Using MODFLOW and GIS to Assess the Changes to the Groundwater System due to Mining Activity

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Abstract **-In the present study surrounding villages of mining region of Korba district, India has been taken up for the study of changes to the groundwater system due to the mining activity. The coal fields cover an area of 530 sq km. The study area covers eight mines including underground and open cast namely Dipka, Gevra, Laxman, Balgi, Kusmunda, Surakachar, Korba, and Manikpur. The study aims to assess groundwater and analyse the subsurface flow pattern using Visual MODFLOW software. *The* data on topographical and hydrological data pertaining to the study area were collected from various government departments and organization of Chhattisgarh.**

The modelling has been done for 240 days (2012-2013). For the calibration, hydraulic conductivity, ground water head, specific yield, recharge are used as input parameters for the model calibration. The model performance has been evaluated by graph between observed head and calculated head, zone budget, mass balance, drawdown contour, depth to water table contour and ground water flow contour computed by the software for three layers.

Based on the results obtained for layer 1, it is seen that drawdown is more towards mining area and groundwater velocity is also high compared to layer 2 and layer 3.

***Keywords: Groundwater flow; Geographic information systems; Visual MODFLOW; Mining environment*.**

I. INTRODUCTION

Subsurface water is a pervasive and valuable resource. Subsurface water is an important component of water resource systems. Extracted from aquifers through pumping wells and supplied to the public for various uses. Activities and processes that occur at mining sites have the capacity to affect the quantity of groundwater surrounding the project area. Depending on the site's local hydrology, mining activities may affect groundwater quantity by lowering the water table elevation, which in turn may impact nearby lake levels and base flow in streams (Department of Natural Resources 2003). Open cast Mining operation conducted below ground water table often affect the drawdown of the water table over large areas which as a consequence, change the natural regional hydrological balance. Therefore natural hydro geological conditions are disturbed quantitatively. MODFLOW is a well-known example of a general finite difference groundwater flow model. It is one of the most widely used and tested software program developed by U.S. Geological Survey for simulating groundwater flow.(Xu et al., 2009) used MODFLOW 2000 coupled with GIS to simulate the groundwater dynamics. Coupling GIS technology with a process-based groundwater model may facilitate hydro geological and hydrologic system conceptualization and planning it is necessary to predict the changes to ground water system due to surface and underground mines. characterization, thus also a proper adaptation of the groundwater flow model to the area under study .

In recent years concern has arisen over the adverse effect of deep and surface mining on the environment with most of the concern being centered around degradation of surface water by coal mine drainage. Depletion of groundwater in areas where excessive withdrawals have emphasize the need for the analysis of flow conditions. For better management and

II. STUDY AREA

Korba district lies between Latitude 22^0 01′50″ to 23° 01′20″ N and longitude 82^{0}07′20″ to 83^0 07′50″E and its height from sea level 304.8m. Korba district boundary covers 7145.44 sq.km area. Korba district is located in East- central part of Chhattisgarh and is known as the power capital of State. The district comes under Mahanadi drainage system. The river Hasdeo (233 km)-a tributary of Mahanadi – enters and flow through the district. Its tributaries are Gagechorai, Tan and Ahiran. Base map of study area is prepared and shown in fig. 1. District falls under hot temperate zone. The average rainfall in the district is 1506.7mm and normal rainfall is 1287.6m. In terms of Geomorphology, the district displays structural plains and plateau, educational hills etc. In Geological terms, the district known for its coal mines, Ferruginous Sandstone with shale and coal seams from Kamthi formation, Gondwana Super group are exposed in Eastern part of district. Coal seams are the economic backbone of the district. The district is known for huge coal and bauxite reserves. Presently there are 14 numbers of mines including Open cast and Deep mines. Two of the largest open cast coal mines are located in the district.

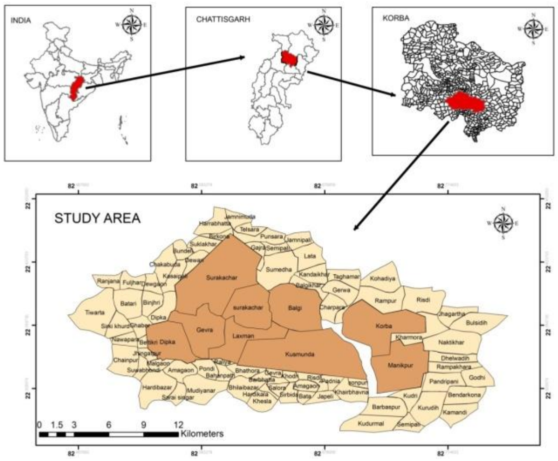

Fig.1.Location map of study area

III. DATA AND METHODS

SR NO	TYPES OF DATA	SOURCES
1	Hydrological data	Water Resources Department, Korba and CGWB ,Raipur
2	Topographical data and Soil data	GSI Raipur, State Data Centre Raipur and CGWB, Raipur
3	Well Data	CGWB, Raipur

In the study the thematic boundary maps were generated in form of shape files (.shp) and then exported to gif format (.gif) which is given as an input to create model in VISUAL MODFLOW. The scanned toposheets were first georeferenced and various thematic layers as required were delineated. Also the clip tool of Arc Info has been used to extract specific region of interest as required. Here in this case the Coal mining areas, village boundaries and well locations surrounding mining region has been extracted from district boundary map.

A. Component of Visual MODFLOW

The Visual MODFLOW is divided in three main sections such as input, run and output section. The input section of Visual MODFLOW is used to

1. Defining 3D finite difference grids,
2. Entering pumping well and observation well location and attributes,
3. Defining soil properties zone, and
4. Assigning boundary conditions locations and attributes.

Details of input sections are given point wise as follows.

1. Grid: The Grid frame contains options for the model dimensions and initial grid discretization. The initial grid will have uniform grid cell size throughout the entire model. For creating a new model, only one sitemap may be used to setup the model grid. There are 150 rows and 150 columns has been taken for the study area. The size of the one grid is 0.5 Km^2.

2. Pumping wells: For input the value of pumping well in the model, village wise draft calculation has been done for the study area. The new well window displays the relevant attributes of the pumping wells, including the well name; X and Y co-ordinates, screen intervals, pumping schedule, draft and the pumping well status (Active/Inactive).Twenty non of pumping wells are selected for study. The pumping schedule table has been used to enter the well pumping rates for specified time periods. Negative pumping rate values are used for extraction wells, each time period require as a valid start time, end time and pumping rates. The start time field is automatically generated to ensure that the time periods are continuous that means start time of one time periods is equal to the end time of the previous time period. Village wise draft data is shown in Table I.

3. Observation wells: The observation well data describes the relevant attributes of the observation well including the well name, X and Y co-ordinates, observation points and observation head. The well location can be viewed in either model co-ordinates or world co-ordinates. The observation table has been used to enter the observed values at specified times. Ten observation wells named as were considered for study area. These observation wells are spread all over the study area, so that the behavior of the entire region can be studied. The observation well data has given with an interval of thirty days. The details of observations wells data are shown in Table II.

4. Flow properties: A ground water flow model requires many different type data to simulate the hydrological process influencing the flow of ground water. The hydro-geological characteristics of the model are classified in to three properties such as conductivity (Kx, Ky, Kz), storage properties (Ss, Sy, Peff, Ptot) and initial heads.

The conductivity parameter value of the model includes Kx-hydraulic conductivity in the direction of model X axis (4 E-4 m/day) Ky- hydraulic conductivity in the direction of the model Y axis (4 E-4 m/day), and, Kz -hydraulic conductivity in the direction of the model Z axis (4 E-5 m/day).

Specific yield (Sy) is known as the storage term for an unconfined aquifer. It is defined as the volume of water that an unconfined aquifer releases from storage per unit area, per unit decline in the water table. Specific yield is generally equals to the porosity. Effective porosity (Peff) is the pore space through which flow occurs and is given as input. For input the initial head in the MODFLOW, clipboard has been used. In the worksheet, values of X and Y co-ordinates are taken from the map, which is imported in the Visual MODFLOW software. Value of the z-coordinate is the RL value of the water level in the observation well. Modeling has been done for 240 days.

5. Boundary condition: Every model requires an appropriate set of boundary conditions to represent the systems relationship with the surrounding systems. In case of a groundwater flow model, boundary conditions describe the exchange of flow between the model and the external system. The boundary conditions considered in this study are

(1) Wall (HFB),

(2) Recharge (RCH),

(3) River (RIV),

(4) Evapo-transpiration (EVT).

6. Wall (HFB) Boundary Condition: Visual MODFLOW supports the Horizontal Flow Barrier (HFB) Package included with MODFLOW. The Visual MODFLOW input data for HFB grid cells is stored in the project name. The Horizontal-Flow-Barrier (HFB) or Wall Boundary as it is referred to in Visual MODFLOW, was developed to simulate thin, vertical, low-permeability features that impede the horizontal flow of groundwater. The thickness of the wall 3 m and hydraulic conductivity 0.0000001 m/day is been considered.

7. Recharge (RCH) Boundary Condition: Most commonly, recharge occurs as a result of precipitation percolating into the groundwater system. This boundary condition is used to simulate a distributed recharge to the groundwater system. The Recharge has been calculated of each village for 120 days and 240 days separately. The recharge in ground water during simulation period is very low. The recharge rate is a parameter that is not often measured at a site, but rather, it is assumed to be a percentage of the precipitation. The recharge has been used for the both simulation period ranges from 2 to 35 mm /month.

Table I. Village wise draft for 120 days and 240days

WELL	WELL LOCATION X (m)	WELL LOCATION Y (m)	DRAFT FOR 120 DAYS (m3/day)	DRAFT FOR 240 DAYS (m3/day)
BHILAIBAZAR	91913656.89	2482658.98	2012.50	3035.00
MALGAON	9183839.165	2483978.56	656.07	989.41
SONPURI	9201232.251	2482501.32	724.50	1092.60
BALGIKHAR	9196559.203	2491291.10	796.95	1201.86
GAJRA	9192998.785	2494072.68	684.25	1074.25
RAMPAKHARA	9211675.513	2483692.61	603.75	910.50
DHELWADIH	92084654.35	2484504.05	668.15	1007.62
KOHADIYA	9204494.484	2491086.38	547.40	825.52
CHARPARA	9199130.158	2487952.87	780.85	1177.58
SIRKI	9181761.216	2487174.37	885.50	1035.40
HARDIBAZAR	9185099.108	2482056.27	2033.25	3217.10
AMGAON	9197338.044	2482167.53	672.17	1013.69
PANDRIPANI	9209724.515	2482417.65	664.12	1001.55
KUDURMAL	92043079.12	2478483.16	547.40	825.52
NAKTIKHAR	9210399.103	2485826.86	684.25	1031.90
GERWA	9199655.654	2490465.75	483.00	728.40
SHUKLAKHAR	9188882.052	2493627.62	503.13	758.76
JAMNIMUDA	9190884.787	2497076.78	663.85	1000.73
RANJANA	9179647.218	2490957.31	714.80	1079.30
LATA	9197115.518	2492848.78	724.50	1092.60

8. River (RIV) Boundary Condition: The River boundary condition is used to simulate the influence of a surface water body on the groundwater flow. Surface water bodies such as rivers, streams and lakes may either contribute water to the groundwater system, or act as groundwater discharge zones depending on the hydraulic gradient between the surface water body and the groundwater system. Monthly river data is assigned in the model. The thickness of the river bed 6.5m is considered and river bed conductance value assigned in the river package ranges from 25000 to 48000 m^2/ day.

9. Evapo-transpiration (EVT) Boundary Condition: The Evapo-transpiration simulates the effects of plant transpiration, direct evaporation, and seepage at the ground surface by removing water from the saturated groundwater regime. In this boundary condition the values are calculated for the monsoon and non-monsoon season separately. The mean evapotranspiration value assigned for the model varies from 3.26 to 7.7 mm/year. The extinction depth 2m has been considered.

B. Creating new model in Visual MODFLOW

A new Model is created in Visual MODFLOW. Steady state simulation has been considered for both the periods. The site map of the study area is digitized by the help of ARC GIS software. The digitized map was imported in the model domain window. Two geo-reference points are assigned after selecting the region of interest. The values of x, y coordinates of the model are given. The new model for the study area has been created in the Visual MODFLOW for further study. A steady state ground water flow model is developed and calibrated against ground water level. The model is developed to simulate the existing hydrological system and the processes that control the ground water flow. The ground water flow equation with the specification of flow and initial head conditions at the boundaries constitutes a mathematical representation of the aquifer system. After giving all inputs, model is made to run for steady state condition. The results obtained are

- Drawdown, Groundwater flow direction, and Water table depth maps.
- Calibration graph between calculated head and observed head, for both simulation periods.

IV. RESULTS AND DISCUSSIONS

1. Model simulation period
-120 Days (August to November 2012)
- 240 Days (December to March 2013)
2. Model Layer -
- 03 Layers (500m each)
3. Model Simulation type
-Steady state
4. Model Output
- Drawdown, velocity, flux and water table depth

A. Drawdown

For better understanding of maps two areas are selected, one situated near mining region and other far away from mining region of the study area .The output map is shown in fig 4 and 5.

1. It is observed that in 120 days simulation, the drawdown difference between the two considered areas is of 1.9m whereas for 240 days it is 1.5 m. From the basis of result in both the simulation period, the drawdown is observed to be higher near mining region due to high amount of daily water pumping activities from mines. The high drawdown difference in 120days (monsoon period) is because of more dewatering process from mines as compared to 240 days simulation.

2. The drawdown increases by 3.5m near mining location and 3.9 m far from mining location in 240 days simulation period as compared to 120 days simulation. This increase in drawdown value in second simulation is due to less recharge percentage, daily pumping activity from well that result in change in high hydraulic head.

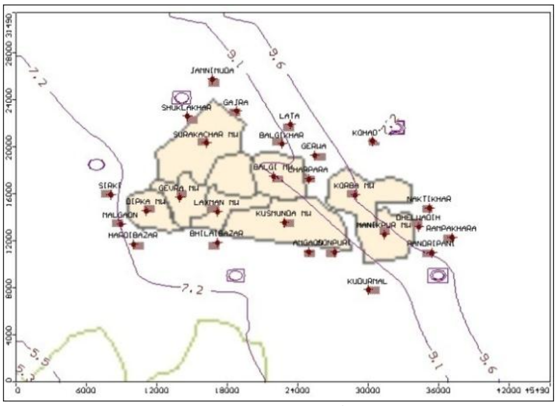

Fig. 4. Drawdown output for 120 days

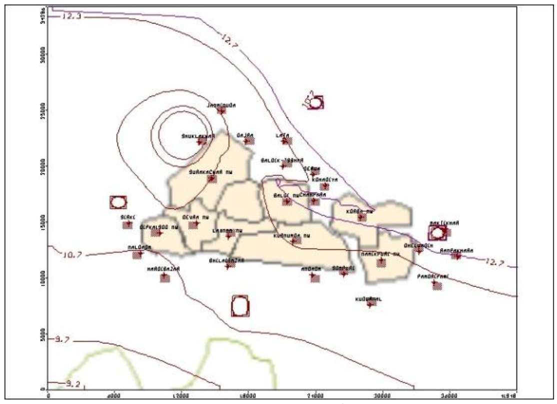

Fig. 5. Drawdown output for 240 days

B. Water table depth

The depth from the top of Layer 1 (i.e. ground surface) to the calculated water table elevation is known as water table depth. It depends on constant head, recharge and evapotranspiration. The water depth is observed only in first layer because of influence of Constant Head. The output map is shown in fig 6 and 7.

1. The water table depth near mining area is 1.1 to 1.4 m below the river bottom bed level in 120 days and it increases to 7.1 m in 240 days.The increase in depth is due to continuous outflow from constant head, daily dewatering activities, less recharge, high plant usage (transpiration rate) and high evaporation rate .

2. This high change in hydraulic head results in decline in water table depth followed by high drawdown in nonmonsoon period i.e. in 240 days simulation.

3. The water table depth value observed is higher near mining region and vice versa for both simulation periods.

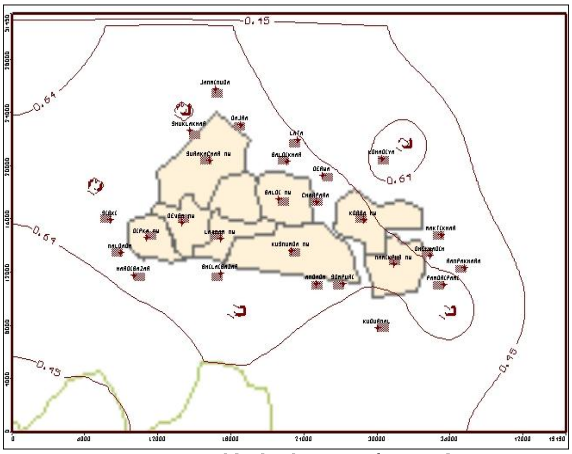

Fig. 6. Water table depth output for 120 days

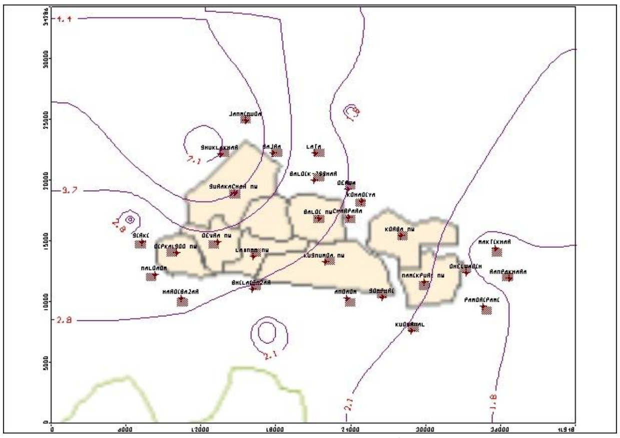

Fig.7. Water table depth output for 240 days

C. Velocity

The magnitude and direction for both the simulation period shows same trend of fluctuation. The higher magnitude is observed in layer 1 and 2 due to the presence of constant head and pumping wells. Whereas low magnitude is observed in layer 3 because of contribution of pumping wells only.

Magnitude-The magnitude of ground water velocity observed is higher in 240 days simulation for all the layers in comparison to 1st simulation period. This increase in magnitude is due to only daily discharge from pumping wells, as velocity changes with respect to discharge .In 120 days simulation because of high precipitation and low evapo-transpiration rate, daily pumping do not affect the magnitude to a higher extent but due to less recharge followed by high evapotranspiration and daily pumping, magnitude increases to nearly 1.2 times more in 240 days simulation.

Directions in Layer1- The flow direction of ground water from surrounding areas are towards mining region. Due to high rate of dewatering from the mines, the ground water moves from surrounding constant heads towards mine areas for both simulation period. Flow direction is shown in fig 8 and 9. Direction in layer 2 and 3- The flow direction of groundwater is also towards mines because of influence of mining pumping activities only for both simulation periodFlow directions are shown in fig 10, 11, 12 and 13.

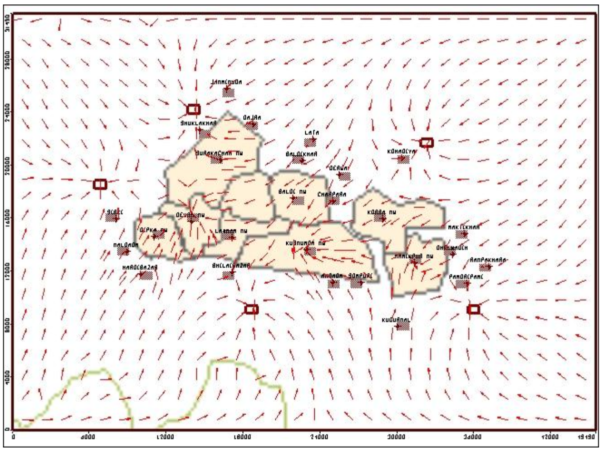

Fig. 8. Velocity output of layer 1 for 120 days

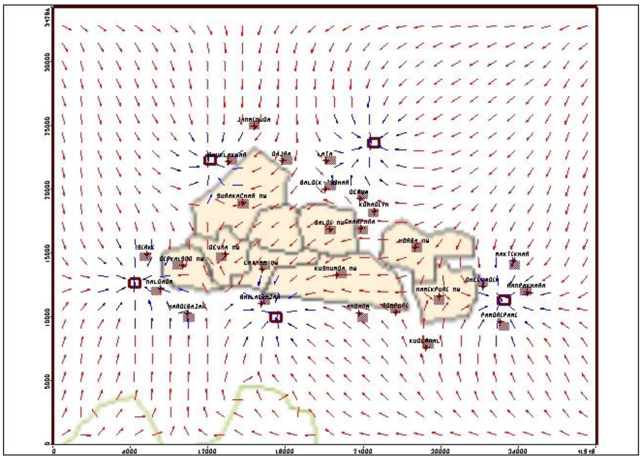

Fig. 9. Velocity output of layer 1 for 240 days

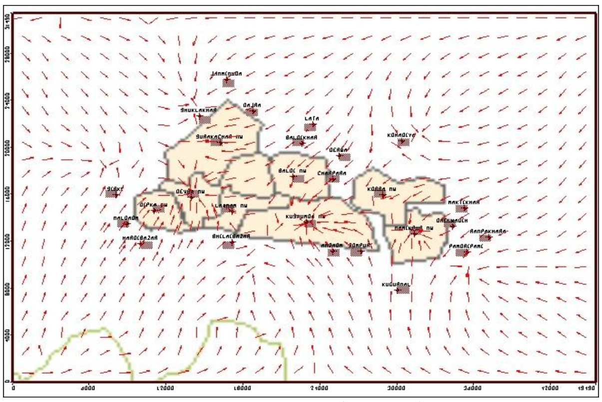

Fig. 10. Velocity output of layer 2 for 120 days

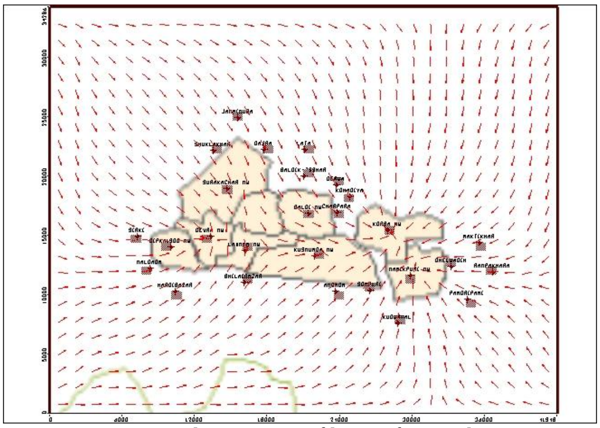
Fig. 11. Velocity output of layer 2 for 240 days

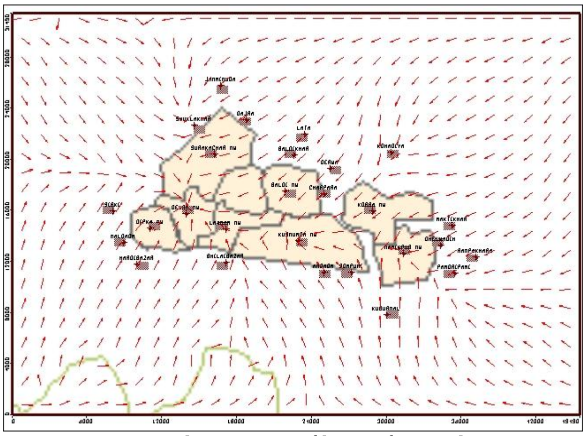
Fig .12. Velocity output of layer 3 for 120 days

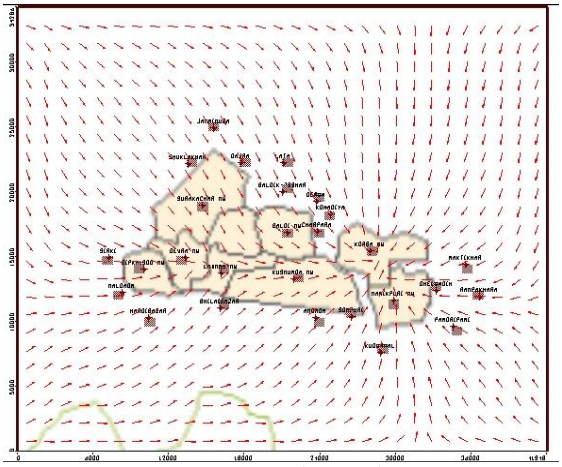
Fig. 13. Velocity output of layer 3 for 240 days

D. Graph Between Observed And Computed Head

Fig. 14 shows the graph between observed head and simulated head (computed head) for the monsoon period. More recharge occurs during this period. Due to the fluctuation in recharge in these periods, there are more difference between the observed head and simulated head.

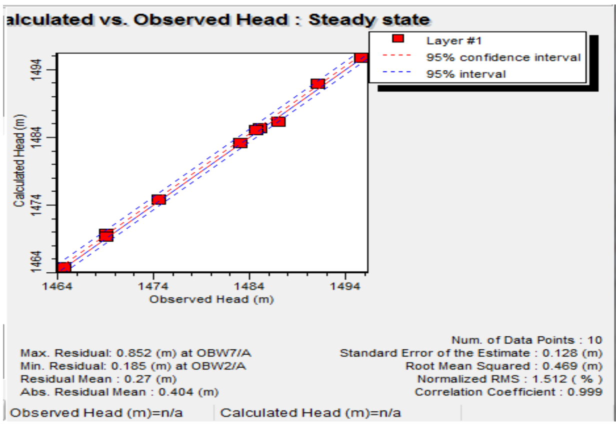

Fig. 14. Output graph of calculated head vs Observed Head 120 days Simulation

Fig.15 shows the graph between observed and simulated head (computed head) for non monsoon period. During this period, the recharge percentages are less, as compared to the first simulation period. Due to less fluctuation in recharge at this period, the difference between the observed head and computed head are less.

For the better results in the modeling, the difference between the observed and computed head should be least. The confidence interval confirms regarding the model. Nine observation well data has been used for the study and most of the data are in between upper and lower confidential limit i,e most of the data are acceptable for the model.

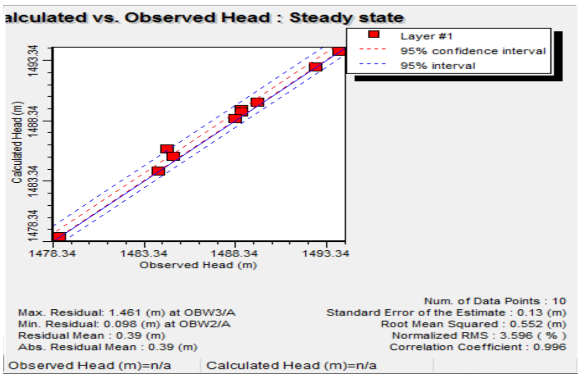

Fig. 15. Output graph of calculated head vs Observed Head for 240 days Simulation

V. CONCLUSIONS

- The result obtained for drawdown is higher near mining areas in both the simulation period and it shows higher drawdown towards North East of mining area.
- The flow direction of ground water is towards mining region due to high daily pumping operation.
- VISUAL MODFLOW is very helpful in analysing sub surface flow system.
- Based on the results obtained, it can be concluded that water table is lowering day by day that will result in less groundwater availability.

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