CHAPTER 7

CONCLUSION

7.1 General

The demand for water is increasing worldwide for various purposes such as industrial use, agricultural use, and to meet domestic needs. However, due to the limited availability of freshwater resources, groundwater and surface water management is becoming a serious issue all over the world. Due to the declining quality and quantity of surface water, groundwater is the primary alternative source of water for various needs. Therefore, sustainable management and utilization of this resource are essential task for us, and groundwater management models can address these issues.

Groundwater modeling is an essential tool to understand the dynamics of groundwater behavior, and correspondingly can be used to identify the best management practices for groundwater resources conservation. Modeling of the groundwater is a complex phenomenon because various hydro-geographical features are required to find the solution. Nowadays, the groundwater model has proven to be a valuable tool over several decades to address a range of groundwater problems and support the decision-making for better management of the groundwater. In this study, transient (time-varying) groundwater modeling was done for the middle part of the lower Ganga basin near Varanasi and adjoining areas. A comprehensive literature review on groundwater management has been carried out to understand the previous works and models.

The study area for which the model was conceptualized is 2,785 km^2, out of which 112.26 km^2 belongs to the Varanasi Urban Agglomeration. The study area is divided into ten administrative blocks. During summer, the temperature in the study area varies from 30 to 46°C, and in winter, the temperature varies from 9.5 to 16.5°C. The average annual temperature is 26.1°C. The study area has an average altitude of 80.71 m, with the highest altitude of 101 m. The area is located in eastern Uttar Pradesh and is situated between two major rivers, the Ganga River and the Gomati River. The Varuna River divides the area into almost two equal parts. The study area is a part of the Indo-Gangetic Plain underlain by Quaternary alluvial sediments of Pleistocene to recent times. However, the unconsolidated sediments form a sequence of clay, silt, and sands of various grades. The development of groundwater resources has increased manifold in the highly productive Gangetic plains with dense Quaternary deposits forming a multi-layered aquifer system.

Significant groundwater recharge occurs by direct infiltration of rainfall, infiltration of the river water, and irrigation return flow. According to the lithological logs and fence diagram, the thickness of the Quaternary deposits varies up to 222 m. Thus, the movement of the groundwater flows from the West to the Eastside.

The mathematical code MODFLOW was implemented in the study area with the use of GMS 10.2 software. The piezometric surface of the period January 2006 was used to describe the initial heads in MODFLOW code. Model calibration was performed by trial and error adjustment of the parameters and accounted for the transient state flow. After the MODFLOW code was applied, the difference between the observed head values and the calculated head values (residual head) varied between 0.07 - 2.81 m, with a mean residual value of 0.79 m.

This variance shows that the model adequately responds to the actual conditions of the aquifer system. Furthermore, model calibration was performed successfully because the deviations between the calculated and observed head values were insignificant. In addition, the model calibration had a root mean square error (RMSE) value of approximately 0.524 m, confirming a reasonable agreement between the observed and calculated heads with the calibration target within ±1 m. Ultimately, MODFLOW simulation concludes that all the parameters were calculated for the hydrological and hydraulic characteristics of the aquifer system and applied in the MOFLOW model approach taking into account the actual field conditions.

In the next stage, groundwater modeling was done using the Analytic Element approach using AnAqSim software. AnAqSim has powerful capabilities for the development of a rapid model under multi-layer, anisotropic conditions. It can import complex base map graphics to make it easier to develop the AEM model and has the analysis tool for post-processing of the model result. For conceptualization of the study area, the base-map file was created in the DXF format in a GIS environment that includes the river, discharge well, and the study area's boundary. The model domain was defined before inputting any model parameters. In AnAqSim, the term domain is referring to the regions within which the aquifer properties are constant. Boundary conditions are defined in the hydrological element itself as the head. Head specified boundary consists of the River Ganga, Gomati, and Basuhi. In the AEM model calibration, the model was run using initial values. Residual error and line boundary conditions were checked.

The model results show that the computed values of the water head are in good fitness of the measured data, which indicates the model is reliable. The collection of model input data is a very challenging task. It can be generated through different sources and techniques, particularly in the absence of direct field values, for example, discharge from each well. Nevertheless, results show that the explicitly computed well discharge data can be used for model development. The field monitoring was also incorporated in the study to verify the model predictions. Finally, a comparison was made between the FDM and AEM methods based on the results obtained, including both the models' limitations and benefits.

Different scenarios were considered, based on the future water demand for the area to understand the impact of various hydrological stresses on the groundwater aquifer. Variation in the groundwater head values was observed, and a sustainable management strategy was suggested for the critical groundwater-stressed areas. Similar studies can be performed for other water-stressed areas for reliable water resources estimation so that better and efficient water resources planning and management can be done.

For model validation, observation wells were selected, and water level data were recorded. The observation wells were selected, keeping in mind that the wells were equally spread over the entire area. The purpose of model validation is to check whether the calibrated model is works well on a model dataset. The calibrated model was validated for the period of January 2014 to December 2017. A Soil Moisture map was prepared for the study area to cross-check the output of the model. The high soil moisture suggests that there is an abundance or surplus water in the soil mass. The soil moisture map helps validate the developed groundwater model, as areas with high soil moisture have higher groundwater levels. Due to the high groundwater level, water can rise in the soil mass due to capillary action.

In the last part of the thesis, a river-aquifer (R-A) interaction study was carried out, in which quantification of the river-aquifer flux was done. 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. 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. For the study area, four stretches of the river were identified, where the river-aquifer interaction phenomenon is taking place. Two stretches are in recharging condition (198.819 m^3/s of river water feeds the groundwater aquifer), while the remaining two are in discharging condition (335.255 m^3/s of groundwater seeps into the river water).

From the study, the following conclusions can be drawn:

1. For the study area, the recharge rate value was found out to be 0.0002 m/d through the calibration process. Sensitivity analysis is also performed, and it was found that the model is sensitive to two model parameters, recharge rate and hydraulic conductivity.
2. In the future, if there is an increase in discharge rate from the groundwater aquifer due to an increase in water demand, then there will be a significant reduction in groundwater level, as compared to declination in the groundwater table due to less recharge into the groundwater aquifer. This concluded that discharge has sufficiently more domination over the recharge rate.
3. A comparison has been made between two accepted groundwater modeling methods, i.e., FDM and AEM, during the process of model development. The results of the models show that AEM solutions were more accurate and efficient than the FDM solutions. As AEM is based on the harmonic function, which gives continuous solution over the domain due to less complex data entry. Although both methods were beneficial and highly accepted among groundwater professionals, the requirement of the given problem can help to decide which method to be used.
4. The study concluded that the FDM approach should be adopted if aquifer layers are not horizontal and non-homogeneous in nature or approximation in the permeability value is not possible. Also, in the case of the FDM, well-defined boundary conditions should be known with suitable head values.
5. The River-aquifer exchange study concluded that the groundwater aquifer of the study area is connected to the Ganga River, and river-aquifer interaction taken place in the study area. The study concluded that 253.674 m^3/s groundwater moves to the river from the East side and 81.581 m^3/s groundwater moves to the river from the North side of the area. While in the south of the area, 187.156 m^3/s water moves to the

aquifer from the riverside. Additional groundwater pumping can cause a change in the flow direction from the aquifer to the river and vice versa.

7.2 Limitations of the study

The study has achieved all the significant issues found in the study area, such as over-exploitation of groundwater in some places, leakage from the Rivers, and the problem of the non-scientific and unstudied pumping schedules, that affected both groundwater and surface water resources.

Based on results and analysis, the following are the limitations of the study,

- The present model is developed for transient state conditions with an interval of 91 days. This interval can be more precise to match the different stress periods and for a more realistic representation of the groundwater aquifer of the study area.
- In this study, the analytic function has been used based on of Bakker and Strack (2003). Model efficiency can be increased by incorporating other analytic elements for the more realistic solution of complex study areas. Model efficiency can also be increased using higher-order analytic elements.
- Further, GIS technology can be integrated to generate a user-friendly interface for easy handling of input data and displaying output results. GIS can help to incorporate the new constraints based on the topography of a region.
- Transient modeling is preferable in the FDM as it is not yet completely developed in AEM mode. Using transient AEM, the developed model can be enhanced to find out different management periods according to different stress periods in a year.
- For a large and complex area, the AEM should be chosen for quick model development as in FDM, and it becomes challenging to collect a large number of input data for the whole domain.

- In the river-aquifer exchange studies, the flux of the exchange water can be computed more accurately by refining the model grid and including the effect of the hyporheic zone.

7.3 Recommendations

The optimal method for sustainable water management is the combined use of both water resources (surface water and groundwater). Therefore, some recommendations are proposed to protect the quantity and quality of water resources in the study area.

1. Where water needs to be pumped from wells, indicating and identifying the use of agricultural land will help to reduce the potential risk of the aquifer and provides a future vision that will help the sustainability of this resource. Therefore, along with the locations of these wells, the pumping volume (how much groundwater to be extracted) should be chosen more cautiously to maintain groundwater sustainability in the aquifer.

2. There is a need for continuous monitoring of groundwater levels in the study area for future use, especially in Varanasi city and the areas located near rivers. It is also necessary to maintain the stability of the groundwater resources for future use in areas dependent on the river water.

3. It is likely to worsen the groundwater conditions due to over-exploitation of the groundwater or change in the climatic conditions (temperature rise, high evaporation, and low rainfall). Therefore, a sustainability plan should be prepared in advance. This sustainability plan must be framed keeping in mind the current condition of the groundwater aquifer.

4. The water quality assessment of groundwater aquifers is necessary to examine their suitability for drinking purposes and agricultural and industrial uses.