International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VI, June 2019- Available at www.ijraset.com

Analysis of Ground Water Head for Steady and Transient Conditions and Optimization of Pumping Rates using Visual MODFLOW 4.1

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Abstract: Groundwater is one of the most valuable natural resources and it has become dependable source of water for agriculture, domestic purpose and industries. Numerical models are very useful as a management tool for groundwater. In this study Visual MODFLOW 4.1 is used for preparing simulation model of Padra taluka, Vadodara District, Gujarat, India. The model is prepared by considering three wells located at Chitral, Masor and Ghayaj. The calibration of model is done for both steady state(2011 pre monsoon) and transient state condition(12 stress periods). The calibration of the model is further checked by considering 10 different scenarios, this scenarios includes 10% to 50% increase and decrease in pumping rates. Results of all theses scenarios are within the allowable range of performance indices i.e. Standarad Error of Estimate (S.E.E.), Root Mean Squared Error (RMSE) and Correlation Coefficient. Sensitivity analysis is also carried out for two parameters of the model hydraulic conductivity and recharge. Results of sensitivity analysis shows that hydraulic conductivity is more sensitive to the change in parameter value. Well optimization is done using MODFLOW 96 for the fixed range of 300 to 5000 m3/day for steady state condition using Genetic Algorithm.
Keywords: Ground water model, Visual MODFLOW, calibration, Sensitivity Analysis, Well optimization.

I. INTRODUCTION

Groundwater has become a dependable source of water in all the regions of the world. Even in those areas where surface water is abundant, the groundwater is used as practical source of water for public supply, agriculture and industry due to its quality, easy accessibility, reliability and relatively low cost associated with its use.

The Numerical groundwater modeling is a tool that can help in studying groundwater problems and helps us in understanding of groundwater systems. Models have been applied to investigate a wide variety of hydrogeologic conditions. Recently, groundwater models are being applied to predict the transport of contaminants for risk evaluation. Groundwater model is a simplified version of a groundwater system that approximately simulates the real-world situation.

II. NEED OF THE STUDY

In India, More than 60% of irrigated agriculture and 85% of drinking water supplies are dependent on groundwater. India has 16% of the world's population but there is only 4% of total available fresh water. Due to rapid increase in population an increased amount of groundwater is being withdrawn for fulfilling the demand. Due to rapid industrialization and disposal of their wastes in water resources the quality of groundwater degrades. For, taking care of quantity and quality of groundwater management of groundwater is must. Numerical models are useful for the management of groundwater.

III. OBJECTIVES

A. The Objectives of Study are

1) To prepare a groundwater flow model using Visual MODFLOW
2) To simulate the interaction between surface water sources and sub surface water sources.
3) To check the sensitivity of model parameters.
4) Optimize the pumping rate of the pumping wells in study area using Genetic Algorithm (GA).

IV. LITERATURE REVIE

A. L. Surinaidu (2015)
Worked on groundwater seepage problems in the subsurface tunnels using MODFLOW for a 2.483 km long railway tunnel constructed between Katara and Udhampur in Jammu and Kashmir.

B. Lasya C.R. and M. Inayathulla(April 2014)
Measured the input and output stresses on the aquifer framework for a time of 720days for Jakkur catchment of Banglore city.

C. Nassim(2013)
Done the water budget prediction from the year 2005 to 2015 in Alluvial Aquifer in Evan sub basin(Iran).

D. W. M. Z. W. Ismail (2012)
He identified an optimum pumping rate that would safely achieve the desired drawdown of less than 2m in an area of 300m radius surrounding the Pintu Geng horizontal collector well.

E. Song Yanxun(2011)
Analyzed 8 mining schemes on the basis of simulation prediction using Visual MODFLOW in Balasu water source.

F. B. R. Lamsoge(2009)
He evaluated a groundwater system, its current scenario, prediction of future ground water stress in an over exploited WR-2 watershed in Warudtaluka ,Amravati district , Maharashtra.

V. STUDY AREA AND DATA COLLECTION
The study area selected for this study is Padra Taluka of Vadodara district, Gujarat, India. It is located about 16 kilometers from Vadodara city. Padra is located at 22.23°N 73.08°E and it has an average elevation of 79 meters. There are about 83 villages in Padra block.

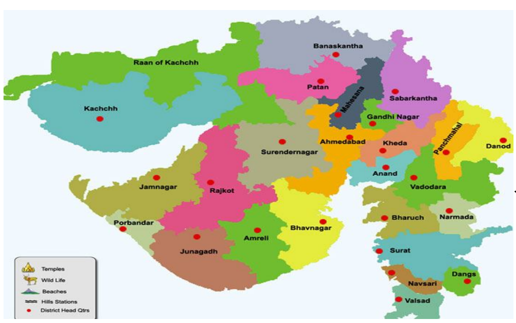

Fig.1 Map of Gujarat State

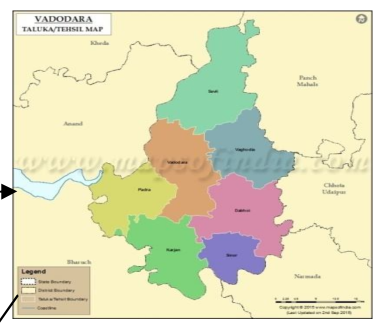

Fig.2 Map of vadodara District

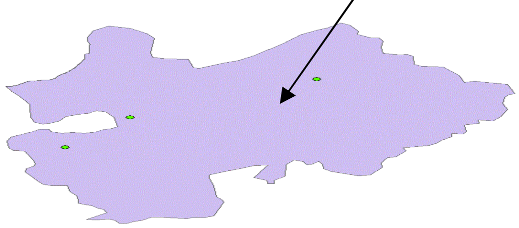

Fig.3 Map of Padra

In this study, pumping rate data, static water level data, rainfall data, hydraulic conductivity data and storage data are used. Rainfall data used in this study is taken from Indian Meteorological Department website. Pumping rate data for all the three wells are collected from the field. The static water level data for the wells are collected from the Water Resources Information System (WRIS) web site.

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VI. METHODOLOGY

The first step in the data preparation is determining the boundaries of the region, the boundaries may be no flow, recharge, river, constant head etc. The second step in this process is to discretize the region(subdividing it into number of grids). The third step involved is to feed the input data including aquifer properties for each grid block such as storage co-efficient, specific yield, hydraulic conductivity . Output of this process generally consists of hydraulic head at each grid of the grid blocks throughout the aquifer at the required time interval covering the period of interest.

After successfully creating new model, input module will display the grids, in this study number of grid cells are 900. Three pumping wells and observation wells are considered at Chitral, Masor and Ghayaj. Input data such as pumping rate , water level data , hydraulic conductivity , storage , boundary conditions etc. are given to all the grid cells in Input module. After input of all the required data the model is run for the calibration.

A. Model Calibration

In the process of calibration, certain parameters of the model are altered in a systematic way and the model is repeatedly run until the computed value matches with field-observed values within an acceptable level of accuracy. Model is calibrated for two conditions steady state and transient state. First of all steady state calibration was carried out. The values of hydraulic conductivity obtained after steady state calibration is used in transient state calibration. The model performance was evaluated by using performance Indices i.e. Standard Error of Estimate, Root Mean Squared Error and Correlation Coefficient.

VII. RESULTS AND CONCLUSIONS

A. Steady state calibration

The steady state calibration was made using the pumping rate of the three pumping wells and head values of observation wells for year 2011(pre monsoon). Hydraulic conductivity values were used as initial values for the steady state calibration. By trial and error method values of hydraulic conductivity were altered and the model was run repeatedly until the match between observed and calculated water level values were obtained. After achieving desired correlation values of K was finalized to be 0.000388 m/day to 0.000207 m/day for layer 1 and 2 respectively. This values were used as an initial values for transient calibration. The steady state calibration gives Standard Error of Estimate as 1.338 m , RMSE as 2.334 m and Correlation Coefficient as 0.874.

B. Transient State Calibration

For transient state calibration the whole simulation time is divided into 12 stress periods and each stress period is divided into 10 time steps. The first stress period starts from 2011(pre monsoon) and the last stress period is 2016(post monsoon). The success of transient calibration mainly depends on the estimation of hydraulic conductivities and boundary conditions obtained from the steady state calibration. The results of Transient state calibration is shown in following table:-

Table I:- Results Of Transient State Calibration

Day	Standard error of the estimate (m)	RMSE (m)	Correlation coefficient
120	1.375	2.539	0.814
360	1.417	2.606	0.892
480	2.337	4.717	0.905
720	1.353	3.563	0.922
840	1.367	6.59	0.702
1080	1.731	3.099	0.902
1200	1.379	4.094	0.924
1440	1.863	3.585	0.832
1560	1.904	3.166	0.62
1800	1.91	4.316	0.889
1920	3.933	6.844	0.844

Results of transient calibration shows that the value of all three performance Indices are within allowable range. The results of all the scenarios are shown in following table.

Table II: Results Of The Scenarioes

Scenario	Standard Error of Estimate (m)		Root Mean Squared Error (RMSE) (m)		Correlation Coefficient	
	Min.	Max.	Min.	Max.	Min.	Max.
1	1.336	3.931	2.350	6.617	0.605	0.916
2	1.334	3.929	2.336	6.645	0.589	0.908
3	1.325	2.321	2.389	6.617	0.559	0.892
4	1.331	3.926	2.400	6.700	0.561	0.893
5	1.329	3.924	2.417	6.728	0.548	0.886
6	1.340	3.925	2.318	6.562	0.637	0.936
7	1.343	3.937	2.303	6.535	0.659	0.948
8	1.345	3.939	2.288	6.507	0.637	0.960
9	1.347	3.941	2.274	6.480	0.691	0.971
10	1.349	3.943	2.259	6.450	0.711	0.980

C. Sensitivity Analysis

Sensitivity analysis for two model parameters, hydraulic conductivity and recharge is carried out by changing their value from 10% to 50% increase and 10% to 50% decrease. While considering hydraulic conductivity the value of RMSE ranges from 3.032 m to 3.478 m. It means that the RMSE value is differ by 0.694 m to 1.144 m, when it is compared with the value of RMSE obtained in steady state calibration, which is 2.338 m. For recharge parameter, the RMSE value for all the 10 scenarios remain same as 3.140 m, which means that the RMSE value is differ by 0.802 m, when it compared with the value of RMSE obtained in steady state calibration, which is 2.338 m.

D. Well Optimization

Well optimization is also carried out using MODFLOW 96 for the steady state condition, after achieving successful steady state calibration. By using the method of Genetic Algorithm(GA) the optimized value of the pumping wells are found out to be 1446 m^3/day, 1455 m^3/day and 2099 m^3/day which are the ideal values of pumping rates for well1, well 2 and well 3 respectively.

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