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A Groundwater Modeling on Hard Rock Terrain by using Visual Modflow Software for Bangalore North, Karnataka, India

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Abstract: ***The present study investigated through mathematical modelling techniques (using Modflow) for the Bengaluru North zone. The present study carried out in Bengaluru North Taluk lies in between 12° 52' N to 130 15' N, 770 22' E to 770 50' E to assess the changes in groundwater heads due to enormous pressure on water availability (especially in groundwater) in the study area for a scientific planning and management of water resources. The present study carried out using mathematical distributed model Modflow, to set up, execute the model, requires several data of which study area boundary (.shp format), geological information to represent the geological layers in to the model using Digital Elevation Model (DEM) obtained from Cartosat I Ver. 3R (Bhuvan site), pumping wells, observation wells etc. Shows the head variation in the study area before adding pumping wells and after adding pumping wells. The final observed and simulated results of the groundwater heads in the Bengaluru North taluk under transient state condition.***

Keywords: Digital Elevation Model (DEM), Modflow.

I. INTRODUCTION

Groundwater is a natural resource periodic replenishment due to rainfall and other hydrologic processes (Varghese et al. 2015). As there are increased constraints on the development of surface water resources due to saturation and environmental stresses, more attention is being paid to the development of the groundwater resources in various parts of the globe (NIH 2000). However, the increase of demand and drastic utilization of groundwater causes: depletion of aquifers, decrease in crops yields etc., Many regions in India experiencing declining water tables due to over exploitation and ill-management of the resources (NIH 2000). Recent studies indicate that 26% of the area of Karnataka State is under over exploited category. The study on groundwater resources is an essential component of the environment and economy (CGWB 2013). Specifically, in the view of the growing concerns of sustainability of groundwater resources, hence it is essential to augment groundwater resources in stressed areas. The study on decline in groundwater table is due to less rainfall, interference of wells, impervious surface (urban areas). To study the groundwater resources, the availability of the groundwater information is quite limited because of number of constraints, therefore in order to address local-scale groundwater issues, the present study investigated through mathematical modelling techniques (using MODFLOW) for the Bengaluru North zone. The data used, methodology followed is discussed in detail below.

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II. STUDY AREA

The Bengaluru district was divided into Bengaluru Urban and Bengaluru rural districts in the year 1986. The Bengaluru urban district comprises of four taluks, with a Bengaluru city –the capital of Karnataka. The city has grown due to progressive trend in Information Technology over a decade has suddenly grown its size and several economic activities, trade, and housing facility etc., The present study carried out in Bengaluru North Taluk (shown in figure 1) lies in between 12° 52' N to 13^0 15' N, 77^0 22' E to 77^0 50' to assess the changes in groundwater heads due to enormous pressure on water availability (especially in groundwater) in the study area for a scientific planning and management of water resources.

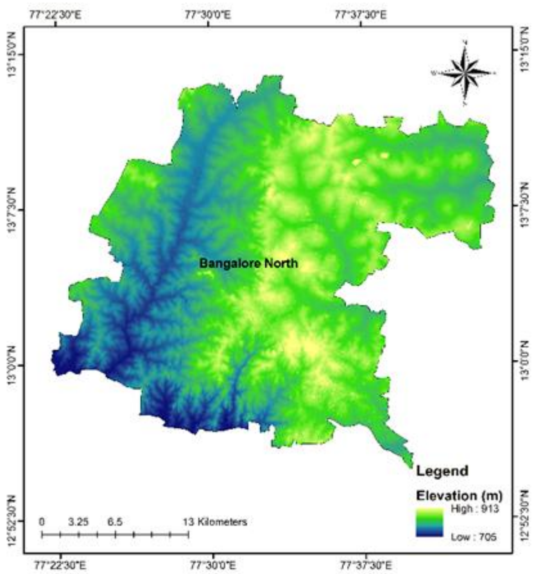

Figure 1: Location of the study area.

III. DESCRIPTION OF THE MODEL

In this study, Visual MODFLOW Flex 2014.2 is used for modelling the groundwater flow. MODFLOW is a three-dimensional regional finite difference model. MODFLOW is considered an international standard for simulating and predicting groundwater conditions and groundwater/surface-water interactions. The model was

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developed by USGS and first published in 1984. The model simulates groundwater/surface systems, solute transport, and groundwater management etc. The governing equation (Darcy's equation) used in the model for a confined aquifer given by:

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

Where,

K_{xx}, K_{yy}, K_{zz} : Hydraulic conductivity along major axes [LT^{-1}].

h : Potentiometric head [L].

W: Volumetric flux per unit volume (source and/or sinks) [T^{-1}].

S_a : Specific storage of the porous material [L^{-1}].

T : Time [T].

A. Data used

The present study carried out using mathematical distributed model MODFLOW, to set up, execute the model, requires several data of which study area boundary (.shp format), geological information to represent the geological layers in to the model using Digital Elevation Model (DEM) obtained from Cartosat I Ver. 3R (Bhuvan site), pumping wells, observation wells etc. Figure 2 shows the pumping wells and observed wells considered for the study.

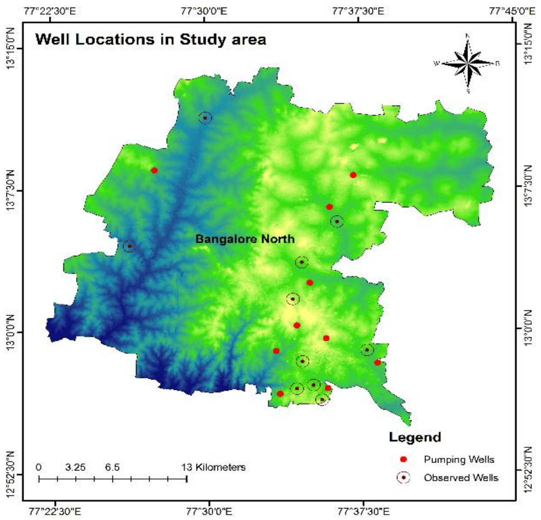

Figure 2: Location of bore wells in the study area

Table 1: Values used while defining model properties (source: NIH, 2000)

Model Properties	Value used	
Conductivity	Layer 1: Sandy Soil	Layer 2: Granite, Genesis
Kx	3E-8	7E-7
Ky	3E-8	7E-7
Kz	3E-9	7E-8
Storage	Layer 1: Sandy Soil	Layer 2: Granite, Genesis
Specific Storage (S_s)	0.001	1E-5
Specific Yield (S_y)	0.12	0.20
Porosity (P_{eff})	0.30	0.14
Total Porosity (P_{tot})	0.60	0.30

B. Water Table Fluctuation

The water-table fluctuation (WTF) method provides an estimate of groundwater recharge by analysis of water-level fluctuations in observation wells. The method is based on the assumption that a rise in water-table elevation measured in shallow wells is caused by the addition of recharge across the water table.

Recharge by the WTF method is estimated as:

$$R = S_y \; x \; A \; x \; W \quad [1]$$

Where, R is recharge, A is area, S_y is specific yield and W is water table fluctuation. The recharge values calculated in the study are for each individual year shown in table 2 and the annual recharge with respect to annual rainfall for each individual period in the study are shown in figure 3. Figure 4 shows the water table fluctuation contours in the study area for the period 2011, 2012, 2013, 2014 and 2015 respectively.

Table 2: Annual recharge in the study area during study period.

Year	Rainfall	Recharge
2011	1183	440.79
2012	616	543.68
2013	1056	426.40
2014	829	425.94
2015	1281	402.15

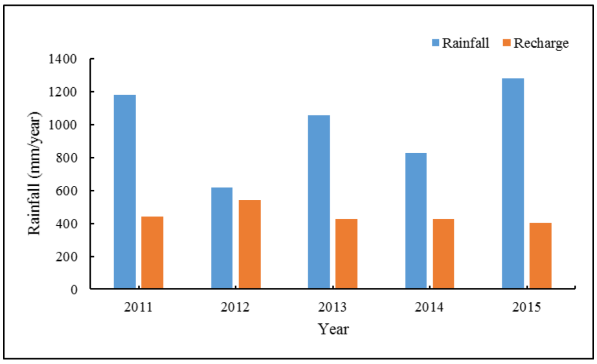

Figure 3: Annual recharge with respect to annual rainfall in the study area

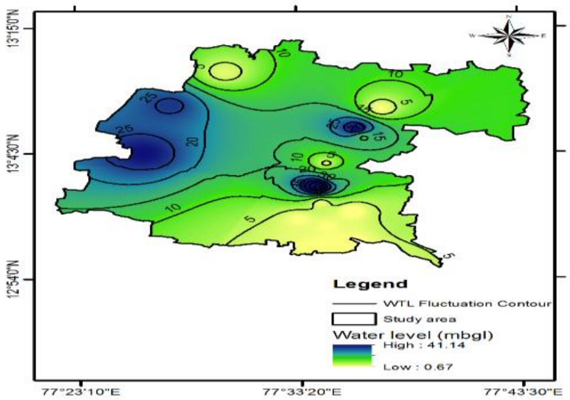

Figure 4 a Shows the water table fluctuation contours during the year 2011.

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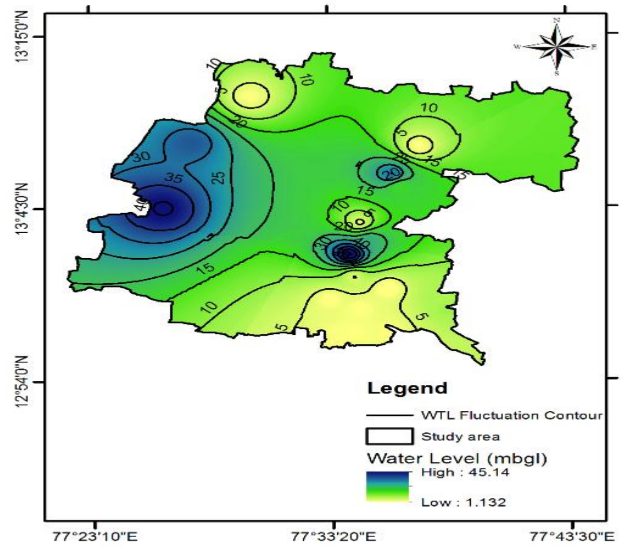

Figure 4 b shows the water table fluctuation contours during the year 2012

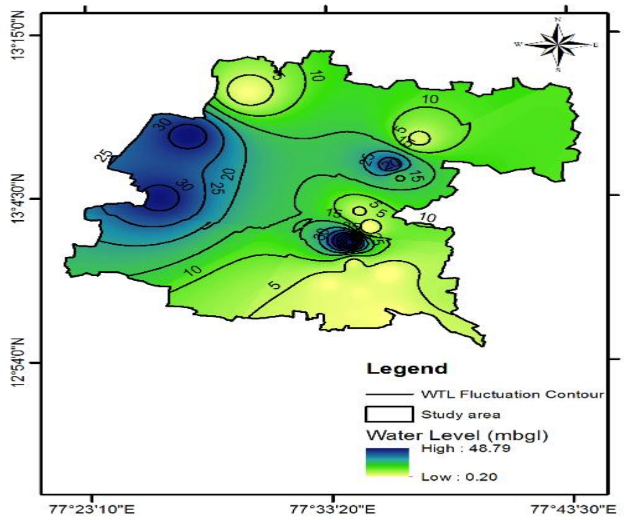

Figure 4 c shows the water table fluctuation contours during the year 2013.

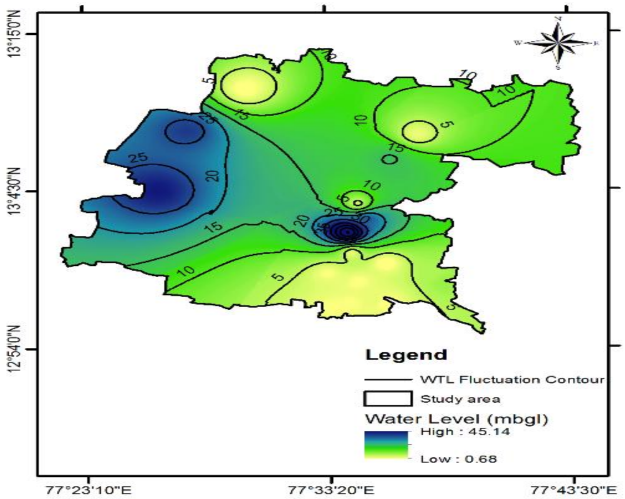

Figure 4 d shows the water table fluctuation contours during the year 2014.

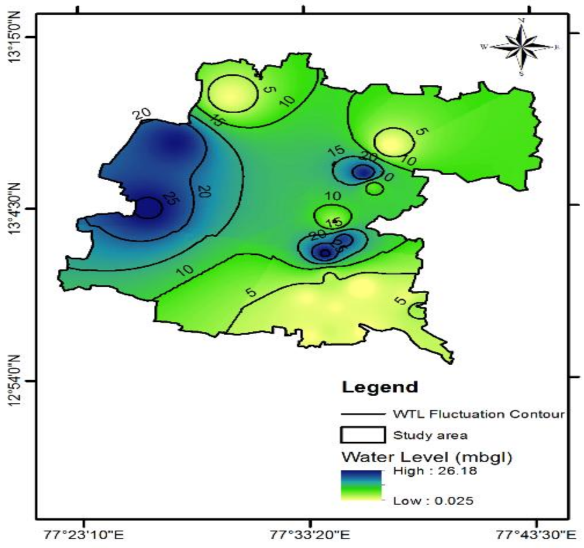

Figure 4 e shows the water table fluctuation contours during the year 2015.

IV. METHODOLOGY

The below Figure 5, shows the flowchart of the working flow process of the MODFLOW model to assess the groundwater flow. The first and initial step of the model is to build the conceptual model using study area boundary, geological layers, defining property zones. The second step is the numerical modelling which includes design model grid/mesh, assign boundary conditions, assign model parameters. Once the model is converted from conceptual to numerical, it is translated and simulated with all the necessary inputs. The model simulated results are compared with observed results to check the model estimated results with observed filed measured data. If the simulated results are not matching with observed the model is to calibrated by changing the input parameters by the sensitive analysis. However, the calibration of the model is continued with the performance evaluation of simulated and observed results. In this case the performance of model simulated results are evaluated with R^2 and residual error. In detail, the model set up and execution is discussed in the below section.

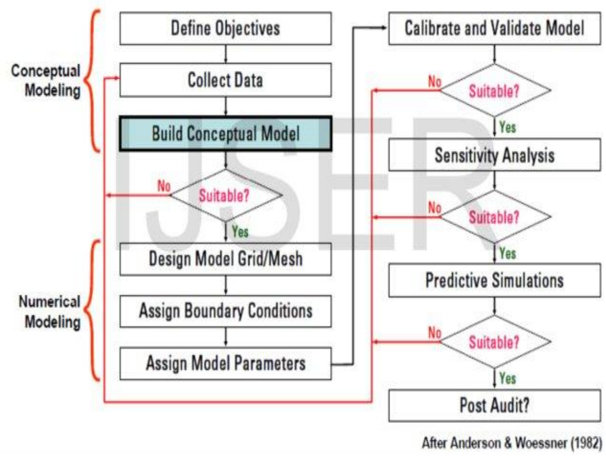

Figure 5: Working flow process of the MODFLOW model (Adopted from Fouad & Hussein 2018).

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A. Conceptual Modelling

The first and initial step of the model, in which the various types of data imported to setup the model for the study area. Note that, to prepare the data as per the model requirement for the study area done by using ArcGIS 10.1 desktop. The data used are, study area administrative boundary (as a polygon in shapefile format), River (as a polyline in shapefile format), geological (top, bottom) layers generated by using DEM data based on the (CGWB 2013; NIH 2000) reports. The top layer of the model lies 25m below from the ground surface and bottom layer of the model lies 60m below from the ground surface. The top and bottom layers are comprised of weathered and shallow fractured of Granites and Gneisses (CGWB 2013; NIH 2000.

B. **Define Property Zones**

In this step, the top and bottom layers are added to create zones representing the respective layers in to the model. The hydraulic properties conductivity (Kx, Ky, and Kz), specific storage (Ss, Sy, K, and) and initial heads values of each individual layers are given to the model.

B. Boundary Conditions

The boundary conditions of the model include Recharge, River, Lakes, Evapotranspiration, pumping wells etc. In the present study, due to non-availability of data, recharge, river and pumping wells is used as boundary conditions. The recharge for the study area is observed from CGWB 2013 report. The river stage, river bottom, river bed thickness, conductivity is used as an input into the model. The pumping well data is to be prepared accordingly as per the requirement of MODFLOW with the well id, latitude, longitude, top screen, bottom screen, heads, pumping starting time, pumping ending time, pumping rate.

C.Define Model Grids

The conceptual model is converted to the numerical model, by defining the mesh/grid size. In the present study the number of rows and columns given 120x120 based on the literature. Then the numerical grid method deformed is used as a default method to convert the conceptual to numerical. Further, the numerical model is translated using translate function in the model and finally simulated under transient state condition.

D.Model Translation and Simulation

Once the model is converted from conceptual to numerical by assigning the grid type, the model is to be translated and simulated with all the given inputs (including boundary conditions and observed wells).

V. RESULTS

Figure 6 and 7 shows the head variation in the study area before adding pumping wells and after adding pumping wells. The final observed and simulated results of the groundwater heads in the Bengaluru North taluk under transient state condition, shown in below figure 8.

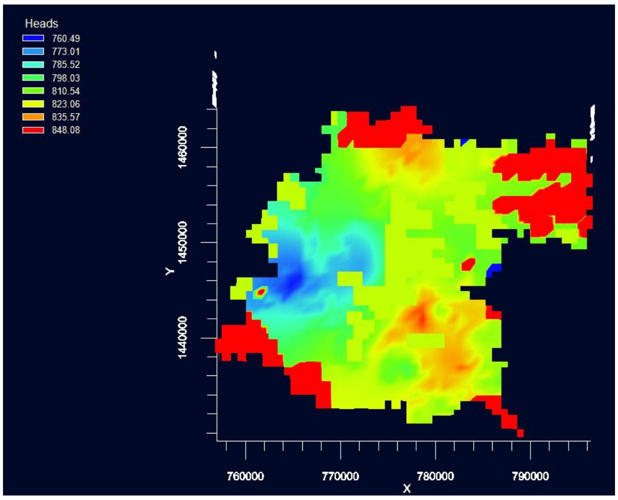

Figure 6: Head variation in the study area without adding pumping wells

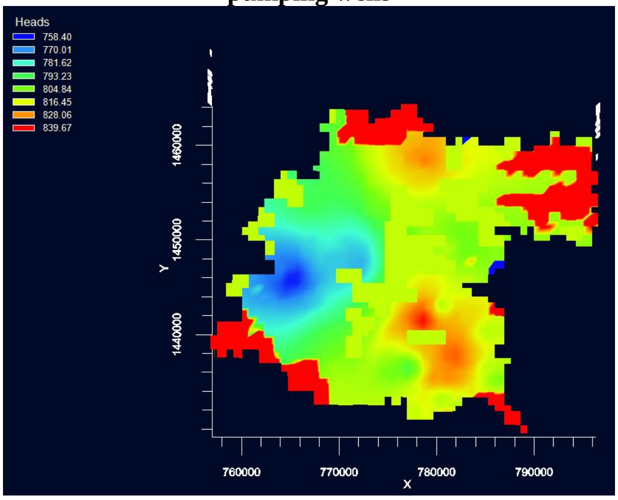

Figure 7 : Head variation in the study area after adding pumping wells

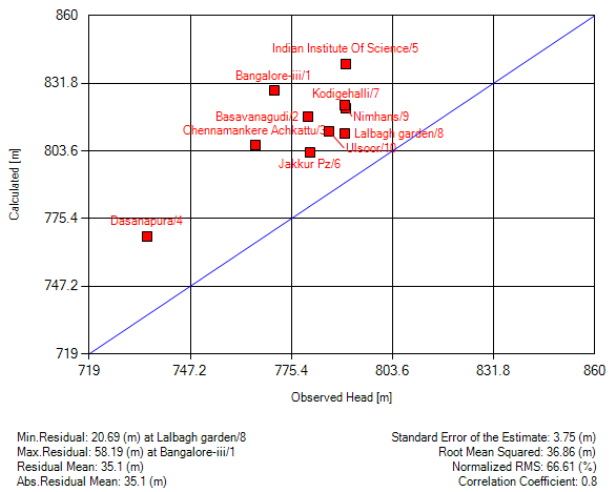

Figure 8: Observed vs. simulated heads in the study area

A.Model Calibration

Model calibration is the process, where the selected model input parameters are adjusted within reasonable limits to produce simulation results to best match with measured or observed values. From figure 8, results show that the simulated groundwater heads are not correlating with observed heads, hence the model is to be calibrated by changing the model input parameters. The comparison of observed vs. simulated heads from the fields are plotted using scatter plot. The graph Y-axis represents simulated values from the model and X-axis represents the observed values from the field. When the data points intersect the 45degree line (where X=Y) represents an ideal calibration scenario. From figure 8, the maximum data points are overlaying above the 45degree line, it seems the model is overestimating than the observed results. Therefore, the model is to be calibrated in order to be use the groundwater model in any type of predictive role.

B.PEST (Parameter Estimation)

In Visual MODFLOW Flex an interface to the popular Parameter Estimation and predictive analysis program PEST, developed by Dr. John Doherty used for model calibration. The PEST is a non-linear optimization package. The algorithm used by PEST is a Levenberg-Marquardt algorithm which searches the optimal solutions. The main objective of the calibration is to minimize the residual sum. These residuals are the difference between observed and simulated heads.

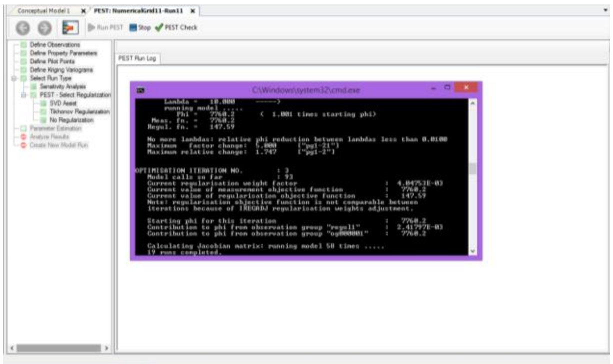

Figure 9: PEST run during model calibration

Figure 9 shows the PEST run during model calibration, based on the results it is observed that the conductivity parameter found the most sensitive parameter. Hence, figure 10 show variation of heads in the study area for different time periods, figure 10 shows the scatter plot on observed vs. simulated during calibration shows that the Correlation Coefficient 0.84, satisfies the model calibration. Where the data is limited for this study, hence study may extended with fine resolution data. The groundwater heads in the Bengaluru Taluk is simulated from 2011-2015 and the head variation between the model period shown with different time steps. The groundwater head variation in the study area shown in below figures 11, 12, 13, 14 respectively.

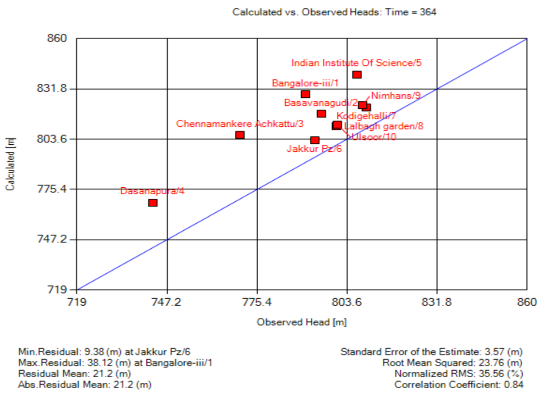

Figure 10: Scatter plot on observed vs. simulated results

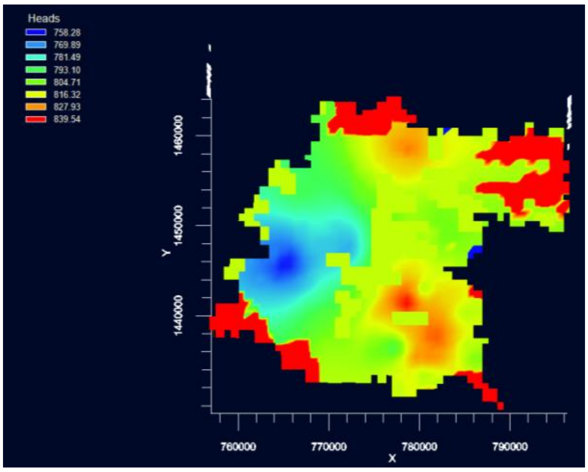

Figure 11: Head variation after 154 days from starting day of simulation

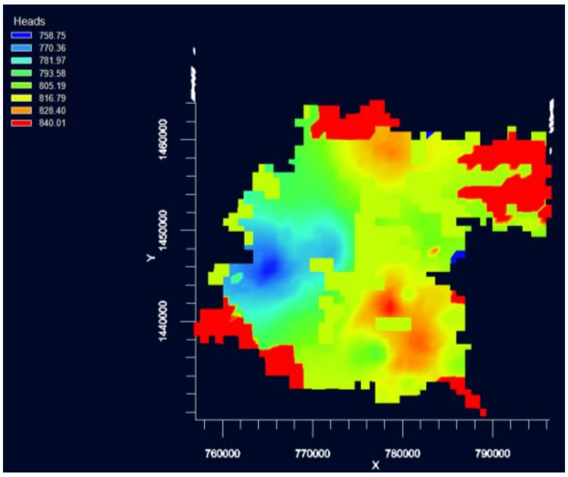

Figure 12: Head variation after 377 days from starting day of simulation

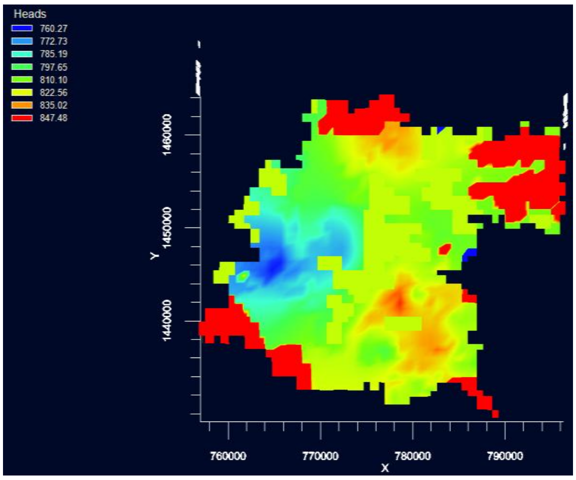

Figure 13: Head variation after 908 days from starting day of simulation

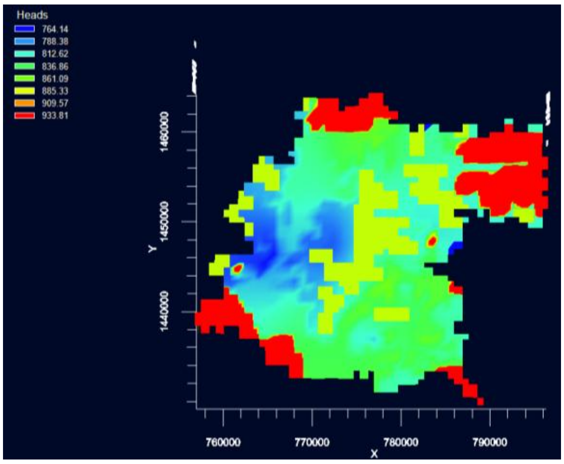

Figure 14 Head variation after 1826 days from starting day of simulation

REFERENCES

1. Coelho, C. D., Faria, A. C. S., & Marques, E. A. G. " Comparative analysis of different boundary conditions and their influence on numerical hydrogeological modeling of Palmital watershed, southeast Brazil". *Journal of Hydrology: Regional Studies*, *12*, 210-219, 2017.
2. Varghese, A. A., Raikar, R. V., & Purandara, B. K "Simulation of Groundwater Levels in Malaprabha Command Area using Visual MODFLOW FLEX". *International Research Journal of Engineering and Technology (IRJET)*, *2*(8), 434-440, 2007.
3. National Institute of Hydrology, Roorkee. "Aquifer recharge of an unconfined aquifer with an injecting well (Karnataka)" 2000.
4. Fouad, M., & Hussein, E. E. "Assessment of Numerical Groundwater Models". International Journal of Scientific & Engineering Research Volume 9, Issue 6, ISSN 2229-5518. Pp. 951-974, 1998.
5. Central Ground Water Board, Bengaluru "Ground Water Information Booklet, Bangalore Urban District, Karnataka" 2013.
6. Jairaj, C., Prathap Kumar, M.T. & Raghunandan, M.E. "Compaction characteristics and strength of BC soil reinforced with untreated and treated coir fibers" Innov. Infrastruct. Solut. (2018) 3: 21. https://doi.org/10.1007/s41062-017-0123-2.
7. Jairaj & Prathap Kumar, M.T. "Long-term Performance Studies on Strength Characteristics of Black Cotton Soil Reinforced with Untreated and Treated Coir Fibre" Int. J. of Geosynth. and Ground Eng. (2018) 4: 25. https://doi.org/10.1007/s40891-018-0143-9.
8. National Institute of Hydrology, Roorkee, "Groundwater modelling in Ghataprabha sub basin of Krishna River basin".1997.
9. Nanjundi P, M.Inayathulla," Runoff Estimation by SCS Curve Number Method for Bangalore North Taluk, Karnataka, India" Jour of Adv Research in Dynamical & Control Systems, Vol. 11, No. 1, 2019.

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