EVALUATION OF GROUNDWATER DROUGHT CHARACTERISTICS FOR FEW BASINS IN BUNDELKHAND REGION OF CENTRAL INDIA

T. Thomas [1*], R. K. Jaiswal[1] and R. V. Galkate[1]

[1]Scientist, National Institute of Hydrology, Regional Centre, WALMI Campus, Bhopal, 462016
* Corresponding author: thomas_nih@yahoo.com

ABSTRACT

Drought is recognised as on the most disastrous extreme events in terms of severity, aerial extent, and the number of people affected annually across the world and is linked to the destabilisation of the hydrological cycle and is initiated by the deficit rainfall. In such situations, groundwater is the only alternative source of water available during periods of drought. Therefore the study of the groundwater availability and ground water drought aspects is rather significant in the context of sustenance of human and aquatic habitats. Bundelkhand region in Central India is in the limelight because of continuous droughts in the last decade resulting in acute water shortages. Groundwater is a the predominant source of domestic water supply as well as irrigation supplies in most districts of Bundelkhand and therefore detailed investigations are required to assess the ground water droughts as the entire population is dependent on this precious resource which has been carried out for few basins including Sonar and Bearma basins in Madhya Pradesh, India.
The trend analysis using the non-parametric Mann-Kendall test of the seasonal ground water levels reveals that significant falling trends in groundwater levels at 5% significance level have been observed at many observation wells in these basins. A standardized groundwater level index (SGLI) has been developed to evaluate the groundwater drought characteristics for the selected basins in Bundelkhand. The negative values of the index reflect the fall in groundwater levels as a consequence of the ongoing drought prevailing in the region. The spatio-temporal variation of the groundwater drought have been studied as there exists a time lag in the translation of a meteorological drought to a groundwater drought, and similarly the groundwater drought continues to remain even after the cessation of the meteorological drought. This analysis helps to identify zones predominantly affected by groundwater drought and understand the progression and withdrawal of groundwater drought in subsequent months and can be effectively used for planning artificial recharge schemes on a priority basis for the replenishment of the depleted aquifers.

INTRODUCTION

The public concern on the climate change aspects are related to the increasing global mean temperatures and it is expected that this will lead to a change in the rainfall pattern leading to climate variability and occurrence of extreme events. Already, the world is experiencing the consequences of the climate change in the forms of severe flash floods, extreme droughts and recurrent dry spells, altered precipitation pattern and distribution, cyclones and hurricanes with much higher frequencies than observed in the past decades and centuries. Drought remains one of the major disasters causing enormous damages to society, environment and economy, despite making considerable progress in its monitoring, forecasting and mitigation. In fact, drought is estimated to be the most pricely natural disaster in the world and the most complex and least understood of all natural hazards, affecting more people than any other hazard. A drought is an extended period when a region notes a deficiency in its water supply (Beran and Rodier, 1985). 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. 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). Among the different types of drought, investigation of the hydrological drought is most important due to its dependence on most of the activities, including industrial, water and power plants. Although groundwater is an important source of water especially during periods of extensive droughts, it is largely disregarded in many drought analyses. A groundwater drought describes a situation where groundwater sources fail as a direct consequence of drought (Calow et al., 1999; Calow et al.. 2010). A groundwater drought occurs when the groundwater heads in an aquifer falls below a critical level, leading to adverse effects (Van Lanen and Peters, 2000). The critical level can be defined as some percentile of the groundwater hydrograph or based on the standardized groundwater levels or based on the long-term seasonal mean and standard deviation. The groundwater drought is defined as a natural decline in the groundwater levels that may result in dewatering of the aquifer completely or partly, or to a point where it could cause serious water supply problems. Generally the groundwater is the last to react to a drought situation, unless the surface water is mainly fed by groundwater. Tallaksen and Van Lanen, (2004) explained that the lag between a meteorological and a streamflow drought varies from days in a flashy catchment to months in a groundwater-fed catchment and the lag between a meteorological and a groundwater drought may amount to months or years.

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 analyzed their applicability for drought prediction and management in the specific context of South Asia. 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. The groundwater drought characteristics can be evaluated using the percentile approach or an appropriate drought index. 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 Standardized Precipitation Index (SPI) and groundwater levels. Bloomfield and Merchant (2013) analyzed the groundwater drought for different consolidated aquifer types in the UK using Standardized Groundwater Level Index (SGI) which is a variation of SPI used to evaluate the meteorological drought characteristics. In this study, an attempt has been made to evaluate the groundwater drought characteristics by developing a Standardized Groundwater Level Index (SGLI) for few basins in the Bundelkhand region. The Sonar, Bearma and Bina basins have been selected and the study has been carried out to mainly evaluate the groundwater characteristics and characterize the spatial and temporal variation of groundwater drought.

STUDY AREA

Bundelkhand in Central India comprises of six districts in Madhya Prdesh (MP) viz., Sagar, Damoh, Chhatarpur, Tikamgarh, Panna and Datia and seven districts in Uttar Pradesh (UP) viz., Jhansi, Lalitpur, Jalaun, Hamirpur, Banda, Mahoba and Chitrakoot. The region receives an average annual rainfall varying between 514.4 mm to 1260.1 mm, 90% of which occurs during the south-west monsoon. The rainfall pattern of this region is highly erratic and uncertain with very high variability. The Sonar and Bearma rivers are the major tributaries of the Ken River system whereas the Bina river is the tributary of Betwa. The Bina river and Snar river is located in the Sagar district whereas the Bearma basin is located in Damoh and Sagar districts. Most of the agriculture in these basins are rain-fed and the farmers depend heavily on groundwater for irrigation of non-monsoon (rabi) crops. Soyabean and wheat are the principal crops grown in the basin during monsoon (kharrif) and rabi season respectively. The location map of the study area is given in Figure 1.

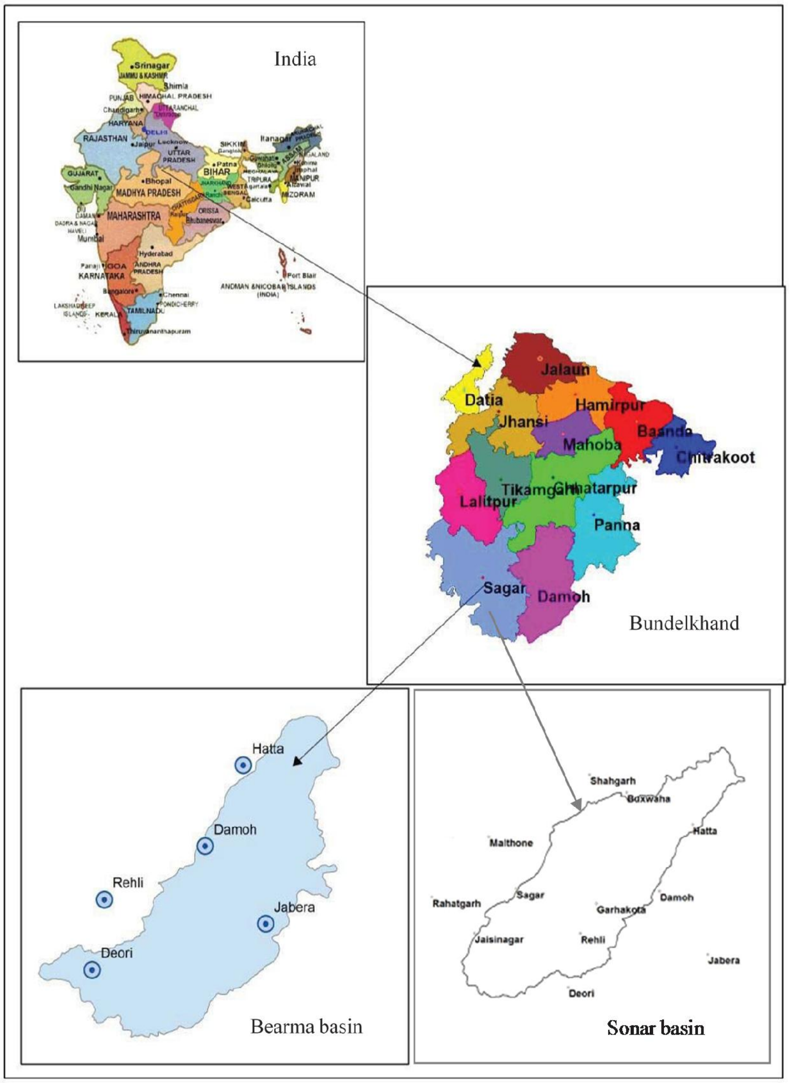

Figure 1: Index map of the study area

MATERIALS AND METHODS

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 and Bearma basins. Both the basins are located in the Sagar and Damoh districts and the groundwater levels at

100 wells in each district were collected for carrying out the detailed analysis for drought investigations. The duration of the quarterly ground water data availability is for a period of 26 years from 1984-2010. 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 has been computed as given below:

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

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 has been compared with the time series of adjacent locations for identification of any possible outliers. The processed data has been subsequently used in the development of the standardized groundwater level index (SGLI) and evaluation of groundwater drought characteristics.

The most well-known methods used in the analysis of groundwater drought from groundwater 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 SGLI 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 SGLI. The SGLI is an indicator of water availability status and an indirect measure of recharge, and therefore an indirect reference to drought. The SGLI is computed as given below.

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

GWL_{ij} = seasonal water level for the i^{th} well and j^{th} 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 SGLI which is the summation of the continuous negative SGLI values gives the groundwater drought severity of that particular event and the length of this continuous negative SGLI values give the duration of the groundwater drought. The standardized SGLI values vary between -2.0 to +2.0. The SGLI has thresholds indicating the range of wetness from extreme drought to extremely wet conditions. The 'drought range' of the SGLI indicates extreme drought conditions at SGLI < -2.0, severe drought at -1.5 > SGLI > -1.99, moderate drought at -1.0 > SGLI > -1.49 and mild drought at -0.99 > SGLI > 0. No drought/normal conditions are indicated by SGLI > 0 The SGLI is considered to be one of the best indices in assessing groundwater drought severity. The SGLI can be used to assess the groundwater deficit and groundwater surplus also. The standard ranges of the SGLI along with its classification for identifying the various classes of drought are given in Table 1.

The ground water levels in all the observation wells located in Sagar and Damoh districts of Madhya Pradesh have been used to compute the SGLI in Sonar basin. The groundwater drought classification based on SGLI 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 OB wells located in an around the basin based on the computed SGLI.

Table 1. Standard ranges of SGLI and their classification

S. No.	SGLI 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

RESULTS AND DISCUSSIONS

Evaluation of Groundwater Drought Characteristics

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

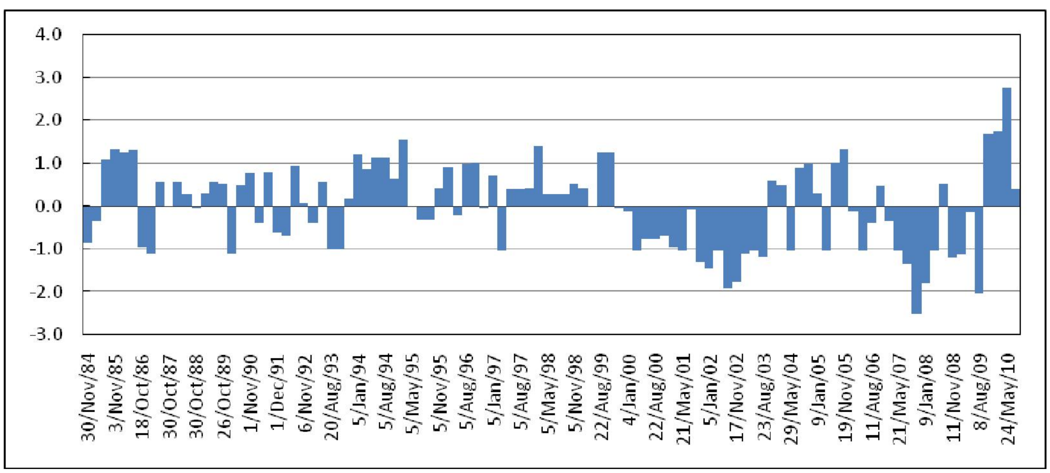

Figure 2. Temporal variation of SGLI in Dhana OB well in of Sagar district

Figure 2 illustrates that the groundwater drought duration as well as its severity have 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 SGLI based drought characteristics have been computed for all the OB wells in Sonar basin falling in Sagar and Damoh districts and the groundwater drought characteristics at Dhana 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 SGLI value of -0.12 and continued up to August 2009. Extreme groundwater drought have been observed during November 2007 and August 2009, whereas during the remaining months mild to moderate groundwater droughts have been experienced at Dhana. The total severity for this ground water event which is the summation of all the negative SGLI values is -11.71 and lasted for a duration of 43 months. The summary of the groundwater drought characteristics at Dhana during the entire period of analysis from 1984 to 2010 is given in Table 3. The groundwater drought with maximum severity of -16.17 occurred during November 1999 to August 2003 for a duration of 45 months followed by the drought beginning January 2006 and lasting up to 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. Similar analysis have been carried out for all the OB wells in and around the Sonar, Bearma and Bina basins and a generally similar pattern in the groundwater drought characteristics have been observed and 2002 and 2007 witnessed widespread droughts in these three basins located in Bundelkhand.

Table 2. Groundwater drought characteristics at Dhana OB well during 2006-09

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

Table 3. Summary of groundwater drought characteristics at Dhana OB well

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

Spatio-temporal Variation of Groundwater Drought

The spatial variation of the groundwater drought characteristics have been studied for the Sonar, Bearma and Bina basins based on the identified groundwater drought years. 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 3 and the area falling under various groundwater drought classes based on the histogram details of the same during 2002 are given in Table 4.

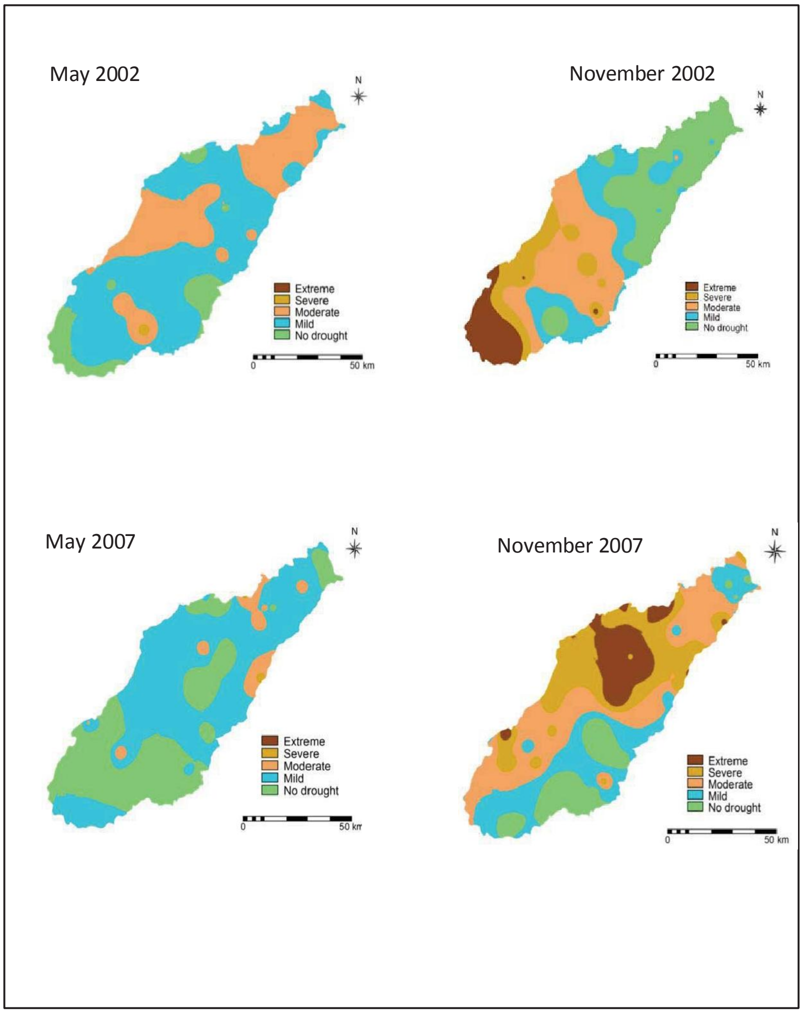

Figure 3: Spatio-temporal variation of groundwater drought in Sonar basin during 2002 & 2007

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. Similarly the spatio-temporal variation of groundwater drought during 2007 is also shown in the same Figure 3.

Table 4. Spatio-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

The spatial-temporal variation of the groundwater drought characteristics in Bearma basin have been studied based on the drought severity classification of SGLI for the selected observation wells in the basin falling in Sagar and Damoh districts during various months of the identified drought years 2002. The spatial and temporal variation of drought classes in the Bearma basin for the various seasons during for the drought year of 2002-03 is given in Figure 4. The percentage area in basin falling under the various groundwater drought severity classes during 2002-03 is given in Table 5. In August 2002, more than 70% of the basin area was under normal conditions and only 28.57% area was under mild droughts. Mild groundwater drought conditions were experienced at Ghana, Kesli, Chandpur, Pura, Gunjhora, Devron and Damoh along the western boundaries of the basin adjoining Sonar basin. However with the shortage of rainfall due to failing monsoon, the groundwater drought progressed quite steadily, the drought conditions became more severe and widespread and the area under various drought classes increased, with 4.2% under extreme drought, 6.83% under severe drought, 13.10% under moderate drought and 27.18% under mild drought. This indicates that during November 2002, the combined area under all groundwater drought categories increased from 29.11% in August 2002 to 52.31%. Moderate to extreme groundwater drought conditions were felt towards the southern portion of the basin. However during January 2003, more than 89% of the area was under normal conditions due to favorable water availability scenario and only some areas experienced mild drought conditions.

CONCLUSIONS

The evaluation of groundwater drought characteristics has been carried out in Sonar, Bearma and Bina basins in Bundelkhand region based on the SGLI. Groundwater drought conditions frequently occur in the basin in combination with the meteorological drought but continues further, even after the cessation of the meteorological droughts. The severity of groundwater drought varies from region to region and each groundwater drought event has its own characteristics including duration, severity and intensity. It is felt that SGLI 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 spatio-temporal analysis of groundwater droughts has help to understand the variation of groundwater drought and its areal influence during various seasons of a drought years. The study reveals that each groundwater drought event is unique in its characteristics and has varying degree of influence in different zones of the basin. Integrated water resources management (IWRM) approaches can be followed along with the sustainable exploitation of the groundwater resources with efforts towards recharging the aquifers 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.

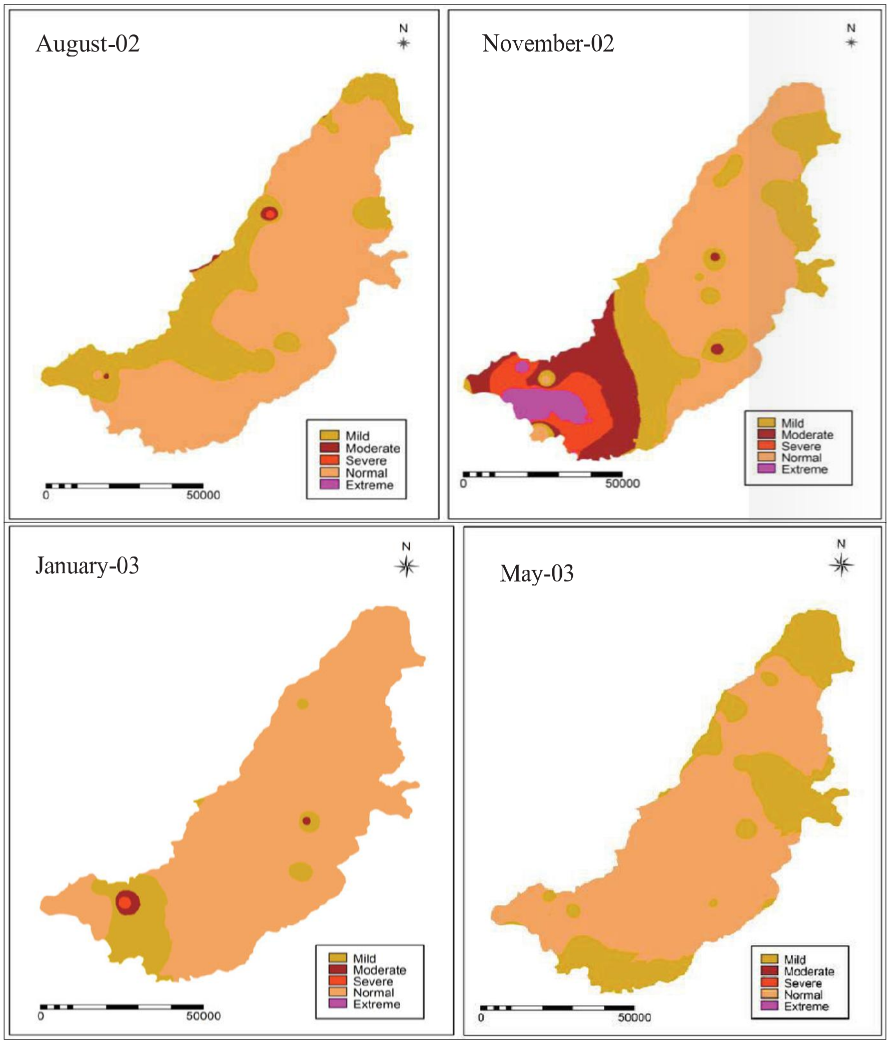

Figure 4: Spatio-temporal variation of groundwater drought in Bearma basin during 2002

Table 5: Spatial and temporal variation of groundwater drought during 2002

Sr. No.	Drought severity	Percentage of area under different severity classes (%)			
		Aug-02	Nov-02	Jan-03	May-03
1.	Extreme	--	4.20	--	--
2.	Severe	0.10	6.83	0.20	--
3.	Moderate	0.44	13.10	0.76	--
4.	Mild	28.57	27.18	9.80	28.78
5.	No drought	70.89	48.68	89.24	71.22

REFERENCES

Adhikary, S. K., Saha, G. C., and Chaki, T. (2013). "Groundwater drought assessment for Barind irrigation project in north-western Bangladesh", *20th International Congress on Modelling and Simulation*, Adelaide, Australia.

Beran, M. A. and Rodier, J. A. (1985). "Hydrological aspects of drought: a contribution to the International Hydrological Programme", *World Meteorological Organization,* Studies and Reports on Hydrology, Paris, 39.

Bloomfield, J. P., and Merchant, B. P. (2013). "Analysis of groundwater drought using a variant of the Standardised Precipitation Index", *Hydrol. Earth Syst. Sci. Discuss.*, 10: 7537–7574.

Calow, R., Robins, N., Macdonald, A., and Nicol, A. (1999). "Planning for groundwater drought in Africa", *Proceedings of the International Conference on Integrated Drought Management: Lessons for Sub-Saharan Africa*, IHP-V, Technical Documents in Hydrology 35: 255–270.

Calow, R. C., Macdonald, A. M., Nicol, A. L., and Robins, N. S. (2010). "Groundwater security and drought in Africa: linking availability, access and demand", *Ground Water,* 48: 246–256.

Choi, M., Jacobs, J. M., Anderson, M. C., and Bosch, D. D. (2013). "Evaluation of drought indices via remotely sensed data with hydrological variables", *Journal of Hydrology*, 476: 265-273.

Heim, R. R. (2002). "A review of twentieth century drought indices used in United States", *American Meteorological Society*, 1149-1162.

Hisdal, H. and Tallaksen, L. M. (2003). "Estimation of regional meteorological and hydrological drought characteristics: a case study for Denmark", *Journal of Hydrology*, 281: 230-247.

Liu, L., Hong, Y., Bednarczyk, C. N., Yong, B., Shafer, M. A., Riley, R., and Hocker, J. E. (2012). "Hydro-climatological drought analyses and projections using meteorological and hydrological drought indices: a case study in Blue River Basin, Oklahoma", *Water Resources Management*, 26: 2761–2779.

Mishra, A. K., and Singh, V. P. (2010). "A review of drought concepts", *Journal of Hydrology*, 391: 202-216.

Shahid, S., and Hazarika, M. K. (2010). "Groundwater droughts in the north-western districts of Bangladesh", *Water Resources Management*, 24(10): 1989-2006.

Smakhtin, V. U., and Hughes, D. A. (2004) "Review, automated estimation and analysis of drought indices in South Asia", *Working Paper 83*, Colombo, Sri Lanka. International Water Management Institute.

Tallaksen, L. M., and Van Lanen, H. A. J. (2004). "Hydrological drought, processes and estimation methods for stream flow and groundwater", *Development in Water Science*, 48: 579.

Van Loon, A. F., and Van Lanen, H. A. J. (2012). "A process-based typology of hydrological drought", *Hydrol. Earth Syst. Sci*., 16: 1915-1946.

Van Lanen, H. A. J., and Peters, E. (2000). "Definition, effects and assessment of groundwater droughts", Vogt JV, Somma F (ed) *Drought and Drought Mitigation in Europe*, Kluwer Academic Publishers, Dordrecht, The Netherlands.