Spatial Groundwater Modelling of Micro Watersheds – A case study at Junewani watershed, Hingna Taluk, Nagpur, Maharashtra

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Abstract. A model is a simplified representation of the complex natural world. The groundwater model provides a quantitative framework for synthesizing field information and for conceptualizing hydrogeological purposes. The present study aims to utilize remotely sensed data, Geographical Information System (GIS), and limited flow modeling to identify the groundwater recharge management practices carried out in the Junewani watershed of the Nagpur district. In this study, Modflow-NWT, in conjunction with spatial analyses, is used for modeling Groundwater flow in Junewani Watershed located at 78.90°E and 21.03°N in Nagpur District, Maharashtra. Since minimal data on flow parameters are available and aquifer systems are also heterogeneous, water level data observed from dug wells has also been used to generate the groundwater flow directions. The study area consists of 1st, 2nd and 3rd order streams and is covered with Black cotton soil and Vesicular Basalt underneath. Watershed boundary conditions, elevation details, drainage patterns, layer properties, permeability values, average rainfall, etc. are given as input for the model. The initial input data has been procured from GSDA Nagpur and through field observations. This study discusses the micro watershed groundwater modeling carried out mainly in a spatial environment supported by results of limited flow modelling, but the results and insights from this study will help in better understanding the GW flow regime after the recharge decisions were taken and the recharge practices were operated. It has been observed that recharge practices in surface dams and desilting have been beneficial at some places, while groundwater has decreased at other places. Thus it helps in decision making regarding the development of GW recharge and utilization.

1. Introduction

Groundwater is one of the major sources of fresh water in major parts of the world. Though its availability may be limited, the dependency on the GW is heavy, thus the maintenance and management of the same is very essential. For achieving the above, a precise estimation of the availability of water quantity and quality is a must. The estimated available groundwater should be sustainably maintained so that the resource is not over-drafted and depleted, leading to a water crisis. Recharge structures are an effective way to increase the GW Table, but the strategic placing of these structures also plays a key role in this context. Every groundwater hydrologist has to face questions regarding the groundwater flow system, GW availability, so on, and so forth. Answering such questions require considerable specific hydro-geologic information and analyses. Modelling can be used as one of the tools to assess the hydro-geology and answer the above questions.
A model is a simplified representation of a complex real world scenario. A simple groundwater model provides a quantitative framework in fieldwork and conceptualizing the hydro-geologic process. Although not all hydro-geological problems require a model, almost every groundwater problem will benefit from some type of model, if only as a way to organize field data and test the conceptual model. The groundwater model generally consists of two components. One is a conceptual model that requires an understanding of the hydrological process [1]. The other one is mathematical model, which is based on the equations of basics of science and mathematics [2, 3, 4, 5]. In past two decades computer based numerical models are iteratively used to get groundwater flow information at sub basin, basin and watershed areas. San Juan and Kolm (1996) [6] said that the numerical model would not be designed to be utilized as a management tool, but the results of modeling effort could be incorporated into the development of more numerical model for complex management decisions and for developing data collection strategies. Brunner et al., (2017) [7] have also studied the groundwater and river interactions which are also relevant in the present study which envisages recharge through manipulations on the surface streams. Modelling for future assessment has been attempted for knowing the future water levels and quality as well [8, 9]. Crucial aspect in analyzing groundwater is the budgeting of groundwater. In recent days, to determine the groundwater budgeting, various methods have been discovered in which mathematical/numerical modeling is a cost-effective way to use digital computing techniques. Usage of modern techniques has a major role in optimizing water resources management and research on the qualitative and quantitative aquifers' parameters. Combined use of Geographic Information System (GIS) and mathematical modeling increase our ability to manage and sustain groundwater resources, one such tool to integrate GIS and Numerical modeling is Model Muse.

The study's objective is to understand the groundwater flow regime in a micro-watershed where limited data is available, to quantify the flow values and determine the prospect of recharge activities to be followed. This watershed has been selected for study since groundwater recharge practices have already been carried out in the watershed and study aims to evaluate these measures' performance. The weirs, small check dams have been constructed in the watershed at various drainages of varying drainage order. Also, desilting has been carried out up to 3-4 m in various drainages. The results will help better understand the GW scenario in a micro level watershed and help in making decisions regarding the groundwater-related issues.

2. Study Area
This work's study area is Junewani micro-watershed at geographical coordinates 78.90°E and 21.03°N in Hingna Tehsil, Nagpur district Maharashtra. The study area is southern to Nagpur city and covers an area of 886.852 ha. The study area is shown in Figure.1. The topographic elevation varies from 294m to 415m. The whole watershed has an elevation difference of 121m. The top soil layer in the watershed is of Black cotton soil up to a depth of 1.5m. Lithology in the study area shows that extensively vesicular basalt in various weathering levels is found as per the GSDA study catalogs. The drainage pattern (figure.2) shows the majority of the drainage streams are of order 1st order and 2nd order are found with little area covering 3rd order streams. The monthly rainfall in the study area has been considered from 2005 to 2019, a span of 15 years from http://maharain.gov.in/ and also from the reports of GSDA annual groundwater assessment. The study area's evapotranspiration is taken from Goddard Earth Sciences Data and Information Services Center (GES DISC) and maximum evapotranspiration value has been considered for safer values. The recharge values have been calculated using empirical recharge formula as per as per Thomas et.al. (2009)[10].

3. Materials
Spatial modelling using time series satellite data for Junewani watershed with limited numerical groundwater modeling procedures were followed in the current study to develop understanding on the groundwater status of the watershed after groundwater recharge measures were taken during last few years. Conceptual model development was carried out with field data and hydrologic conditions. The following data are assigned as inputs to spatial analyses.
1. High-resolution time-series satellite data from 2010 to 2020
2. Aquifer characteristics with hydrologic properties
3. Vertical and horizontal conductivities
4. Rainfall data
5. Groundwater Levels
6. Agricultural practices and crop patterns obtained through interaction

The above-mentioned data are systematically given as inputs for the present analysis. The Modflow-NWT, coupled with horizontal flow barrier package has been selected as flow packages since the study area contains barriers constructed for groundwater recharge purposes. Using GIS, digitization of the horizontal obstacles are done and given as input under HFB package. In this study, steady state has been modeled since the requirement is to determine hydraulic heads in the micro-watershed. From the drainage pattern, it is observed that the flow of water is from South-West to North-East. The objective here is to identify the groundwater flow regime with respect to understand the pattern and flow direction in the study area, before and after the runoff management structures for groundwater recharge were constructed. The drainage pattern in the study area is shown in Figure 2. The recharge structures have been built on these streams. We shall see which are the places where they reported an increase and where they report a decrease and whether it is related to wrong recharge mechanisms.
4. Methodology
The methodology adopted in the present analysis may simply be given in the steps as given below.
   a. Rainfall analysis for last twenty years to assess the total average runoff generated in the watershed with respect to the total precipitation
   b. The groundwater level variation determination in the watershed before and after the groundwater recharge structures were constructed and desilting was carried out.
   c. Comparison of crop condition in the watershed before and after the groundwater recharge structures were constructed using the high resolution time series satellite data.
   d. Commensurate with the elevation variations in the watershed, identification of the suitable groundwater recharge measures depending on the recharge and discharge area identification.
   e. Interacting with the farmers to generate information on whether the recharge practices have increased or decreased groundwater availability in the watershed. Specific formats of interaction were designed for this purpose.

5. Hydrogeology of the area
The dug wells in the study area show that the wells are lined up to the depth till the soil is present. Below the lining, the outcrops of the aquifer material are exposed. It was observed that the outcrop belongs to basaltic aquifer, which is weathered and jointed. The basaltic aquifers also have vesicles at places, which further enhances the aquifers’ groundwater potential. Since the study area's lithology is Vesicular Basalt, which has vesicle developing porosity and permeability, also responsible for storage [11, 12], the water flow was good towards downstream.
6. Results and Observations

The Maharashtra government has taken up groundwater recharge structures construction in the study area where numerous weirs have been constructed at most suitable locations. Also, deepening of the drainage canals by removing silt was done during years 2015 to 2016. These were done regarding maintenance and recharge of groundwater and sustainable development of groundwater. Before the project was taken, the water flow was completely underground since the whole drainage canals were silted till the ground level. Field data was collected through designing the questionnaire to collect the data for input into the model and validating the results. As per the local farmers, even though the water was not flowing on surface, groundwater availability was enough for their cultivation purposes, but after the construction, they observed a little drop in the groundwater levels.

The modeling showed the flow and heads of groundwater levels in the study area and they are comparable to the observed ground truth values. It has been observed that the flow where the weirs were constructed, the water flowed into the ground and went to downstream instead of recharging the local aquifers and the same was observed on the field as well. The groundwater level on the downstream increased 1 to 1.5m whereas the groundwater level on the upstream decreased. The modeling showed that the water that should flow from the canals to groundwater is flowing from ground to canals, leading to a decrease in level of groundwater in upstream side. Field survey also supports this.

The crop status as observed on high resolution satellite data has been shown as sample only for two dates however the analysis has been carried out between 2000 and 2020. It may be seen in Fig. 3 that the crop is good in January 2003 in comparison with the situation of crop in January 2020. This shows that the groundwater and surface water as source of irrigation has declined in the area. Hence, based on the analysis and groundwater level variations in the area, smaller recharge structures have been proposed in the watershed shown in Figure 4.

![Figure 3](image-url) Status of crop in January 2003 (left) and January 2020 (right), as seen on Google earth images
Figure. 4 The existing recharge structure locations (pink) and proposed locations of small recharge structures (black)

7. Conclusions
Farmers have reported that groundwater levels have increased at specific locations after constructing the groundwater recharge structures. The farmers at many places have been taking two crops already since decades and at some places, farmers also complained of reducing groundwater levels. The downstream farmers’ well water level increased by a small amount, but the overall change was negated by the decrease in the upstream groundwater level. The construction of recharge structures is a generally better choice for groundwater level improvement, but in this case, no significant difference in the groundwater before and after the construction of the groundwater recharge structure was observed.

The study found that deeper groundwater recharge should be adopted in the watershed as Gondwana formations are present below the Deccan basalts, which must be recharged. The groundwater flow is from west to east and the surface runoff follows the slope in the area. Only surface techniques will not be fully effective in this, and hence recharge through wells must be adopted in the bed of the streams where recharge shafts can be constructed.

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