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STUDY OF SPATIO-TEMPORAL VARIATION OF GROUNDWATER DROUGHT IN CONFINED AQUIFER OF BEARMA BASIN 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 areas in Bundelkhand region in Central India. Drought lead to water scarcity for people and this problem becomes one of the important challenges for the central zone of India. Bearma basin is one of the considerable groundwater resource fields in South portion 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 study of the spatio-temporal variation of groundwater drought. The quarterly groundwater levels of 76 observation wells falling in Bearma basin have been used. The spatial-temporal variation of the groundwater drought characteristics in Bearma basin have been studied based on the drought severity classification of Groundwater Drought Index for the selected 76 observation wells in the basin falling in Sagar and Damoh districts during various months of the identified drought years 2002-03 and 2007-08. An attempt has been made to map the groundwater scenario in the confined aquifer in Bearma basin for which the groundwater levels in the piezometers tapping the unconfined aquifer have been used. This 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. The groundwater drought distribution and pattern is completely different in two of the meteorological drought years of 2002-03 and 2007-08 with the southern portion of the basin facing worse drought scenario during 2002-03 whereas in 2007-08 the northern portions of the basin faced more severe drought conditions.

KEYWORDS:*Groundwater drought, groundwater drought index, Bearma, Bundelkhand, spatio-temporal variation, Sagar and Damoh*

INTRODUCTION
Much of the recent public concern over climate change tends 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 the most 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 notes a deficiency in its water supply (Beran and Rodier, 1985). Different types of drought are meteorological, hydrological, agricultural and socio-economic (Hisdal and Tallaksen 2000; van Loon and van Lanen 2012). 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. In this research mainly groundwater drought is investigated. Groundwater is an important source of water; van Lanen& 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 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. The groundwater drought characteristics can be evaluated using the percentile approach or an appropriate drought index. In this study, an attempt has been made to evaluate the groundwater drought characteristics by developing a Groundwater Drought Index (GDI) in Bundelkhand region. The Bearma basin has been selected as a pilot basin and the study has been carried out to mainly characterize the spatial and temporal variation of groundwater drought.

MATERIAL 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^o 07′ to 24^o 18′ N and longitudes 78^o 54′ to 80^o 00′ E.

Hydrological data

To investigate the groundwater drought, there are 26 years (1984-10) quarterly groundwater levels of 76 observation wells falling in Sagar and Damoh districts have been used for identifying the groundwater drought characteristics in Bearma basin. The groundwater levels are being monitored by the State Groundwater Survey, Govt. of Madhya Pradesh.

Groundwater levels

The reduced level of the ground (RL_G) as well the height of measuring point (H_{MP}) 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 reduced level of the groundwater table has been computed from the equation as given below:

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

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

After obtaining the time series of RL of groundwater levels, 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 groundwater level data are the threshold level approach and the Sequent Peak Algorithm (Tallaksen and van Lanen 2004). However, as groundwater 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.

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

Where,

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

GWL_{im}= seasonal mean,

σ = is the standard deviation.

Even though the groundwater levels are being measured from a measuring point above the ground surface, the water levels have been converted to reduced levels based on the reduced level of the ground surface at the observation. Hence negative anomalies correspond to '*water stress*' while positive anomalies represent a '*no drought*' condition. 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 which can be visualized through spatial interpolation.

Groundwater drought characteristics

Based on the base map of the Bearma basin, the observation wells falling in and around the basin have been selected using the GIS operations and a map prepared considering all the wells identified for the analysis. 86 observation wells falling in the study area were selected. Thereafter the reduced groundwater levels have been computed based on the reduced level of ground and height of measuring point above the ground level at each of these 86 observation wells for years 2002-03 and 2007-08. The classification used for identifying the groundwater drought characteristics based on GDI is given in Table 1.

Table 1: Standard ranges of GDI values 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

The negative GDI values indicate a drought condition whereas positive GDI values are indicative of normal and wet conditions. Based on the standard classification, GDI ranging between 0.00 to -0.99 are considered as mild groundwater drought; -1.00 to -1.49 as moderate groundwater drought; -1.50 to -1.99 as severe drought and GDI equal to or less than -2.00 is considered as a severe drought condition. The GDI has been used for identifying the groundwater drought characteristics including the groundwater drought severity, duration 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.

RESULTS AND ANALYSIS

The spatial-temporal variation of the groundwater drought characteristics in Bearma basin have been studied based on the drought severity classification of GDI for the selected 86 observation wells in the basin falling in Sagar and Damoh districts during various months of the identified drought years 2002-03 and 2007-08. The spatial variation of the groundwater drought in the basin has been studied using ILWIS 3.0. A GIS layer (point map) has been created comprising of GDI values at all the wells and subsequently the spatial interpolation using the inverse distance technique is performed. The interpolated map has been classified on the basis of the GDI classification scheme given by**(**van Lanen and Peters 2000)for categorizing the areas into different drought classes.

Spatio-Temporal Variation of Groundwater Drought in the Confined Aquifers of Bearma basin

An attempt has been made to map the groundwater scenario in the confined aquifer in Bearma basin for which the groundwater levels in the piezometers tapping the unconfined aquifer have been used. The spatio-temporal variation of the groundwater in the confined aquifer during 2002-03 is given in Fig. 1 and the areal coverage under various groundwater droughts classes is given in Table 2. The processing and analysis of the piezometer data was also performed in a similar fashion as carried out for the groundwater table in unconfined aquifer. The GDI has been computed all available piezometer locations and subsequently interpolated in GIS environment using ILWIS 3.0. It has been observed that groundwater drought conditions prevailed in the confined aquifer only during the month of August 2002 with about 43.51% under drought scenario mostly concentrated towards the southern portion of the basin given in above Table 2. However, during the other seasons of the year 2002-03, the basin was mostly drought free. This is indicative of the fact that during the meteorological drought of 2002-03, the groundwater drought was more restricted to the unconfined aquifers in comparison to the confined aquifers as the shortages of surface water supply could mostly be augmented by tapping the unconfined aquifer. However a similar pattern is observed in both the unconfined and confined aquifers during the drought of 2002-03 as the southern zones are mostly affected by groundwater drought and the other regions are relatively drought free.

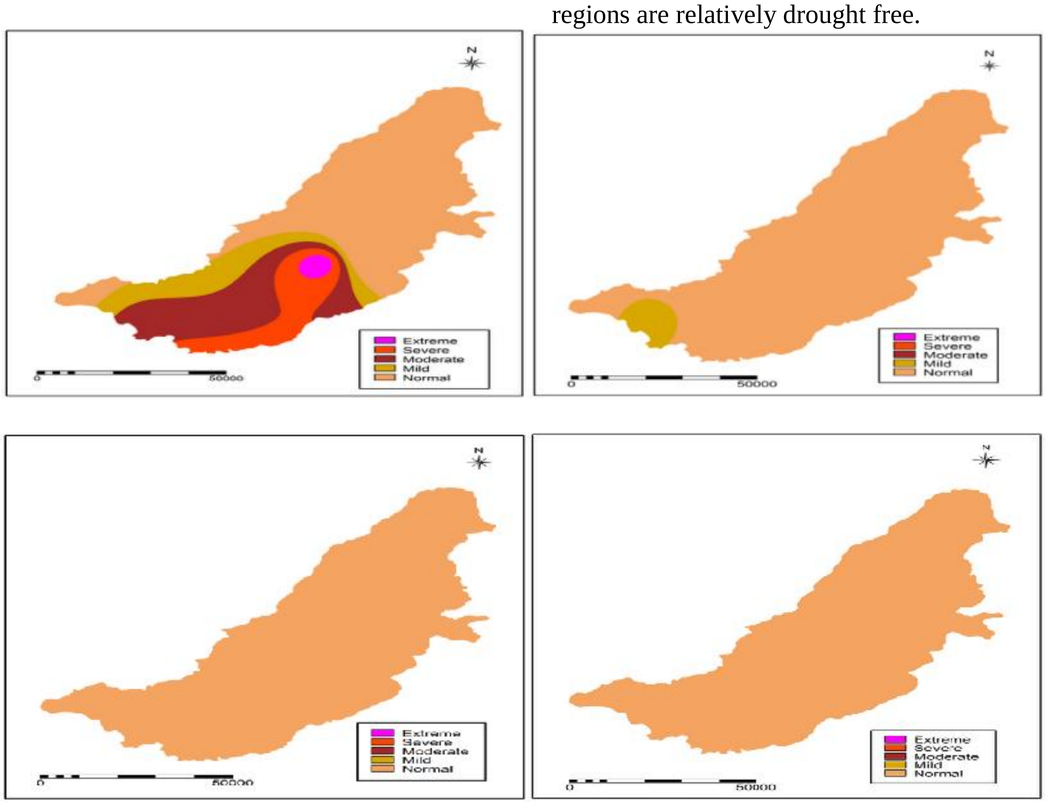

Fig. 1: Spatio-temporal variation of groundwater drought in confined aquifer during 2002-03

Table 2: Percentage area under different groundwater drought condition in confined aquifer during 2002-03

Sr. No.	Drought severity	Percentage of area under different severity classes (%)			
		Aug-02	Nov-02	Jan-03	May-03
1.	Extreme	1.29	---	---	---
2.	Severe	11.11	---	---	---
3.	Moderate	19.47	---	---	---
4.	Mild	11.64	4.05	---	---
5.	No drought	56.49	95.95	100	100

Similarly the anlaysis of the groundwater scenario in the confined aquifer has been carried out during the meteorological drought of 2007-08. The spatio-temporal variation of the groundwater in the confined aquifer during 2007-08 is given in Fig. 2 and the areal coverage under various groundwater drought classes is given in Table 3. Here the groundwater drought pattern is different as compared to 2002-03 and groundwater drought was felt during all the seasons of 2007-08. This may be due to the large scale dependence on groundwater due to the severe widespread meteorological drought of 2007-08 and as the demands could not be exclusively met from the unconfined aquifers as it was completely depleted, the confined aquifers were also tapped for meeting the continuous drought that prevailed in the basin during 2003-07. The groundwater drought pattern was of similar nature at both the unconfined and confined aquifer during 2007-08 as the northern parts of the basin experienced more severe groundwater droughts as compared to the remaining areas in the basin.

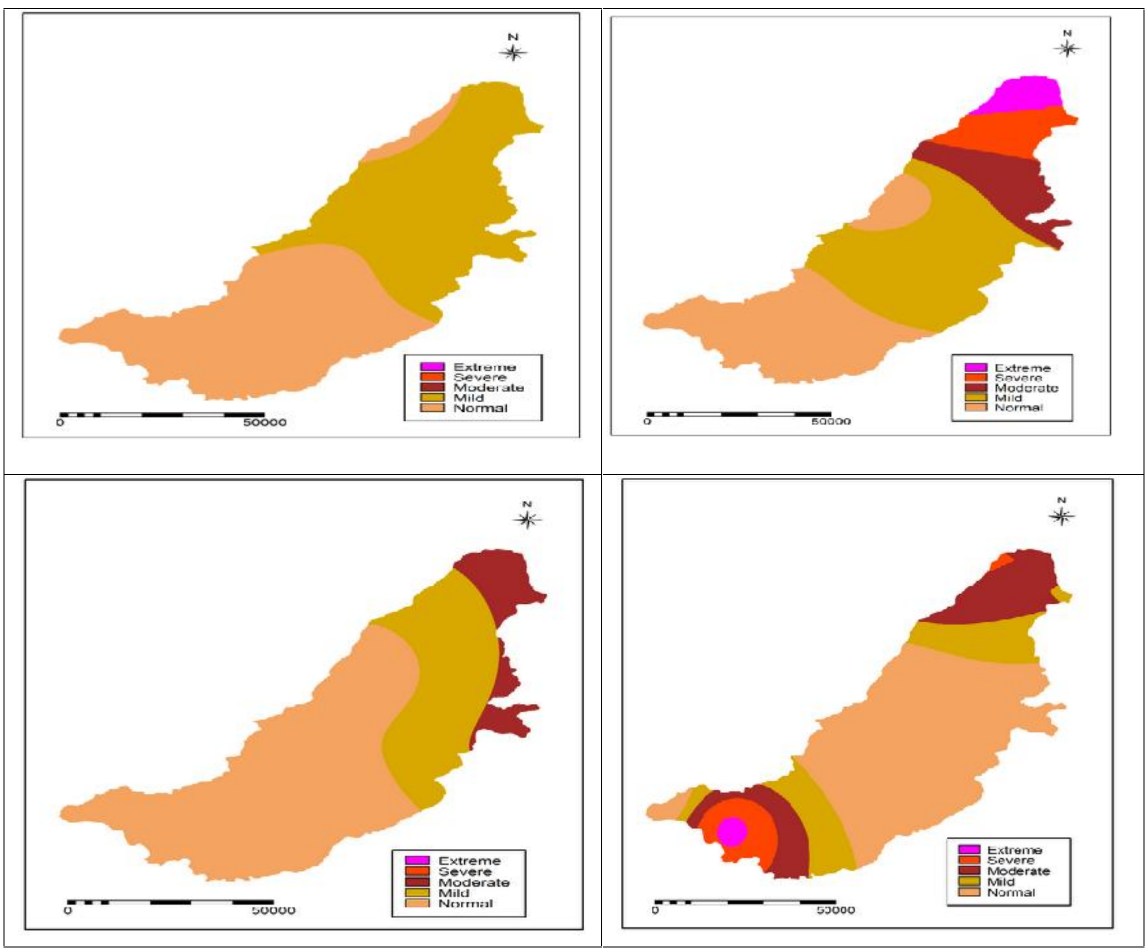

Fig. 2: Spatio-temporal variation of groundwater drought in confined aquifer during 2007-08

Table 3: Percentage area under different groundwater drought condition in confined aquifer during 2007-08

Sr. No.	Drought severity	Percentage of area under different severity classes (%)			
		Aug-07	Nov-07	Jan-08	May-08
1.	Extreme	---	4.32	---	1.27
2.	Severe	---	8.39	---	6.13
3.	Moderate	---	12.12	9.44	16.83
4.	Mild	47.33	38.26	27.63	17.37
5.	No drought	52.67	36.92	62.93	58.40

This spatio-temporal analysis of groundwater droughts therefore explains the fact that each groundwater drought event is unique in its characteristics and has varying degree of influence in different zones of the basin. The groundwater drought distribution and pattern is completely different in two of the meteorologically drought years of 2002-03 and 2007-08 with the southern portion of the basin facing worse drought scenario during 2002-03 whereas in 2007-08 the northern portions of the basin faced more severe drought conditions. However the groundwater drought pattern in the confined aquifers is similar to that of the unconfined aquifers. Nevertheless the extent and severity of drought in the confined aquifer is directly dependent on the severity and areal extent of the meteorological drought during that period of time. It is therefore imperative that sites suitable for artificial recharge be identified in drought prone areas so that the abundant surface water which is available during normal rainfall years can be effectively diverted to recharge the depleted aquifers which provide respite to the local population during times of distress when the disaster of drought sets in. This information along with the identification of areas with increasing trend in groundwater drought situation during the last few years will be useful in identifying groundwater drought vulnerable zones in the basin, so that planning can be carried out for tapping the surface water sources by creating additional storages in these areas.

CONCLUSIONS

This 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. The groundwater drought distribution and pattern is completely different in two of the meteorological drought years of 2002-03 and 2007-08 with the southern portion of the basin facing worse drought scenario during 2002-03 whereas in 2007-08 the northern portions of the basin faced more severe drought conditions.

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