

GROUND WATER MODELING OF VARANASI AND ITS ADJOINING AREA

5.1 INTRODUCTION

Groundwater models can be used to mimic the system's real-world conditions, which can aid in the comprehension of its behavior and performance. The water balance changes because of pumping and other modes are estimated using a groundwater model. With accessible data, geographic information technology offers a lot of promise for visualizing and interpolating the geographical extents of groundwater resources. In this chapter using Integrated MODFLOW and GIS tools for the research region, an effort was made to build a three-dimensional groundwater flow model to describe groundwater flow system and quantitative groundwater budget. The details of the methodology, data used, processing, results and discussions are presented in following section.

5.2 METHODOLOGY

MODFLOW is a United States Geological Survey's modular finite-difference flow model, and it is a computer programme that solves the groundwater flow equation. Hydrogeologists use the software to model the flow of groundwater through aquifers. MODFLOW is a United States Geological Survey (USGS) finite-difference groundwater flow modelling software that enables us to create a numerical representation (i.e., a groundwater model) of the hydrogeologic environment at a field site. The main governing processes of MODFLOW are response to hydraulic gradient and losses from sink, sources, recharges and abstraction from well. The governing equation for a MODFLOW is as follows:

$$\frac{\partial}{\partial x} \left[K_{xx} \frac{\partial h}{\partial x} \right] + \frac{\partial}{\partial y} \left[K_{yy} \frac{\partial h}{\partial y} \right] + \frac{\partial}{\partial z} \left[K_{zz} \frac{\partial h}{\partial z} \right] + W = S_s \frac{\partial h}{\partial t}$$

Where, K stands for hydraulic conductivity in x, y & z direction (L/T), h defines the potentiometric head (L), W stands for volumetric flux per unit volume representing sources and/or sinks of water, S_s represent the specific storage of the porous material and t is time.

The flow chart showing the steps involved in modeling of ground water through MODFLOW is presented in Fig. 5.1. At first conceptualization of model was done with help of input data. After this boundary conditions were defined. Then head, well details, creation of grid frame, setting of hydraulic conductivity were set and map to MODFLOW was generated. After this, conceptual model was run and result were obtained.

5.2.1 Model Conceptualization

The geological, climatic, and hydro-geological parameters of the research area were used to develop the groundwater flow model. GMS 10.2, a MODFLOW-based software, was used to create a GIS-based conceptual groundwater model (Aquaveo 2010). MODFLOW can solve the steady and transient groundwater flow equations, as well as simulate single or multiple aquifer layers with a variety of boundary conditions. (Tamma Rao et al., 2012).

5.2.3 Description of Model

The model domain has covered an area of 292 km² with a grid size of 204 x 147. Therefore, in the model, there is around 2,99,88 grid cells. More fine grids cells can increase the complexity and computational runtime for the model. The top layer of

Ground Water Modeling of Varanasi and its adjoining area

the model was defined by elevation data obtained through SRTM DEM. DEM data were imported in ASCII file and the interpolation was done using scatter points created from DEM. Recharge Rate from the SWAT Model has been used as an Input Parameter. Transient state simulation of the model was done. Transient data was entered in the conceptual model using time values where the time at the beginning of the first MODFLOW stress period was considered as the reference time. In the model, data were entered to the model at the interval of 180 days, beginning from January 2015 to December 2019. For each interval data of hydraulic conductivity, bottom elevation for each year, and recharge rates were entered.

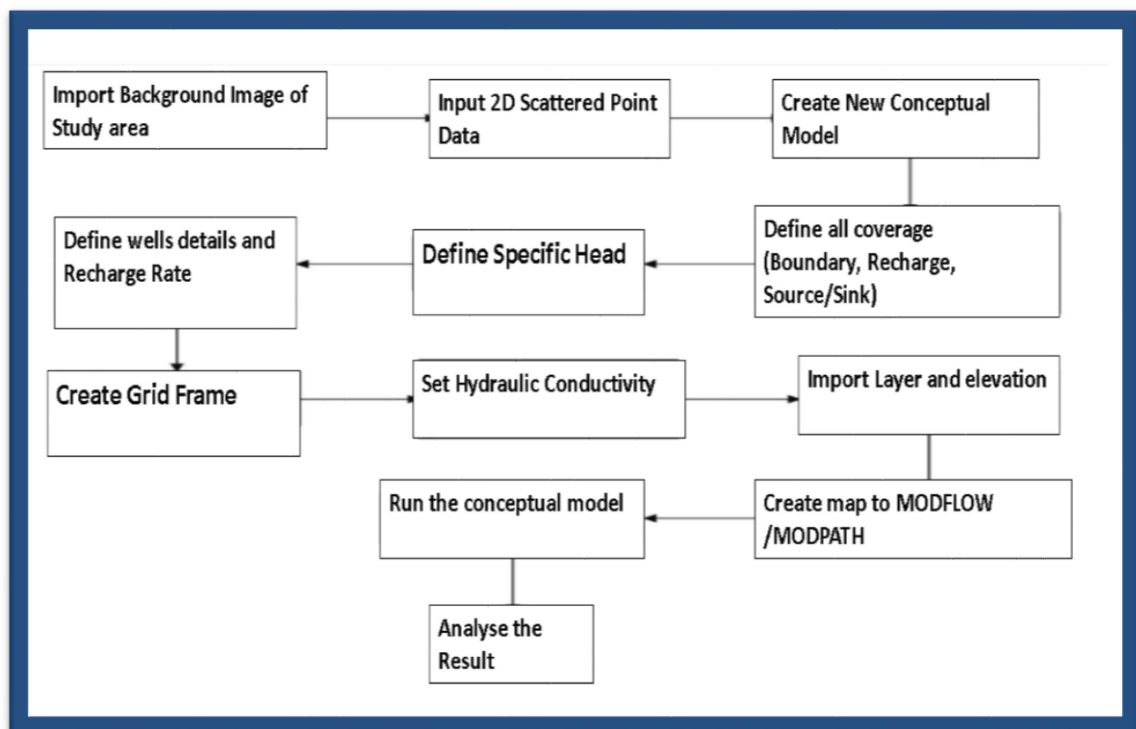


Figure 5.1 Flow chart of MODFLOW

5.3 DATA COLLECTED AND BOUNDARY CONDITIONS

Many data as an input was collected for the study area considered.

5.3.1 Aquifer geometry

For preparing the lateral extent of the aquifer, bore hole data has been taken from the irrigation department and previous literature Dubey P et. al, 2014. Compiling of this data needs too much attention. This data is the main foundation of the model on which accuracy of the model depends. This data was collected for 14 locations covering whole study area. A fence diagram was created using the borehole data, it indicates the aquifer's vertical and lateral position in the research area down to a depth of 200 metres below ground level . The top layer of the study area consists of surface clay, which is varying in depth from 3 to 6 m bgl.

Based on the literature review and data given by central ground water board Varanasi, 3 locations has been taken for constructing a fence diagram. These locations are Manduadih, Jamnagar and Central Jail, based on these a Solid diagram has been created showing clayey loam at top and sandy loam after this proceeding with fine and course sand. Fig. 5.2 and 5.3 shows the lithology of Varanasi and Fence diagram of the soil strata of Varanasi. The DEM of the research area was used to determine the model's top surface. The DEM from the Shuttle Radar Topography Mission (SRTM) was utilized in this investigation, and it was downloaded from the USGS website (<https://earthexplorer.usgs.gov>). The bottom layer was created using data from the Uttar Pradesh Jal Nigam's well logs. Evenly distributed data over the entire area were taken and interpolated to generate the bottom surface. Fig. 5.4 shows the hydraulic conductivity of different regions of the study area. It can be observed that the hydraulic

conductivity is lower in downstream side of river. Fig. 5.5 shows the location of the well used as input in the modeling. Recharge rate, Evapotranspiration, specific storage and specific yield are presented in Fig. 5.6-5.9 respectively.

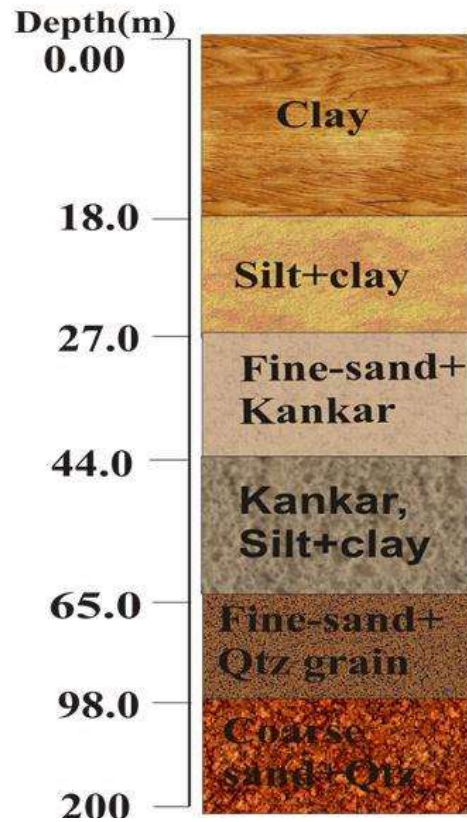


Figure 5.2 Lithology of Varanasi Region

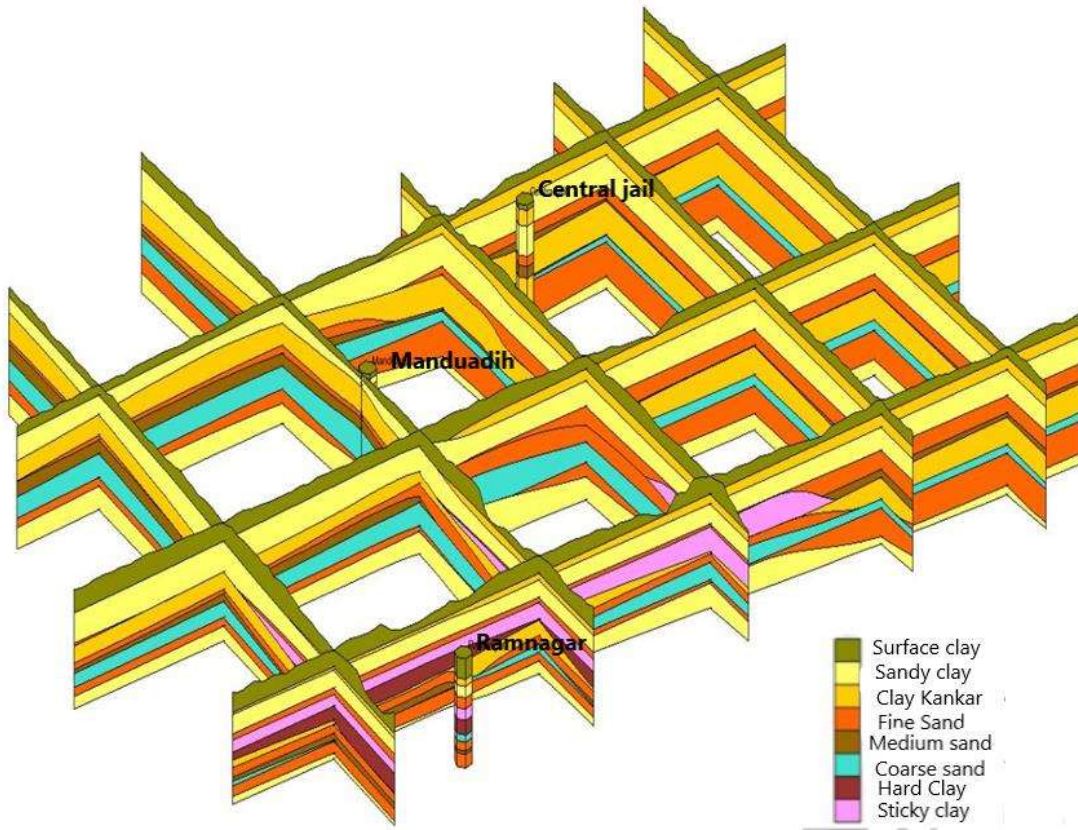


Figure 5.3 Fence diagram of the study area

Ground Water Modeling of Varanasi and its adjoining area

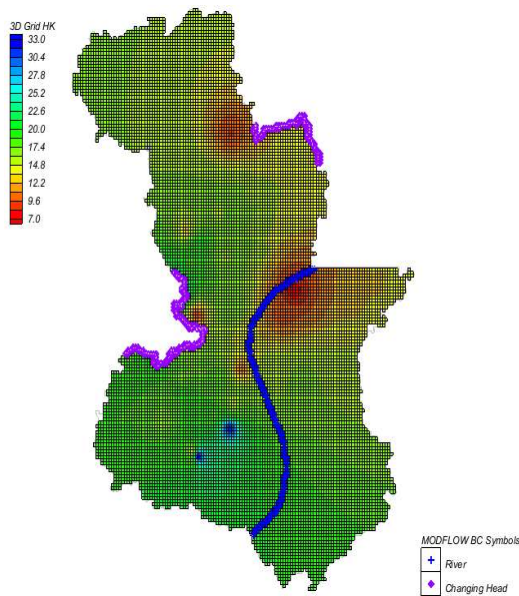


Figure 5.4 Hydraulic Conductivity

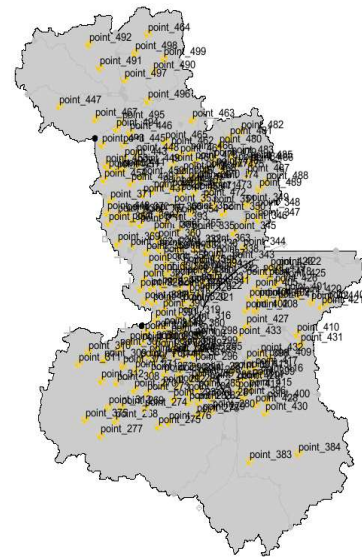


Figure 5.5. Locations of Pumping Wells

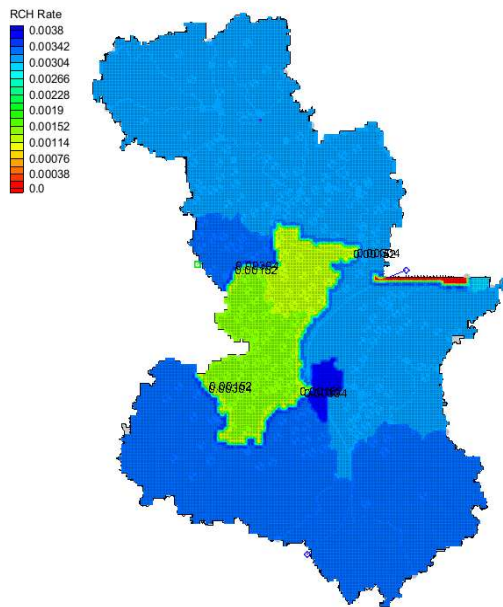


Fig. 5.6 Recharge rate of different regions in the study area

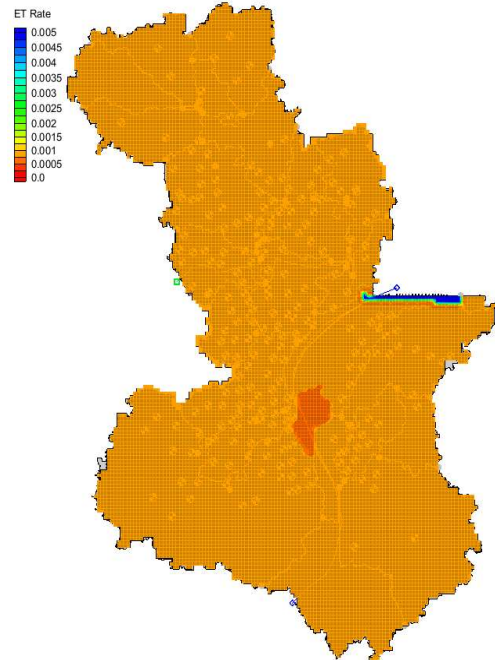


Figure 5.7. Evapotranspiration of different regions of study area

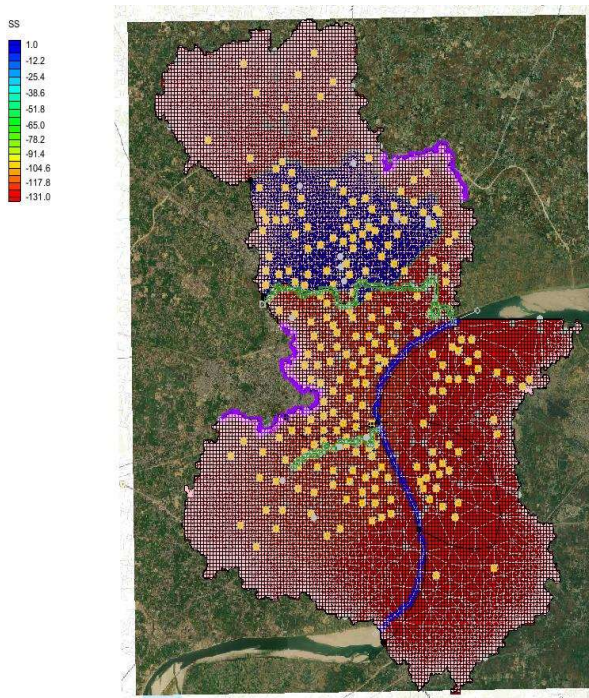


Fig. 5.8 Specific storage of different regions of the study area

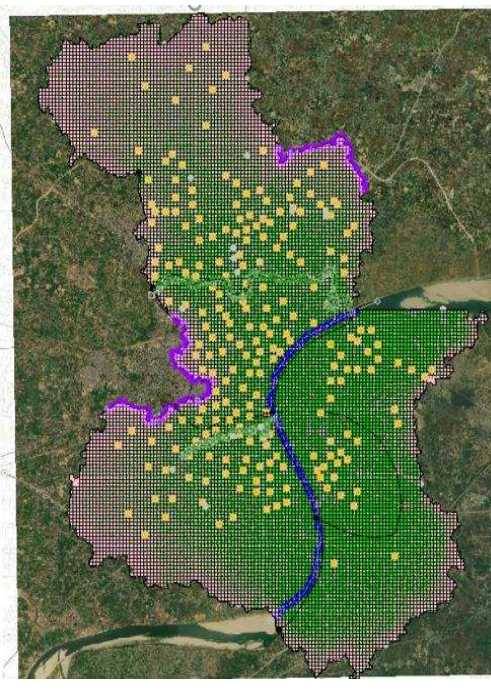


Figure 5.9. Specific yield of different regions of the study area

The wells were decided based on the draft on the basis of population. The positions were randomly given based on spatial distribution of built up area. Total 231 pumping wells are covering the study area which will help in finding the abstraction of water per day. The imageries were classified in five groups i.e. Vegetation, Urban land, Water, Sand/barren Land, Agricultural field. Total water demand was used to distribute the water demand in the form of pumping wells of the study area. Specific yield of the aquifer in the study area was found between the range of 20 lps to 25 lps (1728 m³/day) (Omar et.al 2019). Specific yield is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table.

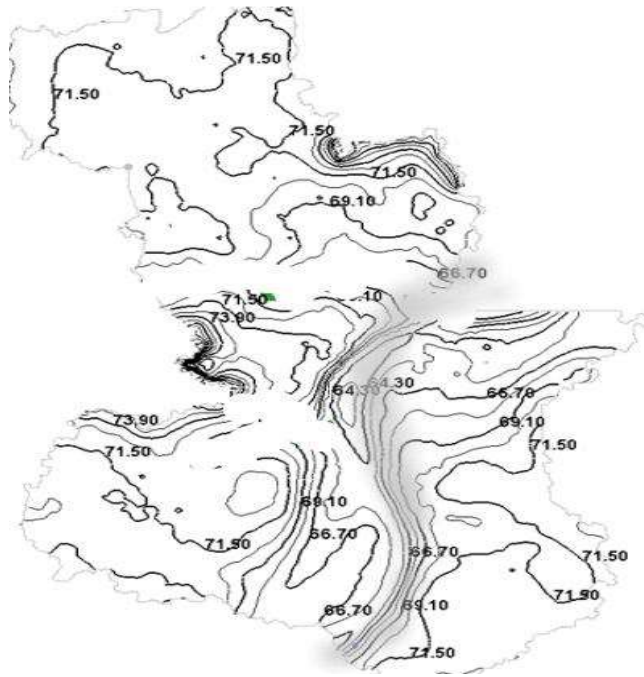


Figure 5.10 head contour of study area

5.3.2 Boundary Conditions

For groundwater flow model applications, these boundary conditions have been used.

Specified heads: - The head remains constant in the specified head boundaries. Movement of the flow (in or out) in the model in such a way that specified head remains maintain. It is also called Dirichlet or type I boundary. In specified head boundaries, head value can be specified as a function of time and place.

No flow boundary: No flow boundary normally occurs at a place where impermeable structure exists and at a line normal to streamline (i.e. normal to flow direction). It's a special case of a *specified flux boundary*. An example of no flow boundary can be a water divide, line connecting the high points on the water table or other potentiometric surface.

Ground Water Modeling of Varanasi and its adjoining area

In this work, the boundaries of the study area are considered specified head boundary because of the watershed. Also, extensive well data has been taken for the study which further suggests to take specified flow boundary (Kumar, C.P., et.al 2015).

In modeling, it is advisable to use physical boundaries (e.g., rivers, stream channels, impervious boundaries, lakes) when possible, as the model boundary conditions. The reason behind this is that it can be identified and conceptualized easily.

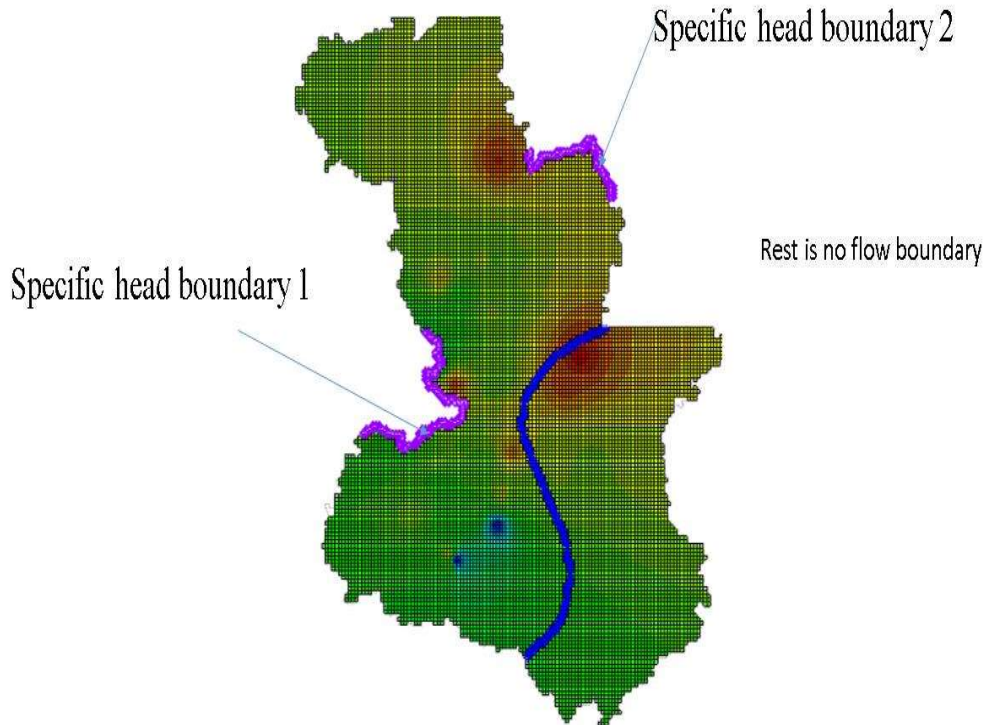


Figure 5.11 Boundary Condition of Study Area

5.4 Model calibration:

Model calibration is the final step in the model construction process. In this study, model parameters are altered within the uncertainty bounds to obtain a model replica of the actual system that meets the previously agreed-upon criteria. The parameter estimate tool was used to calibrate the model (PEST). The Parameter estimate tool entails changing the input parameter values to achieve the best possible agreement between the modelled and observed water heads. The groundwater head was calibrated using a 1.0 m threshold value. For most of the observed wells, the simulated head was deemed acceptable if the difference between it and the marked head was equivalent or less than 1.0 m. Hydraulic conductivity was used as one of the adjustment parameters.

5.5 RESULTS AND DISCUSSION

Results obtained from the modeling are presented in Figs. 5.12-5.16. Fig. 5.12 and 5.13 shows the variation of the head in study area during 2016, 2017, 2018 and 2019 respectively.

The head variation of the different regions of the study area in Jan 2016 and 2017 are presented in Fig. 5.12. The direction of the arrow shown in both of the figures is showing the direction of flow. It can be observed in Fig. 5.12 that head is decreasing towards the river. Since head near the river is relatively lower, so the flow of ground water might be taking towards the river. Further, it can be observed that in middle right part of the region some arrows have become parallel to the river. This is happening because of the relatively lower head in the far downstream side of the river than the nearer river bank. In upper left region of the direction of arrow is away from the river.

Ground Water Modeling of Varanasi and its adjoining area

This is happening due to the presence of small stream. It shows that the presence of small stream or watershed can affect the variation of the head. Similar type of behavior can be observed for the year 2017-2019 (Fig 5.12 and Fig. 5.13).

The comparison of the head variation of different years (Fig. 5.12 vs. Fig. 5.13) shows that the head in 2018 and 2019 in upper side of the study area is greater than the 2016 and 2017. The flood occurred before 2018 might be the reason of the change in the head. Fig. 5.14 shows the water level variation in year 2017 and 2019 of the regions considered in this study. From the figure, it has been observed that in the north of the study area, head was 71.50 m in pre monsoon while the groundwater head has been increased in the post monsoon and it was observed 73.90 m. for the middle part of the study area, Head was 64.30 m in pre monsoon while 68.70 m in post monsoon. This indicates that the groundwater has been recharged by the rainfall in the monsoon and groundwater head has been increased.

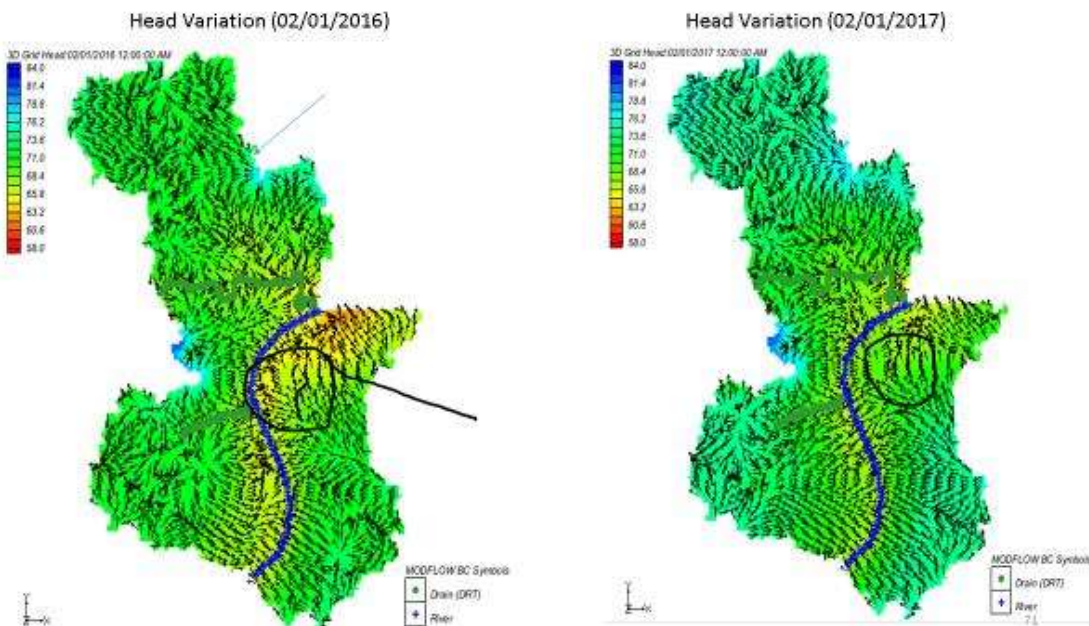


Figure. 5.12 Variation of the head in study area during 2016 and 2017

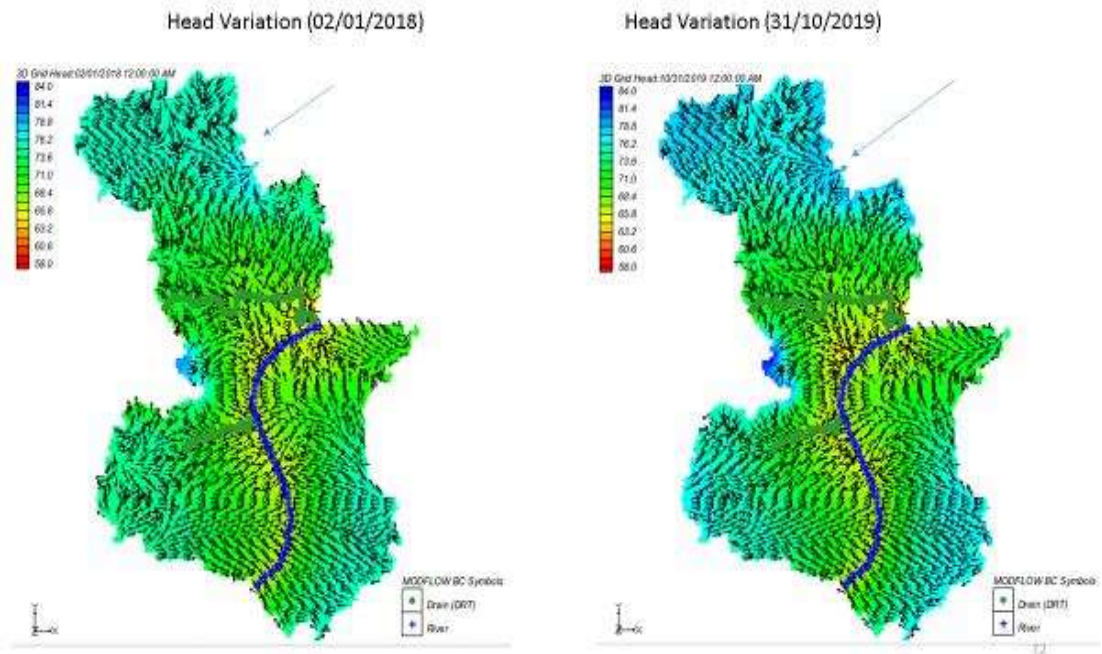


Figure. 5.13 Variation of the head in study area in year 2018 and 2019.

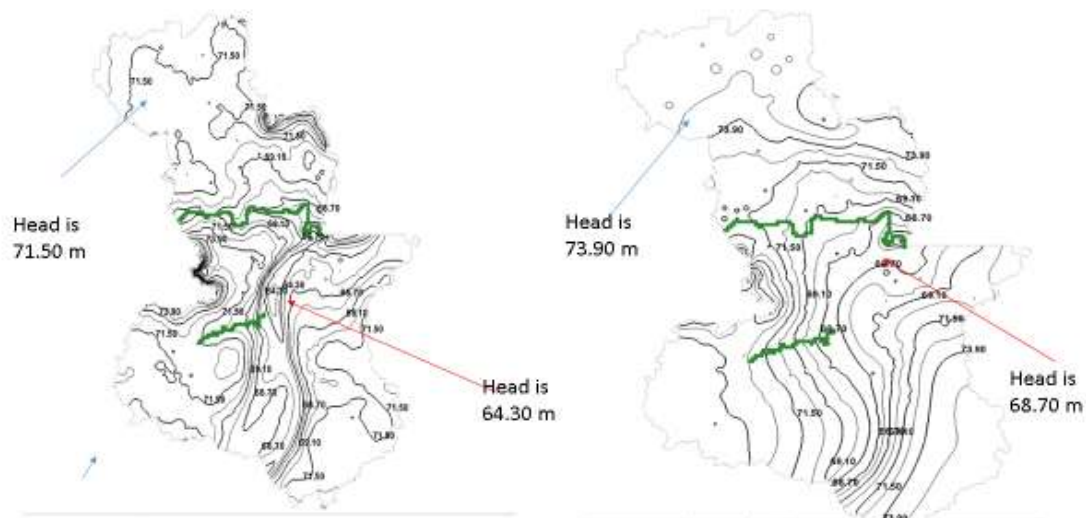


Figure. 5.14 Representation of water level variation in year 2017 and 2019

The variation of head with time is presented in Fig. 5.15. This is basically time series transformation of the head. The comparison of the actual head measured and the head obtained from the modeling is shown in Fig. 5.16. It can be noted that model can satisfactorily predict the head level of the region. R^2 value of the model is found around 0.8972 and SSE is 2.091 which is quite satisfactory

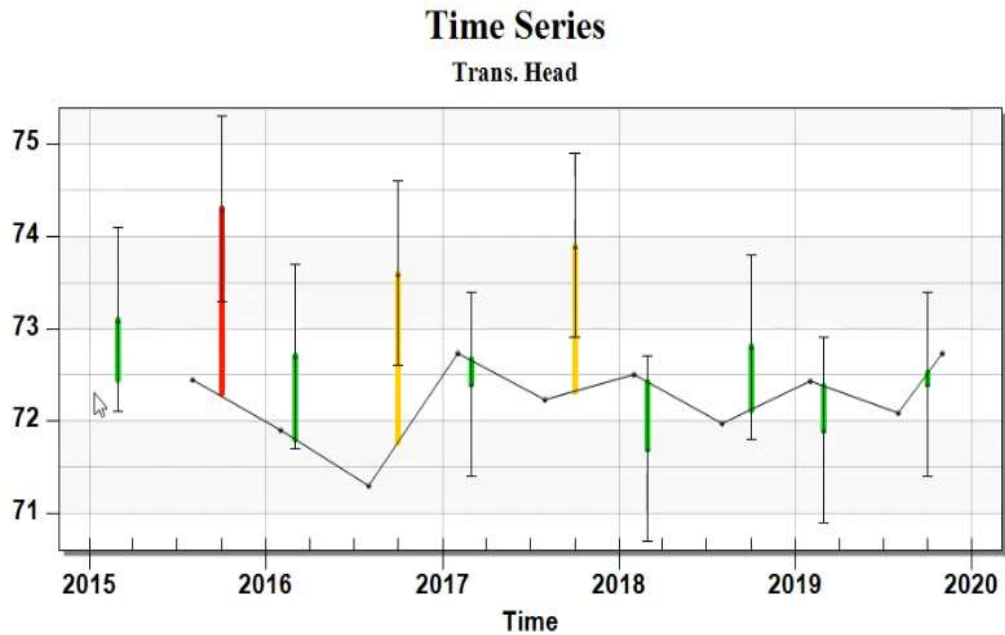


Figure 5.15 Variations of head with time

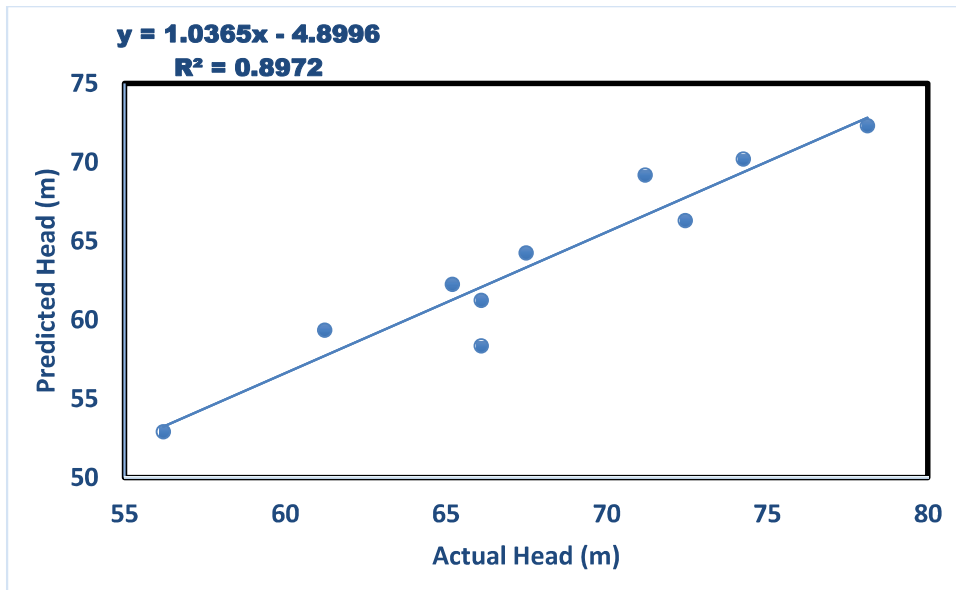


Figure 5.16 Comparisons of predicted head with actual head

Total flow coming in the study area is less than total outflow, which is a matter of great concern. Amount of water entering (Inflow) from river is 44.75 % whereas from the drains it is found to be 45.47 % with respect to total flow. Flow coming out from drainage shows that most of the people are dependent on groundwater and in coming years .People have to suffer due to rapid urbanization in study area. The

Ground Water Modeling of Varanasi and its adjoining area

volumetric flow budget for each model is found with given condition delineated as shown in Table 5.1 and the difference between input and output of these for models are quite satisfactorily. The model was calibrated and validated with respect to observed wells taken during data collection as shown in figure 5.17.

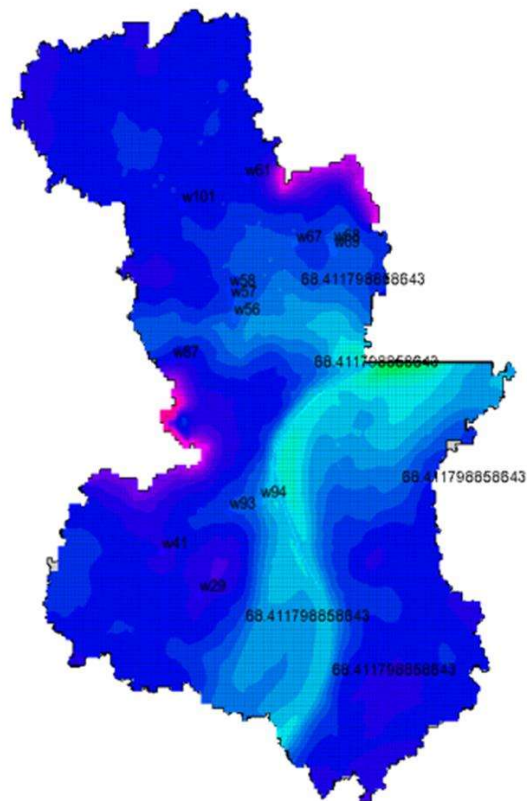


Figure 5.17 Positions of observed well

Table 5.1 Volumetric water budget for entire model

Volumetric water budget for entire model		
Budget Terms		Flow (m ³ /day)
	In	
Constant heads		61,154.38
Wells		0
River		4,332,308.53
Evapotranspiration		0
Recharge		884,489.06
Drains		4,401,784.94
TOTAL FLOW in		9,679,736.90
	out	
Budget Terms		Flow (m ³ /day)
Constant heads		65,960.65
Wells		396,067.27
River		242,154.17
Evapotranspiration		172,295.68
Recharge		0
Drains		8,803,569.87
TOTAL FLOW out		9,680,047.65
Summary		
In – Out		-310.74
Percentage Discrepancy		0.003210238

5.6 CONCLUSIONS

In the present chapter, modeling of the groundwater through the help of the MODFLOW is done. The results were obtained in terms of groundwater head and compared with the actual measured head at different wells considered. The R² value is

Ground Water Modeling of Varanasi and its adjoining area

found at around 0.8972, and SSE is 2.091 which is quite satisfactory. Also, it is found that the head is lower near the river and watershed. Also the results have shown that the variation of head get changed with time and events like flood etc. This impact has a significant impact over the variation of the head. Recharge due to rainfall has significant impact over the groundwater head as it has increased in the post monsoon as compared to pre monsoon. Water budgeting shows that some amount of groundwater has been seep into the rivers, and groundwater level has been decreased at some places of the study area. Thus, there is need of groundwater conservation and management in the study area, which can increase the recharge and compensate the excess groundwater extraction from the study area. The results of the model are in consonance with the observed data. It is proposed that the model could be utilized for assessing the water levels and its fluctuations in the aquifer in the study region.