PREFACE

Groundwater plays a vital role as a source of drinking water and other purposes for billions of urban or rural families. Therefore, sustainable management and planning of groundwater resources became crucial and necessary to predict the impact of global climate change. Groundwater management includes efficient and effective management of groundwater resources at both quantity and quality levels. Due to the depletion of groundwater, conservation measures have become a challenging issue for the current scenario. These possible measures can be assessed by developing various models for groundwater flow simulation, which have also been used as decision support systems.

Groundwater flow modeling is an important technique used by researchers and engineers to study groundwater systems dynamics and provide the information to the decision-makers. Although, a complex groundwater system with a large set of parameters and associated uncertainty with those parameters makes modeling exercise difficult. Groundwater flow modeling provides the head and flows direction that helps in the management of the groundwater under various hydrological stresses. High contamination in the surface water like the Ganga River in Varanasi and surrounding areas forces human beings to use the groundwater to fulfill their daily needs. Thus, excessive and unplanned groundwater extraction is becoming the main reason for the depletion of groundwater in the different parts of Varanasi and surrounding areas. Despite numerous previous studies, the groundwater flow dynamics in the alluvial aquifer and the characteristics of the river-aquifer exchanges are still partially unknown. Therefore, the local water management service requires a decision support system (DSS) based on numerical models to ensure better groundwater management.

In this study, the development of a transient groundwater flow model for the Varanasi district and nearby area was prompted to understand groundwater dynamics and future groundwater resource scenarios in the region. Therefore, modeling exercise has been done using two approaches: the grid-based numerical method (Finite Difference Method - FDM). The second is the analytical method (Analytic Element Method - AEM).

In the first part of the study, a hydraulic flow model has been set up using FDM techniques by considering precipitation, evapotranspiration, groundwater recharge, groundwater extraction, and river-aquifer exchanges. The non-documented groundwater extraction for agricultural use, domestic use, and livestock use has been calculated manually. The model was developed for the area of 2,785 km^2, where aquifer thickness extended up to 222 m. The model grid consisted of 210 rows and 210 columns with each cell size of 250 m × 250 m. The model was built for five layers with recharge entering the aquifer from surface infiltration through the overlying confining unit and seepage through riverbeds to realize the different types of underground formations. The maximum part of the model domain is surrounded by the Ganga River, which was taken as a hydrologic boundary for the model.

Model simulations were made to quantify groundwater flow within the alluvial aquifer as well as flow into and out of the system. The groundwater flow model was developed in the transient state condition for the years 2006 to 2017. Several criteria were used to determine how fine the model simulated conditions in the aquifer during the model development and calibration. Model calibration was done on the values of hydraulic conductivity and recharge rates. These two parameters are fixed based upon the sensitivity analysis of the model. A root-mean-square error analysis was performed during calibration to serve as a criterion to minimize differences between observed and model computed water levels. Further, the model is validated with a simulation of 1096 days. Fourteen points are chosen to evaluate the model efficiency. Then, model validation has been done using another method, i.e., by calculating Soil Moisture Index (SMI). After that, calibrated model was used to analyze the three different scenarios considering the future development and growth of the city.

In the second part of the study, a groundwater flow model was set up with AnAqSim software by considering rivers of the study area and pumping wells in DXF format. AnAqSim software uses the Analytic Element Method approach for the model development. After developing the model, based on the ease of model development, data requirement, and performances, a comparison has been made between FDM and AEM. The study suggested that AEM does not require a fixed boundary condition, and in FDM, pumping wells are approximately located and averaged over the cell, which becomes a cause of the inaccurate location of wells. Therefore, it can conclude that AEM-based modeling is more accurate as compared to FDM-based flow modeling. This study can be beneficial for groundwater professionals in deciding the best suitable method for their study area.

The study of the river-aquifer exchange has been done. In this, groundwater flow direction and quantification of flux exchanges have been calculated with the help of a developed transient multi-layered groundwater model. From the aquifer, 253.674 m^3/sec groundwater moves to the Ganga River over a stretch of approx. 70 km, and 81.581 m^3/sec groundwater moves towards the Gomati River over a stretch of approx. 65 km. Simultaneously, 198.82 m^3/sec water moves towards the aquifer from 75 km-long stretches of the River. In the dry period of the season, this value has been increased, and the aquifer comes under pressure. In the future, when the pumping schedule would like to increases, exchange between River and aquifer will be affected. Reducing the Ganga River level by 0.5 m or 1 m will slightly affect the leakage from the River and the study area's groundwater level. To control the impact on the groundwater aquifer and its connection with the River, it is highly recommended to remove some wells from the pumping schedule and reduce the pumping rate of the other wells, and constantly monitor the behavior of both over time. It is expected that the results obtained from the study can provide critical information for sustainable and effective management of the groundwater resources for Varanasi and the surrounding area.