Groundwater Drought Analysis of Sagar District in Bundelkhand Using Groundwater Drought Index (GDI)

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ABSTRACT: Drought is an important phenomenon in recent years which caused a lot of problems for most of the areas in Bundelkhand region in Central India. Bearma basin is one of the considerable groundwater resource fields of Bundelkhand in Madhya Pradesh, which is sub-basin of Ken River. In the present study the Bearma basin has been selected with the objective to analysis the groundwater drought condition in Sagar district by using groundwater drought index (GDI). The quarterly ground water levels of 17 observation wells falling in and around of Sagar district has been used since 1984 to 2010. The Groundwater drought index for all observation wells were computed with the help of ground-water level of each station. With the help of temporal variations of groundwater drought index (GDI) for each observation well, the groundwater drought characteristics of the basin falling under Sagar district were analyzed. Result showed that the maximum number of 10 frequency of drought events occurred at Kesli with a total severity of -26.82 with a average drought intensity of -0.31 followed by 9 drought events at Copra with a total severity of -28.83 having an average drought intensity of -0.34. The maximum cumulative groundwater drought duration of 130 months has been observed at Chhula with an average drought intensity of -0.20. The maximum average drought intensity of -0.60 has been observed at Gourjhamar followed by -0.59 at Chandpur and -0.57 at Patha. The overall drought intensity in Bearma basin falling under Sagar district is -0.35. The overall average frequency of groundwater drought in Sagar district has been found as once in 5 years.

Key words: Bearma, Bundelkhand, groundwater drought, groundwater drought index (GDI), Sagar, temporal-variation

Introduction

Much of the recent public concern over climate change tends is to focus on rising global mean temperatures. However, climate varies significantly on a regional scale and changing precipitation patterns can be particularly damaging (IPCC, 2007). In fact, drought is estimated to be a pricey natural disaster in the world (Witt, 1997) and the most complex and least understood of all natural hazards, affecting more people than any other hazard (Wilhite, 2000). A drought is an extended period when a region faces a deficiency in its water supply (Beran and Rodier, 1985).

Understanding different types of drought, including their controlling mechanisms, is of uttermost importance for the management of water resources, where key information on hydrological drought is essential for water resources assessment. The different types of droughts have their own specific spatiotemporal characteristics (Peters *et al.,* 2006; Tallaksen *et al.,* 2009). Different types of drought are meteorological, hydrological, agricultural and socio-economic (Hisdal and Tallaksen, 2000). Meteorological drought simply refers to the atmospheric conditions that result in the absence or reduction of precipitation since its definition relies only on rainfall, meteorological drought can end literally overnight, as soon as sufficient precipitation falls to bring levels close to average.

A hydrological drought is defined as a significant reduction in the availability of water in all its forms appearing in the land phase of the hydrological cycle which includes stream flow, groundwater and lake and reservoir storages (Nalbantis, 2009). Among the different types of drought, investigation of the hydrological drought is most important due to dependence of most of the activities (including industrial, water and power plants) to surface water resources. Within the hydrological drought sequence, groundwater is the last to react to a drought situation. The surface water and groundwater droughts will occur more or less simultaneously. The lag between a meteorological drought and a hydrological drought may amount to months or even years. Also the groundwater storage also recovers slowly, which implies that the effects of a groundwater drought may be felt long even after the meteorological drought has ended. Because of the slow reactions of rainfall on groundwater levels, only the major meteorological droughts finally appear as groundwater drought. Therefore, the time step to be used in the analysis of a groundwater drought should necessarily be large, usually more than a week or a month (Peters and van Lanen 2000). The groundwater drought characteristics can be evaluated using the percentile approach or an appropriate drought index. The requirements of a versatile hydrological drought index includes *viz.,* it should be easily understood, must be carrying physical meaning, be sensitive to wide range of drought conditions, independent of area of application, reveal the drought with a short lag after its occurrence and should be based on the data which are readily available.

van Lanen and Peters (2000) defined that a groundwater drought occurs if the groundwater heads in an aquifer have fallen below a critical level over a certain period of time, which results in adverse effects. The critical level can be defined as some percentile of the groundwater hydrograph or based on the standardized ground water levels or based on the long-term seasonal mean and standard deviation.The groundwater drought is defined as a natural decline in the ground water levels that may result in dewatering of the aquifer completely or partly, or to a point where it could cause serious water supply problems.

In this study, an attempt has been made to evaluate the groundwater drought characteristics by developing groundwater drought index (GDI) for Bearma basin. The Bearma basin has been selected as a pilot basin and the study has been carried out to mainly characterize the temporal variation of groundwater drought. It was indicated from earlier study in Bearma basin that soil moisture availability is drastically reduced in the entire basin and therefore the rainfed agriculture is sure to be damaged due to the vagarises of the rainfall. Therefore, provision for supplemental irrigation is necessary for tiding the period of dry spells for which water resources projects need to be planned in the basin (Shikha *et al.,* 2015).

Materials and Methods

Study area

The river Bearma is one of the important tributaries of Ken river passing through the heartland of Bundelkhand in the State of Madhya Pradesh and is located between latitudes 23° 07′ to 24° 18′ N and longitudes 78° 54′ to 80° 00′ E.

Hydrological data

To investigate the groundwater drought, 26 years (1984-2010) quarterly ground water levels of 17 observation wells falling in Sagar districts in Bearma basin have been used. The ground water levels are being monitored by the State Ground Water Survey, Govt. of Madhya Pradesh.

Groundwater levels

The reduced level of the ground (RLG) as well the height of measuring point (HMP) from where the measurements for the groundwater levels are always carried out have also been collected for each observation well along with the time series of groundwater levels in all four quarters of the water year. The groundwater elevation from mean sea level has been computed from the equation as given below:

$$RL_{GWL} = RL_G + H_{MP} - D_{GWL} \quad \dots\dots\dots\dots \quad (1)$$

Where, RL_{GWL}= Groundwater elevation from mean sea level (m)

RL_G = Ground elevation from mean sea level (m)

H_{MP} = Height of measuring point above ground level (m)

D_{GWL} = Depth of groundwater level below measuring point (m)

After obtaining the time series of groundwater elevation from mean sea level, it was compared with the time series of adjacent locations for finding out the outliers, if any. The processed data have been subsequently used in the development of the groundwater drought index and evaluation of groundwater drought characteristics.

Groundwater drought index (GDI)

The most well-known methods used in groundwater drought analysis from ground water level data are the threshold level approach and the Sequent Peak Algorithm (Tallaksen and van Lanen, 2004). However, as ground water level is a state variable and not a flux like recharge, rainfall and stream flow, the deficit volume calculated with the threshold level approach can identify groundwater droughts or scarcities better compared to other approaches. Although the fixed threshold provides quite acceptable results, the cumulative deficit is preferred as the major droughts can be identified more clearly. The best results can be obtained for a fixed threshold level and the cumulative deficit (van Lanen and Peters, 2000).

The GDI is computed by normalizing quarterly/seasonal groundwater levels and dividing the difference between the quarterly/seasonal water level and its long-term seasonal mean by its standard deviation. For normalization, an incomplete gamma function was used for water level data before using them for calculating GDI. The GDI is an indicator of water-table decline and an indirect measure of recharge, and thus an indirect reference to drought. The GDI is computed as per the following equation given below.

$$GDI = \left\{\frac{GWL_{ij} - GWL_{im}}{\sigma}\right\} \quad \dots\dots\dots\dots \quad (2)$$

Where, GWL_{ij}= seasonal water level for the ith well and jth observation,

GWL_{im} = seasonal mean,

σ = is the standard deviation.

Groundwater drought characteristics

The classification used for identifying the groundwater drought characteristics based on GDI (van Lanen and Peters, 2000) is given in Table 1.

Table 1 : Standard ranges of GDI values and their classification

GDI range	Classification
0.0 to -0.99	Mild drought
-1.0 to -1.49	Moderate drought
-1.5 to-1.99	Severe drought
≤ -2.0	Extreme drought

The GDI has been used for identifying the groundwater drought characteristics including the groundwater drought duration, severity and intensity. The duration of the groundwater drought is supposed to begin when the GDI becomes negative and continues till the time when GDI becomes positive again. The sum of the negative GDI values during this duration is defined as the groundwater drought severity and the severity divided by the duration gives the intensity of groundwater drought for that particular event.

Groundwater drought severity

The groundwater drought severity is the cumulative departure of negative GDI values, which has been taken as the cumulative sum of at least three or more than three continuous negative GDI values during that duration. Whereas the sum of total severity was used to just find the average intensity of groundwater drought of a particular observation well. The cumulative deficit of the summation of negative anomalies of groundwater level below a threshold level over a time period indicates the severity of the groundwater drought in that region.

Results and Discussion

Groundwater drought charactersitics of Sagar district in Bearma basin

The groundwater drought index (GDI) has been computed for 17 observation wells falling in Bearma basin under Sagar district based on quarterly ground water levels. The groundwater drought conditions follow the widespread meteorological drought observed in the region during 2002-03 and 2007-08. The groundwater drought characteristics evaluated at the 17 observation wells in Sagar district are given in Table 2. The maximum groundwater drought intensity of -1.40 was observed at Shajpur during November 2008. The maximum drought with severity of -12.6 was also observed at Shajpur commencing from November 2008 and extending for 9 months (Figure 1). This was followed by the drought event at Patha with a severity of -8.07 commencing from May 2000 and extending for 39 months. It is observed from Table 2 and Figure 1 that the drought of maximum 48 months duration was recorded at Tada with a severity of -7.79 commencing from November 1999. The similar drought duration of 48 months was also observed at Chirari with a severity of -2.49 commencing from June 2000 (Figure 2). The maximum number of 10 drought events occurred at Kesli with a total severity of -26.82 (*i.e.* the sum of severity of all individual drought events) with a average drought intensity of -0.31 followed by 9 drought events at Copra with a total severity of -28.83 having an average drought intensity of -0.34. The cumulative groundwater drought duration of 130 months has been observed at Chhula with an average drought intensity of -0.20 (Figure 3). The maximum average drought intensity of -0.60 has been observed at Gourjhamar (Figure 3) followed by -0.59 at Chandpur and -0.57 at Patha. The overall drought intensity in the observation wells in Bearma basin falling under Sagar district is -0.35. On an average, the frequency of occurrence of groundwater drought varies between once in 3 years to once in 9 years in Sagar district. The overall average frequency of groundwater drought in Sagar district has been found as once in 5 years.

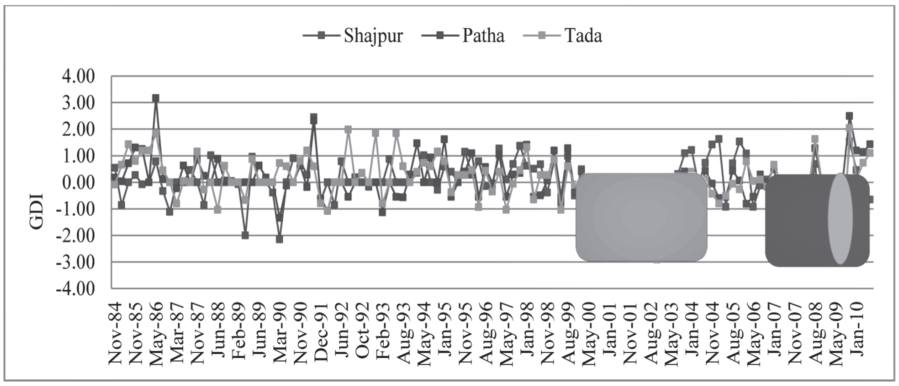

Fig. 1 : Temporal variation of groundwater drought index (GDI) at Shajpur, Patha and Tada

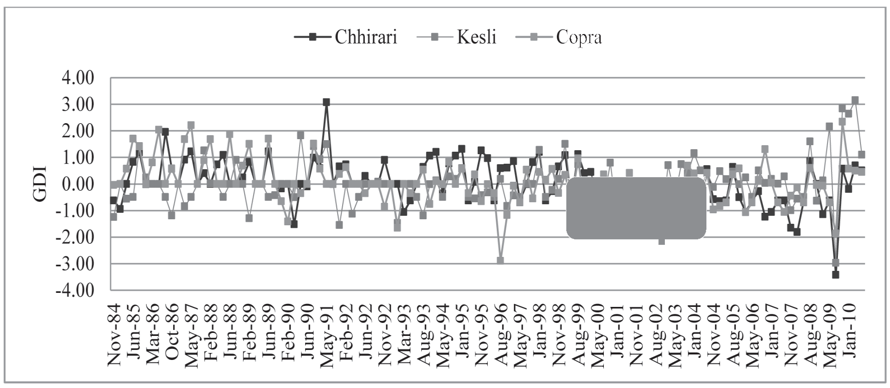

Fig. 2 : Temporal variation of groundwater drought index (GDI) at Chhirari, Kesli and Copra

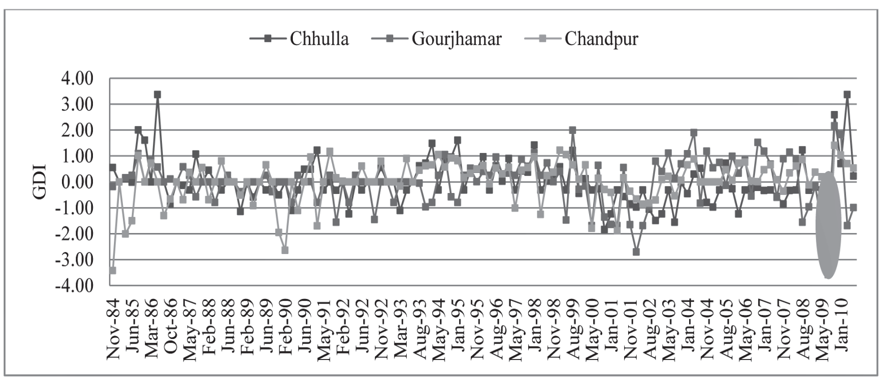

Fig. 3 : Temporal variation of groundwater drought index (GDI) at Chhulla, Gourjhamar and Chandpur

Table 2 : Groundwater drought charactersitics of Sagar district in Bearma basin

Name of village	Duration of drought	Duration (Month)	Severity	Intensity
Chheola	2/5/86 to 5/18/87,5/25/00 to 8/29/03,5/21/07 to 5/6/08	15,15,12	-7.24,-7.29, -1.4	-0.48,-0.48, -0.12
Reechai	11/19/84 to 10/31/87,11/13/88 to 11/5/90,5/26/00 to 1/4/02	35,12,19	-5.98,-7.27, -4.23	-0.17,-0.6, -0.22
Titarpani	11/22/84 to 6/15/85,12/2/91 to 11/17/93, 5/21/96 to 11/1/96,5/21/00 to 5/27/01,11/1/01 to 5/27/03	6,23,5,12,19	-3.71,-5, -1.6,-1.76, -2.41	-0.62,-0.21, -0.32,-0.14, -0.13
Patha	12/6/91 to 5/27/92,2/26/93 to 8/19/93,5/21/00 to 8/28/03,11/17/04 to 5/27/05,1/25/07 to 5/27/08,11/4/08 to 5/25/09	6,5,39,6,16,7	-2.24,-2.24, -8.07,-1.2, -4.04,-1.52	-0.37,-0.4, -0.20,-0.18, -0.25,-0.22
Kachhi-pipariya	2/24/92 to 6/8/92,5/29/00 to 5/6/04,11/6/04 to 5/31/05,11/8/06 to 5/30/08,1/18/09 to 8/20/09	3,47,7,19,7	-1.4,-4.16, -2.94,-4.72, -5.09	-0.46,-0.08, -0.42,-0.25, -0.72
Chhirari	11/6/89 to 6/12/90,6/3/00 to 5/5/04,11/5/04 to 5/25/05,11/6/05 to 5/28/08,1/10/09 to 8/8/09	7,48,7,31,7	-1.79,-2.49, -1.86,-6.4, -5.19	-0.25,-0.05, -0.27,-0.2, -0.74,
Chhula	10/24/86 to 5/4/87,5/22/88 to 5/23/90,5/26/91 to 6/17/92,5/30/00 to 1/10/04,11/8/04 to 5/31/05,11/6/05 to 5/31/08,11/6/08 to 8/26/09	6,24,11, 41,7,31, 10	-1.31,-3.98, -2.2,-5.1, -2.09,-2.72, -3.49	-0.21,-0.16, -0.2,-0.12, -0.29,-0.08, -0.35
Maharajpur	10/15/92 to 5/16/94,11/11/94 to 11/14/95,5/26/00 to 5/26/01,11/30/01 to 5/25/02,11/30/02 to 8/27/03,11/4/04 to 5/31/05	19,12,12,6,9,7	-7.34,-4.77, -4.09,-2.23, -3.71,-2.23	-0.38,-0.39, -0.34,-0.37, -0.41,-0.32
Shajpur	5/24/00 to 5/24/01,11/3/03 to 5/31/04,11/10/04 to 5/30/05,11/16/05 to 5/28/06,11/17/06 to 5/30/07,11/4/07 to 5/14/08,11/4/08 to 8/3/09	9,7,6,6,6,6,9	-2.55,-0.45, -0.76,-2.08, -1.88,-5.95, -12.6	-0.28,-0.06, -0.12,-0.34, -0.31,-1,-1.4
Ghana	11/16/84 to 6/8/85,2/6/89 to 11/8/90, 2/6/89 to 11/8/90,5/29/91 to 11/18/94, 11/18/99 to 8/31/02,1/31/08 to 8/2/08	7,20, 41,33,7	-2.19,-3.34, -2.03,-5.3, -2.63	-0.32,-0.17, -0.04,-0.16, -0.37
Kesli	11/15/84 to 6/6/85,6/27/86 to 5/19/87,2/6/89 to 3/7/90,12/6/91 to 5/20/92,2/28/93 to 11/28/93,5/30/95 to 5/30/96,11/17/96 to 5/30/97,11/17/99 to 8/30/00,1/24/01 to 11/4/02,11/4/07 to 5/14/08	5,11,13,6,9,12,5,9,21,6	-2.29,-3.02, -2.71,-3.17, -3.17,-2.28, -1.77,-2.02, -4.36,-2.03	-0.45,-0.27, -0.2,-0.52, -0.35,-0.19, -0.35,-0.22, -0.2,-0.33
Tada	11/20/99 to 11/7/03,11/17/04 to 11/8/05,5/25/07 to 5/27/08,1/11/09 to 8/9/09	48,11,12,7	-7.79,-2.08, -1.79,-4.29	-0.16,-0.18, -0.15,-0.61
Copra	11/7/89 to 5/13/90,6/25/92 to 5/25/93,11/12/95 to 5/11/97,11/12/99 to 5/28/00,11/11/00 to 5/28/01,11/11/01 to 8/26/03,11/7/04 to 5/31/05,5/26/07 to 5/4/08,11/19/08 to 8/27/09	6,11,18,6,6,21,7, 11,9	-2.43,-3.23, -5.2,-2.28, -3.5,-3.98, -2.5,-3.03, -2.68	-0.4,-0.29, -0.28,-0.37, -0.58,-0.19, -0.35,-0.27, -0.29
Chandpur	11/29/84 to 6/10/85,6/12/86 to 3/4/87,11/7/89 to 5/13/90,11/11/00 to 5/28/01,11/11/01 to 11/11/02	7,8,6,6, 12	-6.93,-2.67, -5.7,-2.6, -3.41	-0.99,-0.33, -0.94,-0.43, -0.28
Gunjora	11/10/86 to 5/4/87,2/12/88 to 2/25/89,12/5/91 to 3/9/93,5/20/95 to 5/20/96,11/7/96 to 5/20/97,11/7/99 to 8/21/03	7,12,15, 12,7,46	-2.63,-1.89, -4.57,-1.9, -1.46,-4.15	-0.37,-0.15, -0.3,-0.15, -0.2,-0.09
Deori	12/3/91 to 5/14/94,5/4/95 to 5/4/96,11/25/96 to 5/4/97,1/2/00 to 1/10/03	30,12,6, 36	-5.93,-3.33, -1.61,-5.94	-0.19,-0.27, -0.26,-0.16
Gourjhamar	8/15/93 to 1/17/94,11/17/99 to 5/24/00,11/13/00 to 5/24/01,11/12/01 to 8/28/02	5,6,5,9	-1.81,-2.14, -4.7,-7.02	-0.36,-0.35, -0.93,-0.77

The extreme groundwater drought condition was found in year 2009 in most of the observation wells except Patha, Shajpur, Gourjhamor and Copra. It indicates that the groundwater level suddenly falls down to its normal condition due to persisting long duration of drought and this way it affecting the normal agricultural practices. There was found four observation wells *i.e.* Ghana, Kesli, Deori, and Gunjhora for regular features of long duration mild to extreme groundwater drought condition during 1984-03 whereas five stations *viz.,* Titarpani, Patha, Chhirari, Maharajpur and Copra were found for mild to extreme groundwater drought during 1989-2009.

Conclusion

The groundwater drought characteristics of Bearma basin falling under Sagar district was more affected due to its undulating topography and less amount of precipitation occurrences. The elevation of ground varies from 385 m to 546 m and annual precipitation ranges between 1100 to 1150 mm. Due to this people always suffering from scarcity of surface water problems and thus they lastly depend upon groundwater dewatering for agricultural practices and their livestock's. The large amount of groundwater extraction reduces the normal level of groundwater results in groundwater drought condition. Groundwater drought characteristics indicates the imbalance between the groundwater recharge and discharge. So, this situation threatens that there should be proper management of surface and groundwater for sustainable development through augmenting groundwater recharge.

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