GROUND WATER QUALITY MODELLING FOR THE STRETCH OF THE RIVER VRISHABHAVATHI USING VISUAL MODFLOW FLEX

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ABSTRACT: *Vrishabhavathi River is a constituent of the Arkavathi River Basin, the River has two origins – One originating from the Peenya industrial suburbs and the other from Gavipuram in Guttahalli. Both the streams join together near Nayandahalli, flow as a single unit from there and ultimately joins the River Arkavathi which is a tributary of River Cauvery. The length of the river course being 52 km. There are about 21 major and 58 small scale industries which directly discharge their effluents into the river. The wastewater flow into the Vrishabhavathi Valley is about 300 MLD. The study area covers 15619 acres (63.2 km²) from Nayandahalli to Kengeri satellite town. For this study a buffer zone of 4 km surrounding the river stretch considered. The groundwater monitoring data, litho logy, hydro geological parameters, topography, rain fall data obtained from CGWB, Survey of India, India Metrological Department are used in the model. The MODFLOW and MT3D models are calibrated and validated, after which future groundwater conditions were predicted.*

Key words: *MODFLOW, MT3D, CGWB, calibration, validation, prediction.*

1. Introduction

Groundwater contamination and soil pollution have become recognized as important environmental problems over the last 20 years. With the increasing sense of awareness about the environment and the recognition of the need for its protection, the study of solute transport related to groundwater contamination has become the focus of numerous researchers. Specially, during the last three decades, research activities in this area have accelerated to revolutionary level. Different investigators have studied the solute transport from different perspectives. Groundwater modelling is an established tool to study the aquifer response for given input output stress. The findings, in turn, help evolve and select optimal groundwater management policy. In India pollution and over extraction are important component of the groundwater problem. Mass transport modelling in recent times helps to understand the migration behaviour of pollutant in the saturated region. Mass transport results are in turn used to devise the remedial measures to clean the aquifer system.

2. Objectives

- To assess the suitability of the model for the present study.
- To assess the groundwater quality (Total dissolved solids) for a stretch from Nayandalli to Kengeri, and Predict the future groundwater quality of the study area.
- To suggest remedial measures so as to improve the future groundwater quality of the study area.

3. Literature review

A. Sushanth Kumar et al., (2017), The study focused on groundwater recourse assessment through steady-state flow modelling in Bina River basin. Bina River is a tributary of Betwa River and is the main source of water for domestic water supply and irrigation supply. This study reports a simulation study for better understanding of the groundwater balance at Bina River Basin using Visual MODFLOW. The model involved a steady-state hydro geological simulation of the two-layered aquifer. The model was calibrated to static water levels during 2009 pre-monsoon in each block of Bina River Basin. The overall model results are comparable with the observation well data. The sensitivity of the calibrated model was tested by systematically changing one parameter or input variable at a time and it was found that the model is highly sensitive to changes in ET and recharge rate.

B. R.Rajamanickam et al., (2010), studied Amaravathi river basin at the downstream of Karur Town which is severely polluted due to discharge of partially treated effluent by the textile bleaching and dyeing units. It was found that about 14600 m³ of coloured effluent is discharged into the river daily. The effluents had a total dissolved solids (TDS) in the range of 5000-10000 mg/L. The study was conducted using Visual MODFLOW 2.8.1 , the MODFLOW, and MT3D models were calibrated and validated. The validated model was used for simulation of groundwater quality for next 15 years under 5 different scenarios: (i) if the present system with 10,000 mg/L TDS discharge into river continues, (ii) if the CETPs meet the TDS discharge standards of 2100 mg/L and discharge the effluent into river, (iii) if the quantum of discharge is doubled with TDS level of 2100 mg/L, (iv) if the dyeing units go for reverse osmosis plant and recycle the entire effluent and achieve zero discharge, (v) 1.5 time groundwater recharge and zero discharge by the units. The simulation results showed that there is no improvement in groundwater quality even if the effluent met discharge standards for the next 10 years. They concluded that the units opt zero discharge then there would be an improvement in the quality of groundwater over a period of few years.

C. N. Sridhar et al., (2018), in this study used Visual MODFLOW to predict the effects of hydrological changes like groundwater extraction or irrigation developments on the behaviour of the aquifer in lower Ponnaiyar Sub-basin, Tamil Nadu, 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 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 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.

4. Methodology

4.1 Study area

4.1.1 Location of the study area: The Vrishabhavathi River flows mainly in Bangalore Urban and Ramanagara Districts. It covers an area of 360.62 Km^2 which lies between latitudes 12° 44^{1} 37^{11} to 13° 2^{1} 31^{11} N and longitudes 77°23^{1}14^{11} to 77° 34^{1} 59^{11} E representing seasonally dry tropical climate.

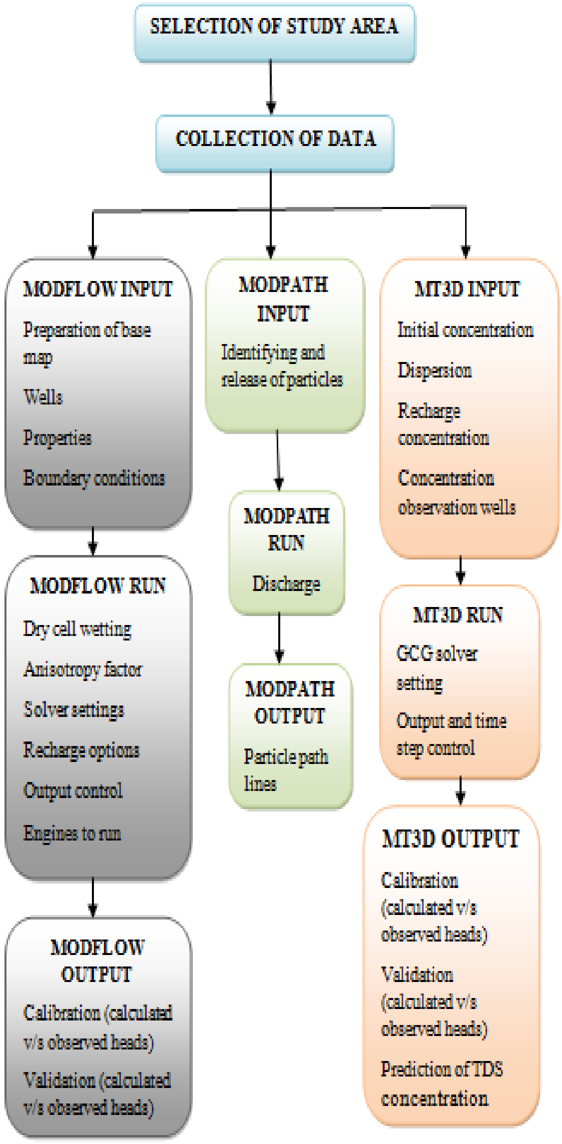

Figure 4.1: Flowchart of the modelling process

4.1.2 Soils: A major part of the district is occupied by red sandy soil (60%), and the remaining by red loamy soil in undulating land slopes. These soils are derived from acidic rocks, granites and granitic gneiss. These soils occur on gently sloping pediplain. They are dark brown colour with loam to sandy loam composition on the surface and sandy clay loam to clayey soils in the sub surface horizons. (CGWB, 2017)

4.1.3 Hydrogeology: In terms of hydrogeology, most of the Arkavathi sub- basin is underlain by hard-rock that consists of gneisses and granites. The shallow aquifer consists of the highly-weathered zone extending to about 20 m BGL. The fractured zone, extending from 20–50 m, contains joints and cracks, some of which are well-connected to each other and can function as conduits. Yields drop off greatly beyond 60 m. At deeper levels, there are a few joints and fractures that have been enlarged by dissolution and can extend to considerable depths. (CGWB, 2017)

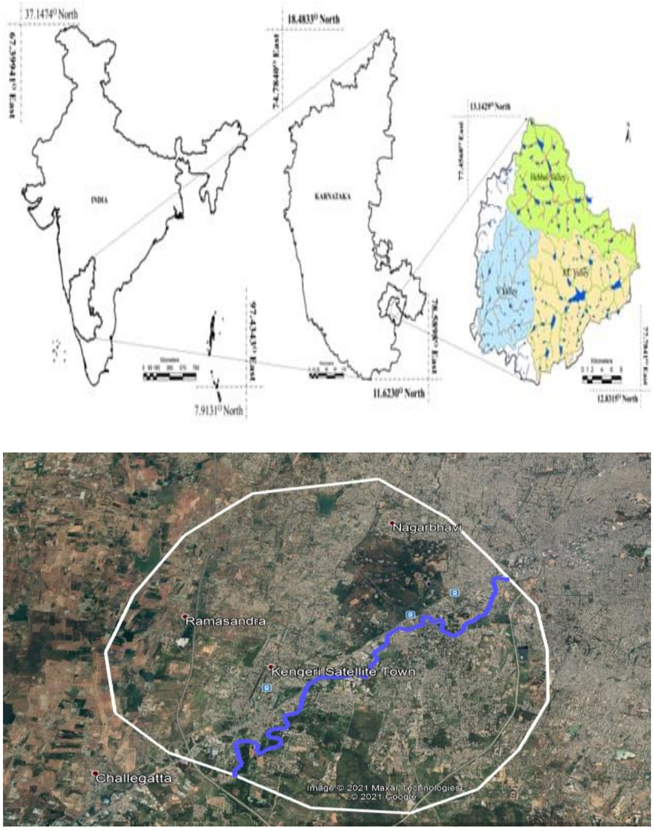

Figure 4.2: Location of the study area

4.1.4 Water quality of Vrishabhavathi River

The Vrishabhavathi river once used as a major drinking water source to the populace living across the river. This source has been the victim of pollutants discharged by industrial, agricultural and domestic effluents.

In the recent years ground water pollution across Vrishabhavathi river has emerged as a severe environmental issue, constraining its use drastically.

The polluted river water is extensively used for irrigating farm lands across the river on either side from Kengeri to Byramangala tank for about forty five kilometres away from the origin of the river.

Figure 4.3: Polluted water flowing through the Vrishabhavathi River

4.2 Data collection

4.2.1 Rainfall: An annual average rainfall of 1082mm was recorded in the Bangalore urban district in 2020, this information was obtained from KSNDMC.

4.2.2 Base map: Base map of the study area was marked from Survey of India Toposheet numbered 57H-5, 57H-6, 57H-9 and 57G-12 which was downloaded from NAKSHE online portal of Survey of India (SOI). It was converted into .SHP format with ArcGIS.

4.2.3 Ground surface elevation : Ground surface elevations above MSL at various points in the study area were derived from Google Earth Pro and were converted to .grd format using surfer.

4.2.4 Groundwater level Data: The groundwater levels at different observation wells in the study area from the year 2013 to 2019 were obtained from State Ground Water Board, and from literature studies.

4.2.5: Layer Properties: The Layer Properties such as conductivity, storage and initial heads were collected from the CGWB literature reports, Groundwater Year Book and were loaded into the model.

4.2.6: Vrishabhavathi River Details: The input parameters such as River Stage, River Bottom, Riverbed thickness, River width, Riverbed conductivity were collected from Minor Irrigation Department.

4.2.7 TDS Concentration: The TDS concentration in groundwater for the observation wells present in the study area for the last 7 years i.e 2013 to 2019 were collected from Ground water directorate office. The wells COBS1, COBS2, COBS3 and COBS4 were located at Ramasandra, Nagarabhavi, Pattangere, and Kengeri respectively.

Table 4.2.1: Groundwater levels (in m, above MSL) for four Observation Wells for the years 2013 to 2019

Groundwater level observations (in m, above MSL)							
OBSERVATION WELLS	2013	2014	2015	2016	2017	2018	2019
HOBS1	794.1	795.11	793.15	801.77	799.35	796.9	795.88
HOBS2	794.39	786.58	793.18	793.18	795.6	794.45	792.98
HOBS3	786.04	77939	779.44	779.44	794.92	797.59	797.85
HOBS4	791.41	788.04	784.74	784.74	792.65	792.35	791.74

Table 4.2.2: Layer Properties of study area

Sl. No.	Properties	Layer I (upper layer) Subsoil	Layer II (bottom layer) Granite, Gnessis
1	Hydraulic conductivity in longitudinal direction K_x, m/sec	3E-8	7E-7
2	Hydraulic conductivity in lateral direction K_y, m/sec	3E-8	7E-7
3	Hydraulic conductivity in vertical direction K_z, m/sec	3E-9	7E-8
4	Specific storage S_s (1/m)	0.001	1E-5
5	Specific Yield S_y	0.12	0.20
6	Effective Porosity	0.30	0.14
7	Total Porosity	0.60	0.30

Table 4.2.3: TDS Concentration (in mg/l) for four Observation Wells for the years 2013 to 2019

TDS Concentration (mg/l)							
OBSERVATION WELLS	2013	2014	2015	2016	2017	2018	2019
COBS1	930	875	852	865	891	732	738
COBS2	1210	1100	989	1056	987	920	1390
COBS3	680	712	792	881	843	880	1012
COBS4	880	850	865	819	814	820	858

Table 4.2.4: Vrishabhavathi River details

1	River Stage	638 m
2	River Bottom	635 m
3	Riverbed thickness	2.5 m
4	River width	14 - 40 m
5	Riverbed conductivity	1E-7

5. Data analysis and interpretation

5.1 Model input

5.1.1 Preparation of Base Map The base map was clipped using Survey of India Toposheet and georeferenced using ArcGIS. Base map was imported into the model screen in .SHP format.

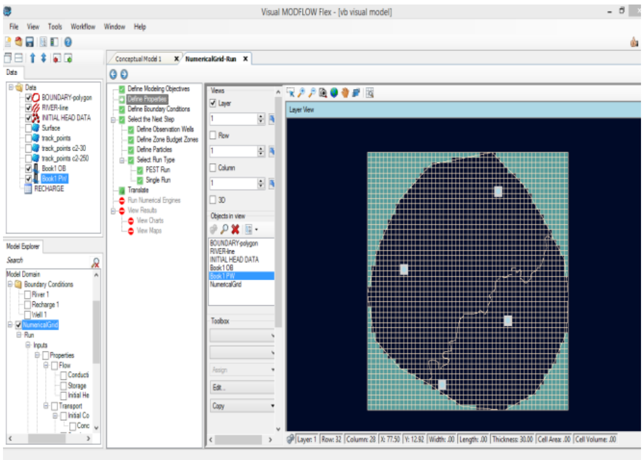

Figure 5.1: Model Screen with study boundary, river boundary and inactive cells

5.1.2 Assigning Layer Elevations (Above Mean Sea Level)

For modeling purpose two layers were considered throughout the study area. The top layer is shallow weathered zone of thickness 30m and the bottom layer is deeper fractured rock with thickness of 250 meters.

By using Google Earth Pro, the actual elevation (amsl) of the layer 1 top surface (ground surface) was entered by importing the text file, which contained the elevation data.

5.1.3 Boundary conditions

River Boundary: The input parameters such as River Stage, River Bottom, Riverbed thickness, River width, Riverbed conductivity were collected from Minor Irrigation Department.

Recharge rate: The recharge package is designed to simulate aerial distributed recharge to the groundwater system. Most commonly, aerial recharge occurs as a result of precipitation that percolates into the groundwater system.

Pumping rate: A uniform pumping rate of 100m^3/day was assigned into the model.

5.2 Model run

After completing the input parameters, run model is selected from the screen. By selecting [Run] in the Main Menu, Select Run Type dialogue box appears, the model was run under transient condition.

WHS solver parameters, rewetting options, recharge options, output control options, anisotropy factor are assigned accordingly.

The wetting of a cell is controlled by either the head in the cell directly beneath or by the heads in the four adjacent horizontal cells, plus the one beneath. The first method is generally more stable and is particularly good when the adjacent horizontal cells are poor indicators of whether a cell should become wet. The model is translated and made to run.

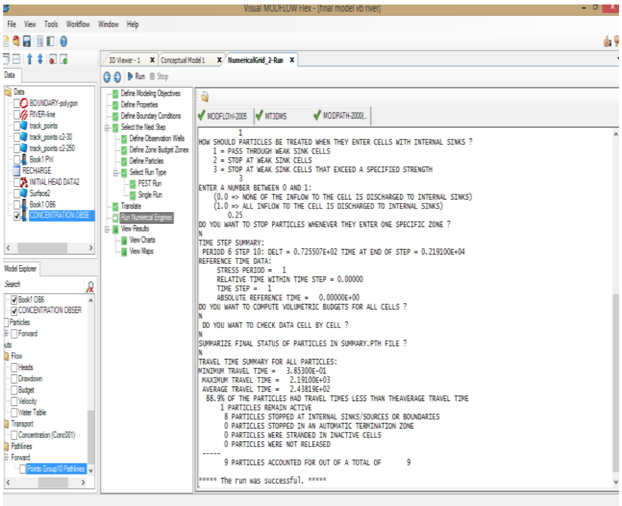

Figure 5.2: Window showing run successful for MODFLOW, MODPATH and MT3DMS

5.3 Model output

MODFLOW output provides graphs of calculated vs observed heads.

Transient State Calibration: The hydraulic conductivity values, boundary conditions and the water levels are used as the initial condition in the transient model calibration. The above are used along with the specific storage and specific yield distribution and time variable recharge. The transient (dynamic) calibration is carried out for the time period from year 2014 to year 2018 (1706 days). The storage coefficient and hydraulic conductivity values are varied iteratively so that a reasonably good match was obtained between computed and observed water levels. It is only storage coefficient values which effectively varied during transient calibration. From the graph (Figure 5.3 and 5.4) of calculated head vs. observed head for 365days and 1095 days respectively and also other days, it is understood that the calculated head is well matching with observed heads.

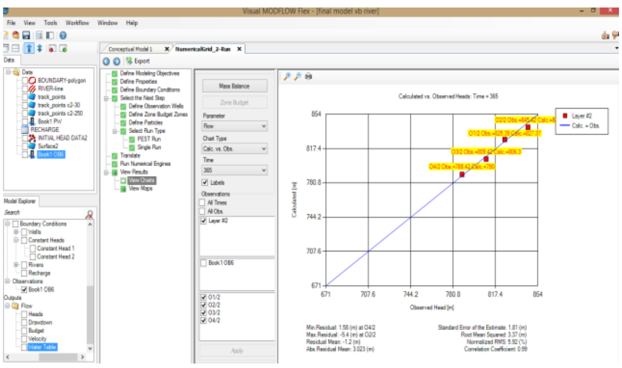

Figure 5.3: Calculated vs observed groundwater level (above MSL) for the year 2015

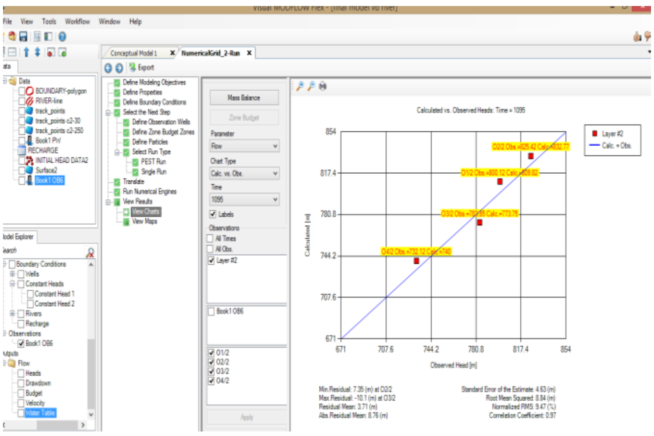

Figure 5.4: Calculated vs observed groundwater level (above MSL) for the year 20172

Model Validation: Following calibration, the groundwater flow model needs to be validated. This is accomplished by testing the system with data, which are not used for calibration. The model, is validated with the year 2019 water level data. The observed groundwater levels and those calculated by the calibrated model for the 4 wells as shown in Figure 5.5 gives a very close correlation.

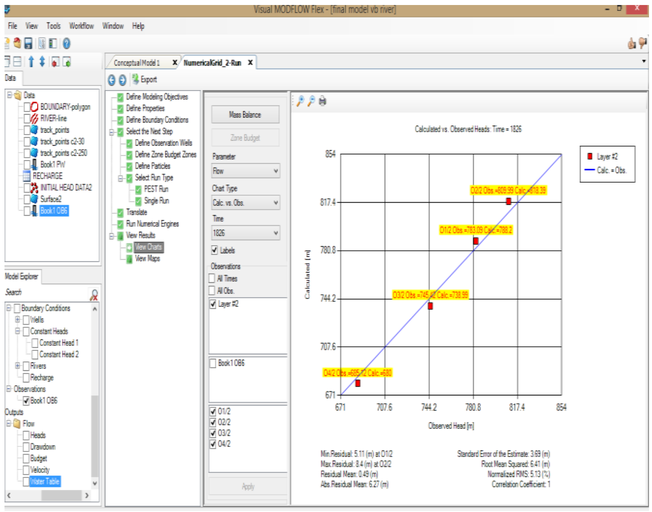

Figure 5.5: Calculated vs observed groundwater level (above MSL) for the year 2019

5.4 MT3DMS

MT3D input

- Initial Concentration: The initial concentration of TDS level for the study area was assigned based on 2014 groundwater quality data. The initial TDS concentration is assigned in terms of polygon ranging. By using copy option, the layer-1 properties are copied to layer-2 where ever applicable.
- Dispersion: longitudinal dispersivity of 30 m and transverse dispersivity of 10 m were uniformly assumed for the entire study area. It was assumed that TDS do not influence the density and viscosity

values which may affect the groundwater flow and pollutant migration.

- Recharge Concentration : In the recharge concentration option, TDS concentration that accompanies the flow boundary is specified in the corresponding flow boundary. Due to rapid urbanization and by considering the rise in the TDS concentration, suitable recharge concentrations were assigned to the model.

MT3D output : MT3D output provides calculated versus observed TDS concentration graph. The calibrated results showing good match for 365 and 1095 days is shown in the figure 5.6 and 5.7 respectively.

After the calibration the model was validated to data observed in the year 2019 and a good match with Root Mean Squared (RMS) value being less than 10 was observed, which is shown in the figure 5.8. Now the model is ready for predictive simulations.

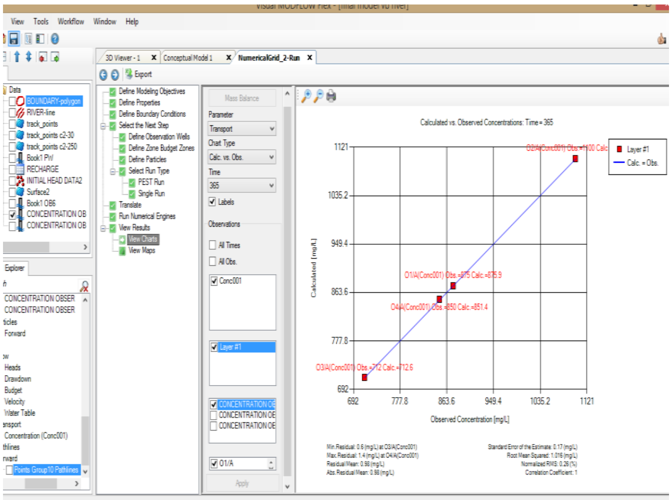

Figure 5.6: Calculated vs observed TDS concentration for the year 2015

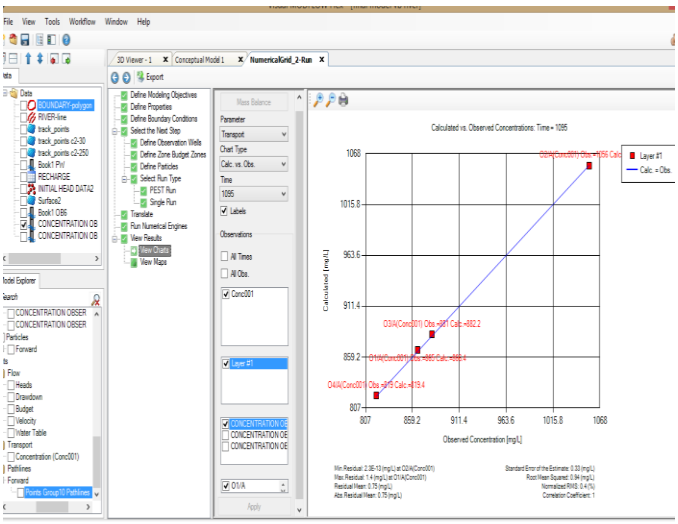

Figure 5.7: Calculated vs observed TDS concentration for the year 2017

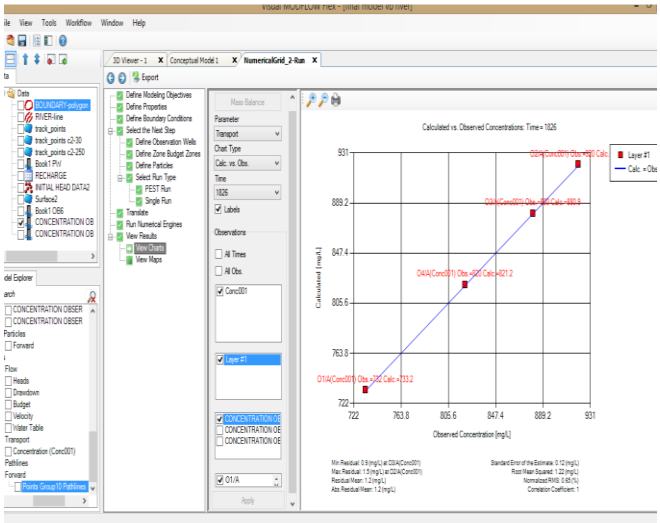

Figure 5.8 : Calculated vs observed TDS concentration for the year 2019

6. Results

The validated MT3D model is used to simulate the TDS concentration in the study area under various conditions. Prediction is done for next 10 years i.e. 2019 to 2029. For model prediction purpose, all four observation wells were considered and predicted for all the three scenarios discussed later. Groundwater flow is towards southwest, in case of any improvement in the river water quality, the impact will be felt in the downstream. The model was run for the following scenarios.

- ✓ If the present scenario i.e river pollution without any control measure continues for next 10 years, what will be the impact on the groundwater quality by the end of year 2029.
- ✓ If control measures are taken, such that the TDS concentration in the effluents received by the tank is reduced to 500mg/l for next 10 years, what will be the impact on the groundwater quality by the end of year 2029.
- ✓ If improved control measures are taken, such that zero discharge is practiced by the industries for the next 10 years, what will be improvement in the groundwater quality by the end of year 2029.

The four observation wells located at Ramasandra, Nagarabhavi, Patangere and Kengeri, for the above three scenarios the forecasting is been present in below figures 6.1,6.2,6.3 and 6.4 respectively.

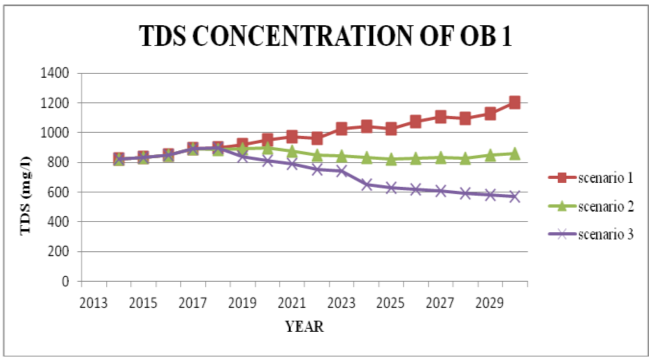

Figure 6.1 : Forecasted values of TDS concentration in groundwater at Ramasandra observation well from year 2019 to 2029 for three different assumed scenarios.

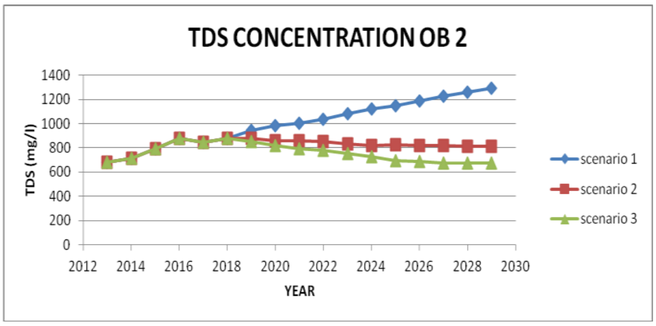

Figure 6.2 : Forecasted values of TDS concentration in groundwater at Nagarabhavi observation well from year 2019 to 2029 for three different assumed scenarios.

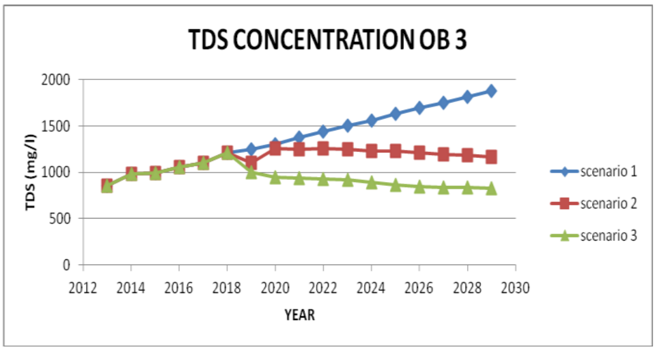

Figure 6.3 : Forecasted values of TDS concentration in groundwater at Patangere observation well from year 2019 to 2029 for three different assumed scenarios.

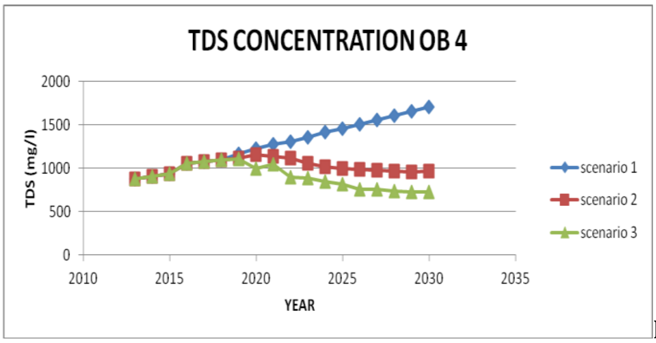

Figure 6.4 : Forecasted values of TDS concentration in groundwater at observation well from year 2019 to 2029 for three different assumed scenarios

7. Conclusions

The following conclusions can be drawn from the study based on the results obtained after simulating the model;

1. From this study, we can conclude that Visual MODFLOW can effectively be used for studying the pollutant migration in a river aquifer interaction. Thus, the role of the water quality models in the field of groundwater quality and pollutant transport in groundwater studies are fully affirmed.

2. The output from MODFLOW, MODPATH and MT3DMS are as follows:

   a. The head (i.e, groundwater level) calibration and validation for all 4 observation wells carried out using MODFLOW, shows a good match between observed values and model calculated values. For instance, in the year 2019, at the observation well located in Ramasandra the groundwater level observed was 783.09m and the model calculated value was 788.2m showing good correlation. The velocity vectors showing the direction of groundwater flow was also obtained from MODFLOW. The direction of groundwater flow is from Northeast to Southwest of the study area.

The particle pathlines have been derived using MODPATH. It was found that the pollutant is moving towards the south direction.

   a. The TDS concentration calibration and validation for all 4 observation wells carried out using MT3DMS, shows a very good match between observed values and model calibrated values. For instance, in the year 2019, at the observation well located at Nagarabhavi the observed TDS concentration was 920mg/l and model calculated value was 922.0mg/l showing a close correlation.

3. The prediction of the model for the three scenarios are as follows:

   a. TDS concentration in the groundwater at the end of 2029 under the present condition i.e. scenario 1 shows that, there is a severe increase in the pollution with the TDS concentration reaching 1210mg/l, 1294.434mg/l, 1879.296mg/l, 1702.363mg/l at Ramasandra, Nagarabhavi, Patangere, and Kengeri observation wells respectively.

   b. TDS concentration in the groundwater at the end of 2029 for scenario 2 i.e., reducing the pollution load and maintaining TDS concentration at 500 mg/l shows that, the pollution with TDS concentration reaching 860mg/l, 810mg/l, 1170mg/l and 967.2mg/l at Ramasandra, Nagarabhavi, Patangere, and Kengeri observation wells respectively .

   c. TDS concentration in the groundwater at the end of 2029 for scenario 3 i.e., the industries practice zero discharge, shows that, the pollution with TDS concentration reduces to 570mg/l, 673mg/l, 830mg/l and 723.5mg/l at Ramasandra, Nagarabhavi, Patangere, and Kengeri observation wells respectively.

3. It can be suggested that with the implementation of various control measures a significant effect on improvement of future groundwater quality maybe obtained.

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