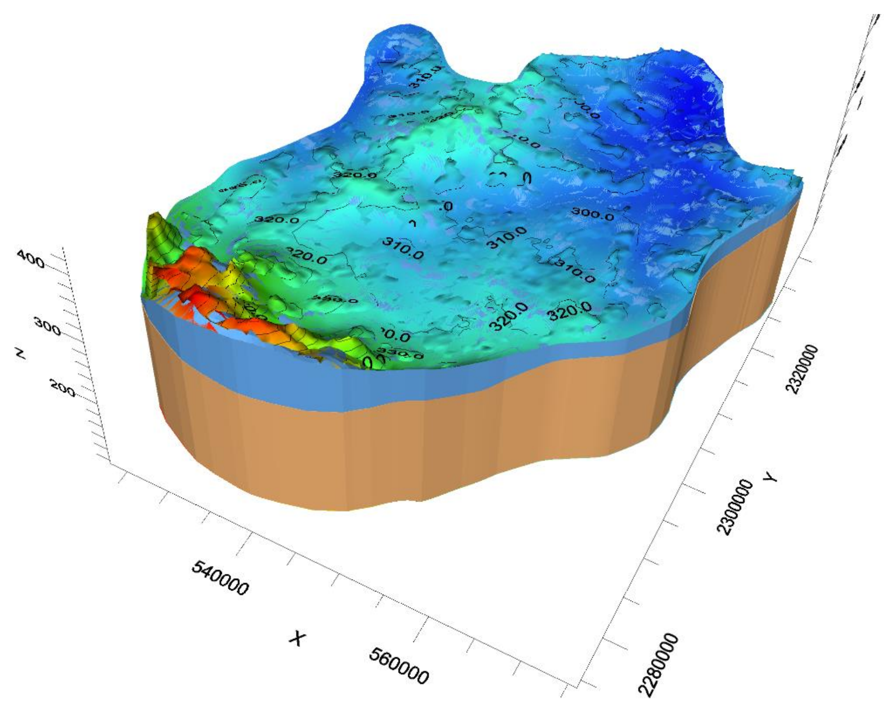
Report on

Ground Water Flow Simulation through numerical groundwater model for Upper Kharun Aquifer system, Chhattisgarh



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CONTENTS

1. INTRODUCTION

1.1 Background

The upper Kharun sub basin covering an area of 2200 km was taken up during the 4 weeks Tailor-made Training Program from 14th March 2018 to 6th April 2018 held at UNESCO, IHE, Delft, Netherlands under National Hydrology Project. The Aim of the training was to know principles and procedures of groundwater flow modelling and the use of computer models for groundwater resources management. The experiences of modelling will be obtained through a series of hands-on exercises in computer workshops and a real case study from India. The objective was to know how to create a groundwater model following the procedures of building a groundwater model: definition of model objectives, construction of hydrogeological conceptual models, design of numerical models, preparation of model inputs, model calibration and model application. During the training, the most popular groundwater model codes: MODFLOW, PMPATH, and a graphical user interface PM8 was used for hands on exercise. PM8 interface was used to apply groundwater models for analysis of groundwater flow systems and water budget; delineation of capture zone of well fields, and evaluation of groundwater development scenarios.

The upper Kharun area was taken up as case study during the training course. On the completion of the course, the area 10000 sq km area was taken up during the AAP 2018-19 and 2019-20 including 2200 sq km area of upper Kharun sub basin as a part of AAP 2018-19 for groundwater modelling to simulate groundwater flow and formulate development scenarios.

1.2 Study Area

The upper Kharun sub basin in parts of Balod, Durg, Dhamtari and Raipur districts located in the south-western part of Chhattisgarh Basin. The sub-basin covers parts of Balod, Durg, Dhamtari and Raipur districts. 8 nos of Blocks falling in the area namely Balod, Doundi, Gurur and Gunderdehi blocks of Balod district, Durg and Patan blocks of Durg district, Dhamtari and Kurud blocks of Dhamtari district and Abhanpur block of Raipur district. 5 nos of Block headquarters Balod, Gurur, Dhamtari Gunderdeli and Patan falling in the area.

The Upper Kharun sub-basin is bounded by East longitudes 81°13'& 81°44'and by North latitudes 20°34'& 21°10' falling in the Survey of India topo-sheets nos. 64G/8,12 & 64H/1,2,5,6,9,10. It covers an area of 2200 sq.km. In all, a total of 569 no. of villages are existing in the area.

Table-1 Block wise details of study area in

Sl.NO	**Blocks**	**District**	**Area sq km**
1	Abhanpur	RAIPUR	83
2	Dhamtari	DHAMTARI	251
3	Kurud	DHAMTARI	276
4	Patan	DURG	470
5	Gunderdehi	BALOD	389
6	Daundi	BALOD	7
7	Gurur	DHAMTARI	517
8	Balod	BALOD	207
		TOTAL	**2200**

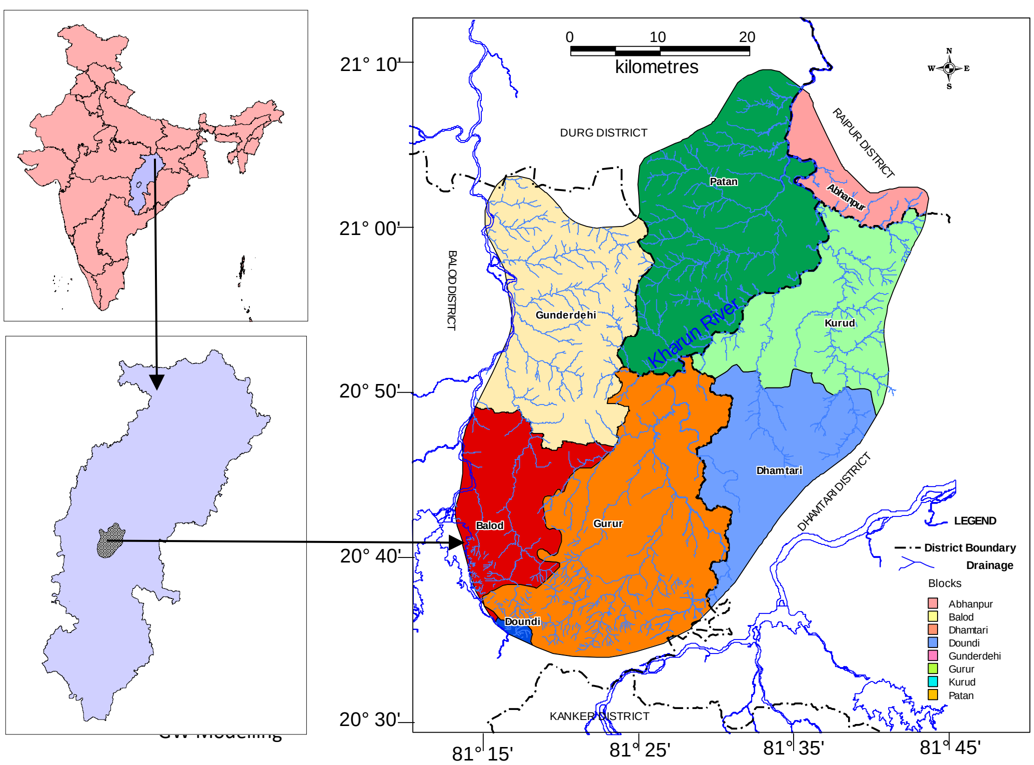


Fig-1 Location of Upper Kharun, Sub Basin, Chhattisgarh

1.3 Hydrometeorology

The are experiences sub-tropical climate and is characterized by extreme summer and winter seasons. The summer months are from March to May and the months of April and May are the hottest. The mean daily maximum temperature in summer season goes up to 46°C. The rainy season extends from the month of June to September with well distributed rainfall through southwest monsoon. Monsoon generally breaks in the third week of June and is maximum in the months of July and August and is generally pleasant. Winter season is marked by dry and cold weather with intermittent showers during the months of December and January. January is the coldest month with mean daily maximum temperature at 30°C and the minimum is around 10°C. The evaporation is maximum in the month of May and minimum during the months of December and January. The atmospheric humidity is usually low during summer months around 25%. However, humidity slowly starts building up from third week of May and it reaches maximum around 85% during monsoon period. The humidity again decreases in winter season and it varies between 30 to 40% during winter season. The wind flows easterly or westerly during the southwest monsoon period. During post-monsoon and winter seasons the wind directions are between north and east and sometimes westerly. The wind speed of more than 10 km/hr is recorded during the monsoon months (from June to September). In the post-monsoon and winter months (from October to February), the wind speed is less than 5 km/hr and in the summer months (March to May) the wind speed is more than 7 km/hr.

The area receives rainfall mainly from south-west monsoon. It sets in third/fourth week of June and continues till mid-August/September with heaviest showers in the months of July and August. The average annual rainfall for the district is around 1084 mm (2013-2018).

1.4 Land use, Agriculture & Irrigation:

Nearly 74% of the total area comes under Agricultural use and rest 26% area is Waste/Barren and forest land. Kharif is the main cropping season in the district where Paddy is the main crop, followed by wheat, maize and jawar. The paddy cropped area has an extent of 63% of the total cropped area in the area. Wheat is cultivated in 6% and others 31%. Irrigation by surface water covers almost 21% of the net irrigated area while 79% of the net irrigated area is irrigated by ground water.

1.5 Geomorphology and Soil

Geomorphologically the district displays Structural Plains, Pediment / Pediplain, Structuralhills & valleys, Denudational Slope which can be divided into two distinct physiographic units as Central plains belonging to Chhattisgarh basin area and Southern peripheral undulating terrain of low hills. The northern &eastern part of the district is represented by Structural Plain on Proterozoic rocks which cover major area. This unit is developed over rocks of Purana sedimentary basin of Chhattisgarh. This unit has extensive cris-crossed fractures and joints. They are having gently sloping erosional surfaces and thin to moderate cover of soil. Southern periphery is undulating terrain of low hills in the district represented by Pediment/Pediplain and StructuralHills & Valleys and Denudationalslope.The Pediment/Pediplain is developed in the south-western part of the district. They are also control by fractures and joints. They are having gently sloping smooth surface of erosional bed rock between hill and plain with veneer of detritus.The Structural Hills and valleys are developed in the southern part of the district. This unit is associated with folding and faulting. They are generally having a high relief steep sided linear to arcuate hill which shows definite trend lines covered with thin soil and forest. The Denudation slope is developed in the extreme southern part of the district. This unit is also control by fractures, joints and lineaments. They are formed due to differential erosion along the plains. The area has general slope towards North-east direction with average elevation of 283 m amsl. The highest elevation recorded in the area is 446 m (1463.25 ft) above mean sea level in the southern western part of the area in Gurur block and the lowest point is 275 m (902.23 ft) above mean sea level (in the south-eastern part of the district along Kharun river course in Patan block.

Three types of soils occur in the district viz. Alfisols, Vertisols and Ultisols.

Alfisols-There are also two types of Indian equivalent of this soil is found in Balod district namely Red loamy and Red sandy soil. They both covered the southern part of the district. **Vertisols**-There are two types of Indian equivalent of this soil is found in Balod district namely Medium black soil and Deep black soil. They are exposed in northern part of the district. **Ultisols**-The Indian equivalent of this soil found in Balod district is Lateritic soil. It is exposed in northern part in small patch. They are characterized by a humus-rich surface horizon and by a layer of clay that has migrated below the surface horizon.

1.6 Drainage

The area are mainly drained by Kharun River and Tandula River their tributaries are Aman ala Chorha nala and Devrani Jethani Nala and . These rivers are part of Mahanadi River basin.

2. GEOLOGY AND AQUIFER SYSTEM

2.1 Geology and Hydrogeology

Geologically, the area comprises of rocks of Archaean basement of Meso to Neo-Proterozoic ages. The oldest rocks belong to Archaean and mainly comprise the basement granite gneiss with meta-sedimentary and meta-igneous enclaves belonging to the Bengpal Group. The overlying Bailadila Group includes Banded Iron Formation, Shale and Phyllite belonging to Archaean-Lower Proterozoic age. It is unconfirmably overlain by the rocks of the Nandgaon Group belonging to the Paleo-Proterozoic age. The Meso to Neo-Proterozoic sequence is represented by the Chhattisgarh Supergroup, which comprises the Chandrapur and Raipur Groups. Chandrapur Group consists of sandstone, siltstone and conglomerate. Shale and siltstone occur as interbands within sandstone. Raipur Group comprises Charmuria Formation and Gunderdehi Formation.Charmuriya Formation mainly comprises grey bedded limestone with minor phosphatic clay bands. Gunderdehi Formation consists of purple to reddish brown calcareous shale. Laterite is dark brown to red in colour, pisolitic to massive and forms cappings on ferruginous sandstone of Deodongar member. Quaternary is represented by

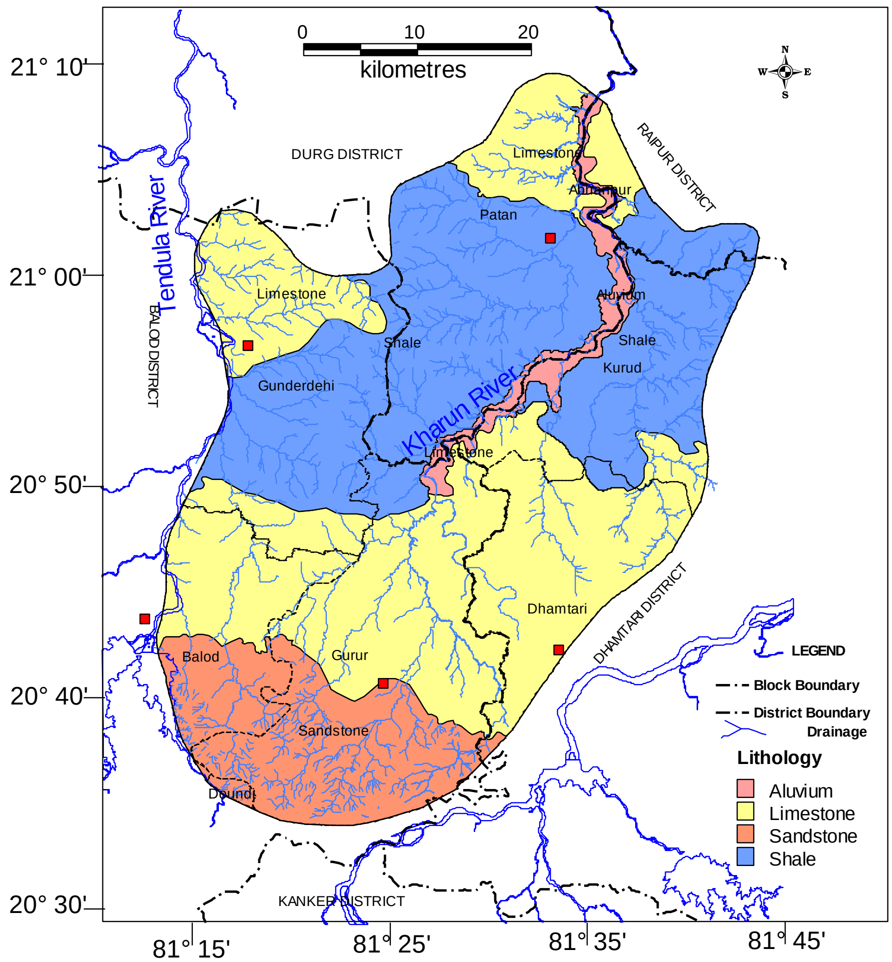


Fig-1 Principle Aquifer of Upper Kharun, Sub Basin, pebble beds, (Khamaria pebble bed). The Generalized geological successions in Balod district are given in Table 1.

Table 1 Generalized geological successions in Balod district

Lithology	**Stratigraphic status**			**Age**	**Nature and Characteristics**
Pebble bed	Khamaria Pebble bed			Quaternary	Epiclastic, extra formatic, polymictic gravel of fluviatile origin
Laterite				Cainozoic	Red, dark brown, pisolitic, massive, cavernous, hard, compact, ferrugenous
Purple caicareous shale	Gunderdehi formation	**Raipur Group**	**Chhattisgarh Supergroup**	Neo to Meso Proterozoic	Purple to white, fine grained,friable,calcareous with intercalations of stromatolitic limestone
Grey bedded/flaggy limestone	Charmuriya Formation				Dark grey, hard, compact flaggy/well bedded, calcareous rock, pyritiferous at places, with pockets of phosphatic clay
Sandstone with shale and siltstone, intercalations and conglomerate		**Chandrapur Group**			Grey to yellowish, medium grained, compact, glauconitic, pebbly at places (viz. conglomerate, arenite). Shale is fine grained, soft, with thin intercalations of siltstone

The depth of dugwells varies from 6 to 12 m. Deep and shallow tubewell fitted with handpumps varies from the depth of 50 to 150 m. The pre monsoon water level recorded in dugwells varies from minimum 2.24 m to Maximum 23.74 m with an average depth of 7.70 m below ground level. The post monsoon depth to water level in the area varies from 0.71 mbgl to 5.81 mbgl with average depth to water level in post monsoon in the area is 2.24 m.

2.2 Aquifer System:

There are three principle aquifer systems (Fig.2) in the area. 1) Shale aquifer. 2). Limestone/Dolomite Aquifer 3 Sandstone Aquifer.

Shale aquifer:

The Shale aquifer covers an area of 819 sq km in parts of Kurud, Gunderdehi Patan and Abhanpur Block. The purple shale is generally calcareous, highly friable in character and is associated with impersistent limestone bands. Locally intra-formational conglomerate lenses are present in the upper part. Besides, lenses and pockets of stromatolitic limestone appearing towards top, indicate a gradational contact with the overlying formation. It is reported that at subsurface Gunderdehi purple shale grades to black shale. yield varies from less than 1 to 3 lps, Transmissivity varies betwe en 1 to 45 m^2/day.

Limestone Aquifer:

Charmuriya Formation mainly comprises grey bedded limestone with minor phosphatic clay bands. The Charmuriya limestones with intercalated shales are good aquifers. The average weathered thickness Charmuriya formation is 19 m. Most of the potential aquifer are below 50m where an average of 02 sets of fracture may encounter. Although 01 set of fracture may encounter between 50 to 100m. Average transmissivity is 101 m2 per day with an average drawdown of 13.84m. The discharge in this formation ranges from negligible to 14 lps having an average discharge of 1.79 lps. Cumulative thickness of fracture in this formation is up to 1m. The development in these formations is by the way of tubewells and borewells.

Chandi Formation: This Formation comprises a dominant stromatolitic limestone sequence. The topmost unit (Nipania member) comprises of pink to purple dolomitic limestone. Towards upper part it changes into bedded limestone and purple shale and is devoid of stromatolitic structure. This formation has very good ground water potential due to development of caverns at places. Chandi Limestone is moderate potential yielding 1 to 5 lps. Transmissivity varies between 1 to 400 m2/day.

Sandstone Aquifer:

The Chandrapur Group of rock mainly consist of sandstone, which is massive, hard and compact with almost no primary porosity. Only 01 set of fractures has been encountered in Chandrapur Sandstone which is exclusively below 50 m. No fracture in any well has been encountered below 50m to 200m. The average thickness of the weathered portion in the area is around 22 m. The transmissivity of the aquifer is very low 2.37 to 10 m2 per day with an average drawdown of 25.50 m. The discharge in this formation ranges from dry to 1.5 lps. The thickness of fractured sandstone is less than 0.2 m. These formations are mostly developed by the way of shallow tube wells and bore wells.

3. GROUNDWATER FLOW MODELLING

The study area is characterized by weathered and fractured aquifer system with very heavy abstraction of groundwater for agricultural purposes in Gurur, Balod, Patan and Dhamtari blocks**.** Balod Dhamtari and Patan blocks falling under Semi-Critical condition and Gurur block under Critical condition in ground water extraction point of views.

3.1 Regional Ground Water Flow

Three-dimensional mathematical models of regional groundwater flow are beneficial to the management of groundwater resources as they allow the approximation of the components of hydrological processes and provide a mechanistic description of the flow of water in an aquifer. Such a modeling study was carried out in Upper Kharun Basin, Chhattisgarh state, India. The model simulates groundwater flow over an area of **about 2200 square kilometers** with 66 rows, 53 columns, with two vertical layer on the regional model. The detailed study area is divided into rows and columns with a size of 1.0 sq.km grids (Figure.1). The model was simulated in steady and transient state condition using the finite-difference approximation of three-dimensional partial differential equation of groundwater flow in this aquifer from June 2012 to November 2017. The model was calibrated for steady and transient state conditions. There was a reasonable match between the computed and observed heads. Based on the modelling results, the aquifer parameters of this aquifer system is established.

Modelling objectives

Numerical three-dimensional groundwater flow model was developed for the Upper Kharun Sub basin, Central Chhattisgarh, India with the following objectives,

- to simulate regional groundwater flow to identify the distribution of heads,
- to establish the aquifer parameters of the area

3.2 MODEL INPUT PARAMETERS

The model was developed by incorporating geologic data, measured and inferred hydrologic data. Two sets of data are required for the development of a groundwater model as given in Table 1. The two sets of data are the physical framework and hydrological stresses.

Table-2 Data required in developing a numerical model

Physical framework	Hydrological stresses
Aquifer geometry Type of aquifer Aquifer thickness and lateral extent Aquifer characteristics	Groundwater abstraction and recharge Solute concentration Aquifer stress

Groundwater flow equation

Anisotropic and heterogeneous three-dimensional flow of groundwater, assumed to have constant density, and described by the partial-differential equation given by Rushton and Redshaw (1979) was used to model the groundwater flow in this study:

$$\frac{\delta}{\delta x} K_{xx} \frac{\delta h}{\delta x} + \frac{\delta}{\delta y} K_{yy} \frac{\delta h}{\delta y} + \frac{\delta}{\delta z} K_{zz} \frac{\delta h}{\delta z} - W = S_s \frac{\delta h}{\delta t}$$

Where,

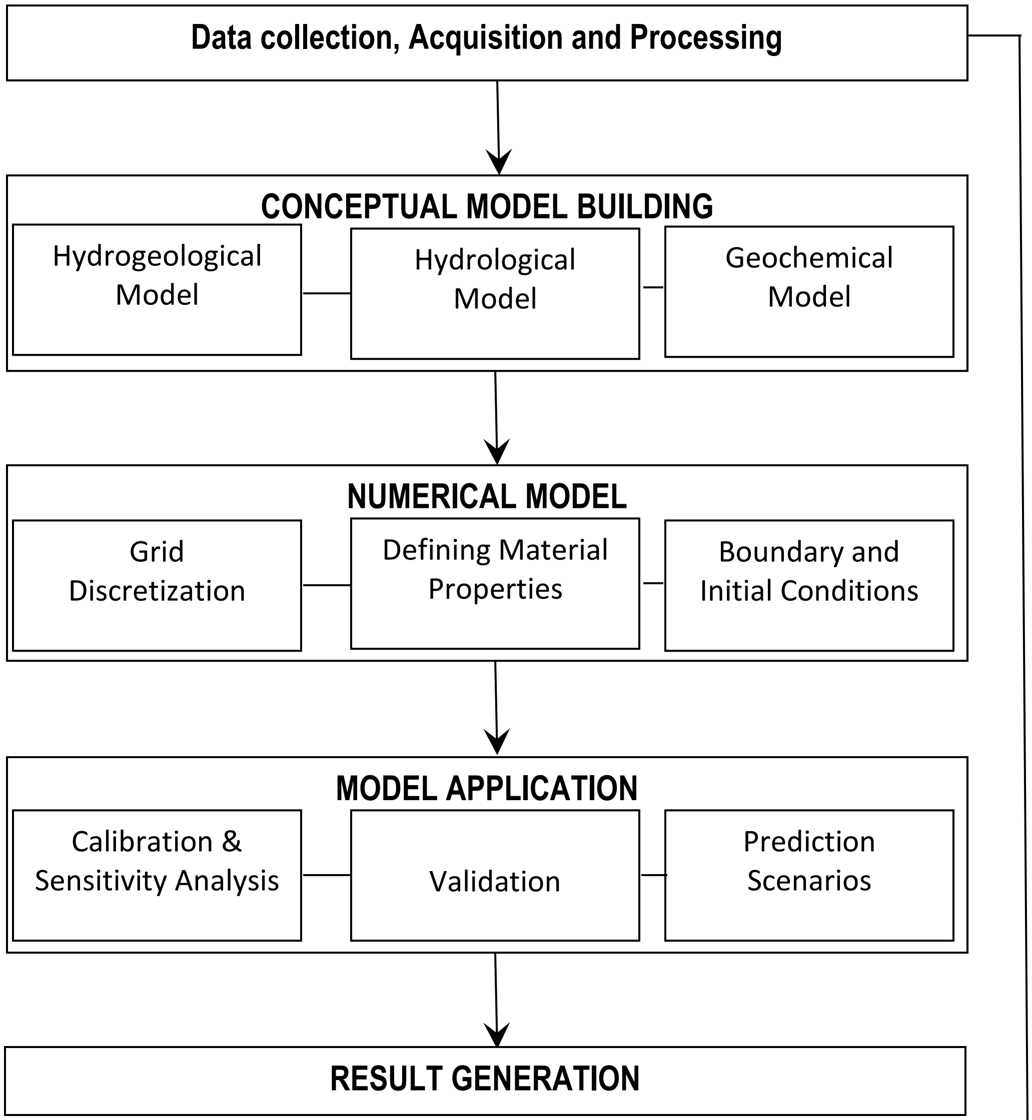
K_{xx}, K_{yy}, K_{zz}	-	components of the hydraulic conductivity tensor
h	-	potentiometric head
W	-	source or sink term,
S_s	-	specific storage
t	-	time

3.3 MODELLING PROTOCOL

The modelling protocol used in this study for the construction of a numerical model involves the following steps:

- Data collection, acquisition and processing of primary data
- Conceptual model building
- Numerical model building
- Model application
- Result generation.

These steps are given in a form of a flowchart (flowchart1).



Flowchart -1 Groundwater modelling methodology (after Bear 1992)

3.4 COMPUTER CODE

The computer software program MODFLOW (McDonald and Harbaugh 1998) developed by the United States Geological Survey (USGS) was used for the present study. The computer program uses the finite-difference technique and block-centered formulation to solve the groundwater flow equation for the three-dimensional steady and transient flow in heterogeneous media. The pre and post processor, **Visual Modflow Flex version 5.1 of 2018** was used to give input data and process the model output. Modelling studies were carried out in the hydrogeological modeling cell of the North Central Chhattisgarh Region, Central Ground Water Board, Raipur.

Coordinate System

Coordinate System- UTM Zone 44N, Datum- World Geodetic System 1984

Unit–

Conductivity -	meter per day (m/d)	Specific Storage -	1per meter
Pumping rate -	Cubic meter per day (m3/d)	Length -	Meter
Recharge -	meter per day (m/d)	Time-	Day

3.5 MODEL CONCEPTUALISATION

The conceptual model of the system was arrived from the detailed study of geology, borehole lithology, geophysical resistivity survey &logs, cross section and water level fluctuations in wells. Groundwater of the study area is found to occur in the weathered formations and in the fractured/jointed formations. Groundwater is found to occur in unconfined conditions in the weathered formation and unconfined/confined in fractured formation.

Boundary conditions

The study area forms a part of the upper Kharun River Sub-basin. The boundary conditions modeled a

re as per the watershed boundary (Figure.3). The western boundary of the study area is bounded by Tendula River was modelled as constant head boundary. The

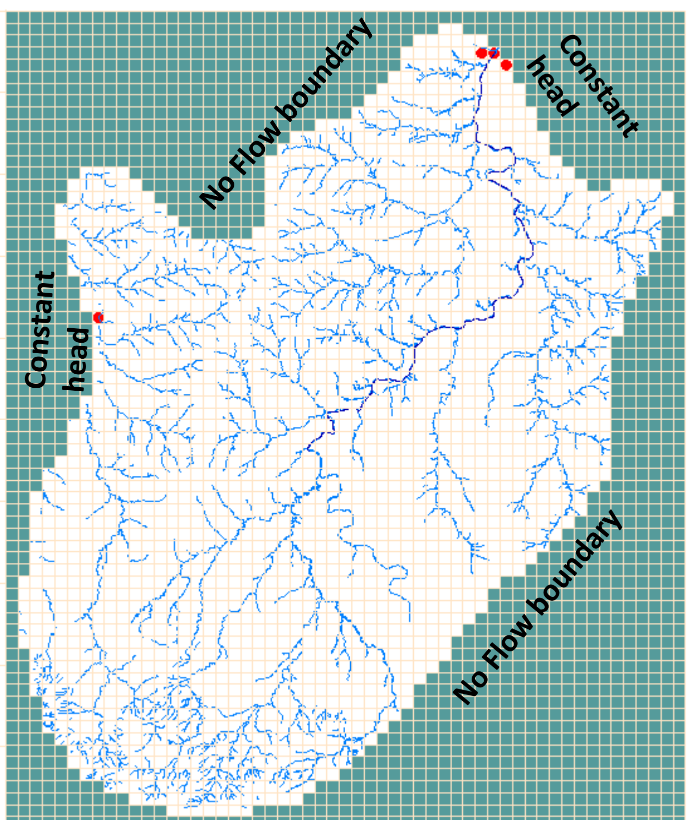


Figure.3 Boundary condition of the study area.

Kharun River flows from the south to north. The boundary where kharun discharging, was modeled as constant head boundary. Except these two regions, the remaining boundary was modeled as no flow boundary as the flow from outside the boundary is negligible.

The aquifer top and bottom were derived mainly based on the lithology of boreholes and by intensive field surveys. The study area has been vertically divided into two layers. First unconfined layer comprises of the topsoil and weathered formation, which is underlain, by fractured/jointed formation, which occurs under unconfined/confined conditions.

GRID DESIGN

The geographic boundaries of the model grid covering 2200 km^2 of the study area were determined using the map module. The map was projected using the metric coordinates in the map module and then imported into the MODFLOW. The finite-difference grid was superimposed on the study area was constructed based on the conceptual model representing the physical properties of the groundwater system. The gird network has a constant spacing 1 km by 1 km. The model gird discretized into 3498 cells cells with 56 rows and 53 columns, and vertically by 2 layers (Figure-4). The length and width of model cells is 1000 m cells with 56 rows and 53 columns, and vertically by 2 layers (Figure. 4). The length and width of model cells is 1000 m along the North and South directions of the study area.

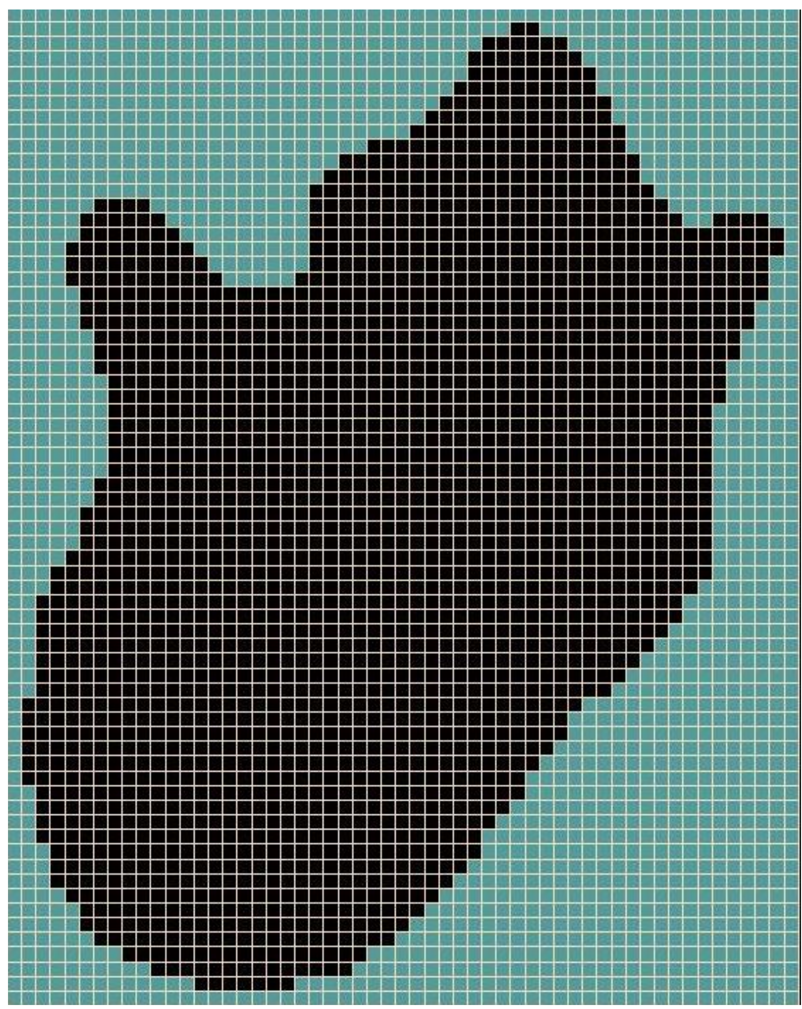


Figure.4 Discretization of the study area.

3.6 INPUT PARAMETERS

Initial Groundwater head

The initial groundwater head of the study area is shown in figure-5. After detailed analysis of the hydrographs, rainfall and water level fluctuation, it was decided that the groundwater head data of June 2012 represents the spatial groundwater distribution of the study area. The during this period the rainfall was also normal and the groundwater fluctuation was representative of the normal year.

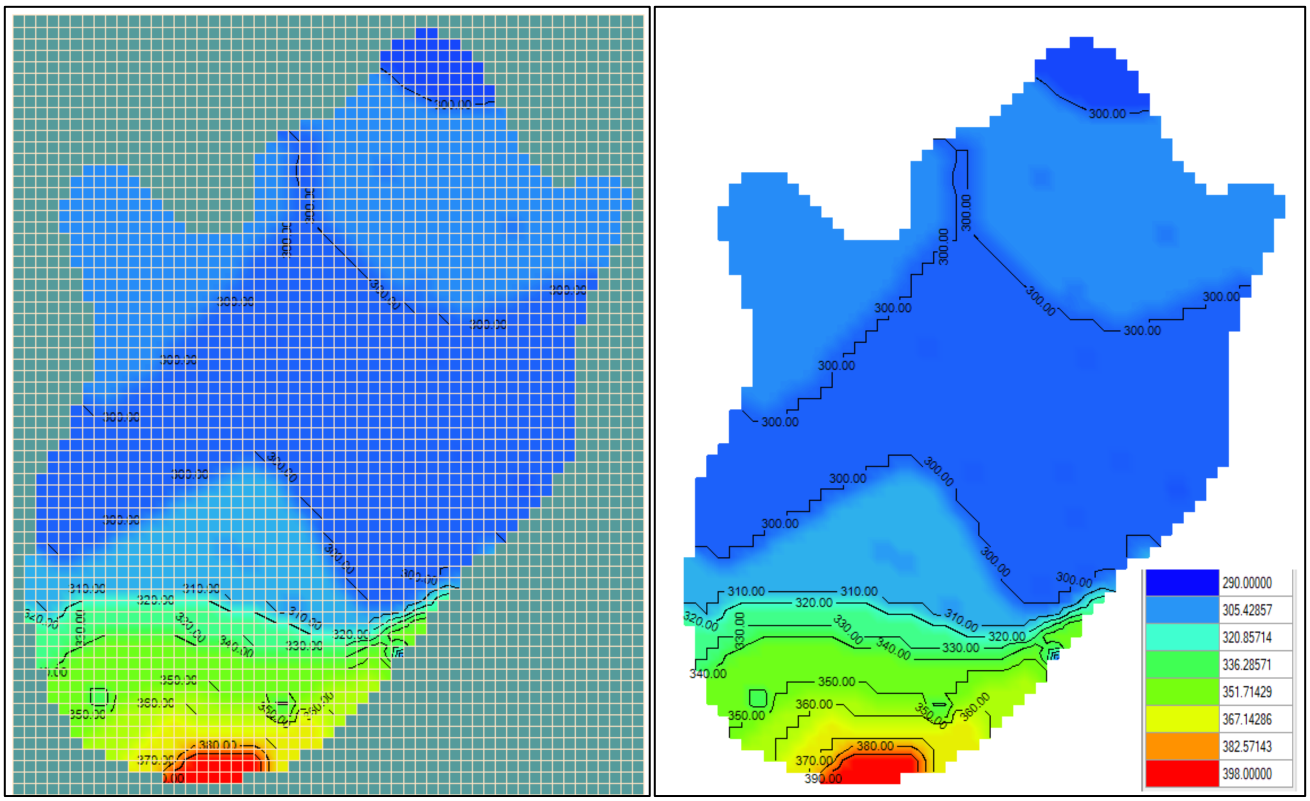


Figure.-5 Initial groundwater head of the study area during June 2012.

Aquifer geometry

The aquifer geometry includes defining the aquifer top of Ist layer, Top of IInd layer and bottom of IInd layer for all the cells (Figure 6a, b& C). They were mainly derived from the subsurface characterization using the lithologs, resistivity data and geological field work. These values were extrapolated for the entire area considering the lithological variations and field study of well sections. The Ist layer is characterized by weathered formation with a maximum thickness of 62m and is underlained by fractured/jointed formation with a maximum thickness of 140m.

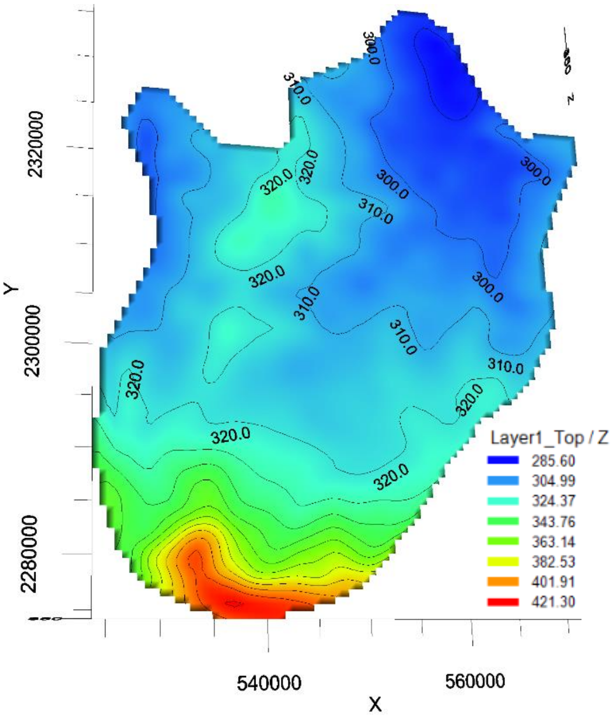


Figure-6a Top elevation of the study area.

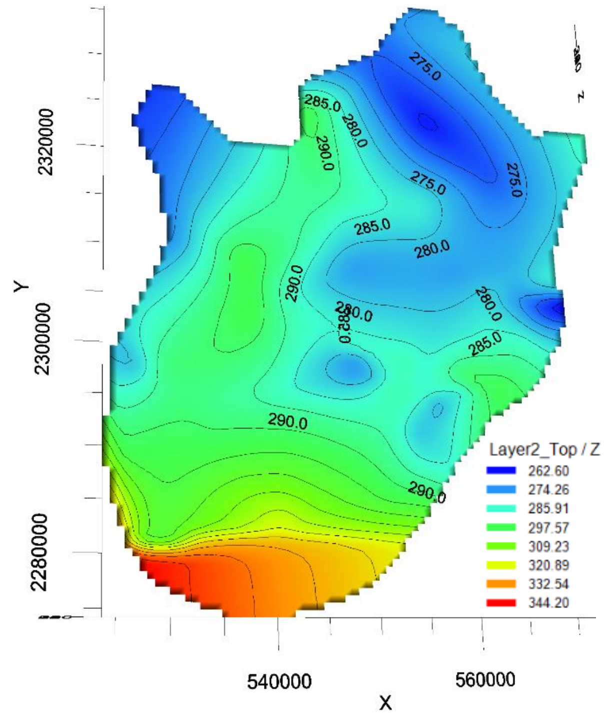


Figure-6b Top elevation of II^nd layer of the study area.

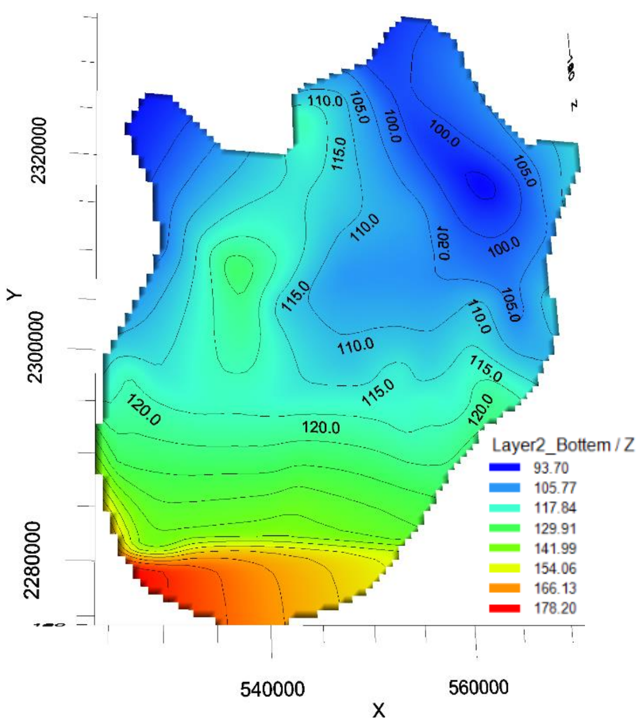


Figure-6c Bottom elevation of II^nd layer of the study area.

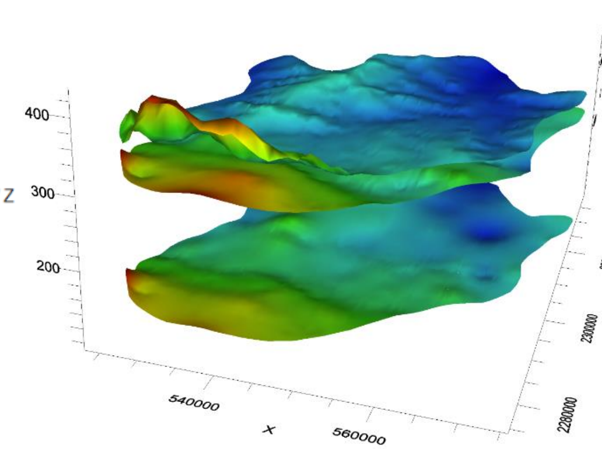


Figure-6d elevation of Top and bottom of I^st & II^nd layer

The aquifer properties such as horizontal hydraulic conductivity, Specific yield and storativity (figure 4a & b) used in the model was derived from pumping tests results and is given in the Table 2. The data of the pumping test is enclosed in table-2a.

Table.3 Hydraulic Conductivity values for Aquifer

Formation	Hydraulic conductivity (k in m/day)	Specific Yield (%)	Storativity
Weathered Limestone	5 to 11	0.015 to 0.06	-
Weathered Sandstone	4 to 8	0.015 to 0.05	-
Weathered Shale	6 to 10	.005 to 0.01	
Alluvium	10 to 20	0.15 to 0.2	
Fractured/jointed Limestone	3 to 5	0.034 -0.05	0.00017 to 0.00073
Fractured /jointed Sandstone	2 to 4	0.01 to 0.04	0.00008 to 0.000041
Fractured /jointed Shale	3 to 4	0.01	0.00032 to 0.000041

LEGEND

Hydraulic Conductivity of Ist Layer

Lithology	Formation	Kx	Ky	Kz	Zone
Limestone	Charmuria Formation	10	10	1	
Sandstone	Chandrapur	4	4	0.4	
Limestone	Chandi Formation	5	5	0.5	
Shale	Gunderdehi Formation	3	3	0.3	
Limestone	Chandi Formation	5	5	0.5	
Aluvium	Recent	20	20	2	

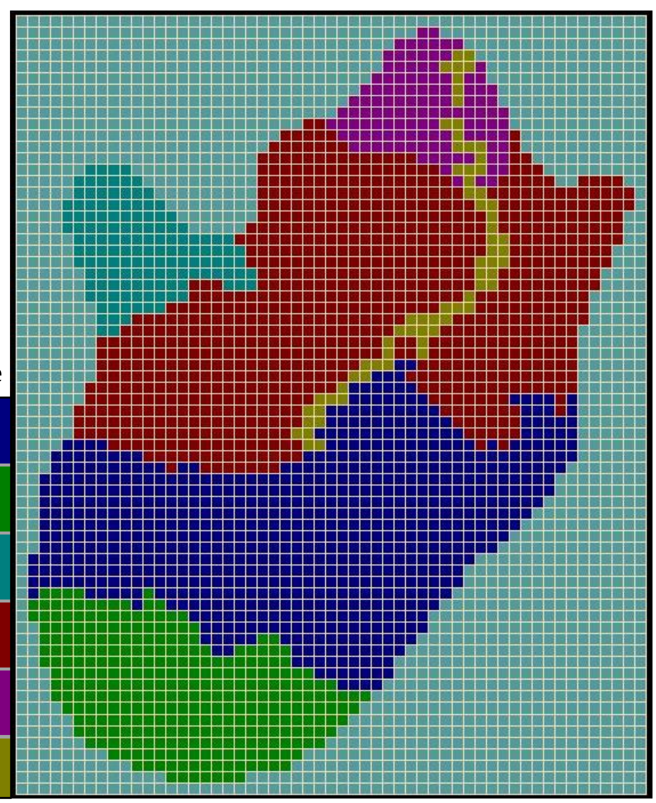


Figure-7 Hydraulic Conductivity values for Aquifer

Groundwater Abstraction

The groundwater of the study area is abstracted for irrigation, drinking water supply and domestic purposes. Agriculture activity of the study area is mainly dependent on groundwater resource and small region of canal/dam command area. The Land use and landcover map was prepared to demarcate the area under cultivation. Information on the number of wells (open and borewells) available in the study area (Figure.5a&b) was collected from the department of economics & Statistics and from the electricity board. The data obtained from electricity board included the number of wells energized and their horsepower of the pump (Table.3). The domestic and drinking water requirement of the study area was calculated based on population.

Table.4 Groundwater draft details

BLOCK	Basin area (sq.km)	Mansoon Abstraction for all uses ham	Non-Mansoon Abstraction for all uses ham	Total Abstraction for all uses ham
Abhanpur	82.59	90	577	667
Balod	208.30	222	1636	1858
Dhamtari	250.89	398	2966	3364
Doundi	6.27	2	15	17
Kurud	276.32	485	3747	4232
Gurur	516.87	603	4701	5304
Patan	470.13	579	3667	4246
Gunderdehi	389.12	313	1941	2254

Table.4 Groundwater draft details

BLOCK	Basin area (sq.km)	Mansoon Recharge for all uses ham	Non-Mansoon Recharge for all uses ham	Total Recharge for all uses ham
Abhanpur	82.59	976.62	407.31	1383.93
Balod	208.30	1403.51	980.62	2384.13
Dhamtari	250.89	3367.88	1663.52	5031.40
Doundi	6.27	30.78	6.81	37.60
Kurud	276.32	3735.86	1848.23	5584.09
Gurur	516.87	3565.13	2273.06	5838.19
Patan	470.13	4240.41	1645.24	5885.65
Gunderdehi	389.12	7221.53	2377.49	9599.02

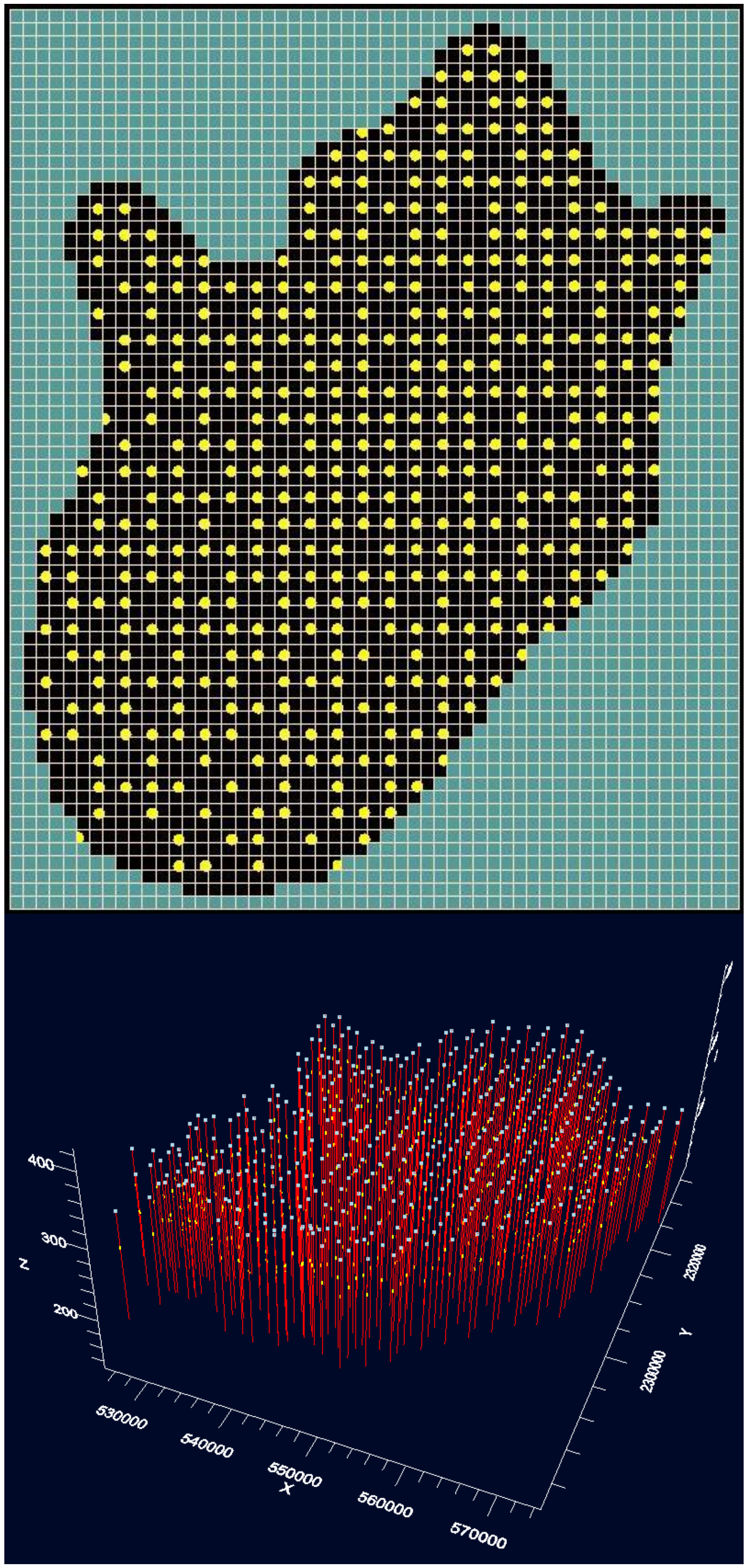


Figure-8 Distribution Pumping wells in the study area.

Groundwater Recharge

The recharge of the study area aquifer varies considerably due to differences in landuse pattern, soil type, geology, topography and relief. The recharge to the aquifer system is from rainfall, irrigation and inflow from the river and storage tanks. Rainfall is the principal source of groundwater recharge. The rainfall hydrograph was studied to understand the recharge pattern in the study area. The aquifer gets recharged and groundwater level shoots with rainfall above 40 mm. The entire portion of the study area is geologically covered by top soil, weathered and fractured/jointed formation. The infiltration capacity of formation ranges from 0 – 10 % (Groundwater resources estimation committee report, 1997). The table 4 shows the rainfall infiltration factor used in modeling for groundwater recharge calculation.

Table 5 Rainfall vs infiltration factor used in groundwater recharge calculations.

s.no	Rainfall (mm)	Infiltration factor (%)
1	500 -700	5
2	700 -800	6
3	800 -1000	8
4	1000 -1200	10
5	1200 -1400	12

The rate of leakage between the river and aquifer was estimated using the difference between the river head and groundwater head. The rivers situated in the study area and its contribution to groundwater recharge was calculated based in the difference between the head in the adjoining wells and reservoir head. The data of the river head was inputted in the model. Ponnaiyarriver flows only for few days during August, September & October.

Three recharge zones have been demarcated in the study area and they comprise of top soil zone, weathered Gniessic/charnockitic formation and ultramafics zone. The recharge zones of the study area is shown in figure.7

3.7 MODEL CALIBRATION

The calibration strategy was to initially vary the best known parameters as little as possible, and vary the poorly known or unknown values the most to achieve the best overall agreement between simulated and observed. Steady state model calibration was carried out to minimize the difference between the computed and field water level condition. Steady state calibration was carried out with the water level data of June 2012 in 19 wells distributed over the study area. The area under study has lack of data related to aquifer parameters. Out of all the input parameters, the Specific yield value is the only poorly known as only 22 pumping test data were available in this area. The lithological variations in the area and borehole lithology of existing large diameter wells were studied. Based on this it was decided to vary hydraulic conductivity values up to 10% of the pumping test results for layer in order to get a good match of the computed and observed heads (Fig. 9). The figure indicates that there is a very good match between the calculated and observed water heads in most of the wells of the study area. Root mean square error and the mean error were minimized through numerous trial runs.

Transient state condition.

Transient state simulation was carried out for a period of 5 years from June 2012 to May 2017 with Two stress periods Monsoon and Non monsoon. The trial and error process by which calibration of transient model was achieved by several trials until a good match between computed and observed heads over space and time. The hydraulic conductivity values incorporated in the transient model were modified slightly from those calibrated by the steady state model. Based on the close agreement between measured and computed heads from 1st June 2012 to 31st May 2017 at 19 observation wells distributed throughout the aquifer, the transient models were calibrated satisfactorily. The sensitivity of the model to input parameters were tested by varying only the parameter of interest over a range of values and monitoring the response of the model by determining the root mean square error of the simulated heads compared to the measured heads.

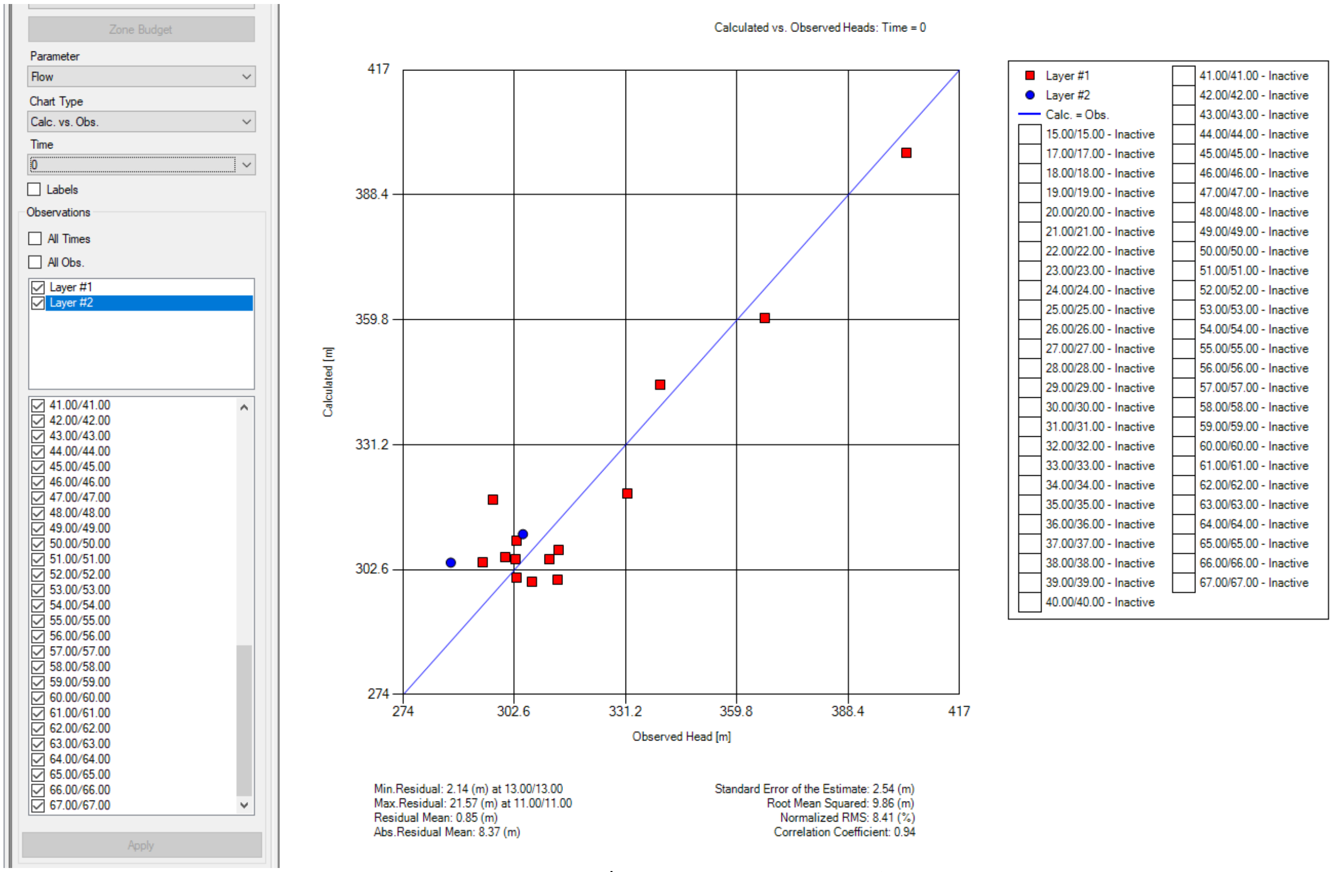


Figure-9a Calculated V/s Observed head value of June 2012.

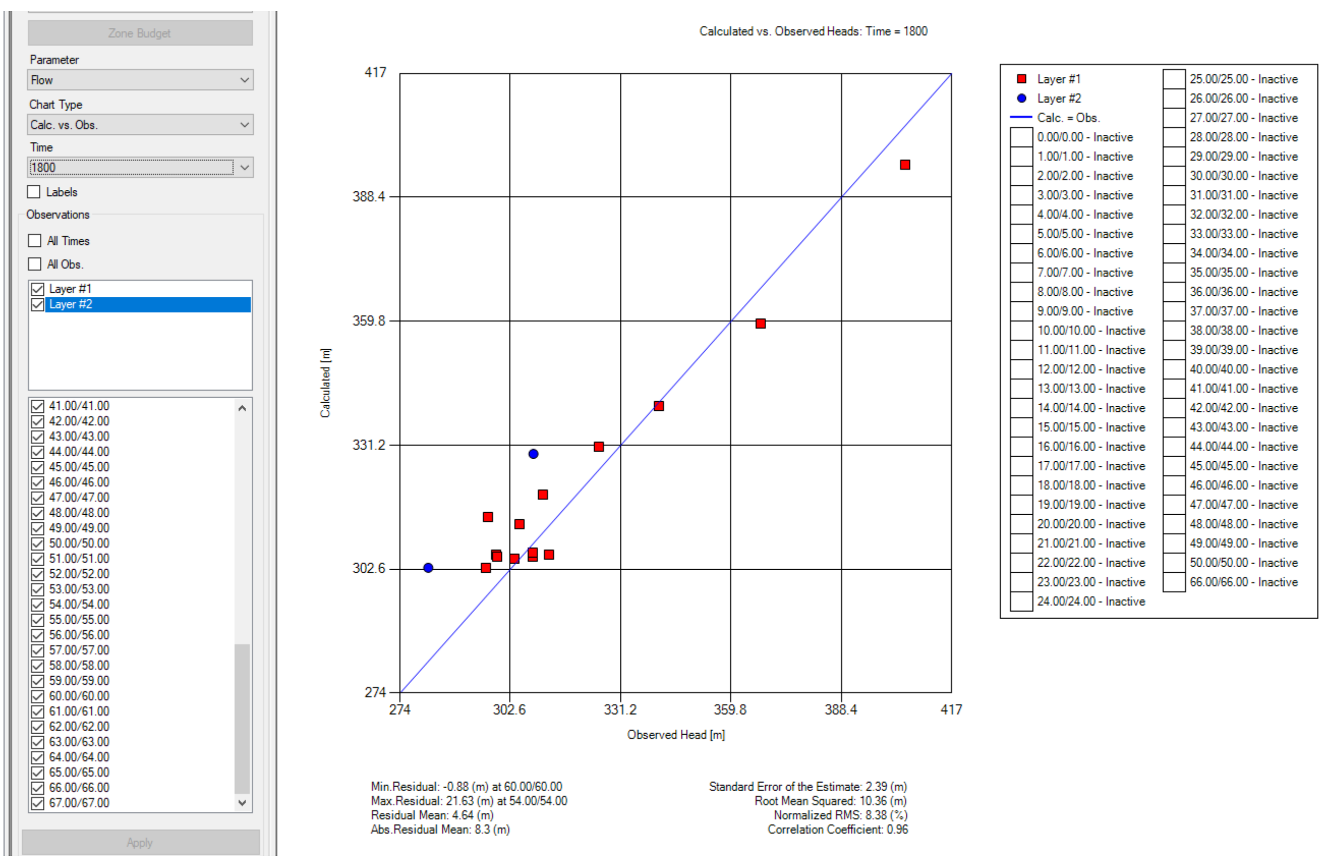


Figure-9b Calculated V/s Observed head value of June 2017.

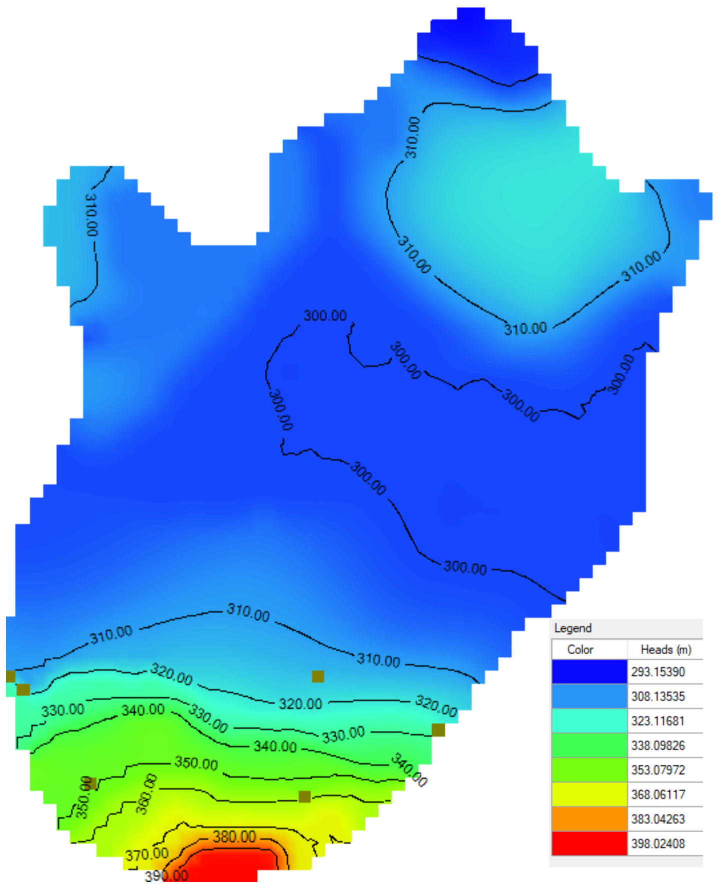


Figure-10a Head after 120 days (October 2012)

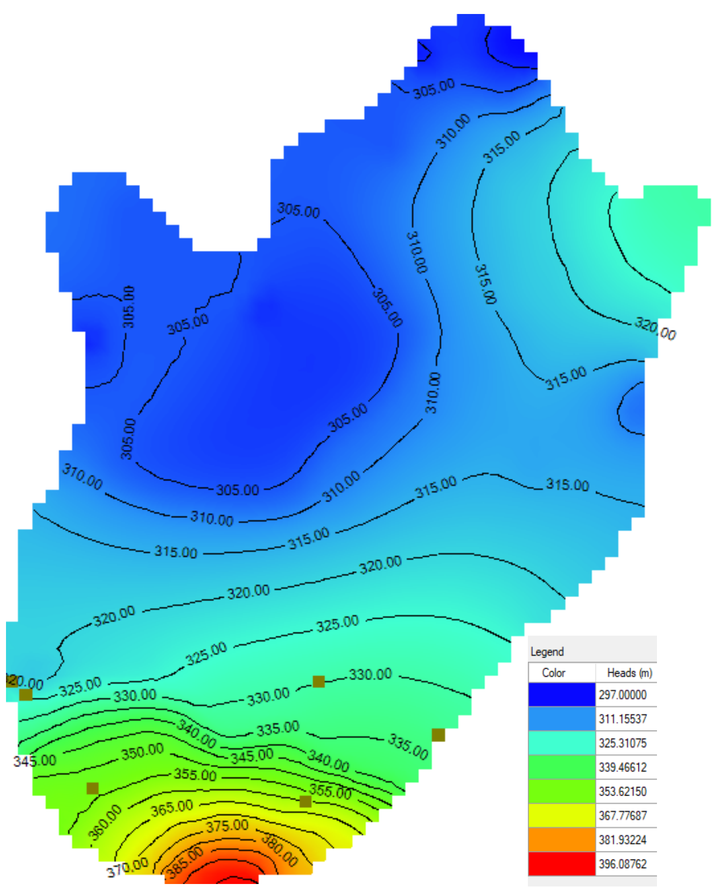


Figure-10b Head after 1825 days (May 2017)

Sensitivity Analysis

In order to understand the variation of the model parameter on the computed water levels, the sensitivity analysis was carried out. The effect of rainfall recharge on the computed water level was studied. The study state runs were made without rainfall recharge the computed water levels for the upper aquifer indicated that there was no change in the water level without rainfall recharge. this is mainly due to the insignificant quantum of recharge to ground water system when compared to the pumping rate. Thus, it can be concluded that rainfall recharge did not play any major role in the hydrodynamics of aquifer system for sub basin under study state condition on 1st June 2012. The result of sensitivity analysis indicated that in the upper aquifer under study state condition, the hydraulic connectivity is inversely proportional to the head. However, it has no impact on the water level in lower aquifer of the sub-basin. The negligible impact has been observed in the upper aquifer due to change in storage.

3.8 Simulation Results

The model was simulated in transient condition for a period of 5 years from 1st June 2012- 31st May 2017. There was good agreement between the computed and observed heads (Figure-10a to 10b). A study of the simulated potentiometric surface of the aquifer indicates that the highest heads are found on the southern side of the study area, which is a general reflection of the topography. During the simulation period, it is observed that few patches in the north eastern part gets dried up (Figure-10a & 10b). The number of dry cells gradually increases with the summer season and number of dry cells reduces with arrival of monsoon. The regional groundwater flow direction is from South-west to North-east. The groundwater flow vectors for the month of 1st June 2012- 31st May 2017 is given in figure.11b & 11b. The comparison of observed and computed heads in given in figure 9a to 9b.

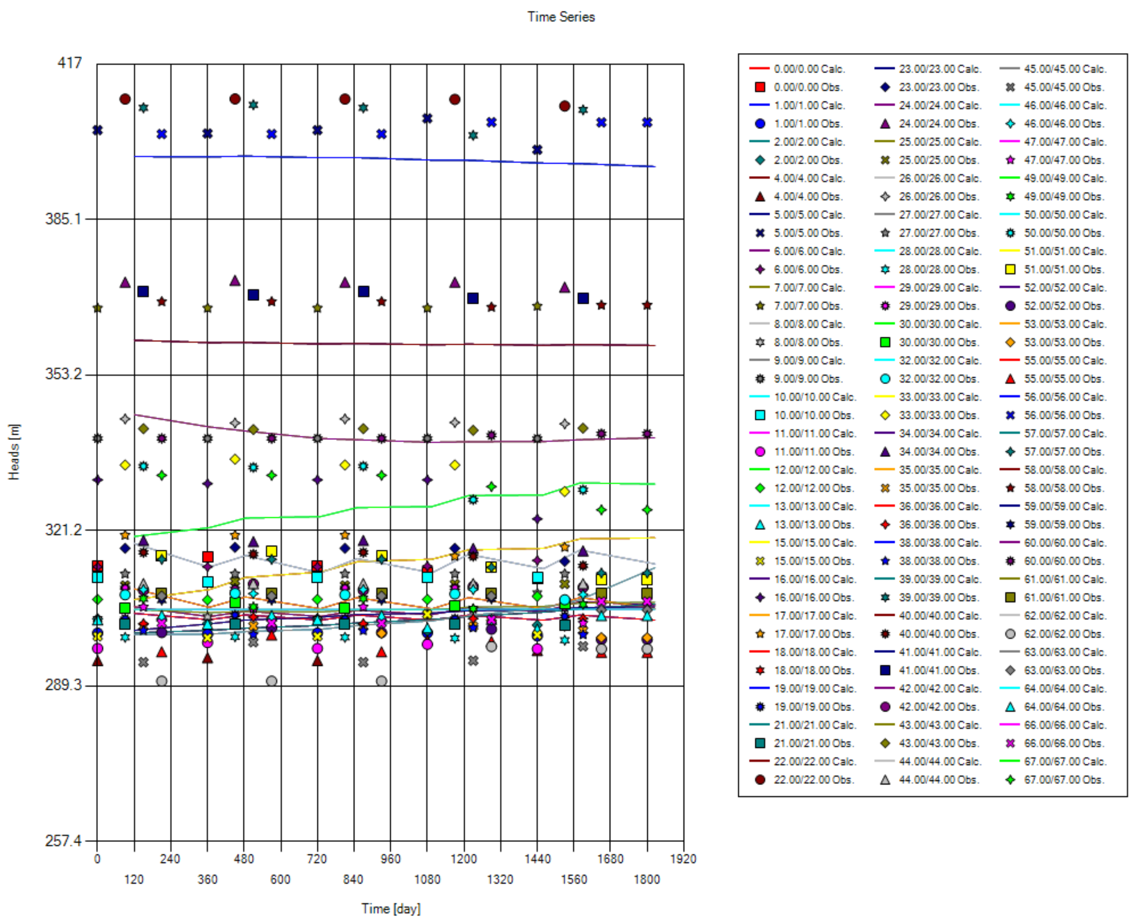


Figure-11a Time Series Analysis for Ist Layer

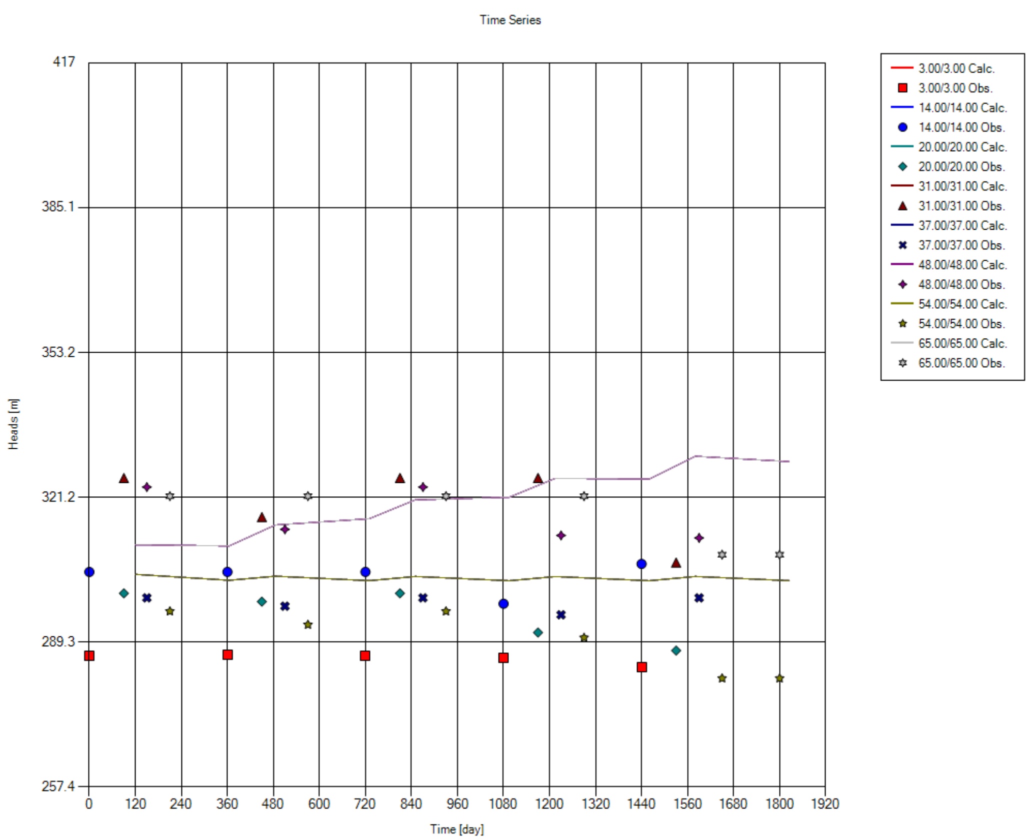


Figure-11b Time Series Analysis for IInd Layer

3.9 Conclusion

Double layer finite-difference flow model was used to simulate the groundwater head in Upper Kharun Sub-basin aquifer system for a period of 5 years (1st June 2012- 31st May 2017) for better understanding of the aquifer system. There was data gap for the aquifer parameters such as Transmissivity, Permeability and Specific yield. The simulated results with input of data by trial and error was able to establish the aquifer parameters of the both weathered and fracture aquifer in the sub basin. The spatial groundwater head follows the topography. The groundwater water flows from the north west to south east. The computed groundwater head mimics the observed groundwater head in several locations.

Groundwater modelling results suggest that there is a rising of ground water heads in central Part of the sub-basin covering Gurur block as compare to 2012 and 2017. It proves that Stage of Ground water extraction in 20113 was 102 % and it improved by 98% in 2017 estimation.

However, this is the first simulation and there is lot of scope of refinement like model boundary to be modified, data used to be further refined and it needs to recheck and require further celebration in view of Root Mean Squared.

Overall this ground water flow modeling exercise has been able to know the ground water scenario of the weathered and fracture aquifer system of the Upper Kharun Sub-basin.