Effect of Subsurface Development on Groundwater Regime of an Urban Aquifer - A Review Paper

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***Abstract*— Groundwater has emerged as an important source to meet the water requirements of various sectors including the major consumers of water like irrigation, domestic and industries. The sustainable development of groundwater resources requires precise quantitative assessment based on reasonably valid scientific principles. An urban aquifer is likely to be affected by the surface and subsurface development, unlike rural areas. Hence, quantitative assessment of groundwater should be based on the residential areas, commercial complexes and utilization services. Chennai, being a metro city in an urban aquifer, has attained a drastic change in the development in the recent years. Its groundwater is in trouble since the parameters are varying from its usual limits, both quantitatively and qualitatively. The work carried out in this thesis work was on identifying the watersheds in the political boundaries, thereby creating a base map for the city of Chennai. Also, the depth of the observation wells chosen for the study is to be evaluated. The land use map of the region is obtained by the LANDSAT image and classifying it using ERDAS IMAGINE 2014. By collecting data such as the litho logy, hydrogeology, rainfall, pumping details from wells and water supply data from Chennai Metro Water Supply and Sewerage Board (CMWSSB), giving the inputs to Visual MODFLOW 2011.1, the spatial and temporal variations along the Chennai city's groundwater regime was known. It was found that the groundwater level in the observation well has changed over the years. Also, the average head resulting from the Built-in three-dimensional environment has varying values along the period before and after urbanization. The velocity and direction of the flow was attained from the model results. Based on the changes, suitable conclusions and recommendations were given to maintain the groundwater quantity in the urban aquifer and possible BMPs to improve the quantity of water in the urban aquifer.**

***Keywords*— Chennai, Groundwater, LANDSAT, ERDAS IMAGINE 2014, Visual MODFLOW 2011.1, BMPs.**

I. Introduction

Groundwater is the water that is stored in rocks and soil and is stored in the ground. Groundwater can be dated to few thousand million years to present date, which is added due to the infiltration of the surface water or rainfall recharge, taking some time to reach the aquifer. Groundwater regime which controls the flow of water through the aquifers gets altered in urban areas due to the subsurface development such as tunnelling, construction of buildings, undergrounds passages, etc., The changes in the subsurface causes changes in flow direction of the regime which may lead to drawdown or nil availability of water in the vicinity.

Chennai Metro Rail Limited (CMRL) is a rapid transit system serving the city of TamilNadu, India. The total length of metro rail underground work is 24 km. The length of the underground work for corridor 1 and II is, 14.3 km and 9.7 km, the stations of Corridor I is located in between Washermanpet to Saidapet and the stations of Corridor II is located in between Central to Thirumangalam.

Chennai city has a land use varying from residential areas, colonies, commercial complexes, industries, transportation sectors and utilization services. Initial subsurface development of the city was only with the construction of petrol tanks, foundations, deep foundations, etc., In the year 2009, when the Chennai Metro Rail Limited started its construction of the underground tunnels, a new issue of blocking or altering the flow of the groundwater in the urban aquifer has attained a serious concern.

The underground corridor tunnels may have disrupted the groundwater regime which alters the direction of flow. Hence a detailed study was made to analyze the flow changes and model the groundwater regime before and after underground tunneling of the CMRL rail network.

Objectives

By which the objectives of the study can be as follows,

- To estimate the groundwater quantity in the observation wells and analyse the changes before and after urbanization.
- To analyse the groundwater recharge pattern due to rainfall in the urbanized area.
- To gather information about the changes made to groundwater regime since urbanization due to residential areas, commercial complexes and utilization services.
- To suggest a solution for the alternate measures to improve the groundwater quantity in the urbanized area.

II. Earlier Research

Groundwater recharges in the tunnelling area, groundwater flow pattern before and after tunnelling, rise/fall of groundwater table before and after tunnelling are to be dealt with this thesis. Various literatures were studied on selected topics such as recharge estimation, groundwater quantity analysis, effect of underground tunnelling on urban aquifer and application of softwares for the groundwater modelling and are categorized. The literatures are reviewed so as to come to a conclusion on choosing the most appropriate methodology in carrying out the project work.

Changes in groundwater regime

Aivars Spalvins, et.al, (2012) This paper is dedicated on the findings of changes in groundwater regime due to a 7 km long and 50 m deep underground transportation tunnel in Riga. Groundwater Vistas package is used to determine the flow changes. Hydrogeological model is used for determining the groundwater flow before and after the construction of the tunnel. Plane codes were given for different soil layers and the tunnel route is mapped and 4 layers were split in the tunnel zones and possible variations are shown.

Kim, et.al, (2009) The 11 km Inge tunnel in Seoul poses some environmental issues since other major tunnels were stopped its services due to serious environmental issues. This paper deals about changes in groundwater level due to tunnelling through numerical modelling by MODFLOW for the continuous model and MAFIC for the discontinuous model. The results were obtained through geophysical, hydrogeological methods and the model shows that 1.29 – 3.2 m drawdown is faced through MODFLOW and 1.72 m in MAFIC model. Waterproof grouting is the best solution to overcome this problem in the problematic site by which the drawdown level is reduced to 0.72 m

Marinnos, et.al, (1997) shows a typical two dimensional steady state analytical model and simulation for the rise in groundwater table when flow is obstructed by shallow tunnels. They also list the adverse effects of the rise in ground water table, before and after tunnelling. Model is based on Galerkin method of weighted residuals and solves the time-dependent, two dimensional flow in a porous medium around a cylindrical object. It says that the steady state water level may be attained at any time and hence the entire life of the permanent tunnelling is to be considered. This paper proposes a simplified analytical method which gives reasonably accurate predictions of the magnitude of the water table rise in a closed form analytical expression. The results are reasonably matching the real time monitoring but the process is quite tedious as compared with MODFLOW.

Sekhar et.al, (2009) conducted studies along the metro rail alignment in Bangalore based on geohydrology. The scope of the work was an inventory for existing well data, to characterize the hydrogeology of the region, assessing the groundwater flow patterns, assessing spatial and temporal groundwater recharge and discharge, modelling and assessing potential impacts of groundwater system and proposing suitable site specific strategies to eliminate any unfavourable effects on groundwater system. Data such as district map, topographic map, DEM, geology map, well hydrographs, etc., are collected and analysis were done based on the standards as given by CPWD, Bangalore city corporation. The analysis concludes that, after obtaining required data, values are imported in MODFLOW and a finite element grid model is created for the period before and after tunnelling. Results show that groundwater flow is not interrupted but polluted to an extent. Proper drainage windows can be provided.

Alain Dassargues, et.al, (1997) studied in detail about the construction of a tunnel longer than 500 m in the alluvial plain of the river Meuse and River Ourthe in the city of Liege (Belgium) for the water table changes. Two piezometric levels of extreme conditions (high and low water level) were chosen in order to obtain their hydraulic conductivities and permeability values. A drainage window was introduced as a study part in order to reduce the barrier effect of the aquifer. MODFLOW was used as a simulation modelling tool and historical data were obtained by which on validating, calibrating and simulating the model, results were obtained, that during lower water table conditions no possible seepage or lowering of water table were recorded due to tunnelling. In extreme flood conditions such groundwater rise was seen in the south zone. Drainage windows can be provided but it induces low value on civil engineering aspect.

Summary

It was observed in this part of the review that, to know the changes in the groundwater regime can be found out by the usage of Visual MODFLOW 2011.1. Also, the required data for the process flow of the software is understood from this review.

Groundwater quantity analysis

Naik, Pradeep, et.al, (2008) present about the groundwater quality and quantity in Solapur, Maharashtra. Knowing the land use pattern and the aquifer in the area, the recharge pattern .and zones are acquired through dug wells and bore wells for the present and ultimate year (future forecasting). Quality of groundwater is compared with BIS standards. The paper concludes that groundwater quantity is stable due to supply to city to meet demands. Also, groundwater quality deterioration is due to general apathy of public on using it. Also, it suggests on advanced action in ensuring for water supply during infrastructure development.

Summary

It was observed that the the groundwater quantity analysis for an urban aquifer can be made by the collection of water level from observation wells and also it was known that the water supplied by the Governing body of an area is an important factor for the recharge calculation, in addition to rainfall.

Rainfall recharge estimation

Brown Henrick Nziku, et.al, (2009) used GIS tool for groundwater recharge estimation in Ma Keng iron mine in Eastern China. Estimation of groundwater recharge requires huge amount of data because it depends on numerous factors ranging from climatic, topographic, land cover, soil and rock formations. PRO – GRADE is an ARC GIS 9.2 plug-in from Environmental Systems Research Institute (ESRI). It requires data of hydraulic conductivity, water table and bedrock elevation. PRO- Pattern Recognition Organizer and GRADE-

Groundwater Recharge And Discharge Estimator uses the mass-balance equation for calculation of the vector quantity for each cell. Hydraulic conductivity is calculated using Kozeny-Carman equation and is converted as raster file. Water table and bedrock elevations shape files are imported and GRADE tool is used from which groundwater recharge rates estimation map is produced. Using DEM or the groundwater recharge rates estimation map, PRO tool is utilized for recharge pattern along the area.

Summary

It has been concluded that PRO-GRADE should not be used in arid and semi-arid regions because it will overestimate recharges in uplands and underestimate in areas around or along surface water bodies.

Application of modflow

Surinaidu, et.al. (2015) The construction of subsurface structures such as tunnel beneath the water table causes the groundwater seepage into the structure and impacts the stability of the structure. A 2.483 km long railway Tunnel was constructed between Katara and Udhampur in Jammu and Kashmir province of India. It is occupied by alluvium with scanty exposures of sandstone belonging to the Middle Shiwalik group. A huge amount of infiltrated water from the perennial canals and agriculture fields is entering the Tunnel. In addition to this, dry Nala/Palaeo channel across the Tunnel alignment contributes significant groundwater seepage during rainy season. A finite difference based groundwater flow model was constructed using the inferences from hydro-geo-morphological features and geologic lineaments to estimate the groundwater seepage and find out the possible solution. The computed flow model indicated that Tunnel would receive groundwater seepage of 78, 133 m3/day. The analysis of the model results revealed that 500 lateral perforated pipes of 5 m in length at an interval of 2 m with an annular space filled with highly permeable geo media can drain out the seepage water. The suggested perforated pipes were successfully installed in the tunnel. They were effective in draining out the groundwater seepage.

Singh, et.al. (2014) This paper deals with the Processing Modflow package for the groundwater flow and solute transport problem. The groundwater basics were discussed. The types of Groundwater modelling available, their advantages were also briefly discussed. The process carried out in the Modflow software includes planning stage, conceptualisation, design and construction stage, model calibration, predictive scenarios, uncertainty, model reporting and review. They concluded that Groundwater models have proven to be useful tools over several decades for addressing a large of groundwater problems and supporting the decision-making process. The software can be developed to solve groundwater problems such as water resources management model, mine-dewatering model and tunnel construction and operation, which provides quantitative estimates of the groundwater inflows and associated drawdown during the construction and operation of a new tunnel.

Summary

From the above papers, the process flow of Visual MODFLOW 2011.1 software package is understood. Also, the recommendations given by these authors were understood thoroughly such that suitable solutions can also be given for the study area of this thesis work.

III. Conclusions

Groundwater is the only fresh water resource in the recent times, since the surface water sources are being polluted. Groundwater quantity is based on the inflow and outflow characteristics such as recharge, rainfall, pumping, etc., Hence complete study on the aquifer has to be done. It involves aquifer parameters such as soil type, depth of the soil layer in each aquifer, hydraulic conductivity, specific storage, specific yield, total porosity, effective porosity of each soil layer in the aquifer. The recharge zones in the aquifer has o be known.

The pumping wells and the observation wells in the aquifer has to be known for their pumping rates, water levels with respect to the datum. Subsurface development involving tunneling, construction of foundations, etc., has to be known and the depth upto which the development has progressed has to be studied. Groundwater flow and rate models have been applied to investigate a wide variety of hydrogeologic conditions. Groundwater flow models are used to calculate the rate and direction of the movement of the groundwater. So, based on the literatures, it is evident that the estimation of the groundwater quantity can be done with the help of Visual MODFLOW 2011.1. Landsat images and their classification may be useful in identifying the changes made in the aquifer before and after the subsurface development. Hence, it canbe concluded that the effect of subsurface development in groundwater regime of an urban aquifer can be identified by the three-dimensional finite difference groundwater models with the known inputs.

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