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Groundwater Flow Modelling Using Visual MODFLOW - A Case Study of Lower Ponnaiyar Sub-Watershed, Tamilnadu, India

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Abstract: **-- The groundwater model is used to predict the effects of hydrological changes like groundwater extraction or irrigation developments on the behaviour of the aquifer and is often named as groundwater simulation model. Visual MODFLOW is the U.S. Geological Survey modular finite-difference flow model, which is a computer code that solves the groundwater flow equation. In this study, the Visual MODFLOW is used to simulate the flow of groundwater through aquifers in Lower Ponnaiyar watershed, Tamilnadu, India. The three-layer model is run with four phases that are model design, calibration, validation and prediction. The model is calibrated in two stages, which is involved a steady state calibration and transient state calibration using observed groundwater levels from 2005 - 2014. The validation is done by using observed groundwater levels from 2014 - 2016. The spatial distribution of hydraulic conductivity and storage properties are optimized using a combination of trial and error method. The simulation results showed that the fluctuations of hydraulic heads are dependent on seasonal variation in recharge from natural infiltration of precipitation and irrigation. The different scenarios are developed to predict aquifer system response under different conditions of the study area. The calibrated parameters are very useful to identify the aquifer properties and to analyze the groundwater flow dynamics and the changes of groundwater levels in the study area. The study suggests that from the prediction the recharge rate must be improved in the villages like Tiruppanambakkam, Karaimedu, Agaram, Kavanippakam, Anangur, Pillur, Tiruppachanur, Pedagam and Perangiyur which are located nearer to the river course. Also, this study concluded that the water level is high in central western part and declining towards the south Ponnaiyar River.**

Index Terms - Visual MODFLOW, calibration, aquifer properties, groundwater level.

1. INTRODUCTION

Groundwater lies almost everywhere below the earth's surface. It is an important source of drinking water supply, irrigation and caters. More than 90% of the world's total supply of drinkable water is groundwater. The use of groundwater models is prevalent in the field of water resource engineering. In general, models are conceptual descriptions or approximations that describe physical systems using mathe¬matical equations; they are not exact description of physical systems or processes. Groundwater models describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, heterogeneity or anisotropy of sediments or bedrock within the aquifer, contami¬nant transport mechanisms and chemical reactions. Because of the simplifying assumptions embedded in the mathemati¬cal equations and the many uncertainties in the values of data required by the model, a model must be viewed as an approxima¬tion and not an exact duplication of field conditions. Groundwater models, however even as approximations, are a useful investigation tool that groundwater hydrologists can use for a number of applications.

2. STUDY AREA

The study area lies in between 79º 15' 13" and 79º 48' 28" E longitudes and 11º 50' 18" to 11º 55' 18" N latitudes with a total area of extent of 598.162 km2 (Figure.1). It includes five taluks namely Tirukoilur, Ulundurpettai, Villupuram, Panruti and Cuddalore with a general elevation of 81.25 m above MSL sloping from West to East. The river is dry for the most part of the year. Water flows during the monsoon season when it is fed by the Southwest monsoon in the catchment area and the Northeast monsoon in Tamilnadu. However, this water flow raises the groundwater table throughout the river basin and feeds numerous reservoirs /tanks. The recorded maximum rainfall is 1851 mm (1996-97), while the minimum is 548 mm (1989-90). The maximum temperature may rise up to 40º C and decreased during winter season up to 27º C. The winter water level ranges from 2.50 to 5.00 m and the summer water level ranges from 3 to 7 m.The Index map of the study area is presented in Figure 3.1.

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2.1 Hydrogeology

The major lithology groups are noticed as clay, sand, silt, sand/clay admixture, horne - blende biotite gneiss and gingee granite. The study area is composed of weathered rocks, sedimentary formations and hard rock areas. The depth of aquifer is taken upto the hard rock areas and varies from 1 to 43 m underneath the area. Generally, the entire area of study area is traversed by hard rock formations (43%) and Sedimentary formations (57%). The depth of water level varies from 15 to 25 m. In the study area, the water is drained into Ponnaiyar basin from West to East.

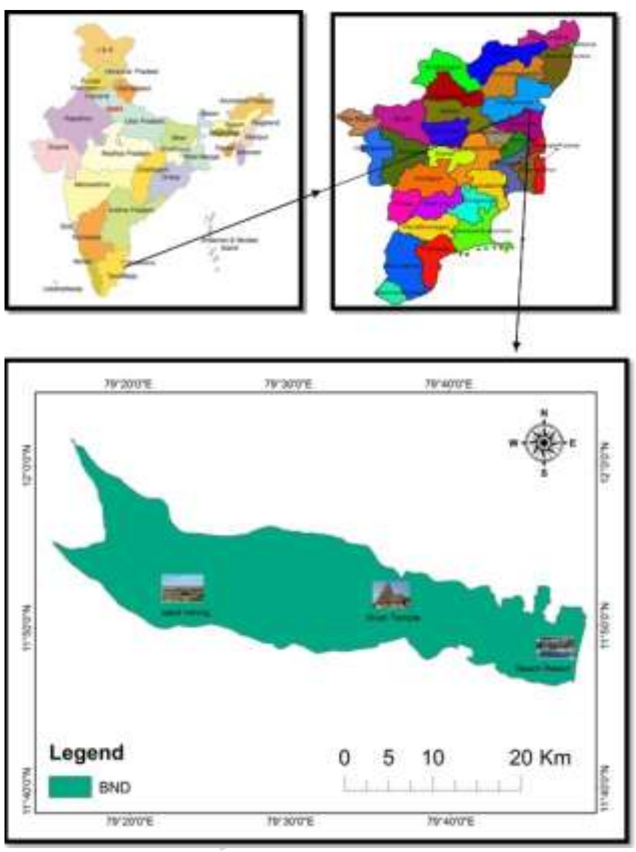

Figure 1 Index map of the study area

3. METHODOLOGY

In this study, the groundwater flow direction has been done for Lower Ponnaiyar Sub- Watershed. The methodology adopted in this study consists of the different phases as shown in Figure 2

3.1 Database

Database on aquifer characteristics such as soil type, borehole details for wells, hydraulic conductivity, porosity and storativity are generated based on borehole lithological data are collected from Central Groundwater Board (CGWB).

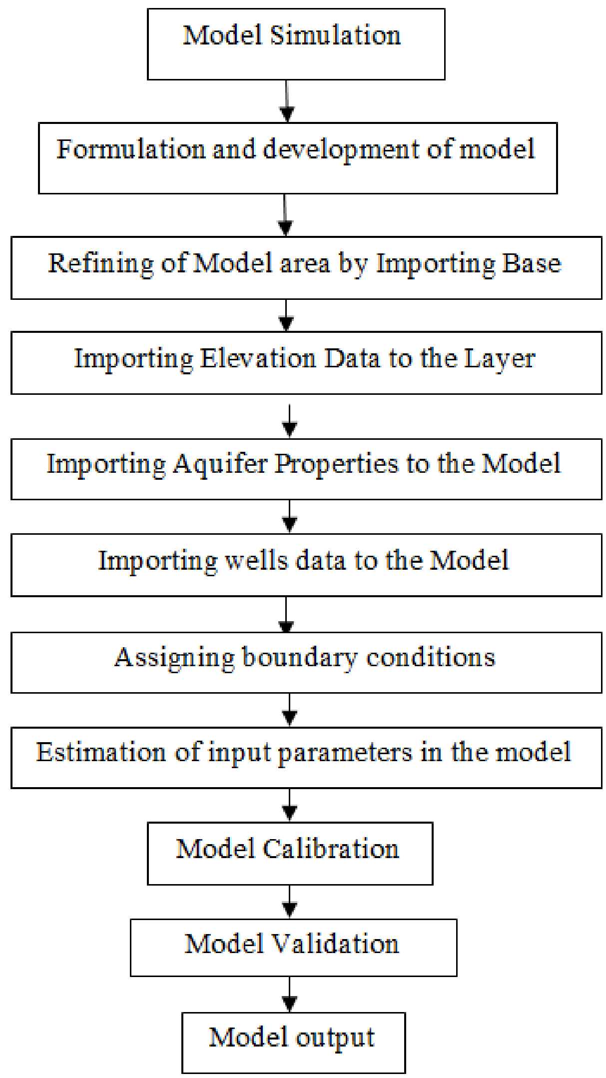

Figure 2 The proposed methodology for Groundwater flow model

The time series data such as water level data for the period from 2005 to 2016 are obtained from Institute for Water Studies (IWS) and Tamilnadu Water Supply and Drainage (TWAD) Board. The base map is digitized in Geo- Media environment. Monthly rainfall data for the period of thirty years (1983 - 2013) is used in the analysis of hydrologic characteristic of the study area and to find the annual recharge. About eight wells in the study area are considered for this study and the information on groundwater level, well location and mean sea level (MSL) are collected.

3.2 Model Development And Formulation
Base map

The base map of the study area is digitized and prepared using Arc GIS 10.1. The vector file format of the base map is directly imported into the model screen in Visual MODFLOW. The study area with total area of 598 sq.km has been discritized into 60 rows and 80 columns. The Base map of the study area in the model screen is flashed in Figure 3

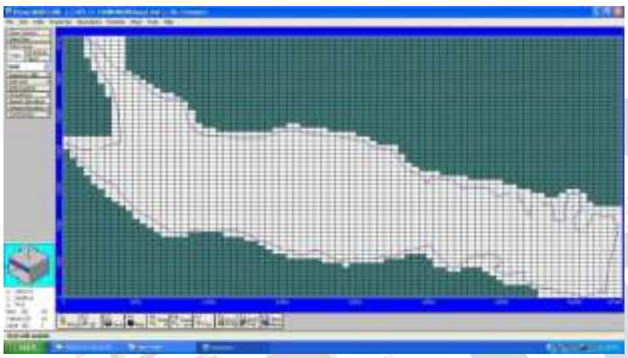

Figure 3 Grid map of the study area

3.3Elevation

Based on lithology and bore well lithology , the study area has been assigned into three layers. The co-ordinates of study area with elevations are taken with help of GPS and then directly imported into the model. The elevations for three layers are imported through the Grid menu in the model screen.

3.4 Well Importing

Visual MODFLOW allows inputting the water level of the observation wells for the estimation of hydraulic head. In this study area, the 8 observation wells which is also act as a pumping wells are taken into account for model development. The groundwater levels from 2005 to 2014 are imported into the model. Well inventory is made on entire stretch of study area and their pumping rates are calculated. The well importing screen is depicted in Figure 4

3.5 Aquifer Properties

An aquifer property includes the hydraulic conductivity (x, y and z directions), specific yield, total porosity, effective porosity and storativity. The study area is categorized into three zones based on the lithology formation. The values of aquifer properties are listed in
Table 1 and assigned aquifer properties in the study area shown in model screen (Figure 5)

Figure 4 Observation wells in the study area

Figure 5 Hydraulic conductivity map of the studyarea

3.6 Boundary Conditions
Generally, the difficulties are arises in the modelling while assigning the boundary conditions. The numbers of boundary conditions are available in Visual MODFLOW such as general head, recharge, constant head, river and no flux boundary conditions. In this study, the river and recharge boundary conditions are considered as model input. Because the river flows from West to East and it is non - perennial river therefore the river is almost dry throughout the year. So the recharge estimated from the Groundwater Estimation Committee Norms (GEC – 1997) which is used in the model as recharge boundary condition (Figure 6)

Figure 6 River boundary condition of the study area

4. RESULT AND DISCUSSION

After completing the assigning of input parameters, run model is selected from the screen. By selecting run in the main menu, select run type dialogue box is appeared. Steady state and transient state run types are available in the model. First, the model is run for steady state condition. After that the model is run under transient condition. Then WHS solver is selected and this WHS solver works on a two-tier approach to a solution at one time step.

4.1 Model Output

MODFLOW output provides contours of head equipotential, head difference, drawdown, elevation, net recharge and water table. It also provides graphs of calculated vs. observed heads, calibration of residual histogram, head vs. time, normalized RMS vs. time, and drawdown vs. time. The model output also provides velocity vectors with direction of flow. By using the input and output screen the model is calibrated. The output of groundwater flow direction is presented in Figure 7.

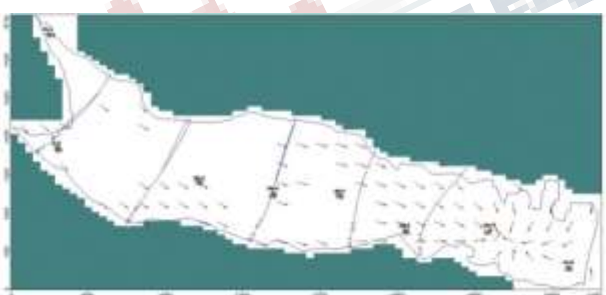

Figure 7 Flow direction of the study area

4.2 Model Calibration

Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criterion. Calibration is carried out by trial and error adjustment of parameters and model calibration requires that field conditions at a site be properly specified. Otherwise, model will not be a reliable representative of actual field conditions. After a number of trial runs, computed water levels are matched fairly reasonably with observed values. In the present study, during calibration, horizontal and vertical hydraulic conductivities and recharge values are adjusted in sequential model which runs to match the simulated heads and measured heads. Head Vs time graph is presented in Figure 8

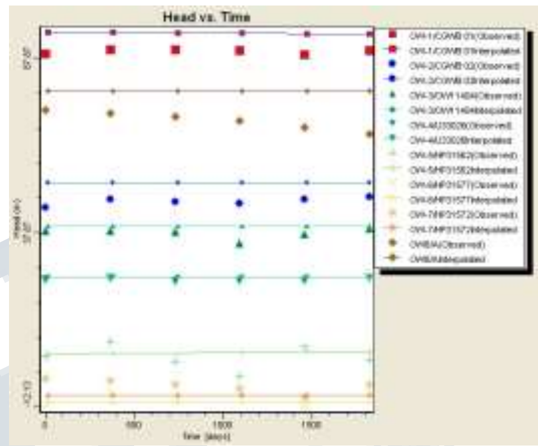

Figure 8 Head Vs Time graph of the study area

4.3 Transient State Calibration

The groundwater flow model has been constructed for computation of hydraulic head distribution. Hani et.al [4] revealed that the minor fluctuation is observed in groundwater level in the area, this indicates that hydraulic gradients do not change significantly with time. Thus groundwater flow is assumed to be under Transient state condition represented by groundwater condition from 2005 to 2014. For transient state simulation eight observation wells and pumping wells are included on the calculated versus observed heads graph for 365 days and 1460 days (Figure 9 and10). The groundwater head in the aquifer model is computed by Visual MODFLOW.

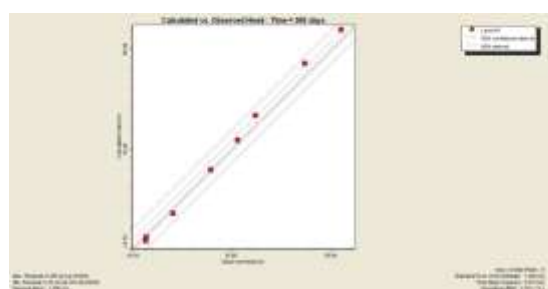

Figure 9 Comparison of Calculated and

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Observed Hydraulic Head for 365 days

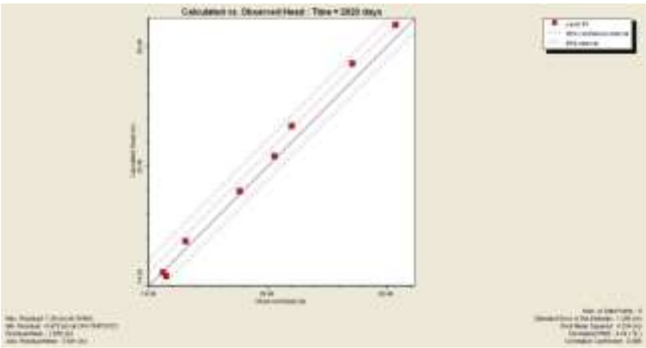

Figure 10 Comparison of Calculated and Observed Hydraulic Head for 1460 days

4.4 Model Validation

To validate the model, transient simulations of a groundwater observation well are performed and the predicted influences compared with collected data during the field visit. The validation period are calibrated from 2014 to 2016. It proves good match exists between observed and predicted head (Figure 11 and Figure 12).

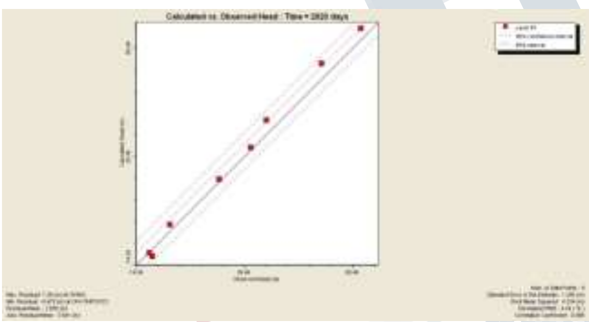

Figure 11 Comparison of Calculated and Observed Hydraulic Head for 2920 days

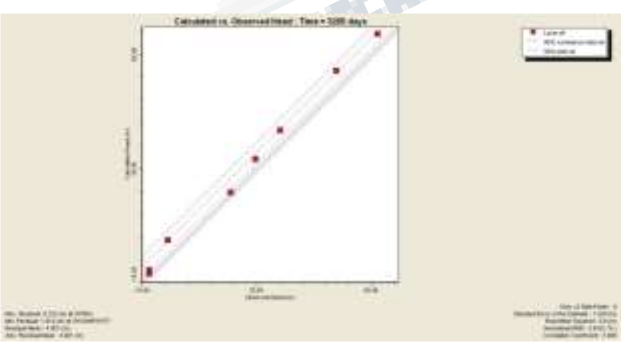

Figure 12 Comparison of Calculated and Observed Hydraulic Head for 3285 days

4.5 Model Prediction

The future scenarios, for the duration of 14 years from 2016 to 2030, are generated through groundwater model by either increasing or decreasing the discharge and recharge of wells in the watershed. In order to predict the groundwater in a study area in all the possible considerations of rainfall, discharge and recharge are applied to the groundwater model as summarized as three Scenarios

Scenario 1: Average rainfall and recharge remains same (Figure 13)

Scenario 2: Average rainfall reduced by 20%, pumping rate increased by 20%

Scenario 3: Average rainfall increased by 20 %, pumping rate decreased by 20%

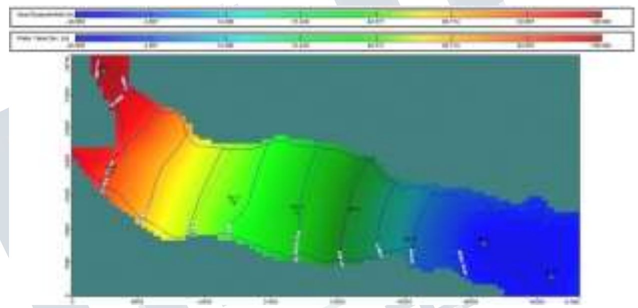

Figure 13 Water Table Elevation for 2030 (scenario-1)

In the first scenario the water table elevation varies from 10 to 12 m (bgl) which influence in villages like Tiruppanambakkam, Karaimedu, Agaram Kavanippakam, Anangur, Pillur, Tiruppachanur, Pedagam and Perangiyur. Then the second scenario impacted the Water table elevation varies from 8 to 10m (bgl), it showed the increasing water level in villages like Ullerippattu, Pakkam ,Tiruppanambakkam, Karaimedu, Kavanippakam, Anangur,Pillur, Tiruppachanur, Pedagam and Perangiyur. Finally third scenario impacted the Water table elevation varies from 10 to 14m (bgl), it showed the decreasing water level in villages like Kavanippakam, Anangur, Pillur,Tiruppachanur, Ullerippattu, Pakkam , Tiruppanambakkam and Iruvelppattu.

5. CONCLUSIONS

Groundwater model has become a commonly used tool for hydrogeologists to perform various tasks. From the above discussion Visual MODFLOW software is suitable in this study to simulate and predict the aquifer conditions. Also represents the natural groundwater flow in the environment and forecast the outcome of future groundwater behaviour. Groundwater flow directions of the study area are simulated using visual MODFLOW version 4.2. The aquifer characteristics, water level data for the observation wells are used as model input. The model is run to simulate water level from 2005 to 2014 and validated with observed value. The validated model was again run to predict water level in 2030. The variation of predicted water level with respect to time is almost same with that of variation of water level in the field. The study suggests that from the prediction the recharge rate must be improved in the villages like Tiruppanambakkam, Karaimedu, Agaram, Kavanippakam, Anangur, Pillur, Tiruppachanur, Pedagam and Perangiyur which are located nearer to the river course. Recommended measures are Check dams, Contour bunds, etc must be constructed along the river course. This would be possible only if the computed flow components are in close agreement with the actual flows hence it can be concluded that the water level is high in central western part and declining towards the south Ponnaiyar River. Ponnaiyar River acts as drainage during 2005 - 2014, the velocity increases as the flow moves towards the river. The velocity of flow is high in the Eastern part of the basin and also in the Northwest and Southwest part indicating recharging in these areas may lead to groundwater movement towards the river and canals.

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