrano, 2005). The SPI calculation for any location is based on the long-term precipitation record (at least 30 years) for a desired period. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation.

Long-term drought forecasts can provide valuable information to help in mitigation some of the consequences of drought. The Bundelkhand region has been in the grip of severe drought in the last decade mainly due to poor, limited and untimely rainfall and its high variability coupled with improper water resources development and management. Lack of developmental sachems and scientific management of the available water resources have worsened the situation to a greater extent as the area is largely rainfed and depend upon the south-west monsoon rains. The recurrent droughts in the last decade had led to large scale migration due to non availability of water for domestic and agricultural activities. The Bearma basin, a major tributary of Ken river system, the life line of Bundelkhand has been selected for the present study to assess the drought scenario in the recent years for the planning to cope up with such situation in future.

Materials and Methods

Study area

Bearma river, a tributary of river Ken is bounded by Sonar basin on the west, Ken sub-basin on the east and lies in Madhya Pradesh. Parts of Narsinghpur, Jabalpur, Sagar, Damoh and Panna districts are drained by river Bearma. Some important tributaries of Bearma river are Lamti, Sun, Bamner, Guraiya, Godhar and Mala. The index map showing the location of Bearma basin is shown in Figure 1.The total catchment area of the basin is 5807 km^2 and it is a leaf shaped elongated basin. The gauge discharge (G/D) site is located at Gaisabad and the catchment area up to Gaisabad is about 5807.23 km^2. In the basin, more than 90% of the annual rainfall occurs during the south west monsoon months of June to October. The average rainfall for the basin is about 1187 mm. The climatic conditions prevailing in the basin vary from semi arid to dry. There are five rain gauge stations in the basin upto Gaisabad namely Deori, Rehli, Damoh, Jabera and Hatta.

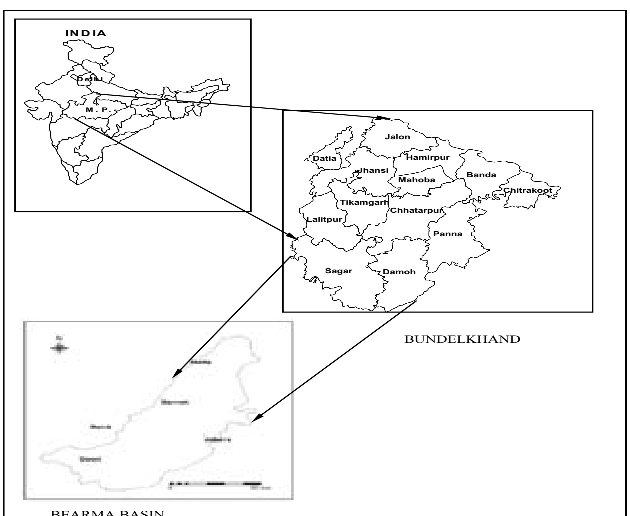

Fig. 1 : Index map of Bearma basin

Basin is covered to a large extend by forests, shrubs, and grasslands. Out of the total geographical area of the Bearma basin, about 36% area is covered by forests, 37% area is agricultural land, 5% is barren and fallow lands and the remaining area is under permanent pastures, miscellaneous crops, and waste land. The major crop grown in the basin is soybean during kharif season and other predominant crops grown in the basin are wheat, oil seeds, pulses and grams in rabi season. The agriculture of the catchment is mostly rainfed.

Data used

The rainfall data of five rain gauge stations falling in Bearma basin namely Hatta, Jabera and Damoh in Damoh district and Rehali and Deori in Sagar district for the period of 1976 to 2005 have been used for identifying the agricultural drought by computation of SPI. The daily rainfall data for the period 1976 to 2005 compiled from the State Land Records Department, Madhya Pradesh and Water Resources Department, Government of Madhya Pradesh were used to interpret the results.

Standardized precipitation index (SPI)

The computation of Standardized Precipitation Index consists of following steps:

(1) Calculate the mean for the normalized precipitation values of the log normal (ln) rainfall series and compute the shape & scale parameter β and α respectively by the equations given here under:

Log mean : $\bar{X}_{ln} = \frac{\sum ln\, X}{N}$ 1

Shape parameter : $\beta = \frac{1}{4U}[1 + \sqrt{\frac{4U}{3}}]$ 2

Scale parameter : $\alpha = \frac{\bar{X}}{\beta}$ 3

Here U is the constant, U = $ln(\overline{X}) - \bar{X}_{ln}$

(2) The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. The cumulative probability given by Gamma distribution as follows:

$$G(x) = \frac{1}{\alpha^{\beta}\,\Gamma\beta}\int_0^x x^{\beta-1} e^{\frac{-x}{\alpha}}\, dx \qquad \text{.................. 4}$$

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

$$G(x) = \frac{1}{\Gamma\beta}\int_0^{t\alpha} t^{\beta-1} e^{-t}\, dt \qquad \text{.................. 5}$$

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

$$H_{(x)} = q + (1-q)G \qquad \text{.................. 6}$$

where, q is the probability of zero.

If 'm' is the number of zeros in a precipitation time series, Thom (1966) states that 'q' can be estimated by [m/N]. He used the tables of the incomplete gamma function to determine the cumulative probability [G(x)]. McKee et al. (1993) used an analytic method to determine the cumulative probability. The cumulative probability, [H(x)], is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI.

The 'z' or SPI is more easily obtained computationally using an approximation provided by Abramowitz and Stegun (1965) that converts cumulative probability to the standard normal random variable Z.

$$Z = SPI = -\left[t - \frac{c_{0+C_1 t + C_2 t^2}}{1+d_1 t + d_2 t^2 + d_3 t^3}\right] \quad \text{For } 0< H(x) \leq 0.5 \qquad \ldots\ldots\ldots 7$$

$$Z = SPI = +\left[t - \frac{c_{0+C_1 t + C_2 t^2}}{1+d_1 t + d_2 t^2 + d_3 t^3}\right] \quad \text{For } 0.5 < H(x) \leq 1.0 \qquad \ldots\ldots\ldots 8$$

where,

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

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

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

A drought event occurs any time during the period when SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. The summation of the negative SPI's for all the days within a drought event can be termed as *drought magnitude* and the division of magnitude by its duration is known as the *intensity of drought* for that particular duration. The SPI represents a cumulative probability in relation to the base period for which the gamma parameters are estimated. The classification used for identifying the agricultural drought characteristics based on SPI is given in Table 1.

Table 1 : Standard ranges of SPI values and their classification

SPI	Condition	SPI	Condition
-2.0 <	Extreme drought	0.50 to 1.00	Mild wet
-1.50 to -2.0	Severe drought	1.00 to 1.50	Moderate wet
-1.0 to -1.50	Moderate drought	1.50 to 2.00	Severe wet
-0.50 to -1.0	Mild drought	> 2.00	Extreme wet
-0.50 to 0.50	Near normal		

Analysis of spatial variation of drought

The spatial variation of the drought for Bearma basin has been determined based on the spatial analysis carried out by interpolating 3-month SPI values at various rain gauge stations through ILWIS 3.6. For example the 3-month SPI value for August is estimated on the basis of rainfall data of previous three months (May to July).The map has further been subjected to image classification operation of ILWIS and the area is redistributed into different classes of dryness and wetness. Subsequently the raster operation has been carried out to obtain the final map showing the various drought classes in the Bearma basin. The area under different drought classes is obtained from the histogram of the final map.

Results and Discussion

Temporal variation of drought

The drought characteristics for the various rain gauge stations in Bearma basin have been evaluated using the Standardized Precipitation Index (SPI). To characterize the drought which has immediate impact on the agricultural sector, SPI for 3-month time scale was used for evaluating the drought characteristics as it is directly related to the build-up of soil moisture essential for the crop growth. A 3-month SPI reflects short- and medium-term moisture conditions and provides a seasonal estimation of precipitation. The monthly SPI values based on the time scale of 3-months for the rain gauge stations namely Damoh and Jabera are given in Figures 2 and 3, respectively. It is observed that both Damoh and Jabera faced maximum drought of 5 and 6 months duration in 1979 respectively during the period of 1950- 2004.

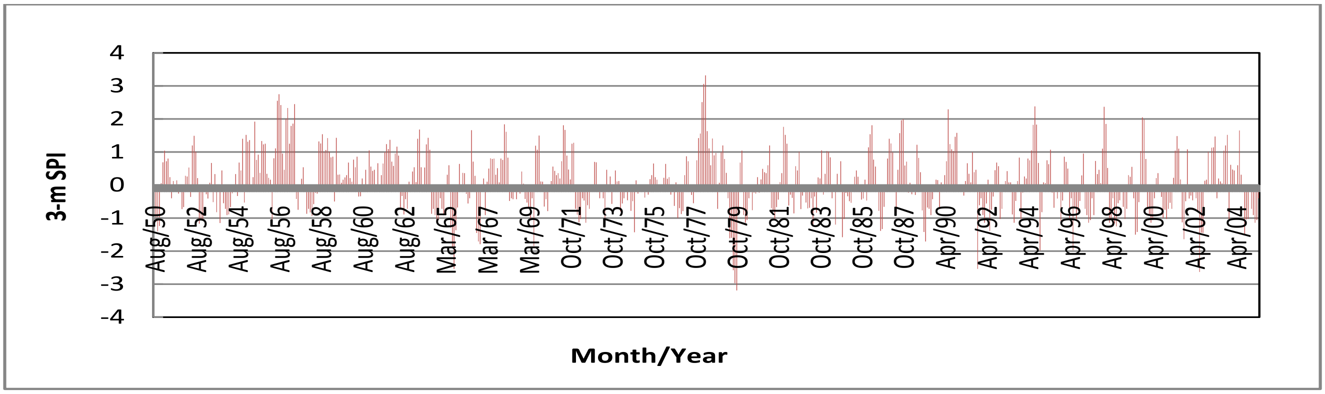

Fig. 2 : Temporal variation of 3-month SPI at Damoh

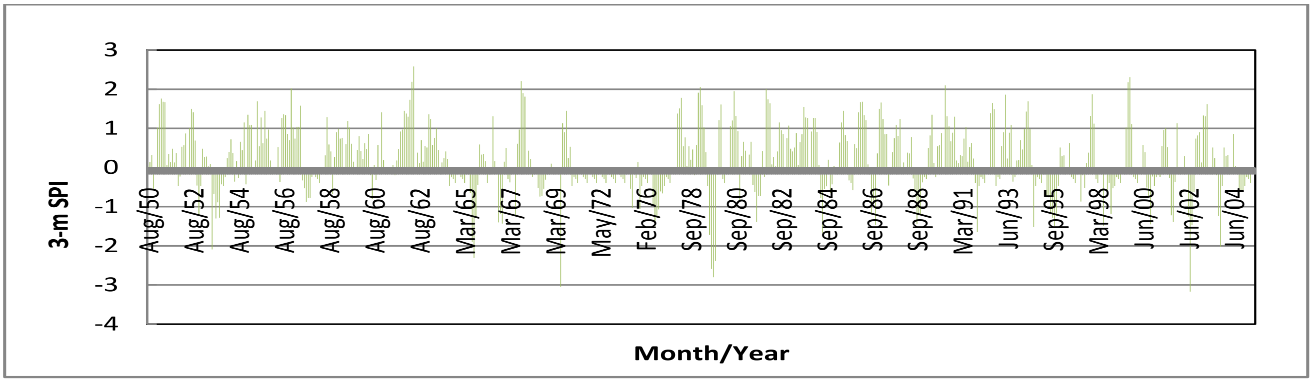

Fig. 3 : Temporal variation of 3-month SPI at Hatta

The drought severity as well as the drought intensity evaluated for the all rain gauge stations in Bearma basin based on the 3-month SPI and is given in Tables 2 to 6. It is observed from Table 2 that Damoh faced droughts of duration of 5 months in 1979 with highest drought severity of -11.95 and an intensity of -2.39 whereas a drought of severity -11.12 occurred during June to November 1979 at Jabera for duration of 6 months (Table 3). Table 4 shows that the maximum intensity of -5.50 was observed at Hatta during July 1984 and October 2000. The drought duration of 4 months has been observed at Deori during June-September 1992 (Table 5) and at Rehli during August-November 1986 (Table 6).

Table 2 : Drought characterisitics at Damoh based on 3-m SPI

Onset of drought	Termination of drought	Duration (months)	Severity	Intensity
Dec-76	Dec-76	1	-1.00	-1.00
Jun-79	Oct-79	5	-11.95	-2.39
Mar-80	Apr-80	2	-2.20	-1.10
Aug-81	Aug-81	1	-1.04	-1.04
Jun-83	Jun-83	1	-1.19	-1.19
Jul-84	Jul-84	1	-1.20	-1.20
Nov-84	Dec-84	2	-2.61	-1.30
Sep-86	Oct-86	2	-2.72	-1.36
Oct-88	Nov-88	2	-3.13	-1.56
Nov-91	Nov-91	1	-2.54	-2.54

Mar-92	Mar-92	1	-1.14	-1.14
Jun-92	Jun-92	1	-1.39	-1.39
Dec-92	Dec-92	1	-1.03	-1.03
Aug-93	Aug-93	1	-1.14	-1.14
Dec-93	Dec-93	1	-1.03	-1.03
Nov-94	Nov-94	1	-1.98	-1.98
Nov-95	Nov-95	1	-1.09	-1.09
Apr-96	Apr-96	1	-1.06	-1.06
Jun-96	Jun-96	1	-1.97	-1.97
Aug-96	Aug-96	1	-1.08	-1.08
Mar-97	Apr-97	2	-2.20	-1.10
Mar-98	Apr-98	2	-2.20	-1.10
Jun-89	Jul-98	2	-2.41	-1.20
Dec-98	Dec-98	1	-1.03	-1.03
Jun-99	Jul-99	2	-2.92	-1.46
Mar-00	Apr-00	2	-2.20	-1.10
Dec-00	Dec-00	1	-1.03	-1.03
Sep-01	Oct-01	2	-2.77	-1.38
Jul-02	Sep-02	3	-5.52	-1.84
Dec-03	Dec-03	1	-1.03	-1.03

Table 3 : Drought characterisitics at Jabera based on 3-m SPI

Onset of drought	**Termination of drought**	**Duration (months)**	**Severity**	**Intensity**
Jun-79	Nov-79	6	-11.12	-1.85
Sep-81	Nov-81	3	-3.29	-1.09
Nov-91	Nov-91	1	-1.44	-1.44
Jul-93	Aug-93	2	-3.13	-1.56
Nov-94	Nov-94	1	-1.43	-1.43
Jun-96	Jun-96	1	-1.51	-1.51
Jun-98	Jul-98	2	-2.61	-1.3
Sep-98	Sep-98	1	-108	-1.08
Nov-98	Nov-98	1	-1.15	-1.15
Oct-00	Nov-00	2	-3.28	-1.64
Sep-01	Oct-01	2	-2.52	-1.26
Jun-02	Jul-02	2	-4.15	-2.07

Table 4 : Drought characterisitics at Hatta based on 3-m SPI

Onset of drought	Termination of drought	Duration (months)	Severity	Intensity
Jul-76	Sep-76	3	-2.09	-0.70
Jul-79	Oct-79	4	-1.30	-0.33
Aug-81	Aug-81	1	-1.28	-1.28
Jul-84	Jul-84	1	-5.50	-5.50
Sep-86	Sep-86	1	-4.01	-4.01
Nov-86	Nov-86	1	-1.23	-1.23
Sep-88	Nov-88	3	-3.05	-1.02
Nov-91	Nov-91	1	-1.04	-1.04
Nov-94	Nov-94	1	-1.23	-1.23
Aug-95	Nov-95	4	-2.09	-0.52
Jun-98	Jun-98	1	-1.30	-1.30
Oct-98	Oct-98	1	-1.28	-1.28
Oct-00	Oct-00	1	-5.50	-5.50
Sep-01	Oct-01	2	-4.01	-2.01
Jun-02	Aug-02	3	-1.23	-0.41
Oct-03	Nov-03	2	-3.05	-1.53

Table 5 : Drought characterisitics at Deori based on 3-m SPI

Onset of drought	Termination of drought	Duration (months)	Severity	Intensity
Aug-79	Oct-79	3	-5.12	-1.70
Jul-83	Aug-83	1	-2.90	-1.45
Jul-84	Jul-84	1	-1.65	-1.65
Nov-84	Nov-84	1	-1.34	-1.34
Aug-86	Oct-86	3	-4.18	-1.39
Jul-89	Jul-89	1	-1.15	-1.15
Sep-89	Sep-89	1	-1.07	-1.07
Sep-91	Sep-91	1	-1.06	-1.06
Nov-91	Nov-91	1	-2.20	-2.20
Jun-92	Sep-92	4	-5.62	-1.40
Nov-95	Nov-95	1	-1.27	-1.27
Jun-96	Jun-96	1	-2.35	-2.35
Jun-97	Jun-97	1	-2.46	-2.46
Oct-00	Oct-00	1	-1.69	-1.69
Jul-02	Jul-02	1	-1.36	-1.36
Jun-03	Jun-03	1	-1.51	-1.51
Jun-07	Jun-07	1	-1.03	-1.03
Oct-07	Nov-07	2	-3.35	-1.67
Sep-08	Sep-08	1	-1.53	-1.53

Table 6 : Drought characterisitics at Rehli based on 3-m SPI

Onset of drought	Termination of drought	Duration (months)	Severity	Intensity
Aug-79	Oct-89	3	-4.79	-1.59
Aug-81	Aug-81	1	-1.52	-1.52
Jul-82	Jul-82	1	-1.47	-1.47
Jun-83	Jun-83	1	-1.12	-1.12
Aug-83	Aug-83	1	-1.56	-1.56
Jul-84	Jul-84	1	-1.54	-1.54
Nov-84	Nov-84	1	-1.19	-1.19
Aug-86	Nov-86	4	-4.87	-1.21
Nov-91	Nov-91	1	-2.07	-2.07
Jun-92	Jul-92	2	-4.11	-2.05
Sep-00	Nov-00	3	-3.78	-1.26
Jul-02	Jul-02	1	-2.24	-2.24
Sep-04	Sep-04	1	-1.26	-1.26
Oct-05	Oct-05	1	-1.38	-1.38
Jun-06	Jun-06	1	-1.02	-1.02
Oct-06	Oct-06	1	-1.06	-1.06
Jun-07	Jun-07	1	-1.07	-1.07
Aug-07	Aug-07	1	-1.01	-1.01
Nov-07	Nov-07	1	-1.44	-1.44
Oct-08	Nov-08	2	-2.42	-1.21

Spatial variation of drought characteristics

The spatial variation of the various drought classes for 2002-03 and 2004-05 is given in the Table 7 and Table 8 respectively. It can be seen from Table 7 that during the drought year of 2002, the progression of the drought commenced with about 39.53% area of basin reeling under moderate drought, which increased considerably to 89% of the area falling under extreme drought conditions and 10.96% area under severe droughts during July 2002 practically meaning that the entire basin was reeling under the spell of extreme and severe droughts. The adequate rainfall during August 2002 has improved the situation to a great extent reducing the area falling under severe and extreme droughts and only 25.72% and 28.60% falling under moderate and mild drought category.

Thereafter due to the increased rainfall availability in August 2002 the drought affected area reduced to 25.72% with moderate drought conditions and in September only 12.9% of the area faced moderate droughts. On comparing the drought of 2004-05 with the drought of 2002-03, it can be inferred that the progression of drought is quite different in 2004-05 with major areas facing moderate drought. The situation further improved during September 2002 during which in more than 60% area near normal conditions prevailed.

Table 7 : Area under different drought classes in monsoon season during 2002

Month	Area covered by drought (%)		
	Extreme	Severe	Moderate
June	-	-	39.53
July	89.00	10.96	0.04
August	-	-	25.72
September	-	-	12.98
October	-	-	28.81

Similarly during 2004 the drought situation varied rapidly between successive months. About 85.64% of the area was reeling under moderate droughts during June 2004 whereas in July and August 2004, the conditions were near normal in the entire basin. However in September 2004 about 39.60% area experienced moderate drought and about 45% faced mild droughts. In October 2004 the conditions improved and about 54.38% area came under mild drought category. No instances of extreme and severe droughts occurred during any of the months in 2004. So it can be observed that in worst case scenarios, more or less the entire basin experiences drought conditions as seen during July 2002 with the drought conditions varying from moderate to extreme. The spatial variation of drought characteristics for Bearma basin in June 2002 to September 2002 is given in Figure 4 to 7, respectively.

Table 8 : Area under different drought classes in monsoon season during 2004

Month	Area covered by drought (%)		
	Extreme	Severe	Moderate
June	-	-	85.64
July	-	-	-
August	-	-	-
September	-	0.03	39.61
October	-	-	-

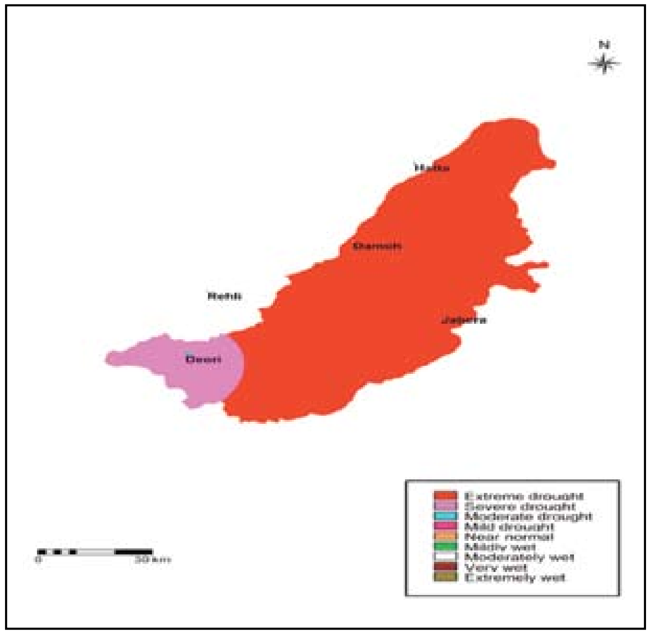

Fig. 5 : Area under different drought conditions in July 2002

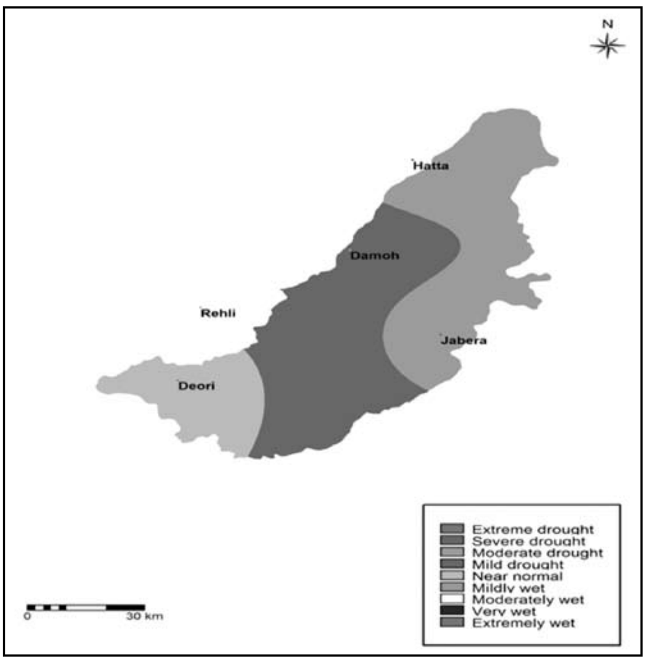

Fig. 4 : Area under different drought conditions in June 2002

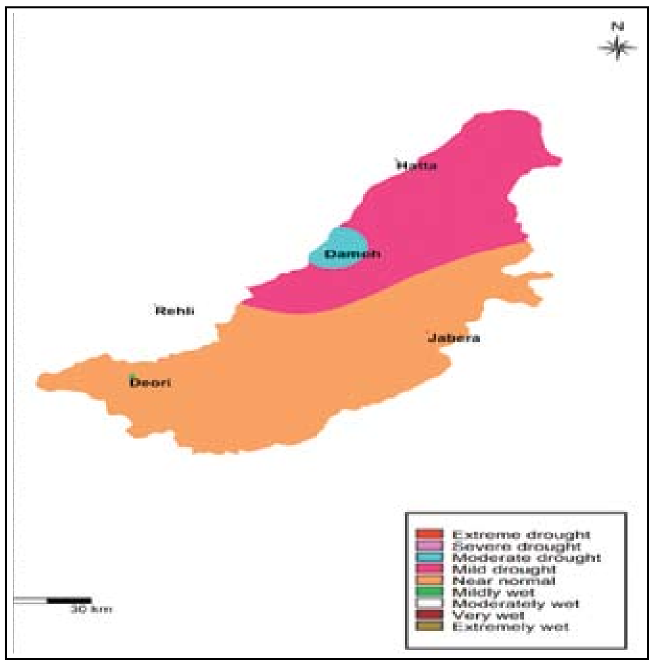

Fig. 6 : Area under different drought conditions in August 2002

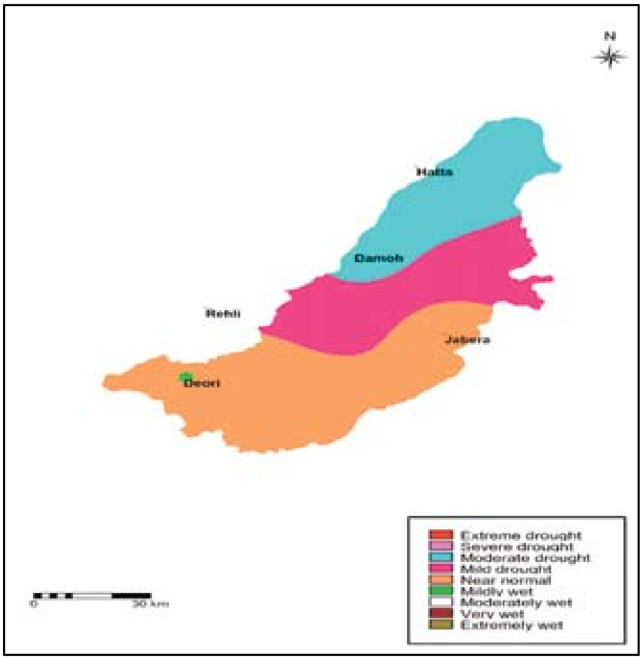

Fig. 7 : Area under different drought conditions in September 2002

Conclusions

Standardized Precipitation Index (SPI) was developed for the Bearma basin. The spatial and temporal variation of drought and its progression into more areas in subsequent months and its withdrawal after the initiation of sufficient rainfall has been studied in detail for drought year 2002 as well as normal year 2004. The analysis indicates that each drought is unique phenomenon and area under its influence varies from one drought event to the other. In July 2002, 100% of the basin was reeling under extreme and severe droughts whereas by October 2002, more than 71% of the basin area was back to normal conditions due to favourable rainfall scenario in that month. The study concludes that during drought years the soil moisture availability is drastically reduced in the entire basin and therefore the rain-fed agriculture is sure to be damaged due to the vagaries of the rainfall. Therefore, provision for supplemental irrigation is necessary for tiding the period of dry spells for which water resources projects needs to be planned in the basin.

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