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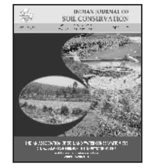

Analysis of groundwater drought characteristics of Damoh district in Bundelkhand using groundwater drought index

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ABSTRACT

Drought is a natural disastrous phenomenon that occurs due to the continuous reduction of rainfall over a short or a long period of time. A deficit in precipitation result in deficit of groundwater recharge, which leads to lower groundwater table and turn in groundwater drought. This is a challenging problem in Bundelkhand region of the Central India, where people mostly suffer from groundwater drought condition. 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 analyze the groundwater drought condition in Damoh district by using Groundwater Drought Index (GDI). The 26 years (1984-2010) quarterly groundwater levels of 59 observation wells falling in and around of Damoh district has been used. The GDI for all observation wells were computed with the help of groundwater level of each stations. With the help of temporal variations of GDI for each observation wells, the groundwater drought characteristics of the basin falling under Damoh district were analyzed. Result showed that the maximum number of 9 frequency drought events occurred at Fatehpur, Hatta and Bari-kalan with total durations varying between 83 to 134 months and total severity varying between -19.40 to -27.96. The cumulative groundwater drought duration of 134 months has been observed at Devron followed by 116 months at Kusumi. The overall drought intensity in the observation wells was found -0.38.

1. INTRODUCTION

A drought is an extended period when a region notes a deficiency in its water supply (Beran and Rodier, 1985 and Panigrahi *et al*., 1995). Generally, this occurs when a region receives consistently below average precipitation. It can have a substantial impact on the ecosystem and agriculture of the affected region. Although droughts can persist for several years, even a short, intense drought can cause significant damage. Drought and its consequences have long plagued ecosystems and society (Le Roy, 1971). The consequences of drought vary greatly depending on its location, timing, extent and the type of society or social sector impacted by the drought (Gleick, 1993 and Panigrahi *et al*., 2002). The different types of droughts have their own specific spatio-temporal characteristics (Peters *et al*., 2006 and Tallaksen *et al*., 2009). Different types of drought are meteorological, hydrological, agricultural and socio-economic (Hisdal and Tallaksen, 2000; Majumdar *et al*., 2010; Van Lanen *et al*., 2012; Karimi *et al*., 2013 and Alam *et al*., 2016). Meteorological drought simply refers to the atmospheric conditions that result in the absence or reduction of precipitation and since its definition only relies on rainfall, the meteorological drought can end literally overnight, as soon as sufficient precipitation falls to bring levels close to average. Agricultural drought occurs when there is insufficient soil moisture required for crop growth and crop production. It is a short-term dryness in soil layers that can reduce crop yields (Park *et al*., 2005). 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 and Van Loon and Laaha, 2015).

The surface water and groundwater droughts will occur more or less simultaneously if the surface water is mainly fed by groundwater. The lag between a meteorological drought and a hydrological drought may amount to months or even years. The ground water 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. A conceptual definition as given by (Calow *et al*., 1999) states that, groundwater drought describes a situation where groundwater sources fail as a direct consequence of drought. This definition of a ground water drought apparently also incorporates human demand of water. 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. It is the 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.

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). 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. One the other hand, groundwater levels characterize the present storage and they 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. Therefore, in most of the cases, groundwater levels are monitored to detect groundwater droughts. (Bloomfield and Marchant, 2013) described a new index, Standardized Groundwater level Index (SGI) for standardizing groundwater level time series and characterizing groundwater droughts.

In this study, an attempt has been made to evaluate the groundwater drought characteristics by developing GDI for Damoh district, 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. The groundwater drought characteristics evaluated using the percentile approach or an appropriate drought index.

The Bundelkhand region in Central India has been in the grip of severe drought in the last decade mainly due to poor, limited and untimely rainfall and its high variability coupled with improper water resources development and management. The summer Indian monsoon is a complex phenomenon and in recent years, its complexity is increasing due to change in numerous atmospheric and land-cover parameters. The monsoon rainfall is the only possible source of groundwater recharge in the Bundelkhand region of semi-arid Central India. A continuous spell of poor rainfall in combination with high temperature in successive years hinders groundwater recharge and imparts stress on groundwater resources leading to severe drought in many parts during both, the monsoon and the non-monsoon seasons. Scarcity of surface water bodies in this region has made people dependent entirely on groundwater resources for public water supply and irrigation. The dependence on groundwater is therefore more pronounced during the periods of extended droughts as there are very few surface storage schemes to rely upon. This has led to a situation of over exploitation of the precious groundwater resources in many of the blocks of the region. Therefore it becomes imperative to study the response of groundwater systems to drought and their performance under drought conditions. When groundwater systems are affected by drought, firstly the groundwater recharge (Singh *et al*., 2017) and subsequently the groundwater levels and groundwater discharge decreases.

It is 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).

2. 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 North Latitudes of 23°07′ and 24°18′ and East Longitudes of 78°54′ and 80°00′. The Bearma basin is a leaf shaped elongated basin with a total catchment area of 5890 km^2. The average rainfall for the basin is about 1186.85 mm and more than 90% of the annual rainfall occurs during the south west monsoon months of June to October. The climatic conditions prevailing in the basin vary from semi-arid to dry. The five rain gauge stations at Deori, Rehli, Damoh, Jabera and Hatta represent the rainfall pattern in the basin.

Hydrological Data

To investigate the groundwater drought, 26 years (1984-2010) quarterly groundwater levels of 59 observation wells falling in Damoh districts were used for identifying the groundwater drought characteristics in Bearma basin. The groundwater levels are being monitored by the State Ground Water 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 alongwith 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:

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

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 reduced level 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 GDI 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 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:

$$GDI = \left\{ \frac{GWL_{ij} - GWL_{im}}{\delta} \right\} \qquad ...(2)$$

Where, GWL_{ij} = seasonal water level for the i^{th} well and j^{th} observation, GWL_{im} = seasonal mean, δ = 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.

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.

3. RESULTS AND DISCUSSION

Groundwater Drought Characteristics of Damoh District in Bearma Basin

The GDI has been computed for 59 observation wells falling in Bearma basin under Damoh district based on quarterly groundwater levels. The ground water drought conditions follow the widespread meteorological drought observed in the region during 2002-03 and 2007-08. The maximum groundwater drought intensity of -2.46 was observed at Kudai (Fig. 1) during the drought event which commenced from November 2008 and lasted for two months up to January 2009. The maximum drought duration of 58 months was observed at Mariadeo (Fig. 2) with a severity of -6.39 and intensity of -0.11 commencing from November 2006. This was followed by another drought event with duration of 53 months at Bandakpur (Fig. 3) with a severity of -7.10 and intensity -0.13 commencing from January 2004. The maximum drought with severity of -13.49 was observed at Kundalpur (Fig. 4) for the drought commencing from November 2007 and extending for 19 months. This was followed by the drought event at Deodongra (Fig. 5) with a severity of -13.18 commencing from May 2006 and extending for 23 months.

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

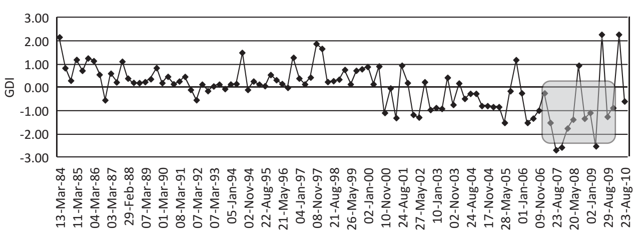

Fig. 1. Temporal variation of Groundwater Drought Index (GDI) at Kudai

The groundwater drought characteristics evaluated at the 59 observation wells in Damoh district are given in Table 2. The maximum number of 9 frequency of drought events occurred at Fatehpur (Fig. 6), Hatta (Fig. 7) and Bari-kalan (Fig. 8) with total durations varying between 83 to 134 months and total severity varying between -19.40 to -27.96 and average drought intensity varying between -0.36 to -0.39. The maximum cumulative groundwater drought duration of 134 months has been observed at Devron (Fig. 9) followed by 116 months at Kusumi (Fig. 10) with an average drought intensity of -0.36 and -0.28, respectively. The maximum average drought

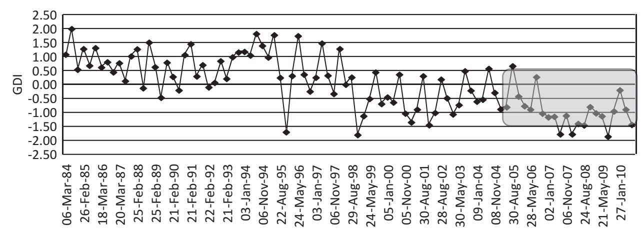

Fig. 2. Temporal variation of Groundwater Drought Index (GDI) at Mariadeo

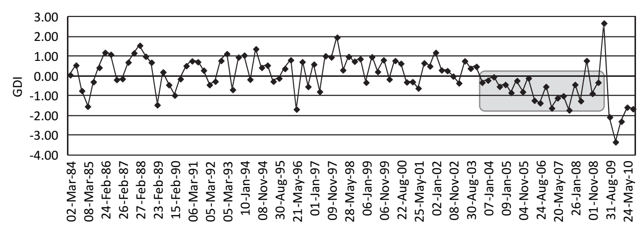

Fig. 3. Temporal variation of Groundwater Drought Index (GDI) at Bandakpur

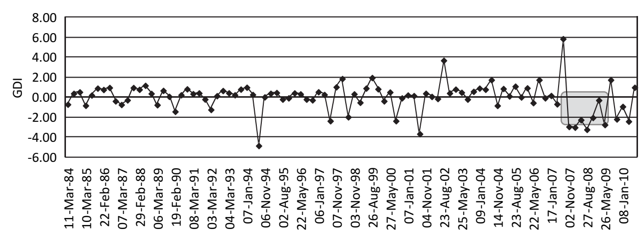

Fig. 4. Temporal variation of Groundwater Drought Index (GDI) at Kundalpur

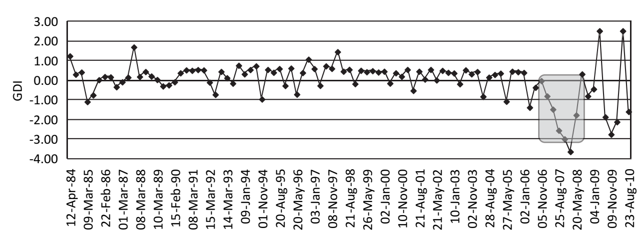

Fig. 5. Temporal variation of Groundwater Drought Index (GDI) at Deodongra

Table: 2
Groundwater drought characteristics in wells of Damoh district in Bearma basin

S.No.	Name of village	Frequency of drought events (number)	Total drought duration (months)	Total drought severity	Average drought intensity
1.	Luharra	6	40	-14.93	-0.35
2.	Khejara	6	71	-22.44	-0.34
3.	Khajari	3	32	-12.79	-0.51
4.	Hathani	5	78	-23.15	-0.43
5.	Bilai	8	66	-19.34	-0.32
6.	Bandakpur	5	86	-23.26	-0.35
7.	Abhana	4	42	-19.74	-0.61
8.	Deodongra	3	40	-20.5	-1.38
9.	Ghatera	6	43	-15.79	-0.37
10.	Banwar	4	51	-16.93	-0.55
11.	Kundalpur	3	32	-20.34	-0.60
12.	Hardua-sadak	4	102	-19.09	-0.37
13.	Bamhori	4	41	-14.5	-0.59
14.	Kusmi	7	116	-21.8	-0.28
15.	Jhalon	6	62	-21.21	-0.44
16.	Tardehi	4	48	-12.81	-0.43
17.	Bamhori (T)	4	52	-15.5	-0.42
18.	Jharoli	5	65	-12.33	-0.41
19.	Purena	8	101	-19.4	-0.39
20.	Palar	7	86	-25.08	-0.39
21.	Sagoni (Kundalpur)	8	109	-28.87	-0.39
22.	Amkhera	1	5	-3.52	-0.39
23.	Ghatpiparia	6	65	-17.66	-0.38
24.	Pura	4	55	-22.3	-0.39
25.	Parsoria	5	59	-23.2	-0.39
26.	Karraiya	2	36	-11.8	-0.39
27.	Hinota	4	66	-20.67	-0.38
28.	Mariadeo	8	105	-22.28	-0.38
29.	Muhari	6	72	-19.84	-0.38
30.	Fatehpur	9	88	-23.47	-0.38
31.	Luhari	5	74	-19.3	-0.38
32.	Hatta	9	83	-26.81	-0.37
33.	Kudai	5	60	-25.08	-0.38
34.	Ghutria	6	60	-14.29	-0.38
35.	Barkhera-chain	6	52	-20.06	-0.38
36.	Kachanari	4	66	-12.3	-0.37
37.	Hanmatpatti	5	79	-21.26	-0.37
38.	Gaisabad	2	61	-9.11	-0.23
39.	Barkhera	6	38	-13.84	-0.37
40.	Bari-kalan	9	105	-24.92	-0.36
41.	Bhainsa	7	86	-23.06	-0.36
42.	Raneh	5	93	-22.64	-0.36
43.	Lidhora (harat)	4	22	-6.81	-0.33
44.	Devron	8	134	-27.96	-0.36
45.	Kumhari	7	93	-20.07	-0.35
46.	Balakota	2	20	-5.05	-0.35
47.	Patana	6	58	-23.06	-0.36
48.	Khamaria	5	37	-18.09	-0.36
49.	Tori	3	23	-15.64	-0.36
50.	Tejgarh (105)	3	26	-15.15	-0.36

Table: 2
Continued...

S.No.	Name of village	Frequency of drought events (number)	Total drought duration (months)	Total drought severity	Average drought intensity
51.	Pura (106)	4	80	-14.55	-0.36
52.	Dhaneta	5	67	-16.22	-0.36
53.	Bakan	3	75	-12.98	-0.36
54.	Batiagarh	5	68	-17.31	-0.36
55	Majhagaon-patol	5	44	-15.89	-0.36
56.	Sanga	2	8	-10.31	-1.29
57.	Sarra	2	17	-4.84	-0.28
58.	Nohta	5	50	-16.6	-0.33
59.	Majhaguwa- patol	1	39	-4.02	-0.10

intensity of -1.38 has been observed at Deodongra followed by -1.29 at Sanga and -0.61 at Abhana, whereas the maximum total drought severity was found at Sagoni (Kundalpur) with severity -28.87. The overall drought intensity in the observation wells in Bearma basin falling in Damoh district is -0.38.

The extreme groundwater drought condition was found in year 2009 in most of the observation wells except Devron, Kundalpur, Mariadeo, Banwar, Jharoli, Palar, Pura, Bakan, Barkhera, Khajari and Batiagarh. It indicates that the groundwater level suddenly falls down to its normal condition due to persisting long duration of drought and this may it affecting the normal agricultural practices. There were six observation wells *viz.*, Raneh, Majhgaon-patol, Kachnari, Jharoli, Banwar and Amkhera found more than extreme groundwater drought condition during 1984-85, whereas a regular features of long duration mild to moderate groundwater drought were found during 1984-2006 in most of all observation wells except Kundalpur, Abhana and Jhalon where a few event observed extreme groundwater drought during 1994-95.

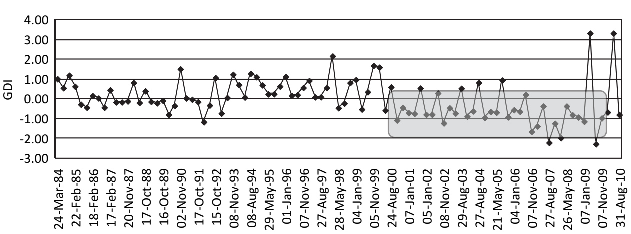

Fig. 6. Temporal variation of Groundwater Drought Index (GDI) at Fatehpur

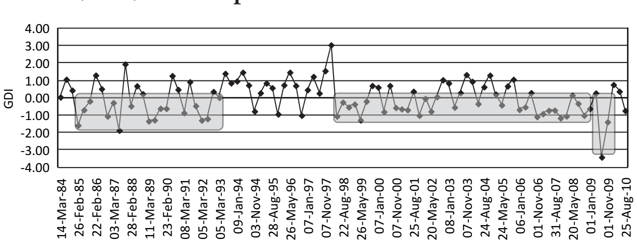

Fig. 7. Temporal variation of Groundwater Drought Index (GDI) at Hatta

Effect of Groundwater Drought on Crop Growth and their Management

This study reveals that, the erratic distribution and fluctuation in rainfall is directly governs the growth, development and yield of crops. Rainfall variability is major factor influencing agricultural

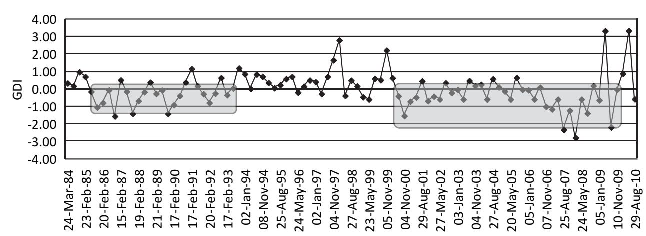

Fig. 8. Temporal variation of Groundwater Drought Index (GDI) at Bari-kalan

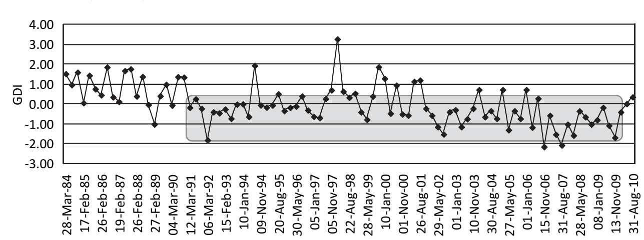

Fig. 9. Temporal variation of Groundwater Drought Index (GDI) at Devron

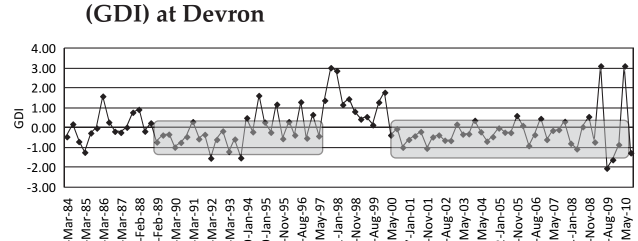

Fig. 10. Temporal variation of Groundwater Drought Index (GDI) at Kusmi

productivity and sustainability, shortage of stored surface water due to undulating land topology, extreme temperature intensity and shallow soil depth and direct domestic use, results in increases the dependency of farmers on groundwater. At this situation farmer lastly start to over extraction of groundwater for completion of their crops irrigation demand in lean period, so decreases the normal level of water table and continue extending this activity for long time, it prolonged the groundwater drought condition. Due to this region groundwater table goes far away and extraction become more economical, thus farmers not able to easily extract groundwater at that time and water demand of crops increases day by day but the water availability decreases according to crop requirement, so plants exposes to shortage of desired levels of moisture, and growth become below to optimum level, thus groundwater drought affects the yield of the crop. So, there should be needed well-planned and properly distributed *in-situ* and *ex-situ* agricultural practices with agronomical and soil and water conservation engineering measures comprising construction of field bunds, gabion structures on first and second order streams, water spreaders in depressions and a series of check dams on third and fourth-order streams not only reduced soil and nutrient loss, but also generate increased water resources besides imparting drought-proofing to control such condition before occurrence of worst (Kumar *et al.*, 2011).

The problem of groundwater drought can also be improved by efficient use of water in agricultural land by adopting "more crop per drop" concept through improved agricultural knowledge and practices, right selection of crops with lower water requirements according to soil and climate, using correct planting time, application of pressurized irrigation techniques (drips and sprinklers) and improved methods of irrigation efficiency, adopting agronomical mulching and fertility practices in moist soil, and discontinuing irrigation on soils that are unsuitable. These can potentially increases farm revenue while reducing groundwater consumption through prepares a ground water resources allocation plan for community consultation. Use of artificial groundwater recharge techniques in over-exploited regions such as water spreading, recharge through pits, shafts, wells etc. for augmentation of ground water, resulting shortage of supply water and intrusion of saline water in coastal areas. Replenishment of groundwater recharge practices can also help in mitigation of groundwater drought by taking steps like; identifying and testing options for enhancing groundwater recharge, evaluating alternative supply options for recharge or to replace groundwater use and built, operate and monitor manage aquifer recharge through sale of recharge recovery allocations or through government support of groundwater management. Organization of motivational programs related to water conservation for farmers helps to learn efficient and manageable use of stored water in lean period for the crop.

Crop Planning Strategies for Farmers in Ground water Drought Condition

This study gives an idea about the shortage of groundwater when surface water has completely dried due to overexploitation, where rate of discharge is more than recharge. In such condition, the concept of GDI work as an indicator for the farmers, to do not over-exploit the groundwater. Because groundwater drought effect does not see at instant time, it is long duration effect, so farmers should carefully use groundwater in adverse condition. Use short variety crops, because very less amount of water needs in whole duration of crop growth. Adopt deficit irrigation techniques and save water for next growing crops. Use pressurized irrigation methods likes' sprinkler and drip irrigation practices; because groundwater level does not change drastically, it is long duration effect because the fluctuation of groundwater table, so prevent excess consumption of groundwater during use of irrigation and domestic purposes. If, groundwater level is more than the normal condition carefully use at that time also, because next year may happen meteorological drought and rainfall may not occurs according to required amount, so save and store groundwater for next growing crop year because meteorological drought is terminated at least once or continuous after three to four years, so in that adverse year's a enough amount of groundwater storage will be available for completion of irrigation and livestock's needs.

4. CONCLUSIONS

This study investigates groundwater drought condition extent in Damoh district of Bundelkhand region by development of GDI from Reduced Levels

(RL) of ground water level approach. Result showed that the maximum number of 9 frequency drought events occurred at Fatehpur, Hatta and Bari-kalan with total duration varying between 83 to 134 months and total severity varying between -19.40 to -27.96. The cumulative groundwater drought duration of 134 months has been observed at Devron followed by 116 months at Kusumi. The overall drought intensity in the observation wells was found -0.38. It has been observed that the groundwater drought occuring on a regular basis in 59 observation wells were more affected by extreme groundwater drought condition during meteorological drought years 2002-03 and 2007-08, whereas the central portion suffered by mild to moderate. There was worst groundwater drought condition in ten observation wells *viz.*, Kudai, Marideo, Bandakpur, Kundalpur, Deodongra, Fatehpur, Hatta, Bari-kalan, Devron and Kusumi among 59 observation wells. The extreme groundwater drought condition was found in year 2009 in most of the observation wells except Devron, Kundalpur, Mariadeo, Banwar, Jharoli, Palar, Pura, Bakan, Barkhera, Khajari and Batiagarh. Due to more elevation difference and deficit of precipitation farmers always suffer from scarcity of surface water and thus they lastly depend on ground water for use in agricultural practices and for their livestocks. The large amount of water extraction from groundwater recourses reduces the normal level of groundwater table which extended for long period and result in groundwater drought condition. So, this situation threatens that there should have proper management of surface and groundwater for sustainable development by augmenting groundwater recharge.

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