CHAPTER 6

RESULT AND DISCUSSION

6.1 General

By using GMS 10.2, the study will explore the current situation of groundwater and its exchange with the surface water (Ganga River) for Varanasi and adjoining areas under various hydrological stress conditions. The study also deals with how one can manage the impact of excessive pumping of the groundwater considering the future demand of the area while keeping the recharge rate as it is now. In the second case, decreases the recharge rate while keeping the current pumping schedule. In another case, both scenarios are kept simultaneously and observe the effect on the groundwater head. Thus, the decision-makers have to study the impact of various cases on both groundwater aquifers and the River Ganga through predicting the impact of the future climate changes.

6.2 Current state of study area and Model output

The average groundwater depth in the basin was found 6 m BGL in pre-monsoon and 10 m BGL in the post-monsoon period. In and around the Kashi Vidya Peeth block of the study area, spatially distributed groundwater level ranges from 8 m to 15 m BGL which shows the highest drawdown along with Chiraigaon block shows maximum drawdown at some places. Area covered with vegetation like Banaras Hindu University (BHU) and cantonment region, groundwater level ranges from 1.5 m to 6 m BGL. Deep water level of more than 18 m BGL occurred in the north-east part of the study area and shallow groundwater level, i.e. less than 4 m BGL found near to the river Ganga, Varuna, and confluence of Gomati and Ganga River.

Figure 6.1 shows the groundwater flow lines along with colour bar and calibration target for fourteen the observation wells. The good calibration shows that this model is actually representing the real field conditions for the study area. In the calibration target, top of the target represents the observed value plus the interval, where as bottom represents to the observed value minus the interval. The center of the target represents the observed value, and just above this point, the target corresponds to the computed value. In the calibration target, the colour bar shows the error. Green colour bar shows that computed value lies entirely within the target value, yellow colour bar shows that compute value is outside the target but error is less than 200% and red colour bar shows error in the computed value is more that 200%. For this calibrated model, 9 colour bars are showing green colour and 5 colour bars showing the yellow bars. This suggested that all the colour bars lies in the target limit, this represents that the model is precisely simulated and well calibrated for the study area.

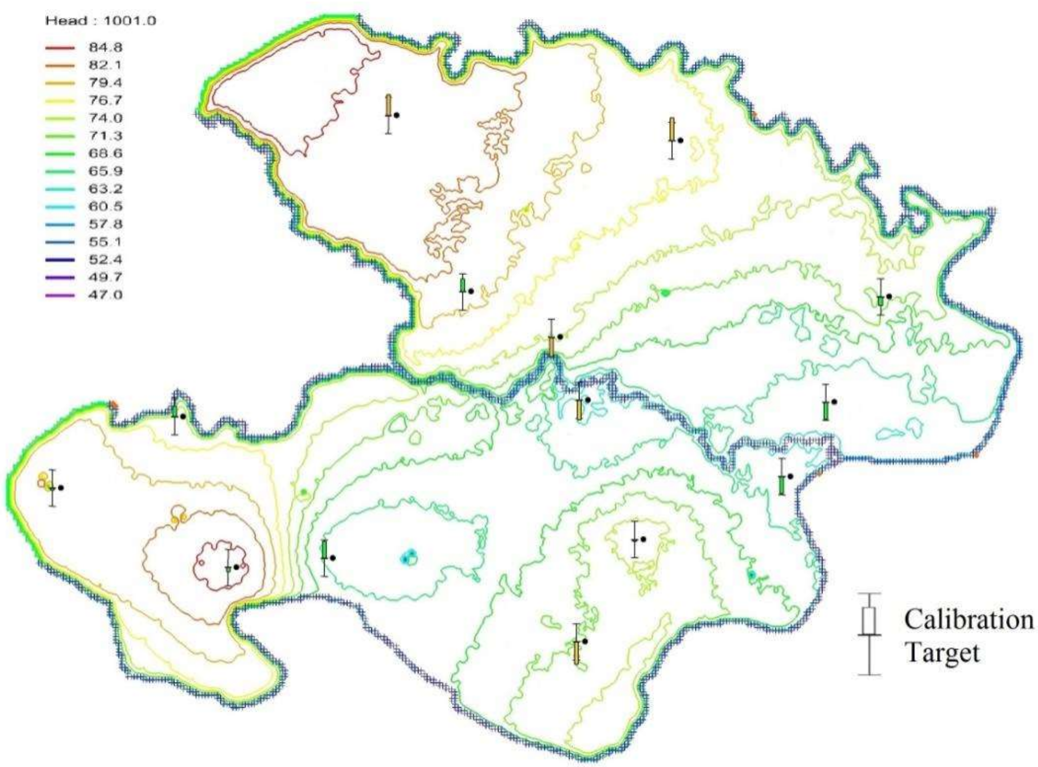

Figure 6.1 Groundwater flow lines along with colour bar, and calibration target

To examine the variance of the computed head with the observed head, a time-series graph is developed. A time-series graph shows repeated measurements taken at regular time intervals, and helps to show trends or patterns.

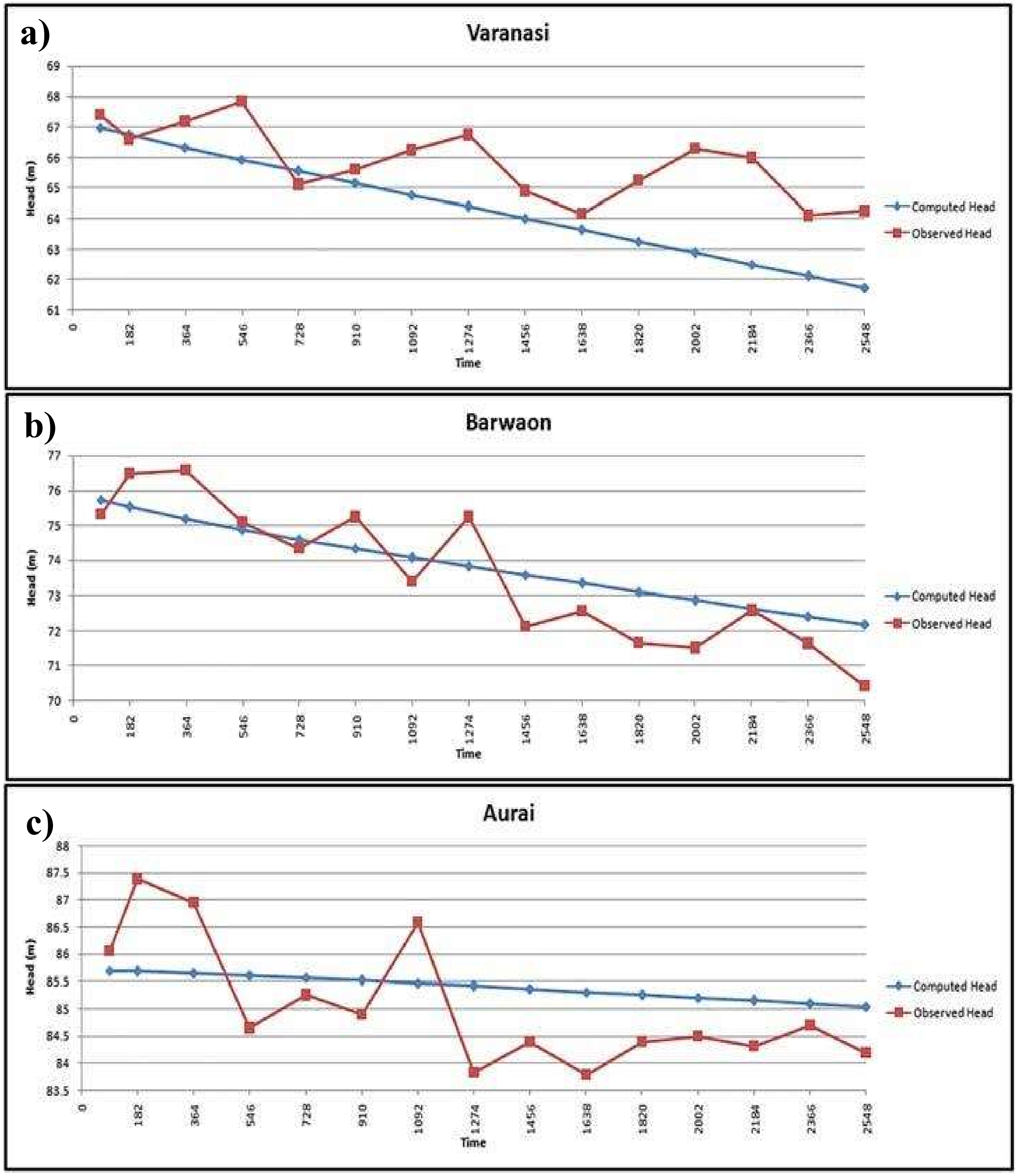

Figure 6.2 Time series graph for three observation wells (a) Varanasi (b) Barwaon (c) Aurai

Time-series graph is prepared for the three observation wells, namely, Varanasi, Barwaon, and Aurai. In each time-series graph, head comparison was done for different stress period as presented in Figure 6.2. For these three observation wells, separate calibration target was drawn. Typically, calibration target shows up next to the observation point. Figure 6.3 shows the calibration target with the observed head values for Varanasi, Aurai, and Barwaon observation points.

Observation wells at Barwaan and Varanasi show that all computed values are within the acceptable range of the head value, while the Aurai observation well shows that the computed head value is four times out of the allowable range of the head value, as marked in red colour in Figure 6.3.

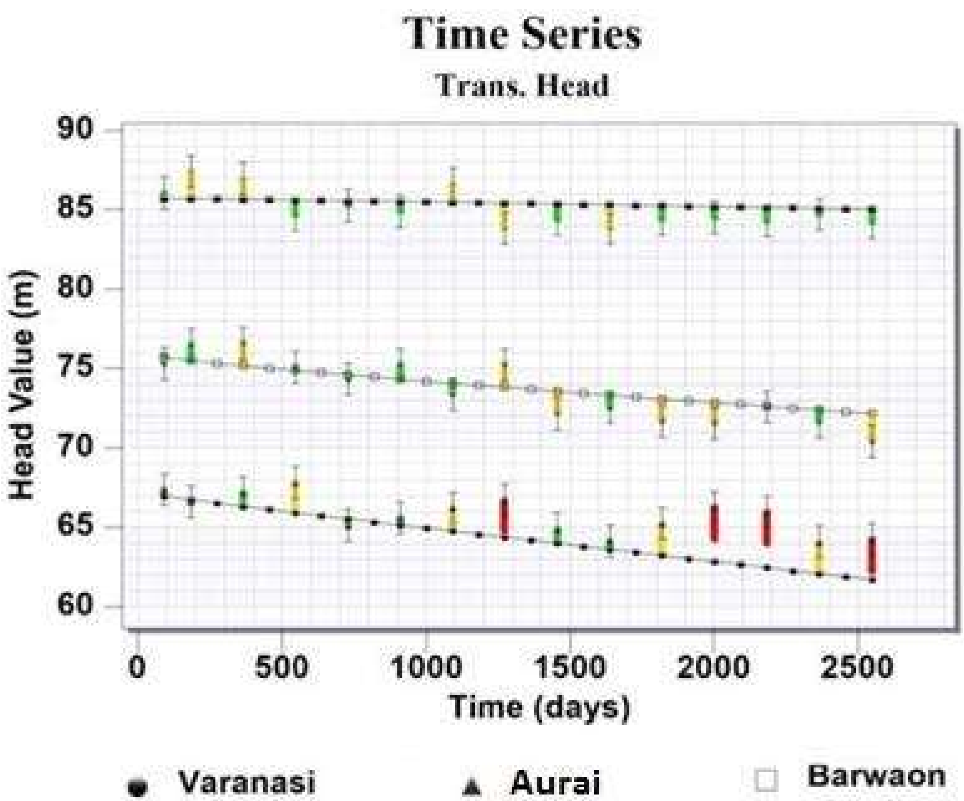

Figure 6.3 Calibration targets with the observed head values

The scatter plots also visualize bias in the calibration. Bias is absent when the points in the scatter plot are more or less evenly distributed around the central line shown on the plot, which indicates a one-to-one correspondence between computed and observed values. Scatter plot was drawn, as shown in Figure 6.4, between the observed head values and computed head values for fourteen observation wells. The scatter plots shows that all the observed wells are within the acceptable limit of the head values and it allow for a quick assessment of the model fit. The scatter plot also verifies that the contour map of the groundwater as shown in Figure 6.1, is perfect matches the actual groundwater condition.

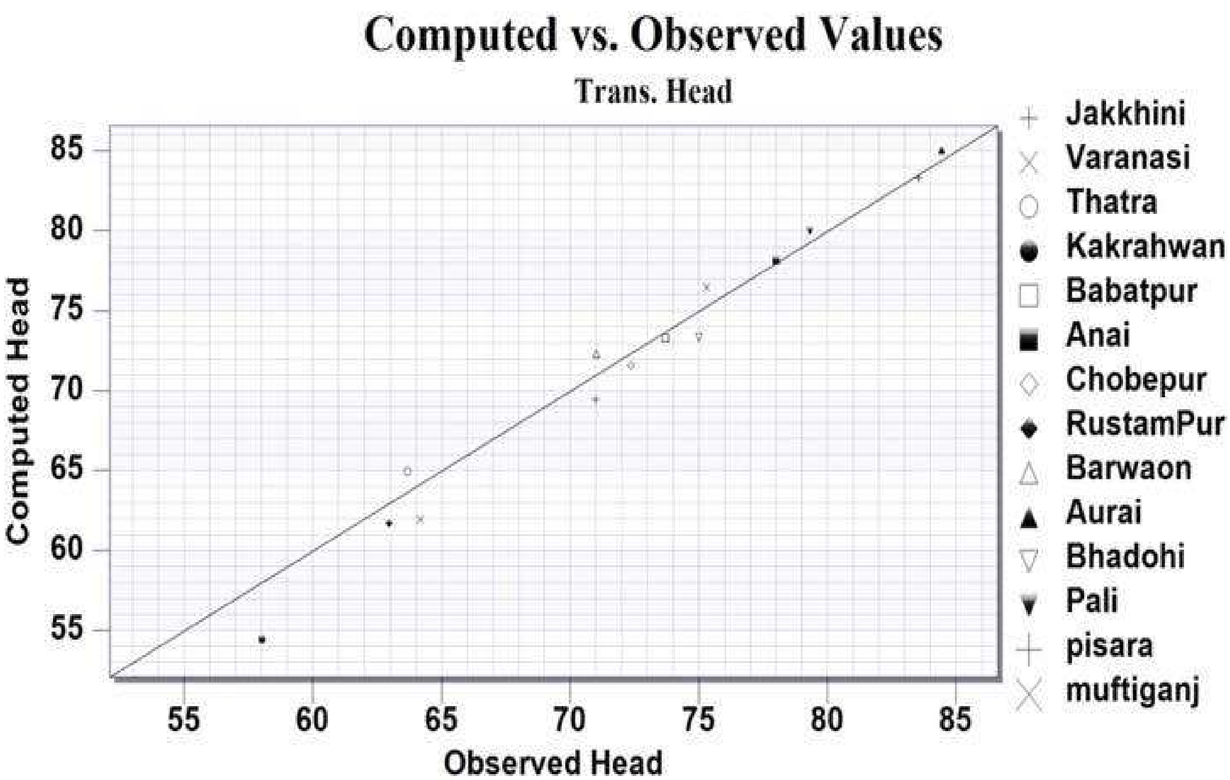

Figure 6.4 Scatter plot between computed head and observed head

Similarly, model output has been generated by the AEM approach. In analytical method, contour map of the groundwater head values has been prepared, which is almost same as shown in Figure 6.1. For accuracy assessment of the model, a graph has been prepared between the modelled head and observed head as shown in Figure 6.5. The graph is developed in AnAqSim software which indicates that the modelled head is greater than the observed head at few observation points along with at some points the modelled head is equal to the observed head. However, from the graph, it can be seen that all the points are close to the best fit line, which indicates that all the points are within the range of the allowable range of the head value.

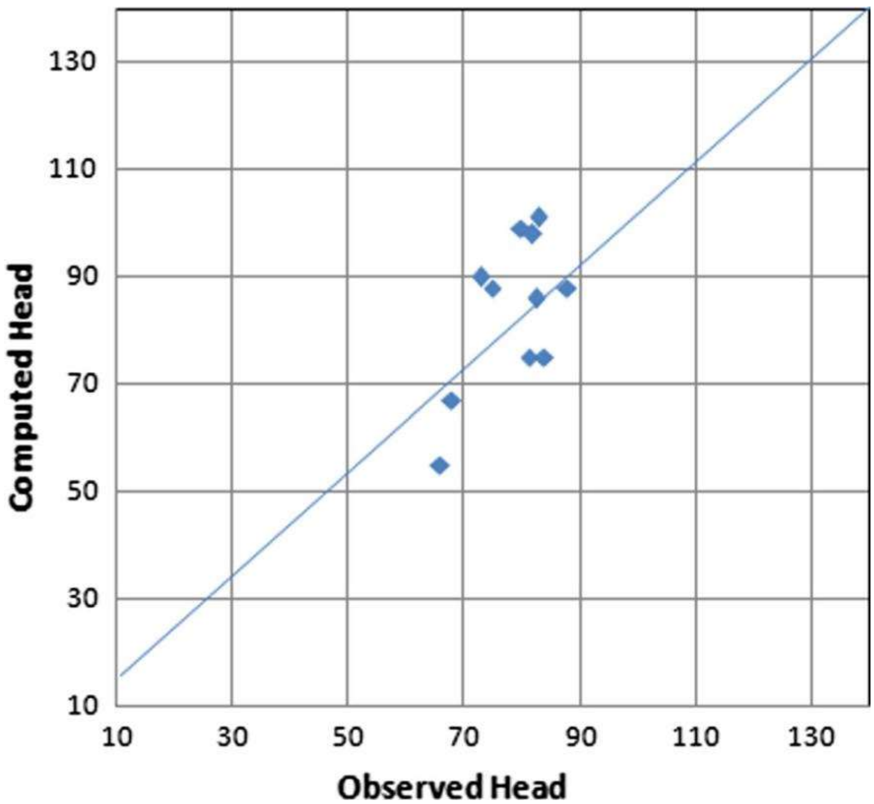

Figure 6.5 Observed head vs modelled head

A residual plot was prepared between the observed head values and residual value. A residual is a measure of how perfectly a line fits to the data points. This vertical distance is known as the residual. For data points above the line, the residual is positive, and for data points below the line, the residual is negative. The closer the residual of the data point is to 0, the better the fit. In this case, a residual plot between the residual value and observed value drawn is drawn as shown in Figure 6.6. A residual is calculated by the difference in the observed head and modelled (computed) head. The difference between the observed head values and the computed head values (Residual head) varied between 0.07 - 2.81 m, with an average value of 0.79 m. This plot is used to show how well the entire set of observed values matches a model solution. As shown in Figure 6.6, the trend of the solution values with regard to matching the observed data was analyzed. It shows that the maximum number of wells close to zero residual lines which shows that the model is behaving like an actual groundwater system for the study area.

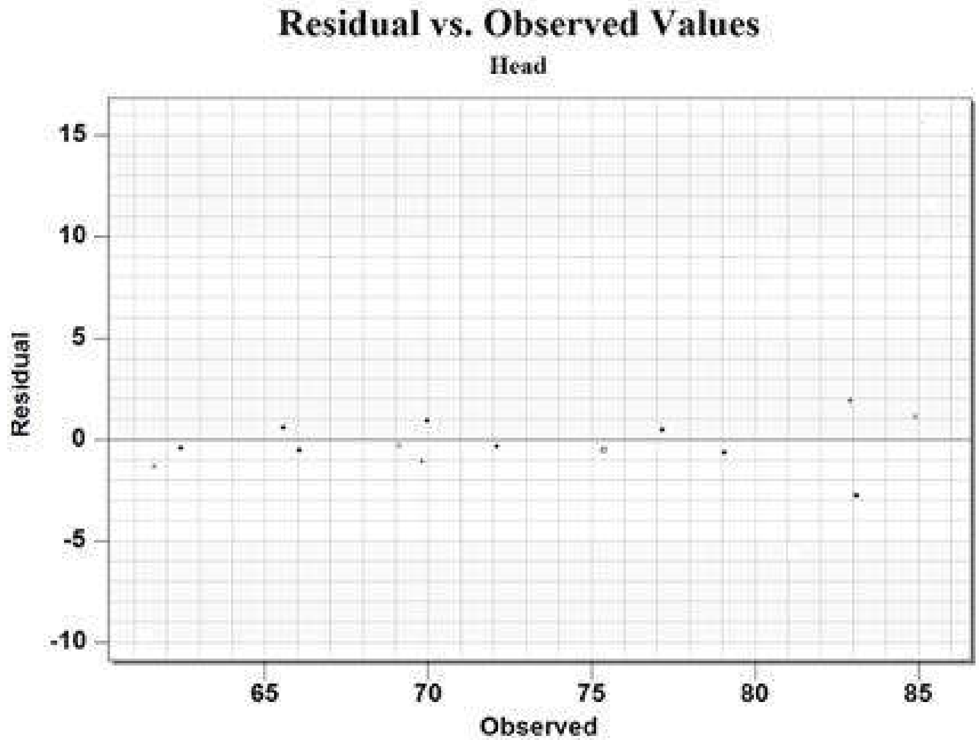

Figure 6.6 Observed head Vs Residual (in m)

The result of the soil moisture study shows that there are three large areas in the study area which show higher soil moisture than the ambient. A detailed discussion of this is already described in the heading 5.12 of Chapter 5. Soil moisture helps in the primary identification of groundwater in the study area, as areas with high soil moisture have higher groundwater levels. Two cross-sections AB and CD are drawn in the soil moisture map of the study area, as shown in Figure 6.7. A soil moisture index values range from 0 to 1, where values near 1 are the areas that present a high level of soil moisture. The values near 0 are the areas with a low level of soil moisture. The soil moisture profile for cross-sections AB and CD shows the variation of soil moisture along the cross-sections. It is clear from Figure 6.8 that the maximum value of soil moisture for cross-section AB is 0.76, while for cross-section CD is 0.8. The value near 1 indicates the wet conditions. Thus, higher values of soil moisture were found near water bodies and the BHU campus, suggesting that in these areas, the soil water content is higher than the area showing lower soil moisture content.

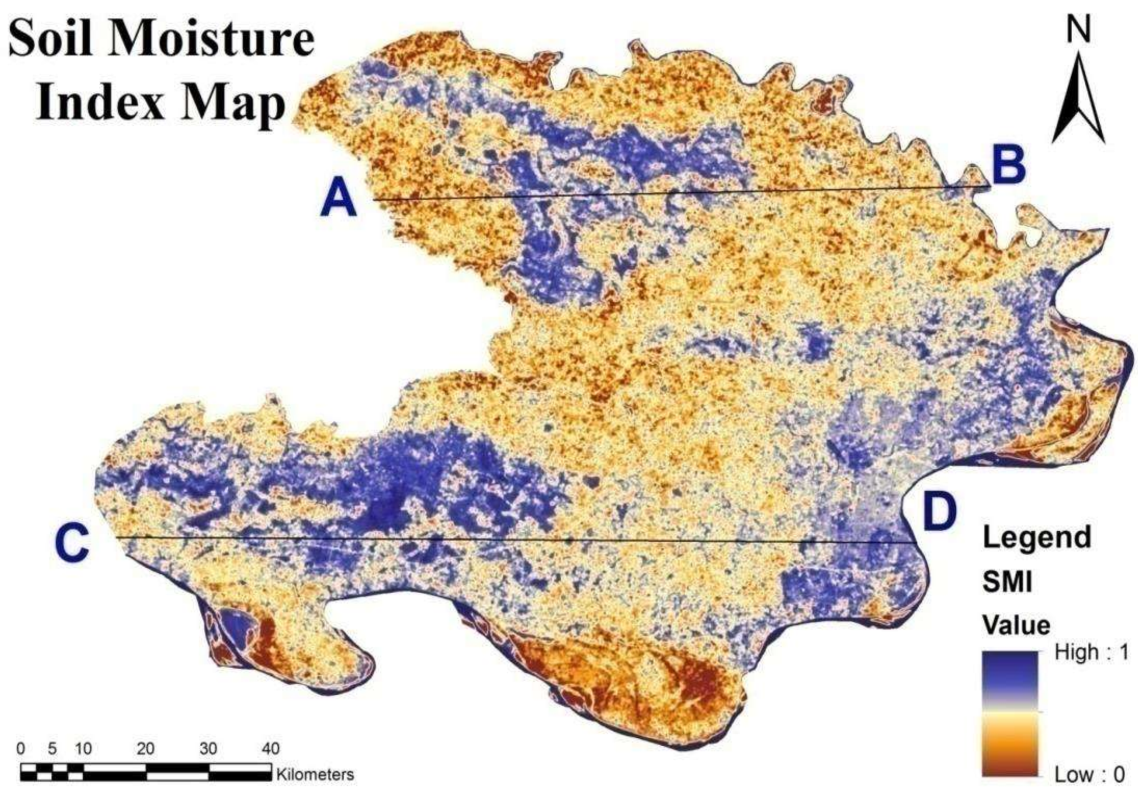

Figure 6.7 Soil Moisture Index map of the study area showing two cross-sections AB and CD

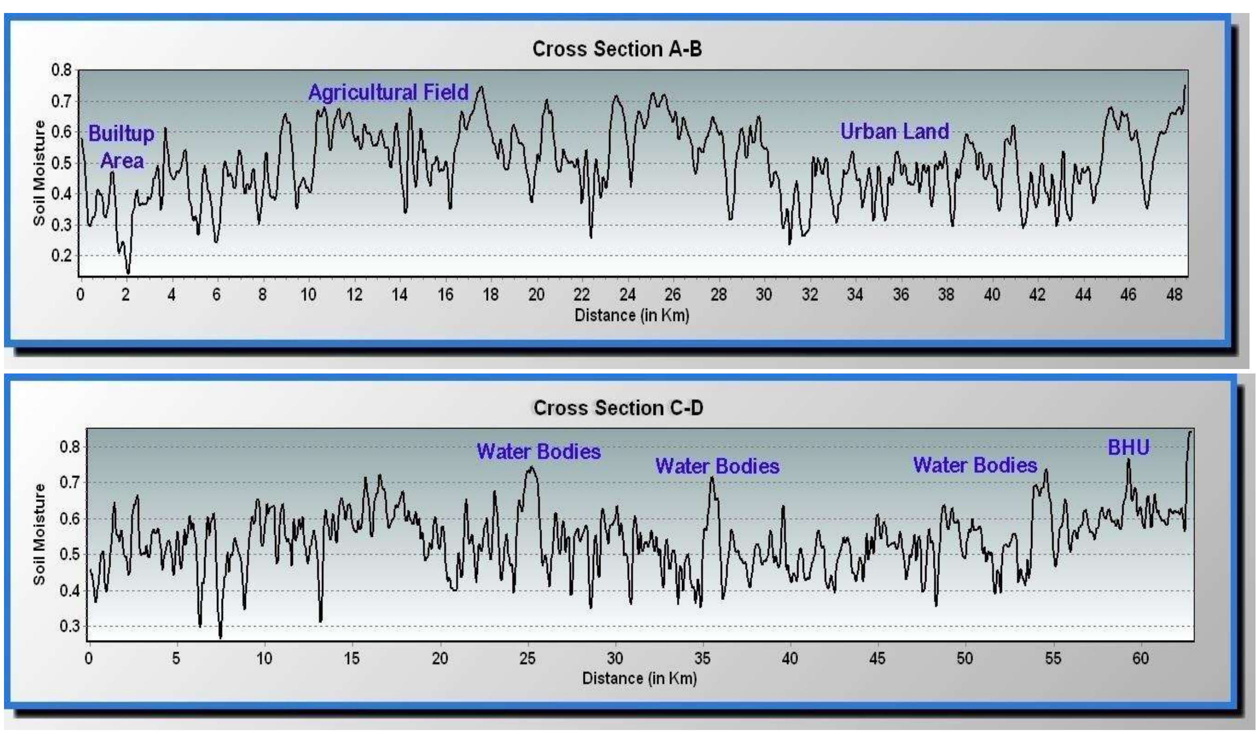

Figure 6.8 Soil Moisture profile at two cross-sections a) A-B, and b) C-D

6.3 Scenario Generation

The results show that the groundwater level in the Varanasi region is falling due to over-exploitation and unavailability of proper management of the water resources. Since Varanasi is a tourist place, its floating population is approximately 25,000 per day (JNNURM Final Report, 2006), which causes huge pressure on the sources of water, surface water as well as ground water. Recently, the Indian government has approved many projects under a master plan for 2031 and smart Kashi, a smart city proposal. Considering the future changes for the study area, three different scenarios were generated, and the developed model was simulated for those scenarios.

Scenario 1: Keeping in mind, the population of the study area for 2031, discharge rate (pumping rate) was increased.

Scenario 2: Considering the urbanization for 2031, the recharge rate was decreased to 8.0 x 10^{-5} m/d.

Scenario 3: Taking above both Scenarios simultaneously.

The observed and simulated groundwater levels for the three scenarios were studied. For the Scenario 1, the population was predicted for the year 2031 and based on that groundwater demand was calculated as 25.193 Mm^3 per month. To meet this increased water demand, pumping wells in the study area were increased and the model was simulated with increased discharge values. In the model simulation, other parameters remain unchanged, and the yield of groundwater aquifers has also not changed. Results show that the drawdown was very uneven. At some places, it was decreased more, i.e., up to 6 m as compared to another prominent place where the chance of depletion of groundwater was more, i.e., up to 4 m. The groundwater level was found to be decreasing near the rivers due to the transfer of river water to the aquifer as additional groundwater discharge increases the seepage of the river water into the adjoin aquifer. This suggests that a gradual increase in groundwater pumping may increase the river leakage into the aquifer.

When considering scenario 2, the low recharge rate was taken to accommodate the decrease rainfall distribution due to climate change. High urbanization in the area will also reduce rainfall infiltration into the groundwater aquifers. Thus, the recharge rate value was taken as 8.0×10^{-5} m/d, while the discharge rate was taken to be the same. Results show less change in the groundwater level as compare to Scenario-1.

In the third scenario, both changes were taken together. The results show that the discharge rate has substantial dominance over the recharge rate. Additional groundwater pumping can cause a change in the direction of flow from the aquifer to the river and vice versa.

6.4 Comparison of outputs produced by FDM and AEM approach.

The results produced by both methods were compared on the basis of boundary conditions, data used & model development. Presence of an alluvium aquifer in the Ganga river basin, the development of the AEM model was observed very fast with the desired accuracy. AEM provides a continuous groundwater level surface while the FDM provides solutions at discrete points in the grid. AEM approach is suitable to follow the sharp changes of the groundwater level while the FDM approach provides the groundwater surface only at discrete points/grids. At the places of sharp variation of the groundwater level, the grid must be dense to map the accurate groundwater level which creates the complexity in the model. The FDM is more rigid under the boundary conditions. It needs to fix boundaries, and each boundary must be defined properly. While in AEM there is no obligation for the fix boundary conditions. It was found that the AEM model is very efficient to develop the local small size model of Varanasi city out of large model for the river basin. In AEM, the selection of solution points for the local desire area can be defined directly instead of generating the solution for the whole model domain which shows that AEM-based modeling is less complicated and less time consuming. AEM modeling is found competent to position the wells more accurately in the domain. In the FDM, the transformation is required of geological and hydro-geological maps to a uniform data set. It requires a larger amount of data which are connected to the grid points.

6.5 Result of River-Aquifer (R-A) Exchange

River-aquifer exchange study is highly spatially variable. For this reason, small-scale river gain or loss estimating methods can't be easily extrapolated to provide flux estimates over the tens to hundreds of kilometers of river length needed for regional water management. Large-scale flux estimates can be provided by the analysis of head gradients, differential flow gauging, river, and groundwater characteristics. In this study, quantification of the river-aquifer flux has been done manually. For each grid, estimation of the value of flux moving towards river or aquifer was done. Flow vector helps in the identification of the movement of the groundwater, as shown in Figure 6.9. From Figure, it can be seen that the flow direction of groundwater movement is represented by the flow vectors or arrows. Flow vectors are important for determining the groundwater flow direction. If the direction of the flow vectors is heading towards the river, it suggests that the movement is towards the river. This indicates that the groundwater releases from the aquifer and if movement is towards the aquifer, it is a recharging condition.

From the model, it was observed that the groundwater flow direction was towards the rivers at some locations, as shown in Figure 6.9. Along the outer river boundary, a total of 4 stretches ('A', 'B', 'C', and 'D') of river-aquifer interaction was identified. In the figure, the circle 'C' part showed that there was a movement of water from the aquifer to the riverside, and circles 'A' and 'B' indicated that there was an outward motion of flow from the study area.

Quantification of the flux was done for these identified river-aquifer exchange stretches. For this, grid cells were selected for individual stretches, and the budgeting provides the quantity of flux exchanges between river and the aquifer. Extreme care must be taken when selecting the grid cells because if a grid cell is missed, it can cause a huge error in the quantization of the river-aquifer interaction. For stretch ‘A’, 187.156 m^3/s of water feeds the aquifer from the Ganga River, stretch ‘B’ feeds 253.674 m^3/s of groundwater to the Ganga River. Stretch ‘C’, feeds 81.581 m^3/s of groundwater to the Gomati River, and stretch ‘D’ feeds 11.664 m^3/s of water to groundwater aquifer from the River Gomati. Table 6.1 shows the summarized details of the rive-aquifer interaction.

The river-aquifer exchange study concluded that the groundwater aquifer of the study area is connected to the rivers of the area, and the river-aquifer interaction phenomenon taking place in the study area. This quantity of flux of the river-aquifer exchange can change when the hydrological conditions of the area are different from the current situation. Any natural condition or anthropogenic activities affecting this phenomenon can also change the direction of water movement.

Table 6.1 Movement of water flow between River and Aquifer

S No.	Sections	R-A Exchange (m^3/s)	Condition	Associated River
01.	‘A’	187.1560373	Recharging Condition	Ganga
02.	‘B’	-253.6742477	Discharging Condition	Ganga
03.	‘C’	-81.58123981	Discharging Condition	Gomati
04.	‘D’	11.66371512	Recharging Condition	Gomati

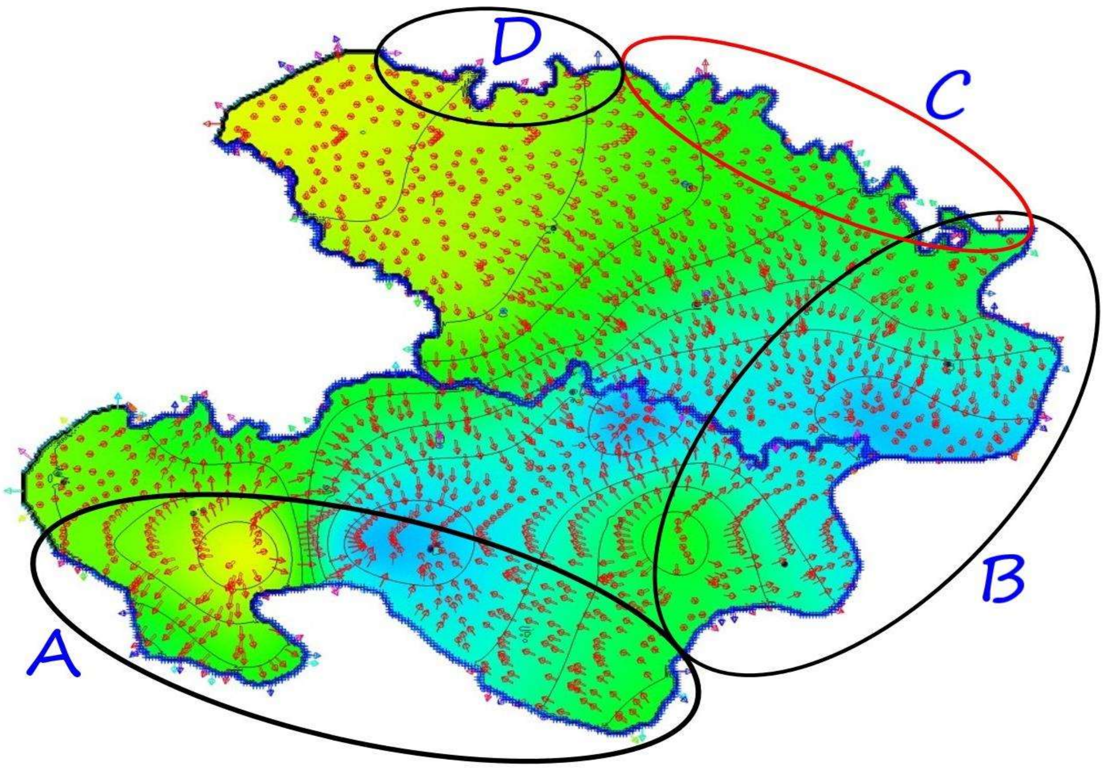

Figure 6.9 Groundwater flow direction map

6.6 Sustainable Management of the Water Resources System

Concerted efforts are needed to make good plans for sustainable management of groundwater and surface water resources. The response to rapid degradation of resource will be inadequate if these sources, particularly sources of the groundwater, are not taken into account for conservation and protection by all users (public as well as government). Since the source of groundwater is not visible, it requires a good understanding of groundwater systems, groundwater flow, basic hydrology, and groundwater depth so that the sustainable theory can be applied as needed. It's everyone's responsibility to conserve all the water resources.

To study the current situation of groundwater aquifer, considering all the hydro-geological factors, groundwater model has been conceptualized for the Varanasi and adjoining areas. This model examines the current situation and found out that there are over exploitation of the groundwater in some areas of the study area. This over exploitation leads to the flow of river water into the groundwater. For the current situation, this over exploitation must be stopped. In another case, three different scenarios are also discussed and presented in this chapter. These scenarios are presented considering the future water demand of the study area. The results can provide decision-makers with a vision to use groundwater sources and surface water sources in an efficient manner that preserves both of them without collateral damage.

6.7 Summary

A three-dimensional groundwater flow model has been developed for Varanasi and adjoining areas for the year of 2006 to 2017 in transient condition. Model was developed by using two different approaches FDM and AEM. The results show that for most of the observed wells, the difference between the observed head and the computed head is found in the 90% confidence level (within acceptable limit). It is found that the AEM does not require a fixed boundary condition, which makes the development of the conceptual model less complicated. In the FDM, pumping wells are approximately located and averaged over the cell, which becomes a cause of the inaccurate location of the wells. It is found that model development in the AEM is less complicated compared to the FDM. It can be concluded that in some cases AEM-based modeling is more accurate as compared to FDM-based flow modeling.

In addition to that, study of river-aquifer interactions has been also done this chapter. Result of this study provides the groundwater flow direction and quantity of water exchanges between groundwater aquifer and the rivers (Ganga and Gomati). In the future, when pumping schedule would like to increases, exchange between river and aquifer will be affected. Reducing the level of Ganga River by 0.5 m or 1 m will affect the leakage from the river and groundwater level of the study area. To manage the effect on groundwater aquifers and its relationship with the river, it is highly recommended to eliminate some wells from the pumping schedule and decrease the pumping rate of other wells also and to continuously monitor the behavior of both over time. It is expected that the results obtained from the study can present significant information for efficient and effective management and planning of the groundwater resources for Varanasi and the surrounding areas.