Simulation of Groundwater Levels in Malaprabha Command Area using Visual MODFLOW FLEX

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Abstract - ***Two layered conceptual model covering an area of 705 km² was prepared using Visual MODFLOW FLEX version 2014.2 to represent the aquifers within Ramdurg, Saundatti (Belgaum district) and Nargund taluks (Gadag district) in the state of Karnataka where the first layer represented the soil layer and second layer was taken as a hard rock layer. Groundwater level data of eight wells available were used for the model simulation. Model domain was split into 120 rows and 120 columns, with each cell having size 472.11 m × 204.03 m. It was simulated for a time period from January 2008 to December 2014 in the transient state with the necessary boundary conditions such as river, reservoir and recharge. After translation and running the model once, it was calibrated by altering the values of sensitive parameters using PEST. Results indicated that the groundwater flow was taking place in two different directions in the study area and was in accordance with the topographical elevation. Dry cells were appearing in the simulated results. which prevented the calibration to be carried out effectively. Hydraulic conductivity, specific storage, specific yield of the first layer and hydraulic conductivity, specific storage of the second layer were sensitive to the model results. Continuous increase in the groundwater head was observed in second layer as the years progressed. Surface water from the Reservoir was contributing to the groundwater in the southern portion of the study area while it remain unaffected to the northern portion of the study area, respectively.***

Key Words: *Groundwater modeling, Malaprabha Command area, Visual MODFLOW FLEX.*

1. INTRODUCTION

Groundwater is a natural resource subjected to periodic replenishment due to rainfall and other hydrological processes. Recharge is the fundamental property which influences both flow and contaminant transport in a porous media. Therefore, modeling of recharge-potential of the region is an important aspect to understand the impact of natural stresses on groundwater systems. In order to model various kinds of stresses, it is necessary to have information such as the principal directions of horizontal hydraulic conductivity or transmissivity, storage coefficient, the variation of permeability and specific storage of the confining layers and the hydraulic connection between the aquifers and surface water bodies. Hydraulic energy, as indicated by water table or potentiometric surface maps the amount of natural recharge. It is a fact that the groundwater information availability is quite limited, therefore there are number of constraints in groundwater assessment. In-spite of the known limitations of the models, the present study aims to understand the groundwater flow in a typical hard rock terrain which is bounded by a river and reservoir in the upstream. For these systems, MODFLOW is one of the best solutions as reported by number of researchers [1, 2, 3]. Varalakshmi, Venkateswara, Suri, and Tejaswini (2014) modeled the groundwater flow in Himayathsagar and Osmansagar catchments in order to predict the impact of pumping on the groundwater balance for the future years [1]. Pradeep and Anil (2014) developed a groundwater flow model to investigate the groundwater availability in Rajshahi City Corporation [2]. In the present study ground water model has been applied to replicate the regional ground water flow in an aquifer system subjected to changes in hydraulic head caused by changes in discharge or recharge. The study involves the modeling of aquifer system in parts of canal command area (Malaprabha) in Karnataka with the help of MODFLOW by adopting the finite difference method.

2. STUDY AREA

The study was confined to Ramdurg, Saundatti and Nargund taluks located in the state of Karnataka in India, covering around 279.46×10^6 m² of area in Ramdurg, 266.36×10^6 m² of area in Saundatti and 159.77×10^6 m² of area in Nargund. From the reports of Central Ground Water Board (CGWB, 2007), Ramdurg, Saundatti and

Nargund taluks had a yearly rainfall fluctuating between 221-836 mm, 224-894 mm and 181–1166 mm, respectively [4]. Malaprabha river, Renuka Sagar reservoir, Malaprabha left and right bank canals were the water retaining structures present in the study area. Reservoir was located in Saundatti on the upward side of the river which enclosed an area of 2564 × 10^6 m^2 [5] as indicated in Fig. 1. Renuka sagar dam was built in the area in order to make use of river water which was flowing through the two canals, with both of the canals being lined with cement concrete. Fig. 2 shows the DEM of the study area. Wheat, cotton, jowar, groundnut were few of the agricultural crops cultivated in the Malaprabha Command area. Canals existing in the command area were opened during the rabi season and the water was available for 3- 4 months that was utilized for agricultural requirements, [6] bathing, cleaning of clothes etc. Canals irrigated an area of 196132×10^4 m^2 located in the districts of Belgaum, Bagalkot, Gadag and Dharwad. Less precipitation and high temperature made the entire command area dry. As a result, residents were forced to take water from the dug wells and bore wells to meet their domestic requirements. Over exploitation of wells to satisfy human needs has caused the present conditions of scarcity for water. According to the present scenario, drilling of new bore wells or dug wells has been banned in the area.

The different soil types covering the area are Clayey, Clayey skeletal and loamy as shown in Fig. 3 with hydraulic conductivity obtained through field tests conducted by National Institute of Hydrology (NIH) which was varying from 5.55×10^{-7}- 1.11×10^{-6} m/s, 1.67×10^{-6}– 2.22×10^{-6} m/s and 3.33×10^{-6}– 5×10^{-6} m/s, respectively. Actinolite Schist, Amphibolite, Argillite, Quartzite, Conglomerate, Arenite, Shale, Dolomite, Banded Haematite Quatzite, Chert Breccia, Greywacke, Sericite, Phyllite, Pink and Grey Granite were the different rocks which existed in the area as displayed in Fig. 4.

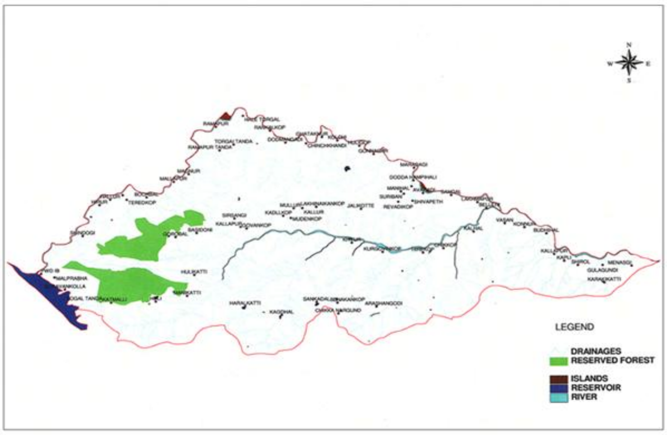

Fig -1: Boundary of the study area

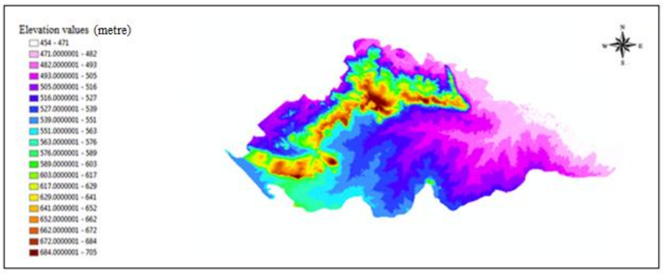

Fig -2: Elevations of the study area

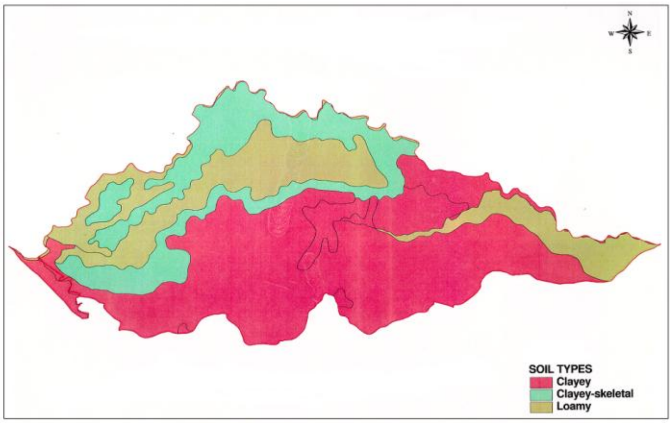

Fig -3: Soil types

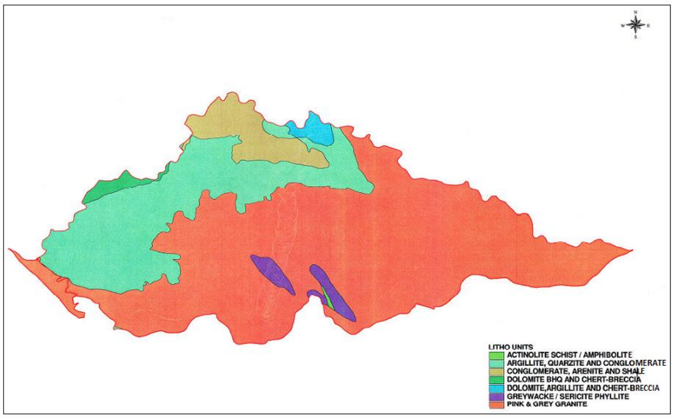

Fig -4: Rock types

3. SOFTWARES USED

Visual MODFLOW FLEX Version 2014.2 was used for modeling the groundwater flow. ArcGIS version 10.1 and Excel 2007 were employed to make the files.

4. METHODOLOGY

4.1 Conceptual model

A conceptual model was prepared by drawing the shape files of the boundary of the study area, river, reservoir, soil, lithology and importing it to MODFLOW. Soil layer and hard rock layer having 30 m and 40 m thickness were taken for the two layered conceptual model. Ground surface elevations was taken from Bhuvan store using Cartosat 1 with a resolution of 32 m. Seven dug wells and one bore well were included in the model as shown in Fig. 5. Initial static water levels of these wells from the Mines and Geology Department, Belgaum were assigned to the model using Excel files. Hydraulic conductivity (Kx, Kz), Specific storage (Ss), Specific yield (Sy), effective and total porosity of various soil and rock types were assigned to the model with their values indicated in Table 1.

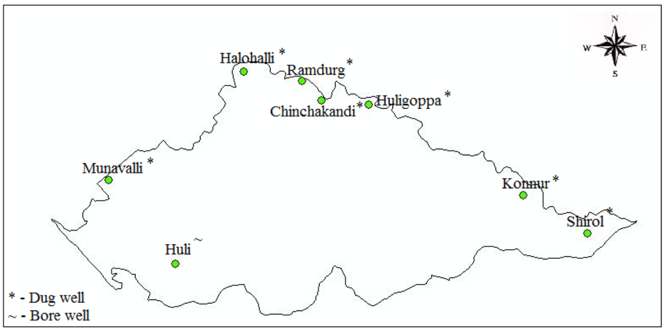

Fig -5: Locations of wells in the study area

Table -1: Input values to the model regarding soil and lithology

Layers		Kx (× 10^{-6} m/ s)	Kz (× 10^{-7} m/s)	Ss (1/ m)	Sy	Effective porosity	Total porosity
Soil	Clayey	1.11	1.11	0.012	0.032	0.151	0.445
	Clayey Skeletal	2.22	2.22	0.021	0.046	0.151	0.445
	Loamy	5	5	0.03	0.1	0..3	0.445
Lithology	Pink and grey granite	1.8055	1.8055	0.11	0.04	0.15	0.35
	Rest all types	1.8055	1.8055	0.09	0.032	0.15	0.35

4.2 Boundary Conditions

4.2.1 River

River marked the northern part of the model domain and was assigned using the river package. Input values assigned for the river is displayed in Table 2.

Table -2: Input parameters for river

Riverbed thickness (m)	River width (m)	Riverbed Conductivity (m/s)
5	50	1.11×10^{-6}

4.2.2 Reservoir

Reservoir was assigned using the constant head boundary package. Water level for the reservoir boundary condition at various time periods displayed in charts 1 to 7 was obtained from the State Irrigation department of Karnataka.

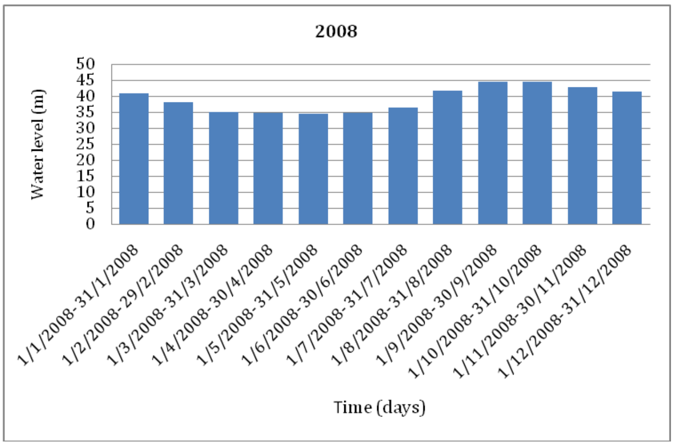

Chart -1: Water levels of reservoir for the year 2008

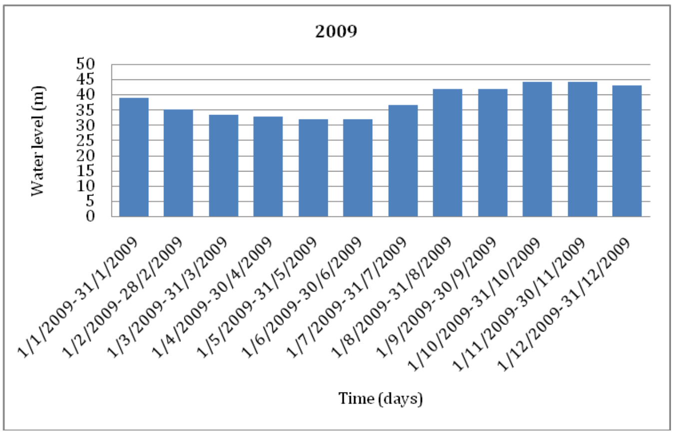

Chart -2: Water levels of reservoir for the year 2009

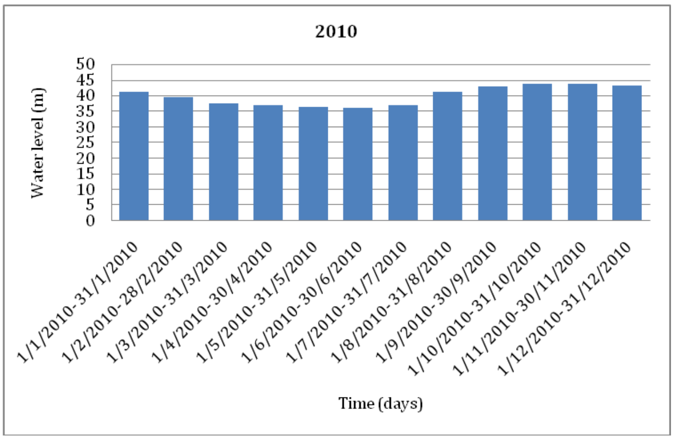

Chart -3: Water levels of reservoir for the year 2010

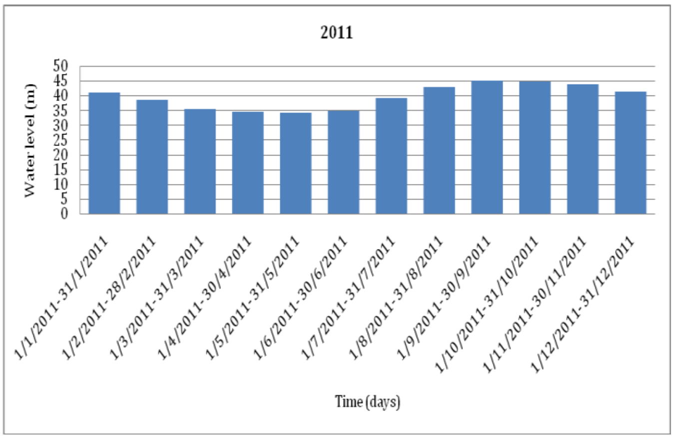

Chart -4: Water levels of reservoir for the year 2011

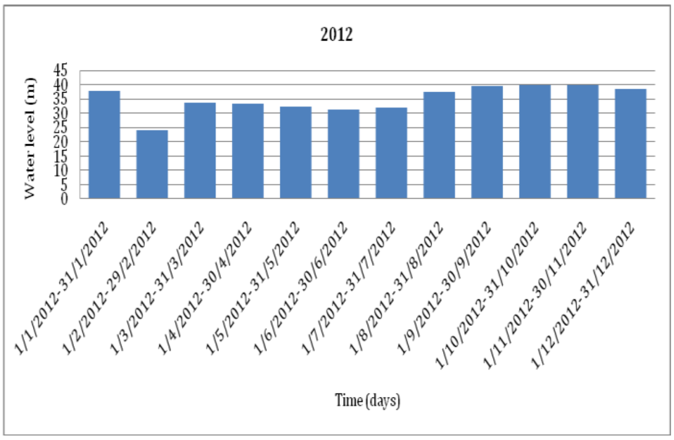

Chart -5: Water levels of reservoir for the year 2012

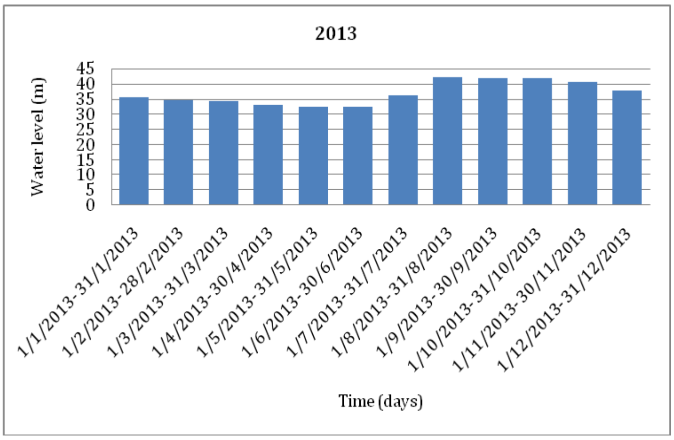

Chart -6: Water levels of reservoir for the year 2013

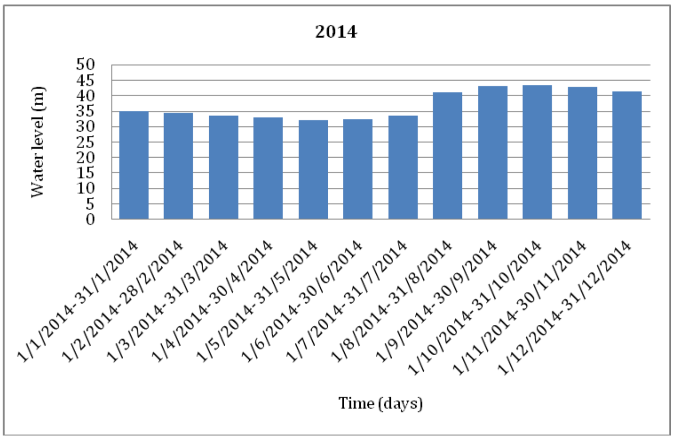

Chart -7: Water levels of reservoir for the year 2014

4.2.3 Recharge

Taluk wise rainfall data was obtained from Statistical Departments in Belgaum and Gadag which was used for calculating the recharge.

R = Sy × A × W……………………………………………..…….(1)[1]
where,
R- recharge,
A - area
Sy – specific yield
W – Water table fluctuation.

Recharge values used in the model are exhibited in charts 8, 9 and 10 which was assigned using the recharge package.

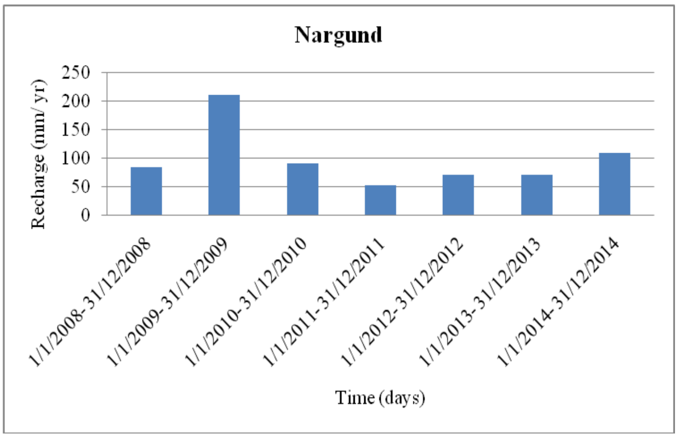

Chart -8: Recharge assigned for Nargund taluk

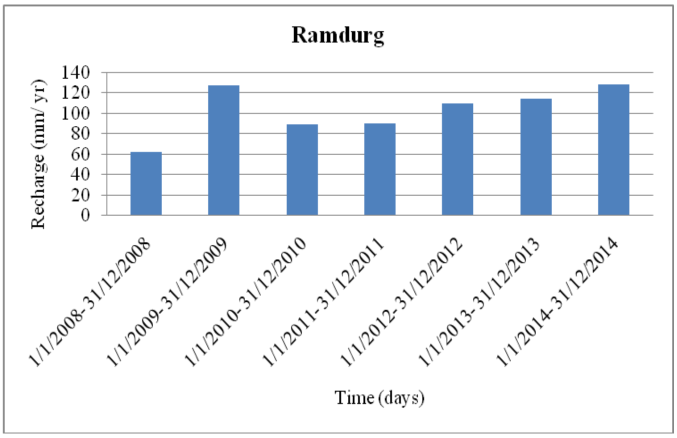

Chart -9: Recharge assigned for Ramdurg taluk

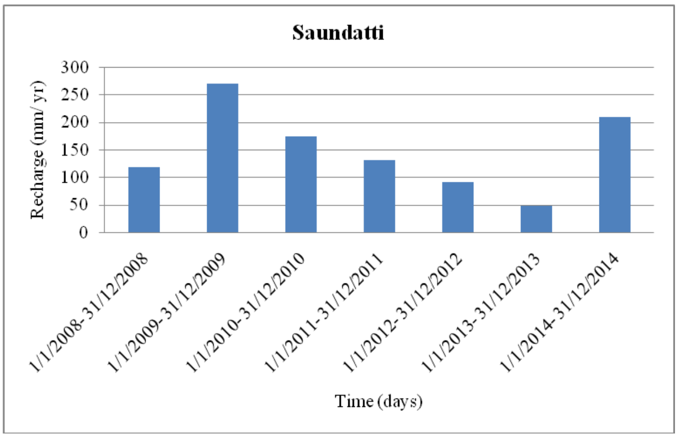

Chart -10: Recharge assigned for Saundatti taluk

4.3 Pumping

For the simulation time period from 1st January 2008 to 31st December 2014, 5 m^3/day was considered as the withdrawal rate for the bore well at Huli and was assigned using the pumping well package.

4.4 Run

Study area in the model was converted into small cells by dividing them with 120 rows and columns each and as a result, size of each cell was 472.106 m×204.028 m respectively. Conceptual model was transformed to a numerical model and thereafter the head values of 8 observation wells for the simulated time period were assigned to the model using excel files. MODFLOW 2005 was chosen as the engine to run the model in transient state for the time period from 1st January 2008 to 31st December 2014. Model contained 84 stress periods in which each month was selected as a stress period. Each stress period was further divided into 10 time steps since the simulated head values for last day of the month was to be exhibited as model results, to be compared with the field data respectively.

4.5 Calibration

Parameter estimation (PEST) which is built in software in visual MODFLOW FLEX was used for calibration by importing pilot points to the model domain with a defined range of Kx, Kz, Ss and Sy. Model was calibrated by running sensitivity analysis initially and finding out the parameters which had an impact on the simulated heads and the sensitive groups were further calibrated. Observed head values of 8 wells for the time period from 1st January 2008 to 31st December 2014 were used for calibrating the model.

5. RESULT AND DISCUSSIONS

The simulated ground water levels before calibration is shown in Fig. 6.

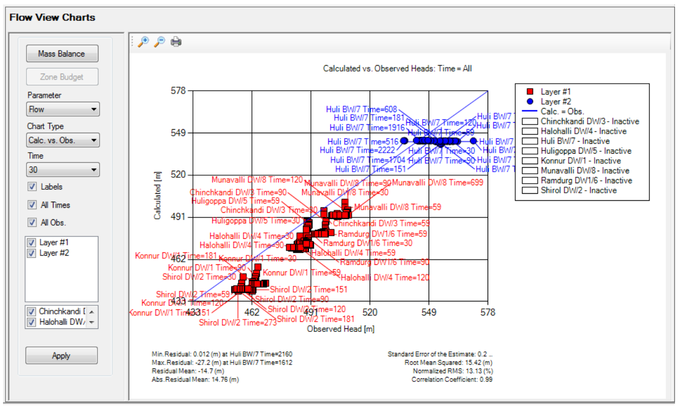

Fig -6: Model result before calibration

From the results displayed in Fig. 6, it is evident that the some of the wells were inactive during the simulation period that was similar to the existing conditions of the study area. The rainfall in the study area is low and large part of the area is covered by black soils with low conductivity and hydraulic properties. This clearly indicates that the groundwater availability is limited. In order to verify the accuracy of the results, model was calibrated by using field derived parameters. The sensitivity of the model was basically dependent on both physical and hydrological characteristics of the region. It was found that parameters like hydraulic conductivity, aquifer discharge and rainfall recharge were quite sensitive to the model. The sensitivity of the model parameters is shown in chart 11 where pg indicates the parameter group. Parameters which influenced the model results from sensitivity analysis are furnished in Table 3. The calibrated model parameters with corresponding RMS (root mean squared) values between the observed and simulated heads are shown in Fig. 7. Due to the presence of inactive cells in the simulated results, calibration was not executed efficiently by PEST as the residual mean got reduced by 1.2 m.

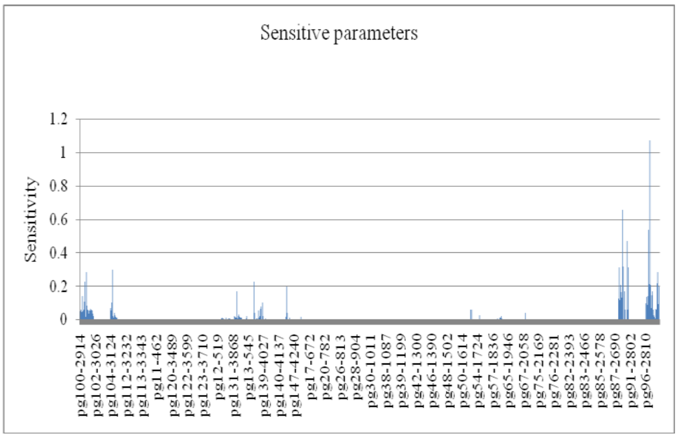

Chart -11: Parameters sensitive to model results

Table -3: Sensitive parameters

	Clayey soil	Clayey skeletal	Loamy	Hard rock
Parameters	Kx, Kz, Ss, Sy	Kx, Kz, Ss, Sy	Kx, Kz, Ss, Sy	Kx, Ss

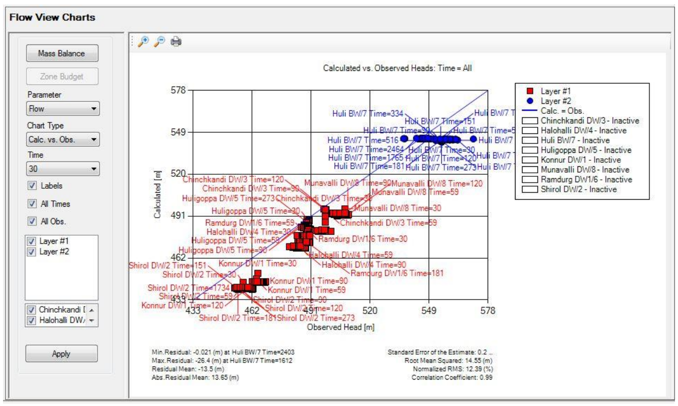

Fig -7: Model result after calibration

The groundwater levels were simulated for the years from January 2008 to December 2014. Simulated groundwater levels during 2008 and 2014 for layer 1 are presented in Fig. 8 and Fig. 9, respectively. The results clearly demonstrated that the groundwater levels in some portion of the study area depend more on the reservoir water levels as compared with rainfall and discharge characteristics. As the reservoir level declines, there is a gradual decline in the groundwater levels, all through the study area. However, there is no significant effect of reservoir water levels on the northern part of the study area which is attributed to the presence of hydraulic barrier (hillocks).

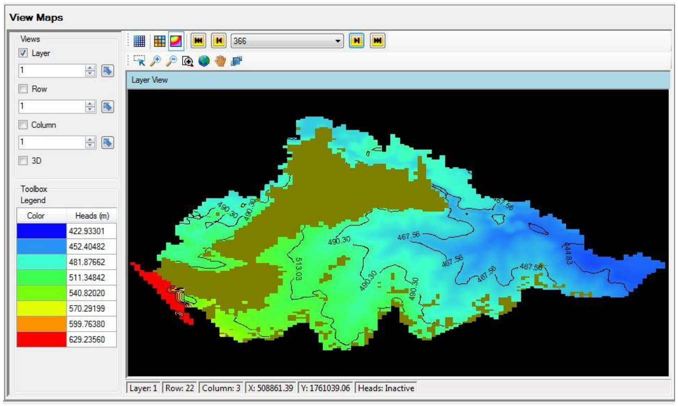

Fig -8: Model result for December 2008 of layer 1

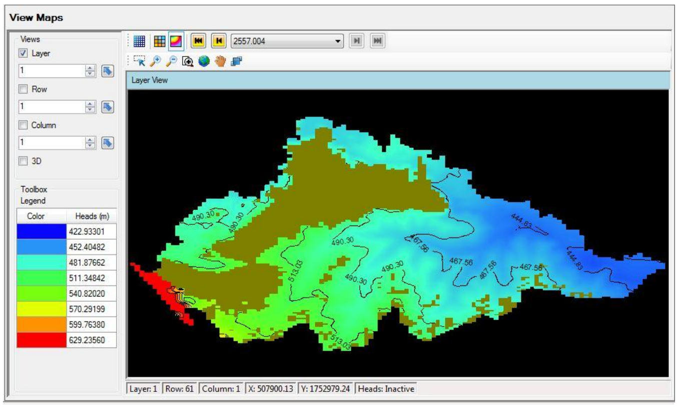

Fig -9: Model result for December 2014 of layer 1

Impact of reservoir water levels on the groundwater of the study area is depicted in Fig. 10 and Fig. 11. Simulated groundwater head at bore well indicated a decline of about 26.4 m from the observed groundwater head due to the change in water levels of the reservoir.

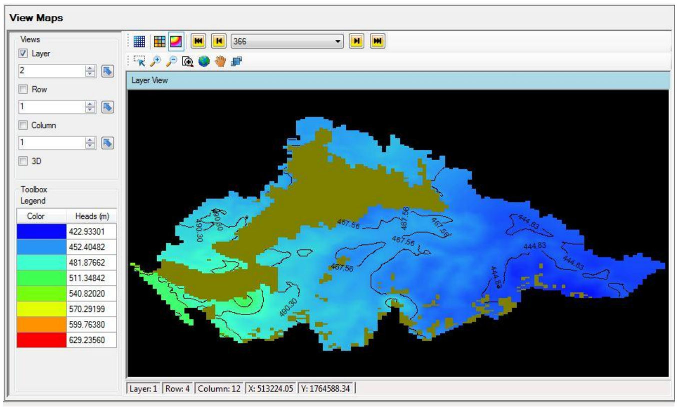

Fig -10: Model result for December 2008 of layer 2

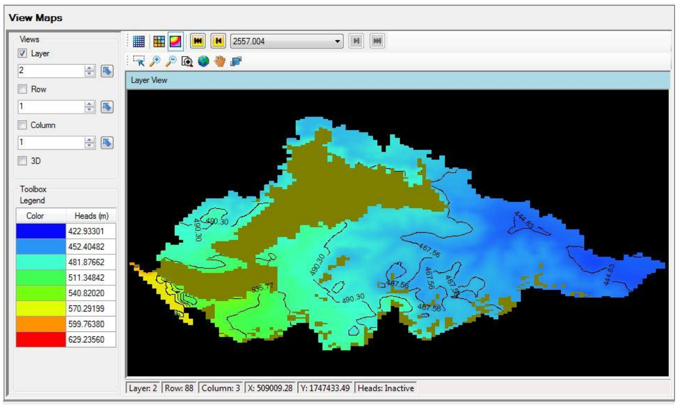

Fig -11: Model result for December 2014 of layer 2

The study also indicated that the groundwater flow in the region was dependent on reservoir storage and rainfall recharge. It was noted that the flows were governed by hydraulic and topographical barriers. Further, it was evident that the river flow does not show any significant influence on the groundwater levels. According to the simulated results, mountains present in the study area were having dry cells due to the rainfall falling on the mountains flowing to the adjacent regions and getting collected there. Dry cells also existed in other parts of the model domain due to less recharge. Study area was having two different flow patterns, following the topographical elevation, on the sinistral and dextral portions of the mountains, moving from east to west and west to east respectively. In the first layer, head was getting reduced in some parts of Nargund taluk and it was getting elevated for the entire area in second layer in the following years which could be due to the second layer regarded as a pressurized confined aquifer.

6. CONCLUSIONS

From the analysis, the following conclusions can be drawn.

- According to sensitivity analysis, model results were influenced by hydraulic conductivity, specific storage, specific yield of the first layer and hydraulic conductivity, specific storage of the second layer.
- Groundwater flow exhibited two distinct flow patterns in which the mountains were acting as a barrier separating the flow patterns taking place in different directions.
- Groundwater head varied with the changes in reservoir water levels.
- Groundwater flow was taking place as per the topographical elevation.
- Groundwater head was rising in the second layer since it was taken as a confined aquifer.

ACKNOWLEDGEMENTS

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