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Assessment of drought characteristics for Dhasan basin in Bundelkhand region

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Abstract

Drought monitoring is an important aspect for assessing and forecasting the drought risk for an area. The various types of drought including the meteorological drought and groundwater drought have been analysed using the appropriate drought indicators for Dhasan basin. This has helped in understanding the spatio-temporal variation of droughts including duration, severity and also helped to capture the progression and withdrawal of droughts during various months of the identified drought years. Based on the Effective Drought Index (EDI), four major drought events have been identified during 1981-82, 1988-89, 2002-03 and 2007-08. The drought severity assessment based on the EDI, indicates that the maximum drought severity of -33.49 had occurred during September 2006 and May 2008 and it was of longest duration (21 months) in the area under Banda rain gauging station. An increasing trend of meteorological drought severity has been observed for all the rain gauging stations in Dhasan basin. Hydrological drought characteristics have been evaluated using Groundwater Drought Index (GDI), which indicates that the groundwater drought severity is increasing gradually in the study area. During August 2002, about 0.78 sq. km. area was under severe drought whereas, during November 2002 about 46.01 sq. km. of the area was under severe drought and only 0.62 sq. km. area was under extreme drought conditions.

Highlights

- Meteorological drought characteristics have been evaluated using Effective Drought Index (EDI) indicates an increasing trend in drought severity for Dhasan basin with maximum severity of -33.49 occurred during 2006 to 2008.
- Spatial and temporal distributions of meteorological drought have also been studied.
- Ground water drought characteristics have also been assessed using Groundwater Drought Index (GDI) to study the hydrological drought situation in the basin area.

Keywords: EDI, GDI, drought severity

India is among the most drought vulnerable countries in the world, with drought frequency of at least once in every three years during the last decades (FAO 2002, World Bank 2003). Several indices have been developed by various researchers to monitor and assess the drought characteristics. Meteorological drought is the situation when there is an extended period with considerable decrease from the normal precipitation amount over a particular region. Pandey *et al.* (2008) observed that, Effective Drought Index (EDI) better represented and quantified the drought severity than any other Index both in daily and monthly time steps. Byun *et al.* (2010) compared the performances of the EDI with 1-, 3-, 6-, 9-, 12- and 24-month Standardized Precipitation Indices (SPIs) for drought monitoring in Seoul, Korea and found that the EDI is more competent than the SPIs in measuring both short and long-term droughts. Wambua *et al.* (2014) had suggested that EDI has a higher accuracy in drought forecasting than the SPI and also better represents its onset, development and departure.

The hydrological droughts which occur due to prolonged dry spells and consequences of meteorological drought includes three constituents namely, surface water drought, groundwater drought and lowering in reservoir storage. Groundwater drought is a part of hydrological drought that occurs when groundwater recharge(R), discharge (Q) and water level (H) depart from average (Van Lanen 2005). The groundwater drought index (GDI) is a representation of water table decline and thereby amount of recharge required thus it indirectly depicts the groundwater drought. The most familiar technique used in groundwater drought analysis using groundwater level data is the Threshold Level Approach and the Sequent Peak Algorithm (Tallaksen *et al.* 2004). However, the groundwater level is a state variable and is not a flux like recharge so the cumulative deficit volume estimated with the threshold level approach is used to identify groundwater droughts better compared to other approaches. The best result is obtained for a fixed threshold level and the cumulative deficit (Van Lanen *et al.* 2000). Thomas *et al.* (2014) evaluated groundwater drought characteristics by using Groundwater Drought Index (GDI) for Central India to demarcate potential areas from where groundwater can be exploited particularly during drought emergency conditions.

Materials and Methods

Study area

This study has been carried out in Dhasan basin (up to Patan village) with a catchment area of 2054.39 sq. km, which falls in drought prone region of Bundelkhand (Madhya Pradesh) to understand and quantify the drought scenario for the region. The area is under the grip of frequent occurrence of droughts since decades due to irregularity in arrival of rainfall, early withdrawal of monsoon, scanty rainfall, and lack of sufficient water in reservoirs which ultimately affect livelihoods. River Dhasan originates from the Jashrathi hill 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. The index map of the study area is given in Fig. 1.

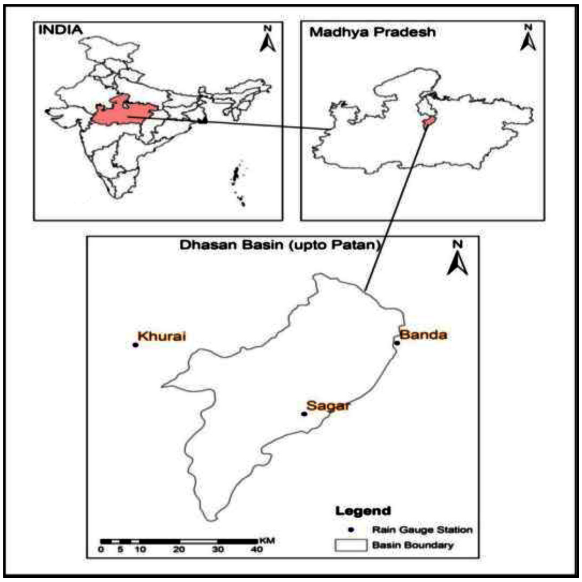

Fig. 1: Index map of Dhasan basin up to Patan

Data availability

For carrying out the drought study, the daily rainfall data (From 1981-2009) at three rain gauge stations viz., Sagar, Banda and Khurai whereas the groundwater levels (From 1985-2010) at 39 observation wells located in and around the basin have been used. The groundwater levels are observed quarterly for four seasons viz., monsoon (August), post-monsoon (November), winter (January) and summer (May). The map showing the area under influence of various groundwater observatories and their locations are represented in Fig. 2.

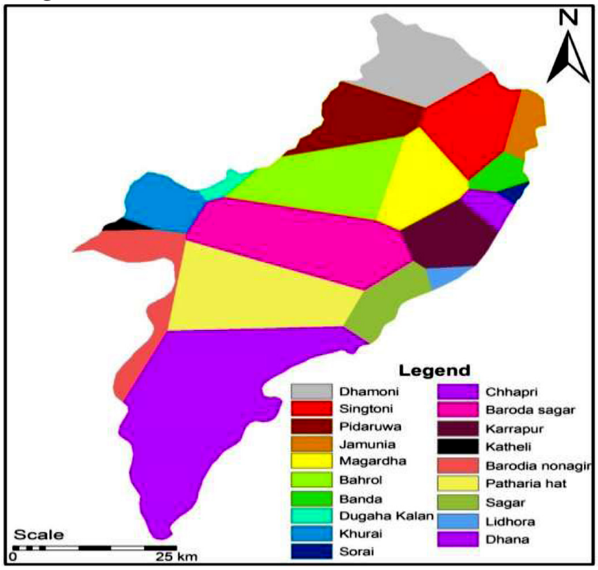

Fig. 2: Location of groundwater observatories of Dhasan basin up to Patan

Meteorological drought characteristics evaluation based on Effective Drought Index

The principle of Effective Drought Index (EDI) developed by Byun *et al.* (1999) is used to analyse drought severity with monthly precipitation data. The EDI is a function of the Precipitation required for a return to normal (PRN). In monthly analysis, the calculation steps for EDI is given as follows:

$$EP_i = \sum_{n=1}^{i}\left[\frac{\sum_{m=1}^{n} P_m}{n}\right] \tag{1}$$

where, EP_i is the effective precipitation parameter (mm), P_m is the effective precipitation in (m-1) months before the current month (mm), i represents the duration of the preceding period (months), n is the total number of periods before the current month (months).

The mean of *EP* for each month are calculated and the *EP* values are converted to deviations from the mean *(DEP)* by subtracting it from *EP* values.

$$DEP = EP - MEP \tag{2}$$

EP is effective precipitation and *MEP* is the mean of each month's *EP*. Precipitation required for a return to normal *(PRN)* values were calculated as a function of *DEP* using the relation:

$$PRN_J = \frac{DEP_j}{\sum_{n=1}^{j}(1/n)} \tag{3}$$

j is actual duration over which precipitation deficit is accumulated, The summation term ($1/n$) is the sum of the reciprocals of all the months.

$$EDI_j = \frac{PRN_j}{std\left(PRN_j\right)} \tag{4}$$

Std (PRN_j) is the standard deviation of each month's *PRN*. The meteorological drought severity classification based on *EDI* values as per the range given by Byun *et al.* (2010) is given in Table 1.

Hydrological drought characteristics evaluation based on Groundwater Drought Index

For assessing groundwater drought, the cumulative deficit (*CD*) from threshold groundwater level is used to identify its severity. The cumulative deficit is the summation of groundwater level departed below a threshold level over a time period. Twenty six years (1985–2010) quarterly groundwater level data collected from 39 sites in the study area is used to represent the spatio-temporal distribution of groundwater drought during various years.

Table 1: Meteorological drought severity classification based on EDI values

Drought severity classes	EDI ranges
Extreme drought	≤ -2.00
Severe drought	-1.50 to -1.99
Moderate drought	-1.00 to -1.49
Near normal	-0.99 to 0.99

The *GDI* values are computed by normalizing quarterly groundwater levels and then the difference between the quarterly level and its long-term mean is divided by its standard deviation. The groundwater level data have been normalised using an incomplete gamma function, which is further converted to reduced levels before computing the *GDI*. The *GDI* is computed as per the following equation:

$$GDI = \left\{\frac{GWL_{ij} - GWL_{im}}{\sigma}\right\} \tag{5}$$

where, GWL_{ij} is seasonal water level for the i^{th} well and j^{th} observation

GWL_{im} is seasonal mean water level

σ is the standard deviation.

The negative values of GDI correspond to water stress, while positive values of GDI correspond to normal conditions. The cumulative summation of negative values of GDI below a certain threshold over a time period indicates the severity of the ground water drought. The groundwater drought has been classified based on Table 2.

Table 2: Groundwater drought severity classification based on GDI values

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

Results and Discussion

Evaluation of meteorological drought characteristics

The application of the EDI based drought analysis has been used for evaluating the meteorological drought characteristics in the region. The temporal variation of the drought characteristics at Sagar, Khurai and Banda are depicted in Fig. 3 to Fig. 5. An increasing trend of meteorological drought severity (decreasing EDI value) has been observed from the analysis. The temporal variation of drought characteristics including its onset, termination, duration as well as its severity can be easily identified from these graphs. Based on the EDI (Fig. 3, Fig. 4 and Fig. 5), four major drought events have been observed during 1981-82, 1988-89, 2002-03 and 2007-08.

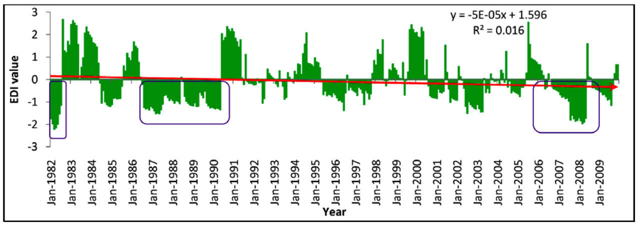

Fig. 3: Temporal variation of meteorological drought at Sagar station

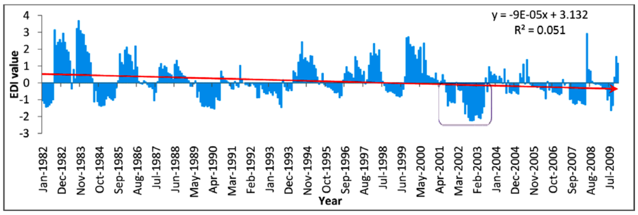

Fig. 4: Temporal variation of meteorological drought at Khurai station

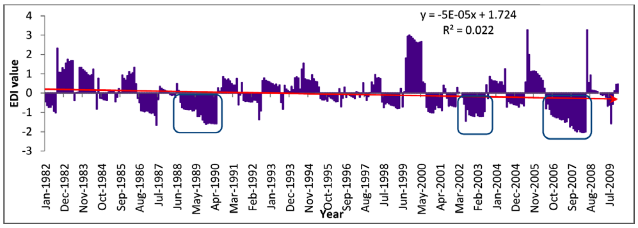

Fig. 5: Temporal variation of meteorological drought at Banda station

A number of drought events faced at all the three rain gauge stations have been analyzed and the results given in Table 3. It has been observed that two extreme drought events occurred at Sagar and Banda, whereas six extreme drought events occurred at Khurai during the period of 1981–2009. A maximum of 17 severe drought events occurred at Sagar and Banda whereas 6 numbers of severe drought events occurred at Khurai. However, the total number of drought events has been distributed in the basin, varying between 51 events at Banda to 67 events at Sagar.

Table 3: EDI based drought events in Dhasan basin

Drought class	Sagar	Khurai	Banda
Extreme	2	6	2
Severe	17	6	17
Moderate	48	42	32
Total	67	54	51

The meteorological drought characteristics, including onset, termination, duration, severity and intensity based on the EDI have been evaluated for the Sagar, Banda and Khurai raingauge station and are given in Table 4.

Table 4: EDI based meteorological drought characteristics of Dhasan basin

Rain gauge station	Onset	Termination	Duration (months)	Severity	Intensity
Sagar	Jan 1982	July 1982	7	-12.73	-1.82
	Oct 1984	Jan 1985	4	-4.58	-1.15
	Aug 1986	June 1987	11	-14.89	-1.35
	Oct 1988	Apr 1989	**7**	-7.91	-1.13
	Sept 1989	May 1990	9	-11.12	-1.24
	Sept 2002	Apr 2003	8	-10.15	-1.27
	Aug 2007	May 2008	10	-17.91	-1.79
Banda	Feb 1987	June 1987	5	-5.87	-1.17
	Jun 1989	May 1990	12	-17.47	-1.46
	Sep 2002	May 2003	9	-10.51	-1.17
	Sep 2006	May 2008	**21**	**-33.49**	-1.59
Khurai	Jan 1982	June 1982	6	-7.58	-1.26
	Sep 1984	Jan 1985	5	-6.46	-1.29
	Sep 1989	May 1990	9	-12.49	-1.39
	Sep 2001	Jan 2002	5	-5.91	-1.18
	Jun 2002	May 2003	12	*-22.68*	**-1.89**
	Oct 2007	May 2008	8	-9.51	-1.19

The drought severity assessment based on the EDI, indicates that the maximum drought severity of -33.49 occurred between September 2006 to May 2008 and it was of longest duration (21 months) drought in the area under Banda rain gauging station. The drought having maximum intensity of -1.89, occurred from June 2002 to May 2003, with a severity of -22.68 in the area under Khurai raingauge station.

Evaluation of hydrological drought characteristics

The groundwater drought has been studied using the Groundwater Drought Index (GDI). The temporal variation of drought at Singtoni based on GDI values is presented in Fig. 6 and the groundwater drought years have been identified to be 2001-02, 2006-07 and 2008-09. From Fig. 6, it is well observed that the groundwater drought of 2008-09 has followed the meteorological drought occurred during 2007-08. The trend of GDI values from Fig. 6, is found to be negative which indicates that the ground water drought severity is increasing gradually. The temporal variations of drought for the rest of observation wells located in and around the study area have also been studied and an increasing groundwater drought severity have been observed for most of the locations.

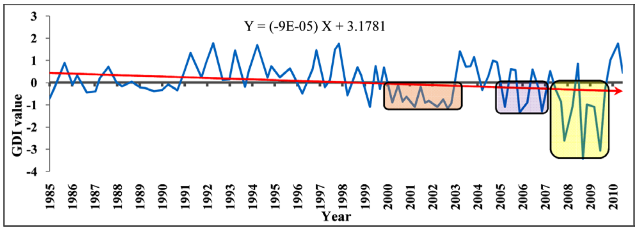

Fig. 6: Temporal variation of drought at Singtoni based on GDI

The spatio-temporal variability of groundwater based on the GDI for August, November, January and May 2002-03 is shown in Fig. 7. The area under the various groundwater drought severity classes is given in Table 5.

Table 5: Area under groundwater drought based on GDI during 2002-03

Drought severity	Area (sq. km.) under various severity classes during 2002-03			
	August 2002	November 2002	January 2003	May 2003
Extreme	—	0.62 (0.03%)	—	—
Severe	0.78 (0.04%)	46.01 (2.24%)	—	—
Moderate	50.52 (2.46%)	2007.76 (97.73%)	3.97 (0.19%)	—
Mild	1996.59 (97.19%)	—	1881.85 (91.60%)	614.36 (29.90%)
Normal	6.51 (0.32%)	—	168.57 (8.21%)	1440.03 (70.10%)

During the drought of 2002-03, about 0.78 sq. km. area was under severe drought in August, whereas 50.52 sq. km. area was under moderate drought condition and the remaining area was under mild drought conditions. During November 2002, about 0.62 sq. km. area was under extreme drought conditions, 46.01 sq. km. of the area was under severe drought and 2007.76 sq. km. of area was under moderate drought condition.

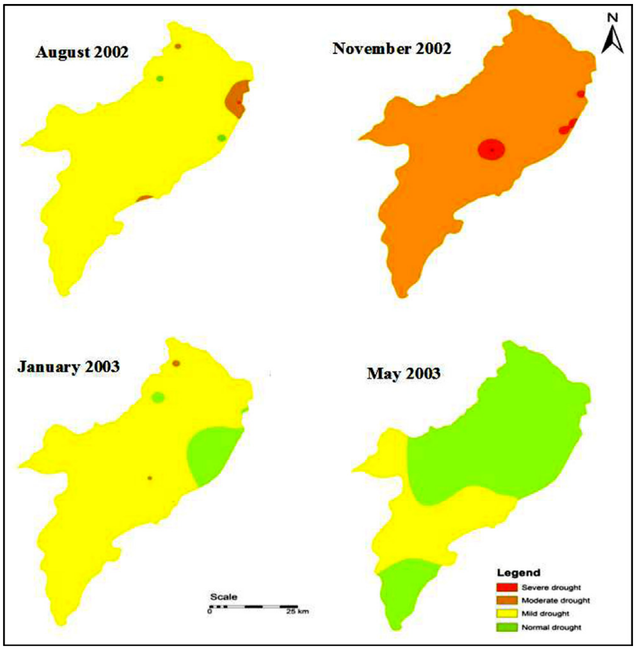

Fig. 7: The spatio-temporal variation of groundwater drought based on the GDI for 2002-03

Conclusion

The meteorological and groundwater drought characteristics have been assessed using two important indices like EDI and GDI respectively. According to EDI, a meteorological drought of maximum severity -33.49 was occurred during September 2006 to May 2008 which was of longest duration (21 months) in the study area (Banda station).

During the groundwater drought of 2002-03 (August), about 0.78 sq. km. area was under severe drought, whereas 50.52 sq. km. area was under moderate drought condition and the remaining area was under mild drought conditions. From the trend analysis, it is found that both the meteorological and groundwater drought severity is increasing gradually during the study period.

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