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Groundwater Drought Scenario In Bundelkhand Region of Central India- A Case Study for Sonar Basin in Madhya Pradesh

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Abstract : Drought which occurs whenever the links in the hydrological cycle are destabilized is considered as one of the most hazardous causes of human hardships. The Bundelkhand region has been under the limelight because of continuous droughts in the last decade resulting in acute water shortages. As groundwater is a predominant source of irrigation in Bundelkhand, evaluation of groundwater drought characteristics is essential in the context of sustenance of human and aquatic habitats. A standardized groundwater drought index (GDI) has been developed by normalizing quarterly/seasonal groundwater levels using an incomplete gamma function and dividing the difference between the quarterly/seasonal water level and its long-term seasonal mean by its standard deviation. The GDI is an indicator of water-table decline and thus an indirect reference to groundwater drought. The spatio-temporal variation of the groundwater drought has also been studied in GIS environment using ILWIS 3.0. During May 2002, 58.04% of the basin was under mild droughts; 31.71% under moderate droughts and only 0.3% under severe groundwater drought condition. However due to the over dependence on groundwater and less recharge due to poor monsoons the area under severe drought increased to 12.10 % and area under extreme drought conditions increased to 9.69%. The upstream reaches of the Sonar basin experienced extreme groundwater drought in 2002 whereas the downstream reaches were under normal conditions. The spatio-temporal analysis of the groundwater drought helps to identify zones where drought is predominant and progressing. This information can be used to restrict groundwater withdrawals from the water stressed zones and for planning artificial recharge schemes during subsequent normal rainfall years for replenishment of depleted aquifers.

Keywords: Groundwater, drought, GDI, Bundelkhand, spatio-temporal

1. INTRODUCTION

Drought remains a major disaster causing enormous damages to people, environment and economy, despite making considerable progress in its monitoring, forecasting and mitigation. The issues related to the identification and prediction of drought is considered to be one of the most complex hydrological research problems. Understanding different types of drought, including their controlling mechanisms, is of uttermost importance for its management, where key information on hydrological drought is essential for water resources assessments. Lack of precipitation over a large area and for an extensive time period is considered to be the primary cause of drought. The water deficit in the atmosphere propagates through the whole hydrological cycle and gives rise to different types of droughts. The different types of drought are meteorological, hydrological, agricultural and socio-economic (Hisdal and Tallaksen 2003; Mishra and Singh 2010; Van Loon and Van Lanen 2012; Liu et al., 2012 and Choi et al., 2013). The different types of droughts have each their own specific spatio-temporal characteristics (Tallaksen et al., 2013).

Although groundwater is an important source of water, it is largely disregarded in many drought analyses. In a comprehensive overview of the 1988-92 droughts in the U.K., Marsh et al., (1994), the effects of the drought on groundwater levels has been discussed, but no definition of groundwater drought is given. A conceptual definition as given by (Calow et al., 1999; Calow et al. 2010) states that, groundwater drought describes a situation where groundwater sources fail as a direct consequence of drought. (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. Generally, a reduced recharge of groundwater aquifer leads to lower groundwater heads and storage (Tallaksen and van Lanen, 2004). Groundwater is normally the last to react to a drought situation, unless the surface water is mainly fed by groundwater. Due to the slow response of groundwater particularly in deeper aquifers, only the major meteorological droughts finally result in groundwater droughts. Tallaksen and van Lanen, (2004) explained that the lag between a meteorological and a groundwater drought may amount to months or years, the lag between a meteorological and a streamflow drought varies from days in a flashy catchment to months in a groundwater-fed catchment.

Drought indicators have been used to effectively evaluate the meteorological, agricultural, and hydrological drought characteristics universally. Heim 2002 carried out a review of the 20th century drought indices used in the United States for evaluation of meteorological, agricultural, and hydrological drought characteristics. Mishra and Singh (2010) carried out a detailed review of fundamental drought concepts, drought indices and relation between droughts and large scale climate indices. Smakhtin (2004) reviewed the existing indices developed for monitoring and quantitative assessment of droughts and analysed their applicability for drought prediction and management in the specific context of South Asia. Groundwater droughts can be identified using three variables viz; recharge, groundwater levels and discharge from groundwater to the surface water system (Tate and Gustard 2000; van Lanen and Peters 2000). Recharge and groundwater discharge cannot be measured directly and they have to be calculated from other measurements or through simulation which makes them sensitive to errors. On the other hand, groundwater levels characterize the present storage and can be measured directly with reasonable accuracy and frequency. The spatial and temporal aspects of groundwater levels indirectly provide the knowledge about groundwater recharge and discharge.

Shahid and Hazarika (2010) studied the groundwater drought scenario in north-western districts of Bangladesh using the cumulative deficit approach from a threshold level and concluded that 42% area suffers from groundwater droughts on an annual basis. Adhikary et al. (2013) carried out an assessment of the groundwater drought for Barind irrigation project in Bangladesh using the cumulative deficit approach and developing relationships between Standardised Precipitation Index (SPI) McKee et al. (1993) and groundwater levels. Bloomfield and Merchant (2013) analysed the groundwater drought for different consolidated aquifer types in the UK using Standardised Groundwater Level Index (SGI) which is a variation of SPI used to evaluate the meteorological drought characteristics. SGI methodology uses a non-parametric normal scores transformation of groundwater data rather than a parametric distribution as done for SPI. In this paper, an attempt has been made to evaluate the groundwater drought characteristics using GDI for which Sonar basin has been selected as a pilot basin, and the methodology can be replicated for the similar drought prone basins in Bundelkhand.

1.1 Description of the study area

Bundelkhand is a cultural-geographic region in Central India bounded by Vindhyan Plateau in south, Yamuna river in north, Ken river in east and rivers Betwa and Pahuj in west and remains administratively divided between Uttar Pradesh (U.P.) and Madhya Pradesh (M.P.). The Bundelkhand region comprises of six districts in M.P. viz., Sagar, Damoh, Chhatarpur, Tikamgarh, Panna and Datia and seven districts in U.P. viz., Jhansi, Lalitpur, Jalaun, Hamirpur, Banda, Mahoba and Chitrakoot. The topography comprises of gently-sloping uplands, distinguished by barren hilly terrain. The region receives average annual rainfall varying between 514.4 mm to 1260.1 mm, 90% of which occurs during the south-west monsoon from mid-June to early-October, but most of it is lost to runoff owing to very few irrigation schemes. In general, the rainfall pattern of this region is erratic and uncertain with very high variability. The Sonar basin is a major tributary of the Ken River and is located adjacent to Bearma basin which is another important tributary of the Ken River. Most of the agriculture in the basin is rainfed and the cultivators depend heavily on groundwater for irrigation of non-monsoon crops in the region. Soyabean and wheat are the principal crops grown in the basin. The basin is located in Sagar district of Madhya Pradesh, India. The location map showing the study area is given in Figure 1.

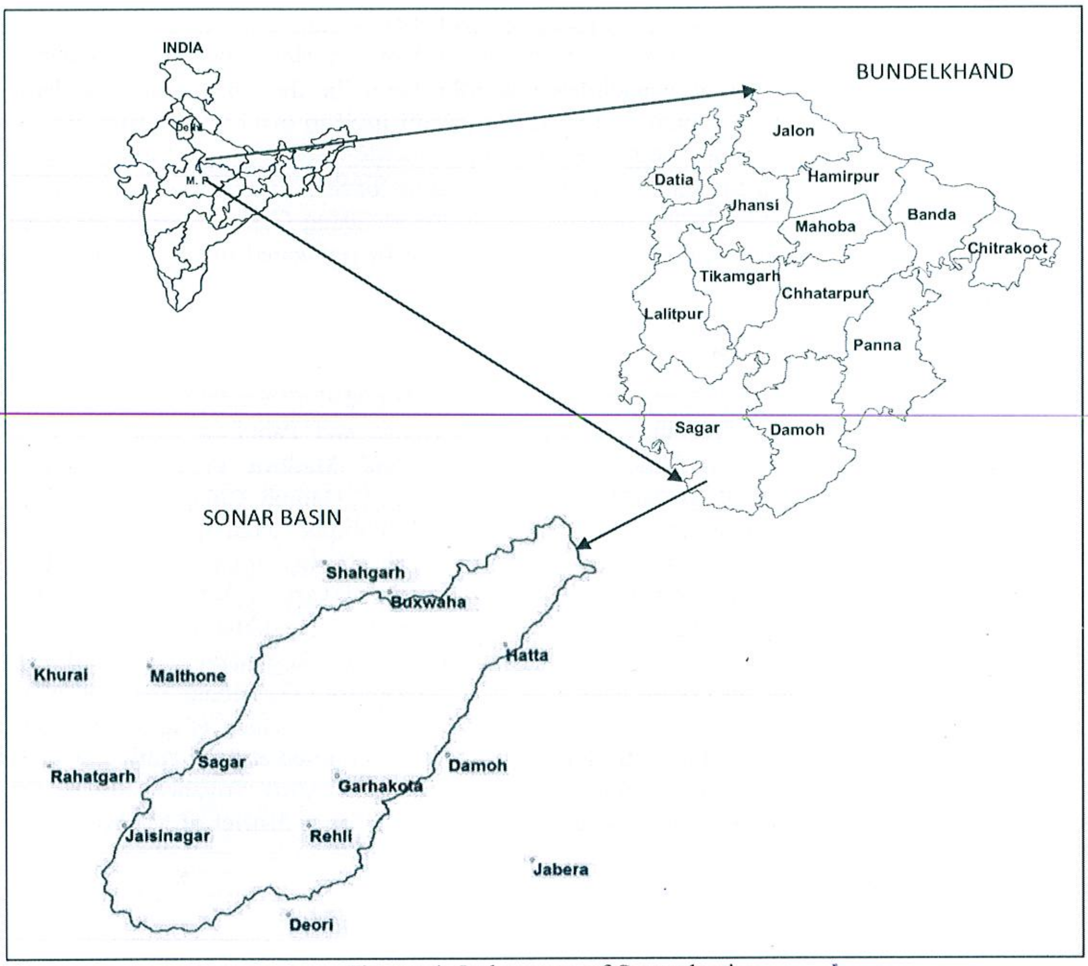

Figure 1. Index map of Sonar basin

2. MATERIAL AND METHODS

Analysis and assessment of the groundwater drought and extent depends on the observed data available in the field. The quarterly groundwater level (GWL) data have been collected from the Groundwater Survey Division, Water Resources Department, Government of Madhya Pradesh for the

observation wells (OB wells) located in an around the Sonar basin. The groundwater observations are recorded with reference to the depth below a fixed measuring point, which may be different for the wells considered. The reduced level of the ground at the observation well location is available with respect to the mean sea level (msl). The reduced level of the groundwater can be computed as given below:

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

where, RL_{GWL} = reduced level of groundwater levels (m); RL_G = reduced level of ground (m); H_{MP} = height of measuring point above ground level (m); $D_{GWL(MP)}$ = depth of groundwater level below measuring point

After obtaining the time series of reduced levels of groundwater levels, it needs to be compared with the time series of adjacent locations for identification of any possible outliers. The processed data can be subsequently used in the development of the groundwater drought index (GDI) and evaluation of groundwater drought characteristics.

The most well-known methods used in the analysis of groundwater drought 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 streamflow, the deficit volume calculated with the threshold level approach can better identify groundwater droughts or scarcities as compared to other approaches. Although the fixed threshold approach provides quite acceptable results, the cumulative deficit is preferred as the major droughts can be identified more evidently. 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 has been fitted to the groundwater level data before calculating GDI. The GDI is an indicator of water availability status and an indirect measure of recharge, and therefore an indirect reference to drought. The GDI is computed as given below.

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

where, GWL_{ij} = seasonal water level for the ith well and jth observation, GWL_{im}= seasonal mean; σ = is the standard deviation.

As the groundwater levels being measured from a measuring point above the ground surface have been converted to reduced levels with respect to msl, therefore the negative anomalies correspond to '*water stress*' while positive anomalies represent a '*no drought/surplus*' condition. The cumulative deficit of the summation of negative anomalies of groundwater level below a threshold value over a time period indicates the severity of the ground water drought in that region, the extent of which can be visualized through spatial interpolation. The cumulative deficit of negative GDI which is the summation of the continuous negative GDI values gives the groundwater drought severity of that particular event and the length of this continuous negative GDI values gives the duration of the groundwater drought. The time step to be used in the analysis of GW drought in cumulative deficit based Threshold Level Method should necessarily be large, usually more than a week or a month, due to the slow response of GWL to rainfall and other hydrologic parameters.

The standardized GDI values vary between -2.0 to +2.0. The GDI has thresholds indicating the range of wetness from extreme drought to extremely wet conditions. The 'drought range' of the GDI indicates extreme drought conditions at GDI < -2.0, severe drought at -1.5 > GDI > -1.99, moderate drought at -1.0 > GDI > -1.49 and mild drought at -0.99 > GDI > 0. No drought/normal conditions are indicated by GDI > 0 The GDI is considered to be one of the best indices in assessing groundwater drought severity. The GDI can be used to assess the groundwater deficit and water surplus also. The standard ranges of the GDI along with its classification for identifying the various classes of drought are given in Table 1.

Table 1. Standard ranges of GDI and their classification

S. No.	GDI range	Classification
1.	0.0 to -0.99	Mild drought
2.	-1.0 to -1.49	Moderate drought
3.	-1.5 to-1.99	Severe drought
4.	-2.0 ≤	Extreme drought

3. RESULTS AND ANALYSIS

The ground water levels in 86 observation wells located in Sagar and Damoh districts of Madhya Pradesh have been used to compute the GDI in Sonar basin. The groundwater drought classification based on GDI suggests that most of the areas in the basin faced extensive groundwater droughts during 2002 and 2007, with groundwater drought severity varying between moderate to extreme during this period. The drought characteristics including the drought severity, drought duration, drought intensity and the onset and termination of drought have been determined for all the for 86 OB wells located in an around the basin based on the computed GDI.

The analysis revealed that the mostly the severity of the groundwater drought varied between mild to moderate but during periods of continuous droughts, the severity of groundwater drought even increased to severe and extreme conditions. The temporal variation of the GDI has been studied based on the plots of the GDI time series which highlights the periods of groundwater droughts as well periods of groundwater surplus. The temporal variation of GDI at the observation wells (OB wells) located at Dhana in Sagar district is given in Figure 2.

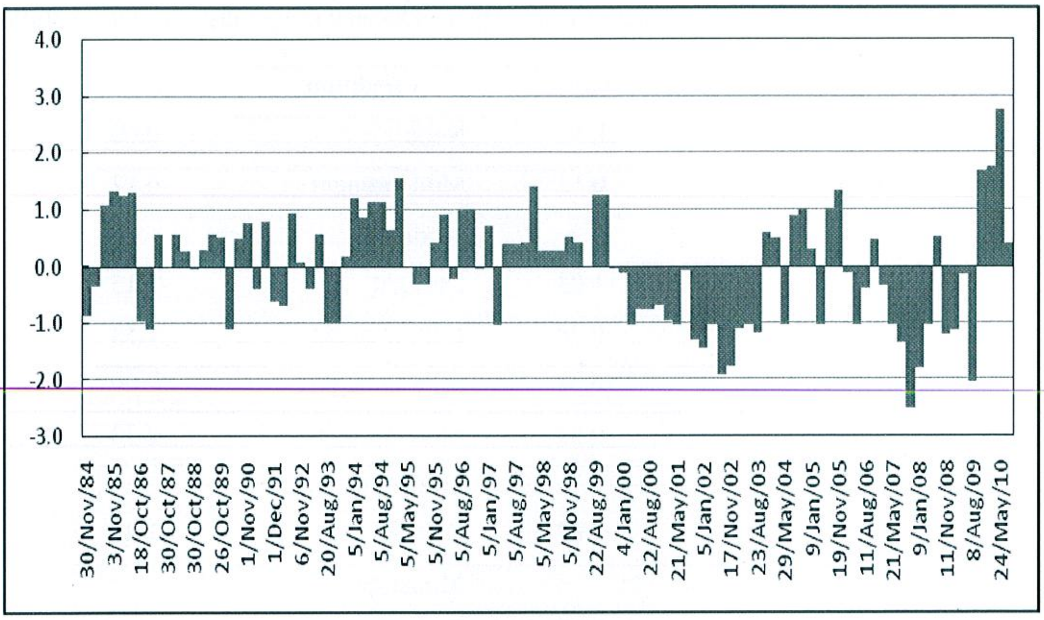

Figure 2. Temporal variation of GDI in Dhana OB well in of Sagar district

It has been observed from Figure 2 that the duration of the groundwater drought and well as its severity has become more pronounced in the last decades. During 2000-03 and 2006-09, the basin witnessed extensive groundwater droughts for considerable durations with higher severities. Here it is also noteworthy that even after normal rains in 2008, groundwater drought scenario continued as the aquifers were over exploited to a very large extent due to the continuous meteorological and hydrological drought that prevailed in Bundelkhand during 2005-06 to 2007-08.

The GDI based drought characterisitcs have been computed for all the OB wells in Sonar basin falling in Sagar and Damoh districts and the groundwater drought characterisitcs at Dhana OB well located in Sagar district during one of the drought events during 2006-09 is given in Table 2. It can be observed that the groundwater drought initiated in January 2006 with the negative GDI value of -0.12 and continued upto August 2009. Extreme groundwater drought were observed during November 2007 and August 2009, whereas during the remaining months mild to moderate groundwater droughts were experienced in the region represented by Dhana OB well. The total severity for this ground water event whcih is the summation of all the negative GDI values is -11.71 and lasted for a duration of 43 months. The summary of the groundwater drought characteristics at Dhana OB well during the entire period of analysis from 1984 to 2010 is given in Table 3. The groundwater drought with maximum severity of -16.17 occured during November 1999 to August 2003 for a duration of 45 months followed by the drought beginning January 2006 and lasting upto August 2009 for a duration of 43 months with a severity of -11.71. A total number of 7 groundwater drought events have been observed at Dhana OB well.

Table 2. Groundwater drought charactersitics at Dhana OB well (Sagar district) during 2006-09

Date	GDI	Condition	Severity
Nov-05	1.34	None	0.00
Jan-06	-0.12	Mild Drought	-0.12
May-06	-1.03	Moderate Drought	-1.15
Aug-06	-0.38	Mild Drought	-1.53
Nov-06	-0.48	Mild Drought	-2.00
Jan-07	-0.33	Mild Drought	-2.33
May-07	-1.03	Moderate Drought	-3.36
Aug-07	-1.36	Moderate Drought	-4.60
Nov-07	-2.51	Extreme Drought	-6.09
Jan-08	-1.79	Severe Drought	-7.50
May-08	-1.03	Moderate Drought	-8.05
Aug-08	-0.53	Mild Drought	-8.25
Nov-08	-1.19	Moderate Drought	-8.41
Jan-09	-1.12	Moderate Drought	-9.54
May-09	-0.15	Mild Drought	-9.69
Aug-09	-2.03	Extreme Drought	-11.71
Nov-09	1.68	None	0.00

Simlarly, the groundwater drought characterisitcs at Hatta OB well in Damoh district during during the drought event of August 2006 to January 2009 is given in Table 4. The groundwater drought condition varied between mild to moderate during the event. The summary of the groundwater drought characterisitics at Hatta OB well is given in Table 5. A total number of 10 groundwater drought events were observed at Hatta OB well. The groundwater drought with a maximum severity of -5.54 and lasting for a duration of 26 months was observed during November 2006 to January2009. Some of the other events with longer duration included the groundwater droughts during May 1998 to August 1999 (15 months) and March 1989 to February 1990 (11 months). However the drought

Table 3. Summary of groundwater drought charactersitics at Dhana OB well in Sagar district

Event	Period	Duration (months)	Severity
1.	Nov-84 to Mar-85	4	-1.18
2.	Oct-86 to Mar-87	6	-2.06
3.	Dec-91 to Feb-92	3	-1.29
4.	Aug-93 to Nov-93	3	-1.99
5.	May-95 to Aug-95	3	-0.65
6.	Nov-99 to Aug-03	45	-16.17
7.	Jan-06 to Aug-09	43	-11.71

Table 4. Groundwater drought charactersitics at Hatta OB well (Damoh district) during 2006-09

Date	GDI	Condition	Severity
Aug-06	0.31	None	0.00
Nov-06	-1.07	Moderate Drought	-1.07
Jan-07	-0.90	Mild Drought	-1.97
May-07	-0.71	Mild Drought	-2.67
Aug-07	-0.69	Mild Drought	-3.37
Nov-07	-1.14	Moderate Drought	-4.51
Jan-08	-1.03	Moderate Drought	-5.54
May-08	-0.17	Mild Drought	-4.64
Aug-08	-0.31	Mild Drought	-4.05

Nov-08	-0.99	Mild Drought	-4.33
Jan-09	-0.60	Mild Drought	-4.24
May-09	0.78	None	0.00

Table 5. Summary of groundwater drought charactersitics at Hatta OB well in Damoh district

Event	Period	Duration (months)	Severity
1.	Feb-85 to Nov-85	9	-2.4
2.	Nov-87 to Jun-87	7	-3.15
3.	Mar-89 to Feb-90	11	-3.76
4.	Oct-91 to Jun-92	8	-2.89
5.	May-98 to Aug-99	15	-3.56
6.	Nov-00 to May-01	6	-1.84
7.	Nov-01 to May-02	6	-1.77
8.	Jan-06 to May-06	4	-1.17
9.	Nov-06 to Jan-09	26	-5.54
10.	Aug-09 to Nov-09	3	-4.76

severity during both these events have been -3.56 and -3.76 respectively which are comapritively less when compared to the severity at Dhana OB well.The temporal variation of GDI at the OB well located at Hatta in Damoh district is given in Figure 3.

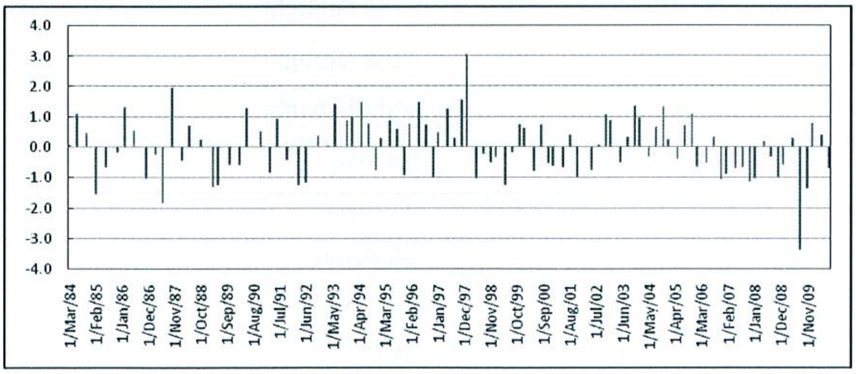

Figure 3. Temporal variation of GDI in Hatta OB well of Damoh district

The spatial variation of the groundwater drought characteristics has been studied for the Sonar basin during the groundwater drought years identified based on the GDI. The analysis has been performed using ILWIS 3.6 for 2002 and 2007. The spatio-temporal variation of groundwater drought in Sonar basin is given in Figure 4 and the area falling under various groundwater drought classes based on the histogram details of the same during 2002 and 2007 are given in Table 6 and Table 7 respectively. It has been observed that during May 2002, 58.04% of the area was under mild droughts; 31.71% under moderate droughts and only 0.3% under severe groundwater drought condition. However due to the over dependence on groundwater and less recharge due to poor monsoons the area under severe drought increased to 12.10 % and area under extreme drought conditions increased to 9.69%. The remaining area of the basin was under moderate drought (27.80%); mild drought (20.3%) and no drought (30.11%). The upstream reaches of the Sonar basin experienced extreme groundwater drought in 2002 whereas the downstream reaches were under normal conditions. The groundwater drought during 2007 was quite different from the groundwater drought of 2002. In November 2007, extreme groundwater drought was felt in the central zone of the basin with the area under extreme drought (12.24%) and severe drought (23.61%) whereas in November 2002 the extreme drought was felt in the upstream reaches of the basin.

Figure 4. Spatial variation of groundwater drought in Sonar basin

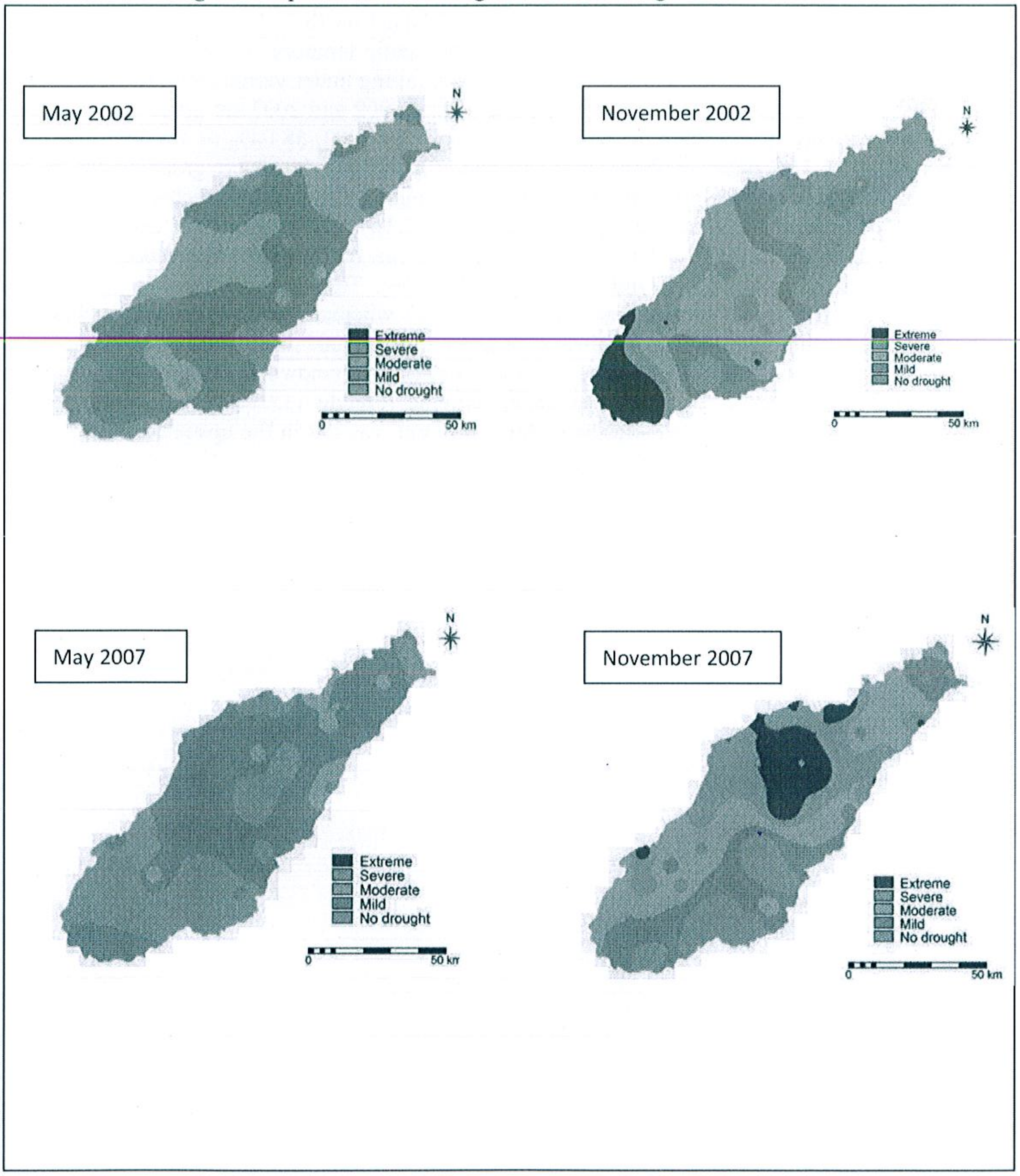

Table 6. Spatial and temporal variation of groundwater drought during 2002 in Sonar basin

S. No	May-02		Nov-02	
	Condition	Area (%)	Condition	Area (%)
1	Severe	0.30	Extreme	9.69
2	Moderate	31.71	Severe	12.10
3	Mild	58.04	Moderate	27.80
4	No drought	9.95	Mild	20.30
			No drought	30.11

Table 7. Spatial and temporal variation of groundwater drought during 2007 in Sonar basin

S. No	May-07		Nov-07	
	Condition	Area (%)	Condition	Area (%)
1	Severe	0.20	Extreme	12.24
2	Moderate	5.38	Severe	23.61
3	Mild	57.03	Moderate	29.65
4	No drought	37.39	Mild	21.20
			No drought	13.30

4. CONCLUSIONS

The evaluation of groundwater drought characteristics has been carried out in Sonar basin in Bundelkhand region based on the GDI. It has been observed that the groundwater drought conditions frequently occur in the basin in conjunction with the meteorological drought but continues further, even after the cessation of the meteorological droughts. The severity of drought varies from region to region and each groundwater drought event has its own characteristics including duration, severity and intensity. The study demonstrated that the GDI can be effectively used to monitor the spatial and temporal variation of groundwater drought including its progression and withdrawal during different periods of drought years, which helps to give a better understanding of the areas reeling under groundwater drought conditions. The holistic approach of integrated water resources management (IWRM) can be adopted along with the sustainable exploitation of the groundwater resources with efforts towards recharging the aquifers through artificial recharge schemes during periods of normal monsoon. This will help to maintain and preserve the precious groundwater source which can be relied upon as a buffer storage during times of widespread droughts in the basin.

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