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Groundwater potential in a drought prone Betwa river basin, Bundelkhand

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ABSTRACT

This study presented a modified concept of assessing groundwater potential and water table level behavior under varying rate of recharge potential for regional scale modeling of Betwa basin using Processing ModFlow for Windows model. Betwa basin of Bundelkhand region which covered the districts of Madhya Pradesh and Utter Pradesh was selected to apply this concept. The model was calibrated and validated using observed water table elevation data for the period 2005–2013, which showed agreement between observed and predicted water table elevation. The coefficient of determination (R^2) ranged between 0.74–0.87 for calibration and 0.63–0.87for validation. Scenario analysis represents the water table elevation under three varying groundwater recharge condition in Shahijina, Garrauli, Mohana and Basoda sub-basin of Betwa basin. Results shows that the scenario based on recharge with 60% of surface runoff combined with river bed recharge and natural recharge has maximum influence on groundwater recharge. Groundwater recharge under the scenario varied from 0.33–1.61 m above reference level. Recharge from 30% of surface runoff combined with river bed recharge and natural recharge varied from 0.16–1.05 m above reference level. The study shall be useful for planning of groundwater development in Betwa basin and to suggest an alternate location for development of soil and water conservation structure. The water table elevation simulation also showed that the recharge levels and the sustainability of groundwater resources cannot be ensured unless water availability in arid to semi-arid region river basin increased.

Key words: Betwa basin, Groundwater recharge, Groundwater modeling, PMWIN model, Water table elevation

Global demand of water for agriculture is expected to increase by 60% in the year 2025 (WWAP2018). In India, groundwater resources available for irrigation, and domestic, industrial and other purposes is 369 BCM and approximately 71 BCM, respectively (CWC 2016). Due to increasing demand of groundwater in agriculture, industry and for domestic purposes, pressure on groundwater is increasing.

The groundwater recharge is a process by which infiltrated water moves through the vadose zone and joins the water table. The water coming through rainfall is not completely flowing as run-off, while some part of it is going to groundwater recharge (Saraf *et al.* 2004). Amount of water reaching to the water table under specific geo-hydrologic and orographic conditions can be termed as the groundwater recharge potential. Hard rock poses a constraint for groundwater recharge in several regions of India (Kumar *et al.* 2008). The annual replenishable ground water resource for whole country has been estimated as 433 BCM. About 58% of the annual replenishable groundwater resources through monsoon rainfall recharge, which is 68% and the share of other sources, viz. canal seepage, return flow from irrigation, recharge from tanks, ponds, and water conservations structures is approx. 32% (CGWB 2016).

Betwa river basin comes under the region of semi-arid agro-climatic region of India. Upper to middle part of the basin received more rainfall than middle to lower region of the basin (Singhai*et al.* 2017, Jeet *et al.* 2017). However, the groundwater table elevation is more in upper part than lower part of the basin. The development of groundwater recharge structure in the basin is poor. The groundwater level in the upper Betwa basin is declining with 65.83% of the total basin area are under moderate groundwater recharge zone (Avtar *et al.* 2010) and this may be improved by construction of percolation tanks, check dams and farm ponds in basin areas (Nayak *et al.* 2015, Singhai *et al.* 2017).Water Storage planning at river basin and regional scales should consider a portfolio of surface and subsurface storage. Therefore, the present study was planned to focus on groundwater assessment through groundwater modelling for the planning and management of groundwater resources at basin level.

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MATERIALS AND METHODS

The Betwa river basin lies between latitude 22°54' to 26° 05' N and longitude 77°10' to 80°20'E. The areal extent of the Betwa basin is approx. 43469 km^2. The total length of basin from its origin in the Raisen district of Madhya Pradesh to its confluence in Yamuna river near Hamirpur in Uttar Pradesh is approx. 590 km. It covers the areas of Bundelkhand uplands, the Vindhyan scrap and the Malwa plateau lands in the districts of Tikamgarh, Sagar, Vidisha, Raisen, Bhopal, Ashoknagar, Shivpuri and Chhatarpur of Madhya Pradesh and Hamirpur, Jalaun, Jhansi, Mahoba, Lalitpur and Banda districts of Uttar Pradesh. The average annual rainfall varies from 700–1200 mm (approx. 958.6 mm), out of which nearly 80% occurs during the SW monsoon (Suryavanshi *et al.* 2014, Jeet *et al.* 2017).

Water table elevation data for a period (2005–2013) was collected from Central Ground Water Board, Faridabad and meteorological data was collected from India Meteorological Department, Pune. Other hydrogeological data, required to construct the model, are Initial boundary condition, horizontal/vertical hydraulic conductivity, specific yield and thickness and type of the aquifer. Shuttle Radar Topographic Mission (SRTM) image was processed in a GIS to make the Digital Elevation Model (DEM) of the basin.

The Betwa basin falls under the Vindhyan sandstone, Deccan traps and Bundelkhand granite geomorphology regions of India. The rainfall recharge factor of different geologic formations varies according to material permeability. The rainfall recharge factor in Betwa basin was varied from 4.65–1%. Singh *et al.* (2012) reported that the total groundwater recharge varies from 14–32% of total rainfall in the sonar sub-basin of Bundelkhand region.

General description of occurrence of groundwater: Aquifer system in Betwa basin is inadequate and non-dependable largely due to the presence of hard rock hydrogeological conditions. Except a belt along the outlet of river basin and a few pockets and there already having tube-well have good water yield. Remaining part is having very low groundwater yield. The depth to groundwater levels in MP and UP ranges from 0.83–49.40 m bgl and 0–38.5 m bgl respectively (CGWB 2015 a, b). In general, the groundwater level in districts of UP in Betwa river basin was found to be 10–20 mbgl (NRAA 2008, CGWB 2015b).

The PMWIN: Processing ModFlow for Windows ((PMWIN ver. 5.3.1) is an integrated simulation system for modeling groundwater flow and transport processes with MODFLOW. It is available with a professional graphical pre-processor and post-processor with the modular three-dimensional finite-difference groundwater model MODFLOW of the U.S. Geological Survey (McDonald and Harbaugh 1988).

Discretization of study area: The Betwa basin having total area approx. 43,500 km^2 and single layer was discretized in 69 rows and 61 columns having 4209 cell with mesh size 5 km × 5 km. The aquifer system was unconfined and assumed isotropic.

Initial boundary condition: Specifying initial conditions is an important part of groundwater modelling. In this study initial water level (or pre-monsoon groundwater level) was considered as a top water boundary and bottom of the aquifer was considered as bottom boundary. A description of the horizontal and vertical distribution of hydraulic head throughout the modeled basin area is required as initial condition for groundwater flow.

Time parameters: Simulation was done for the year 2005. Total simulation period was 365 days (1st January 2005–31st December 2005). The total 3 stress periods with time step of one month in each year were considered for simulation of water table fluctuations. Solution was obtained at each time step. Time dependent boundary condition was changed at the beginning of each stress period. The main input at the beginning of each stress period was net recharge flux.The other input parameters such as hydraulic conductivity and specific yield were kept constant during simulation period.

Input parameters

Hydrogeological parameters: The groundwater extraction in Betwa basin was done from the unconfined aquifer with average depth of 75 m below ground level (mbgl). The specific yield, horizontal hydraulic conductivity and average transmissivity were taken as 0.05–0.10, 5–15 m/day and 0.5–375 m^2/day, respectively (CGWB 2009).

Groundwater recharge: Rainfall is the major source of groundwater recharge in the Betwa river basin. Ground water recharge has to be estimated separately for monsoon and non-monsoon. Recharge from rainfall in entire basin was calculated for the monsoon only, because 80–85% of total rainfall occurs in this season. Only 15–20% rainfall occurs in non-monsoon. Recharge in non-monsoon assumed to be negligible (CGWB 2009). The daily recharge rate was converted into daily net recharge rate by subtracting daily groundwater pumping (Kumar 2011) and was estimated by multiplying daily maximum rainfall during the monsoon with rainfall recharge factor. Daily percolation or shallow groundwater recharge in the basin areas can also be estimated with SWAT model (Lee and Chung 2006). Recharge package of MODFLOW was used to estimate groundwater recharge.

Recharge from river was estimated using the river package, which simulated the interaction between river and aquifer using the river bed conductance, head in river and length, width and thickness of river bed. The flow between aquifer and river is expressed as:

$$QRIV = CRIV\ (HRIV - RBOT)$$

where, QRIV, flow between aquifer and river, (m^3/day); CRIV, river bed hydraulic conductance (m^2/day); HRIV, head in the river (m); RBOT; elevation of river channel bottom (m).

The river bed hydraulic conductance for each grid or mesh was calculated as:

$$CRIV = \frac{K \times L \times W}{M}$$

where, K, hydraulic conductivity of river bed material (m/day); L, length of river channel (m); W, width of the river channel in the mesh or grid (m); M, thickness of the river bed material (m).

The length of river channel was measured to be 590 × 10^3 m and 400 m width. The thickness of river bed material was initially assumed to be 4 m, which was adjusted during calibration. The hydraulic conductivity of river bed material was calibrated.

Groundwater abstraction: The number of groundwater abstraction structures such as bore wells, dug wells, dug-cum-bore wells existing in the area was collected from Central Ground Water Board (CGWB 2014, NRAA 2014). Groundwater abstractions were calculated based on unit draft method (CGWB 2009). The net annual groundwater draft was estimated at 70% of gross annual groundwater draft as recommended by Groundwater Estimation Committee (CGWB 2009).

Calibration and validation of water table elevation: Eight borewell were randomly selected for calibration and validation of observed MODFLOW. Two borewell were selected for calibration and validation of water table fluctuation in each sub-basin. The water table elevation in borewell for the year 2005–2010 was used for calibration and the year 2011–13 was used for validation. To calibrate the model, hydraulic conductivity and specific yield parameters were manually adjusted based on the comparison between hydraulic changes during the year 2005–2010 (Table 1). Bore/dug wells were mainly used for pre-monsoon and post monsoon water level recording in the basin (CGWB 2015 a, b). Phreatic levels in the unconfined aquifer were measured in bore/dug wells installed in the basin. The calibration of model was done by comparing the observed and simulated groundwater table during pre and post-monsoon. The statistical parameters, viz. coefficient of determination (R^2) was estimated to describe the closeness of simulated and observed values of groundwater table level.

Simulation of management scenarios: Scenarios were generated to evaluate the impact of rainfall-runoff on groundwater recharge generation helped in the estimation of net recharge of groundwater in the entire sub-basins of Betwa basin. In scenarios analysis groundwater recharge was calculated by considering different percentage of stored runoff at the outlet of each sub-basin. Runoff was stored at the outlet of each sub-basin assessing that a rainwater harvesting structure will be located at the outlet. The net recharge in scenario-1 was calculated by multiplying daily maximum rainfall in month and rainfall recharge factor. Scenario-1 was based on assumption of the uniform net recharge in each sub-basin (11% of daily rainfall of month in sub basin I and II and 4.5% and in the sub basin III and IV). This scenario explains the uniformity of groundwater availability in the respective sub-basin. Kumar (2011) also generated scenarios based on expected recharge and different rate of pumping conditions. Net recharge in Scenario-2 and scenario-3 was calculated by considering 60% and 30% recharge contribution of water stored at the outlet of each sub-basin and net recharge in scenario-1. Simulation was done for each scenario to estimate the groundwater recharge. The model was simulated by changing the various input parameters such as initial hydraulic conductivity and specific yield (Song *et al.* 2012). Under scenario-1, 11% of daily rainfall of month (for Shahijina and Mohana sub-basin) and 4.5% of daily rainfall of month (for Garrauli sub-basin and Basoda sub-basin) were taken. Under scenario-2 sum of 60% of surface runoff per unit basin area with net recharge in Scenario-1 were taken. Under scenario-3 sum of 30% of surface runoff per unit basin area with net recharge in Scenario-1 were taken.

Table 1 Values of input parameters for MODFLOW

Parameter	S1A	S1B	S2A	S2B	S3A	S3B	S4A	S4B
Aquifer hydraulic conductivity (m/day)	5.50	5.40	11	11	5	5.40	10	15
Transmissivity (m^2/day)	46.32	46.35	46.32	12.49	46	46.3	9.44	9.34
Specific yield	0.10	0.10	0.10	0.10	0.05	0.05	0.10	0.05

RESULTS AND DISCUSSION

Spatial variability of groundwater levels in Betwa river basin: Elevation of groundwater level amsl was determined by subtracting ground water table level, below ground level (mbgl) from the ground surface elevation. Groundwater elevation in upper and middle region of Betwa basin varied from 360–480 and more than 480 m amsl (Fig 1). In middle

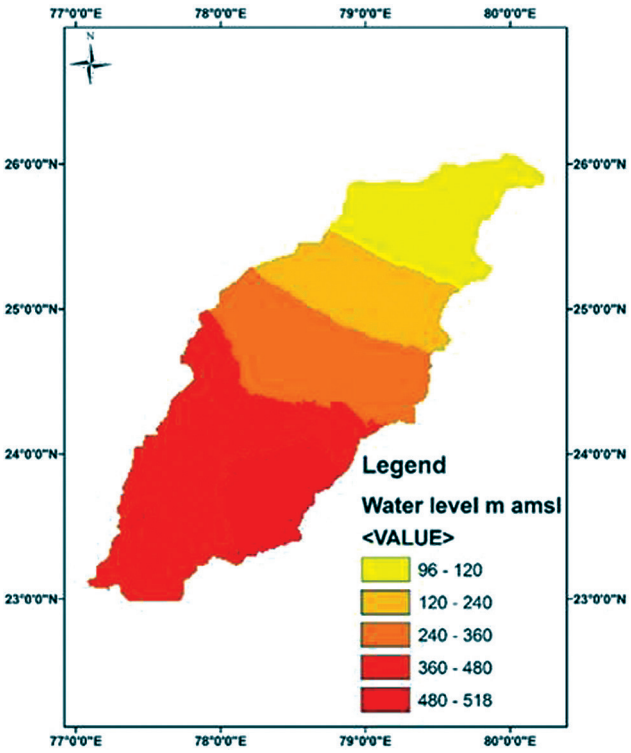

Fig 1 Spatial variability of groundwater level in the basin.

Table 2 Well performance in each sub-basin during calibration and validation

Well No	R^2	
	Calibration	Validation
S1A	0.761	0.633
S1B	0.868	0.872
S2A	0.772	0.794
S2B	0.822	0.689
S3A	0.751	0.699
S3B	0.738	0.651
S4A	0.855	0.666
S4B	0.738	0.749

to lower region, it varied from 120–240 m amsl. In lower region of the basin groundwater elevation was less than 120 m amsl. The difference in water table elevation is due to the difference in basin elevation and geo-hydrological condition. In general groundwater level has declined in the basin except certain pockets. In 2007, there was considerable decline in water level, due to poor rainfall and groundwater recharge.

Calibration and validation of groundwater model: Groundwater model MODFLOW was calibrated and validated using observed water level in eight observations well. Calibration was done for 2005–2011 and validation was done for 2011–2013. The horizontal hydraulic conductivity and specific yield greatly influence the hydraulic head in unconfined aquifer. The calibrated values of horizontal hydraulic conductivity and specific yield for unconfined aquifer were 1–15 m/day and 0.05–0.1%, respectively. The statistsical parameteres, i.e. Coefficient of determination (R^2) was used to show the collinearity between observed and predicted water table elevation (Table 2). Result showed very good linear relatioship between observed and simuated water level in calibration model, but in validation few well showed better performance than calibreted results. For calibration R^2 value ranged between 0.74–0.87, and for validation R^2 0.63–0.87. Results showed the good collinearity of observed and predicted water table elevation during calibration and validation. Model performance indicators during calibration and validation were within acceptable limits.

Water level fluctuation with groundwater recharge: Effect of rainwater harvesting and groundwater recharge was evaluated using calibrated and validated groundwater model MODFLOW. Surface runoff assessed by SWAT in each sub-basin was considered for simulating water table rise if it is retained in the large water harvesting structure. Water level fluctuation mainly depends on the recharge/abstractions, hydraulic conductivity and porosity of geological formations. Three groundwater recharge scenario were considered for Betwa basin. Water stored at the outlet of sub-basin was uniformly distributed throughout the sub-basin. This may also influence the water level in other sub-basins. Groundwater recharge at the outlet of each sub-basin was estimated by subtracting initial hydraulic head with hydraulic head after net recharge in various scenarios. Row and column wise average of predicted water table were taken because shape of sub-basin was not regular and there were large number of cells. Average value of hydraulic head in each sub-basin was calculated by averaging row and column values of hydraulic heads. Amount of groundwater recharge in term of rise in water level during pre and post monsoon period of year 2005 was predicted by calibrated groundwater model MODFLOW.

The scenario analysis showed that the groundwater recharge under each scenario was different due to the different amount of surface runoff available for groundwater recharge. The sub-basin 1 and sub-basin 3 revealed higher recharge than sub-basin-2 and sub-basin 4 under scenarios 1, 2 and 3 (Table 3). This variation in groundwater recharge may be due to soil type, LULC, slope and geologic formation of sub-basin and available surface runoff. For sub-basin 1, 2 and 4 the rise in groundwater was found to be in the range of 2.14–3.75, 0.41–2.01 and 0.89–1.23 m, respectively. Groundwater recharge was maximum in sub-basin 3 was 5.33 m, 5.94 m and 5.64 m in scenario-1, senario-2 and scenario-3, respectively. This result showed that the maximum annual change in water level obtained in Shahijina followed by Mohana sub-basin. This happened mainly due to good rainfall or low to moderate topography of the sub-basin. Upper portion of the basin have very steep slope, so water runoff to middle to lower portion in very less time of concentration. So, adoption of water conservation structure at middle to lower portion of the basin required minimal strategy than upper portion of basin. Water conservation structures such as percolation tank and combination of sub-surface dykes and check dam caused annual rise in groundwater level by 1–4 m and 0.3–2 m, respectively in the downstream command areas of river in Madhya Pradesh (CGWB 2007). The scenario analysis will help in the possibility of groundwater availability. This will enable us in the planning and development of water conservation structure, agriculture production and productivity, and social and economic development of the region. The comparative groundwater recharge under various scenarios showed that in sub-basin 1 the groundwater recharge was 1.61 m more in scenario-2 than scenario-1, in sub-basin 1 the groundwater recharge was 1.05 m more in scenario-3 than scenario-1.

Groundwater modelling is important tool for planning and management of groundwater resources. The aim of this study was to model groundwater for assessing groundwater potential and water table level behavior under varying

Table 3 Groundwater recharge in sub-basin under various groundwater recharge scenarios

Sub-basin	Rise in groundwater level (m)		
	Scenario-1	Scenario-2	Scenario-3
1	2.14	3.75	3.19
2	0.41	2.01	1.21
3	5.33	5.94	5.64
4	0.89	1.23	1.06

rate of recharge in river basin Betwa, India. The basin was delineated in four sub-basin for the estimation of groundwater fluctuation in post monsoon. The variability map showed the post monsoon variation in water level during the year 2005–2013. The horizontal hydraulic conductivity and specific yield for unconfined aquifer was 1–15 m/day and 0.05-0.1% respectively. The results showed that coefficient of determination value were 0.74–0.87 for calibration and for validation coefficient of determination ranged 0.63–0.87. Calibration and validation results showed that river package in MODFLOW can be used for simulating the groundwater recharge potential in the basin. MODFLOW was more sensitive to horizontal hydraulic conductivity, which was followed by specific yield, for predicting hydraulic head in unconfined aquifer. Groundwater recharge from 60% of surface runoff combined with river bed recharge and natural recharge varied from 0.33–1.61 m above reference level. Recharge from 30% of surface runoff combined with river bed recharge and natural recharge varied from 0.16–1.05 m above reference level. This increase in groundwater level helped in increasing production and productivity of food grain and food security and livestock production for livelihood of local or regional population and resource management for sustainable ecosystem.

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