



# Groundwater Modelling Using Visual Modflow in Tirupur Region, Tamilnadu, India

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## ABSTRACT

Most of the textile and dyeing process industries in Tirupur region do not have proper wastewater treatment plants and they discharge the effluents in unlined channels and streams. Due to the issue, the groundwater in Tirupur is highly polluted. For analysing groundwater condition, groundwater modelling is used. For groundwater hydrologist, groundwater models are a vital tool. Nowadays, a lot of computer programs have been used for modelling groundwater. Visual MODFLOW software uses a finite difference method for solving the complexity. They can be used for simulating the behaviour of composite aquifers as well as the effects of irregular boundaries and different processes such as solute transport and groundwater flow. This paper evaluates the impact of industrial effluent in groundwater value in Tirupur region by five different scenarios.

## INTRODUCTION

Groundwater replication is an important assignment in groundwater managing system. Precise simulations of groundwater give information required for managing groundwater resources. A groundwater simulation model, like the modular 3-dimensional model of groundwater flow (MODFLOW) was developed by the United States Geological Survey (Michael et al. 1988). Groundwater modelling is a diplomat scale model of a groundwater aquifer condition which is useful for predicting the effects of hydrological changes such as abstraction of groundwater for irrigation, and industrial development on the performance of the local aquifer (Kujur & Akhtar 2014). Visual MODFLOW is one of the most accepted modelling programs for groundwater in subsistence due to well structure programs, applicable to groundwater modelling and applicable for modifications (Zheng 1990). Simulation of groundwater is an important task in groundwater managing. The parameter of hydraulic conductivity is strongly influencing the simulation of groundwater (Tung et al. 2003).

A systematic understanding of the spatial variation of hydraulic conductivity is useful for constructing an accurate deterministic model of groundwater. The hydraulic conductivity reconstruction field from many experimental

data of hydraulic head raises problem not only about the complexity of the diffusion equation but need to report for physical aspects of the area such as boundary conditions, geology and effective recharge. The reconstruction of the hydraulic conductivity field from numerous experimental hydraulic head data, an inverse problem, raises the issue not only of the complexity of the diffusion equation that links the two variables, but need to account for the physical aspects of the site under study, includes the boundary conditions, the effective recharge, and the geology (Roth et al. 1998). Hydro-geological parameters can be predicted using the methods with trial and error or techniques of optimization (Detwiler et al. 2002, Tung et al. 2002, Abdulla et al. 2000).

Site investigations are indispensable for model development. The outcome consequences depend on the quantity and quality of the data of the area available to define input boundary parameters conditions (Wang & Anderson 1982). Rigorous application of fertilizers and pesticide, industrial effluent and too much groundwater abstraction are few examples of activities that lead to groundwater pollution which have resulted in the deterioration of water resources in various regions (Baalousha 2010). The development of textile industries is seriously vulnerable due to the immense environmental damage caused by the textile processing industries in Tirupur to the Noyyal river and its groundwater system

(Arumugam et al. 2015). The standard for the fundamental hypothesis of the model is the conservation of masses. For the development of models, field investigations are important consequences that depend on the quantity and quality of the available field data to define input parameters and the conditions of the boundary (Kujur & Akhtar 2014). The groundwater and surface water are not a separate mechanism in the water cycle. All the surface water features (estuaries, reservoirs, wetlands and lakes) interact with groundwater. The exchanges take several forms. Surface water contamination can cause the degradation of groundwater features (Dowlatabadi & Zomorodian 2015). The evaluation of groundwater pollution risk requires two important factors, viz. contamination probability and the impact of contamination when a site has a high contamination probability but has a low impact of contamination, the risk is low. However, when both contamination impact and contamination probability are high, the risk is high (Baalousha 2010).

## MATERIALS AND METHODS

The study area is an industrial hub for the textile segment and forms one of the most significant exporting centres of cotton textiles in India. It is characterized by an undulating topography with the height ranging from 290 to 323 meter above the mean sea level and slopes gradually towards east. The geographical extent of the study area is about 450 km<sup>2</sup> and lies between latitudes 11°11'00" N to 11°12'30" N and longitudes 77°13'00" E to 77°30'30" E (Fig. 1). Dendritic drainage pattern has been found. The study area is extracted from the toposheets No.58 E/4 and 58 E/8. The related data are extracted from IRS 1D 23.5m resolution with the aid of Earth Resource Data Analysing System in addition to Arc View GIS 3.2a software. The geomorphologies revealed the

study area is duri crust, shallow buried pediments, pediments, shallow pediments, etc. (Arumugam et al. 2016). The various types of soils are red calcareous, non-calcareous and brown soil. Temperature variation of the study region ranges from 19°C to 38°C and receive scanty rains due to the leeward side of the Western Ghats with the annual average rainfall of 650 mm.

Land use and land cover maps are considered as an essential component for modelling and considerate the earth as a system. Land cover maps are currently being developed from national to global scales. Satellite imagery (IRS 1D 23.5m) has been utilized for mapping of land use/land cover. Due to fast textile industrialization/dyeing activities in Tirupur region, the discharge of industrial effluent is speedily increasing. Most of the effluents discharged in the region are untreated with high concentrated physico-chemical parameters. They are directly affecting the quality of groundwater in the study area. The scope of the investigation is to analyze the impact of industrial effluent to groundwater quality level by five different scenarios. The steps involved to carry out the analysis are:

- Sample collection and analysing the observation well-head measurement data, meteorological information, geological data, quality measurement statistics, pumping data and digital map for the region.
- Determining the horizontal movement of groundwater with the help of the developed regional groundwater model through fixing the proper boundary condition and the parameter optimization.
- Predicting the quality of groundwater for the forthcoming years by using visual MODFLOW software in different scenarios.

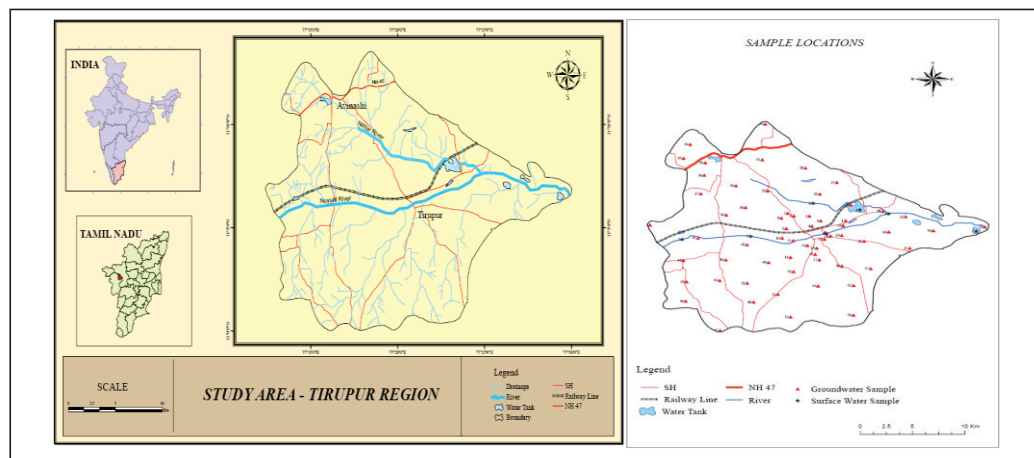


Fig. 1: Location of the study area.

**Aquifer parameters:** The aquifer properties such as transmissivity (T), horizontal hydraulic conductivity ( $k_h$ ) and well yield was composed in the vicinity of the study region. The aquifer thickness, weathered and fractured zone in the study varies from 10 to 30 m below the ground. The level of groundwater reaches the lowest in the location, during summer season after which it starts increasing to reach the highest peak, after the end of the winter season. The rise and fall of the groundwater level depend upon the duration, quantity and intensity of precipitation, depth of weathered rocks, and specific yield of the bedrock and the wide-ranging of the slope of the fresh rock formation towards the drainage conduit.

MODFLOW is a computer program which is originally developed by the U.S. Geological Survey that simulates three-dimensional groundwater flow using a finite difference method. The MODFLOW 4.2 was used here. The partial differential equation of groundwater flow (McDonald & Harbaugh 1988) used in MODFLOW is as given below.

$$\frac{\partial}{\partial x} \left( K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz} \frac{\partial h}{\partial z} \right) - W = S_s \frac{\partial h}{\partial t}$$

Where,  $K_{xx}$ ,  $K_{yy}$  and  $K_{zz}$  are hydraulic conductivity values along the x, y and z coordinate axis which are assumed to be parallel to the major axis of hydraulic conductivity ( $Lt^{-1}$ ), while  $h$  is the potentiometric head (L).  $W$  is a volumetric flux per unit volume that represents sources and sinks of water ( $t^{-1}$ ),  $t$  is the time, and  $S_s$  the specific storage of the permeable material ( $L^{-1}$ ).

**Solute transport equation and model boundary conditions:** The equation represents the associate/movement of the flux of solute mass through the control volume. This states that the summation of all the mass, which consumes or else creates solute with the volume. They must be equal to a change in the reflection of the solute with the control volume.

$$\frac{\partial C}{\partial t} = \left[ \frac{\partial}{\partial x} \left( D_x \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left( D_y \frac{\partial C}{\partial y} \right) + \frac{\partial}{\partial z} \left( D_z \frac{\partial C}{\partial z} \right) \right] + \left[ \frac{\partial}{\partial x} (V_x C) + \frac{\partial}{\partial y} (V_y C) + \frac{\partial}{\partial z} (V_z C) \right] \quad \dots(2)$$

Where,  $V_x$ ,  $V_y$ , and  $V_z$  are seepage velocity in x, y and z direction, m/s ( $Lt^{-1}$ ),  $D_x$ ,  $D_y$  and  $D_z$  are dispersion coefficient  $m^2/sec$  ( $L^2T^{-1}$ ),  $t$  is time in seconds (T) and  $C$  is solute concentration  $mg/m^3$  ( $ML^{-3}$ ). Visual MODFLOW provides contaminant transport modelling and three-dimensional groundwater flow using MT3DMS, MODPATH and RT3D. It involves property and boundary conditions, the graphic design of the model grid, run the groundwater flow visualize mode, path-line and contaminant transport simulations, parameter estimation technique Win PEST, display and interpretation of model output manual method of calibration, in 3D space.

**Model formulation and grid design:** The conceptual model of the hydrogeologic structure was derived from the comprehensive study of the borehole lithology, geology, and fluctuations of water level from the study wells (Fig. 2). The model grid covering  $450 km^2$  was discretized into cells (80 rows  $\times$  80 columns (Fig. 3) and three upright layers based on lithology.

The aquifer top and bottom were derived from the lithology of boreholes. The vicinity of one grid is equal to  $0.07 km^2$ . The upright cross-section of the system next to 29<sup>th</sup> row and 33<sup>rd</sup> column are revealed in Fig. 4 and Fig. 5 respectively. The depth of the topsoil stratum varies from 0-14 m, the lower partly weathered rock bed varies from 0-37 m and the bottom rock vary from 0-71 m.

**Model boundary conditions:** The study region consists of river (Noyyal) boundary at the middle intersected by its tributaries and is surrounded by the variable head boundary (study wells). The boundary of the river is assigned in the top cover based on the river point and river bottom in the region, both in starting and end points, are entered. The var-

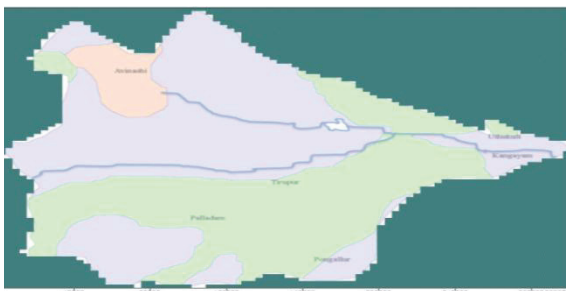


Fig. 2: Model formulated of the study area.

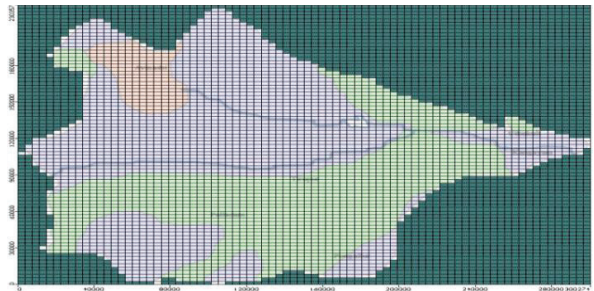


Fig. 3: Discretization of the study area.



iable head boundary is predetermined based on the monthly water level data collected (2014 to 2018) from PWD. 700 mm/yr is assigned as recharge for the entire top stratum of the model and 180 mm/yr is assigned as evapotranspiration. The control of river water level is restricted to 4 km around the location. As a result, the effective cell is taken within the river boundary and linking all the observation wells and pumping wells (Fig. 6).

**Initial head and concentration:** The initial head value at

the initial stress period from the study wells around the study area was taken for the simulation purpose. The initial head for the different grids in the study area is revealed (Fig. 7).

Parameter concentrations at the initial stress period from the observation wells in the study area are accounted for as an initial concentration head for simulation (Fig. 8).

The recharge concentration of parameters is assigned in the study region based on point of injection of effluents from the industries after the treatment from a common ef-

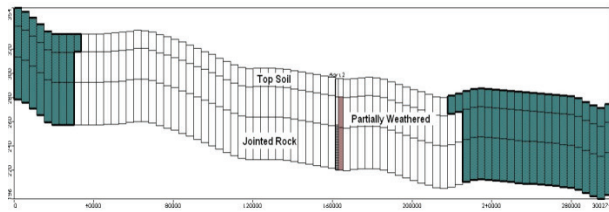


Fig. 4: Cross-section along the 29<sup>th</sup> row.

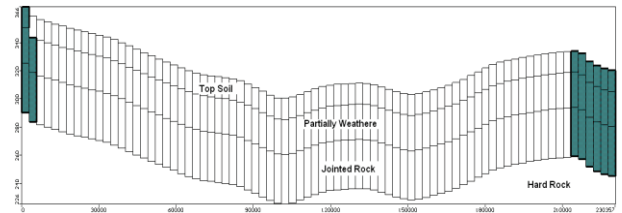


Fig. 5: Cross-section along the 33<sup>rd</sup> column.

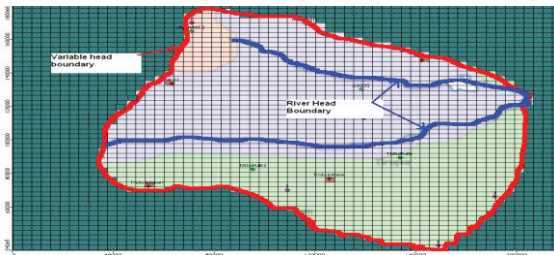


Fig. 6: Model boundary conditions of the study area.

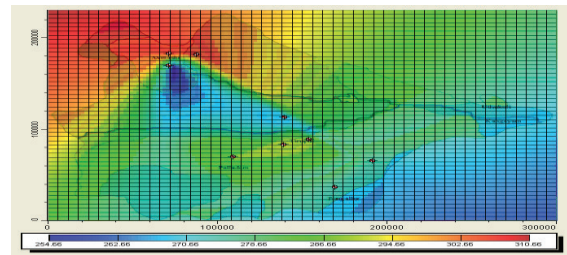
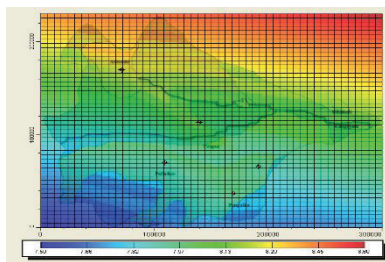
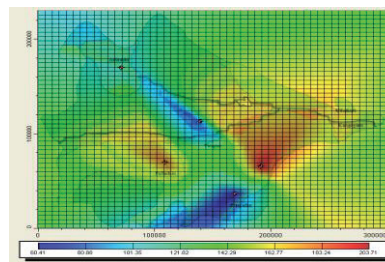


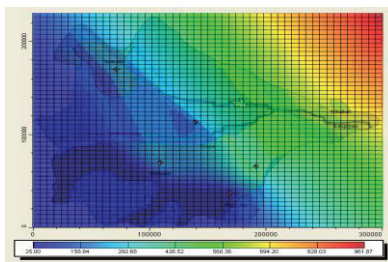
Fig.7: Initial water level head for the study area.



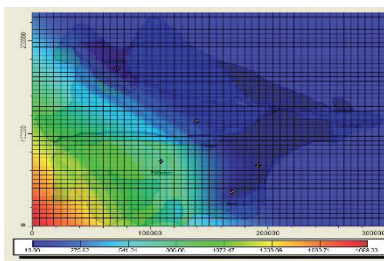
a) pH



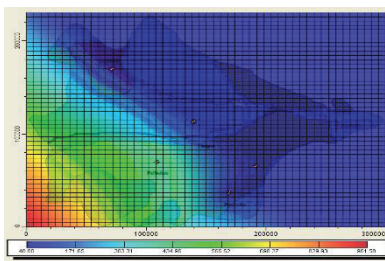
b) Mg



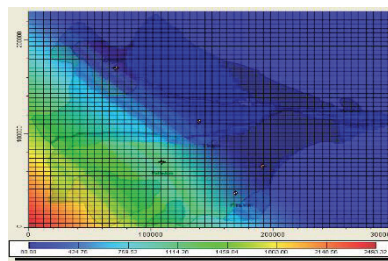
c) NO<sub>3</sub>



d) K



e) Ca



f) Na

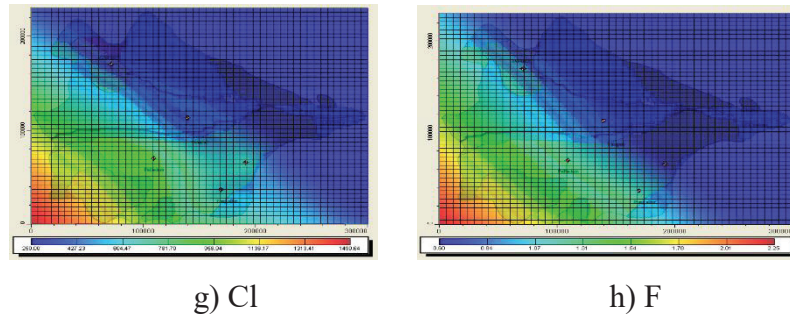


Fig. 8: Initial concentration level for the study area.

fluent treatment plant. Particles are assigned to obtain the pathway from the point of injection. Dispersion coefficient is assigned for both the longitudinal and the layer boundary for the total model.

**Model calibration:** The calibration of groundwater is accomplished by a trial and error modification of the model input data to adjust the model output. The Win PEST provides automotive calibration progression by adopting the prediction factor such as recharge parameters, conductivity and specific yield. The calibration is done for the model data from 2014 to 2018. They are illustrated in Figs. 9 -14.

The reaction of groundwater from the different observation wells in the model calibration and the response of the concentration stage (pH, Mg, NO<sub>3</sub>, K, Ca, Na, Cl and F) from

the observation wells in the model calibration and validation have been done for the wells 1 to 5.

**Model validation:** The model validation periods were done for the periods from 2014 to 2018 (Fig. 15). The concert of the model acceptably predicts the exact aquifer state and reflects the same as in groundwater point and their concentration. As a result, the present model is appropriate for predicting and forecasting the groundwater eminence for the scenarios.

## RESULTS AND DISCUSSION

**Groundwater quality scenarios:** The validated model is used for predicting the groundwater quality for ten years (2021 to 2030) for the subsequent five different scenarios

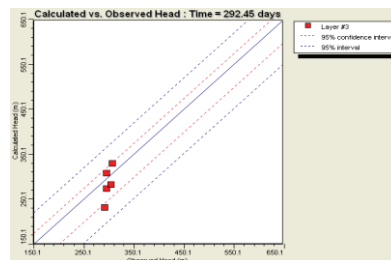


Fig. 9: Predicted head and observed- calibrated on 292<sup>nd</sup> day.

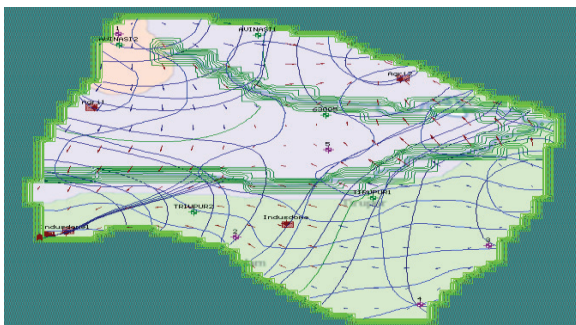


Fig. 10: Model output under steady simulation.

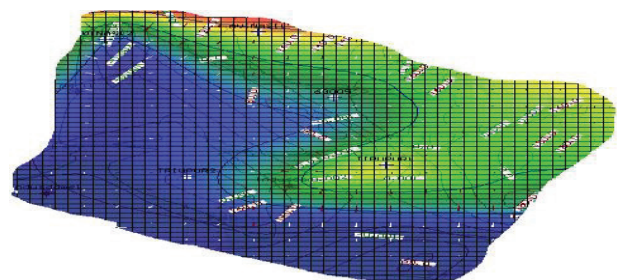


Fig. 11: Model output responses to head level.

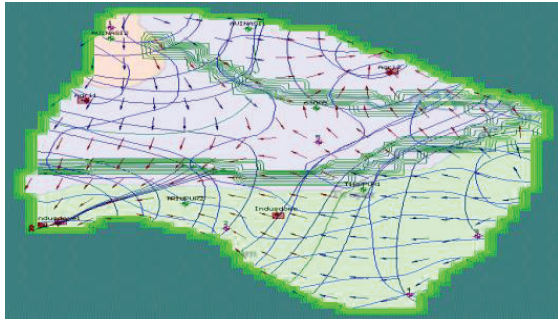


Fig. 12: Model output responses to velocity head.

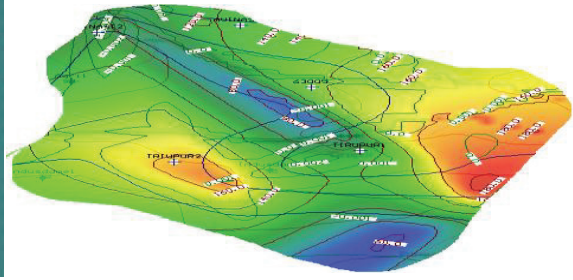


Fig. 13: Model output concentration in the top layer.

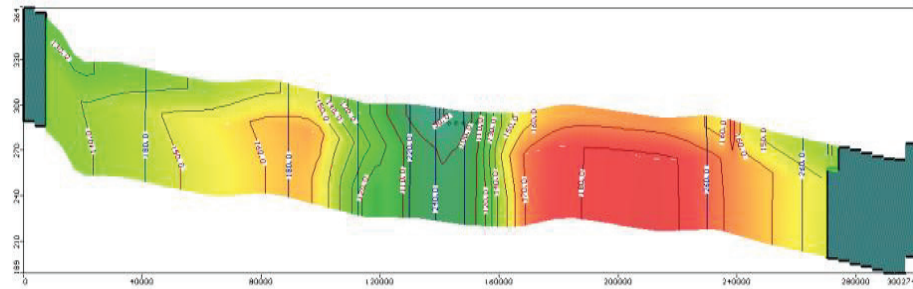


Fig. 14: Model output response to concentration level.

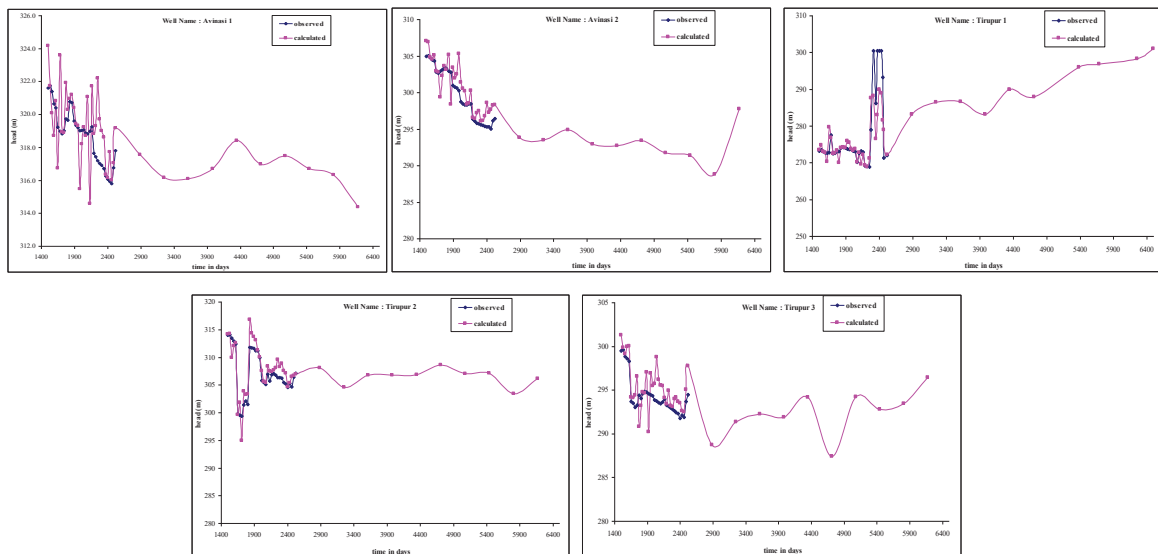


Fig. 15: Response of the groundwater level at diverse observation wells during the validation phase.

namely: The constant level of pumping and the discharge of effluent are same (Scenario number: 1); The pumping rate is reduced using 20 per cent and the discharge of effluent is in the same level (Scenario number: 2); the same level of pumping rate is continued and the discharge of effluent is condensed to 20 % (Scenario number: 3); The same level

of pumping rate is continued and the discharge of effluent is reduced to 50 % (Scenario number: 4) and the same level of pumping rate is continued and the discharge of effluent reduced to 100 % (Scenario number: 5). The five different scenarios and their results regarding the observation wells are illustrated in Figs. 16 to 22.



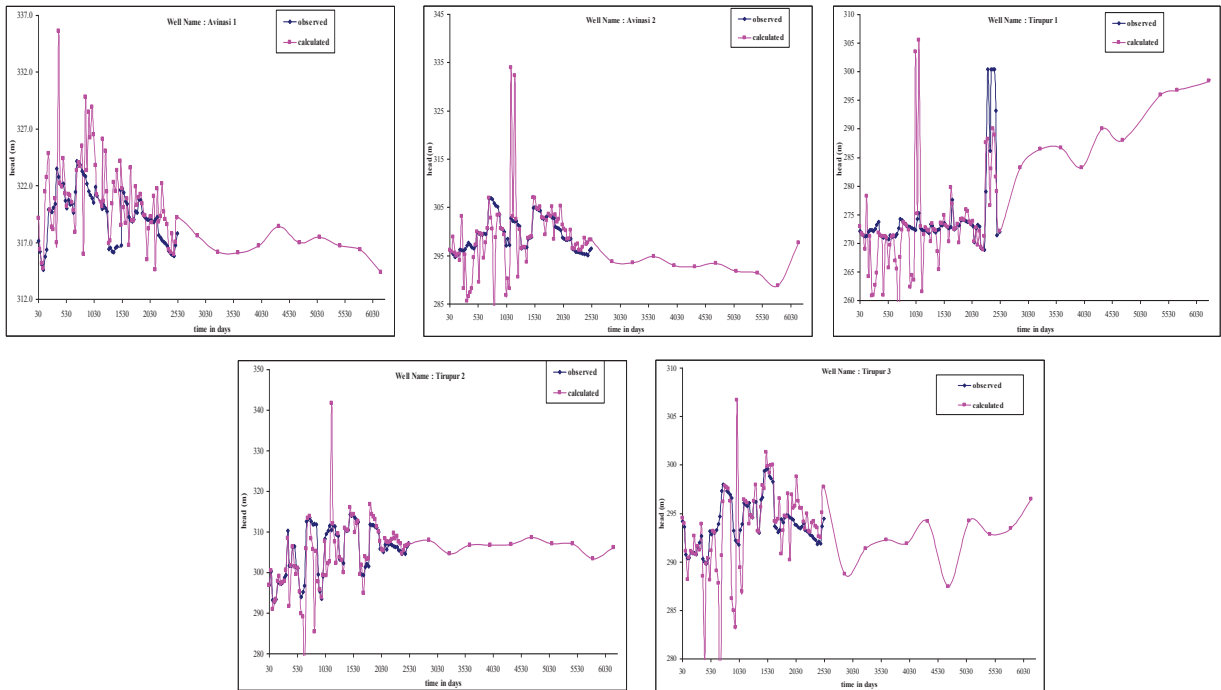


Fig. 16: Groundwater level at different study wells for the scenarios at a constant pumping rate.

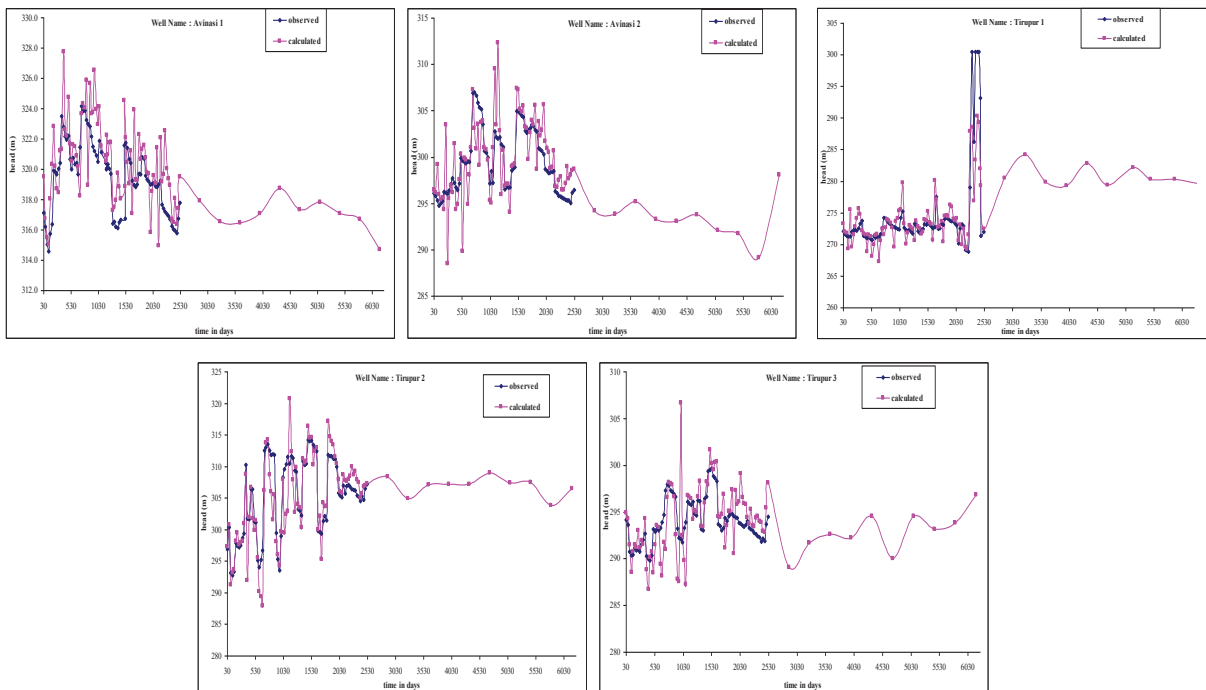


Fig. 17: Groundwater level at observation wells for scenario 2.

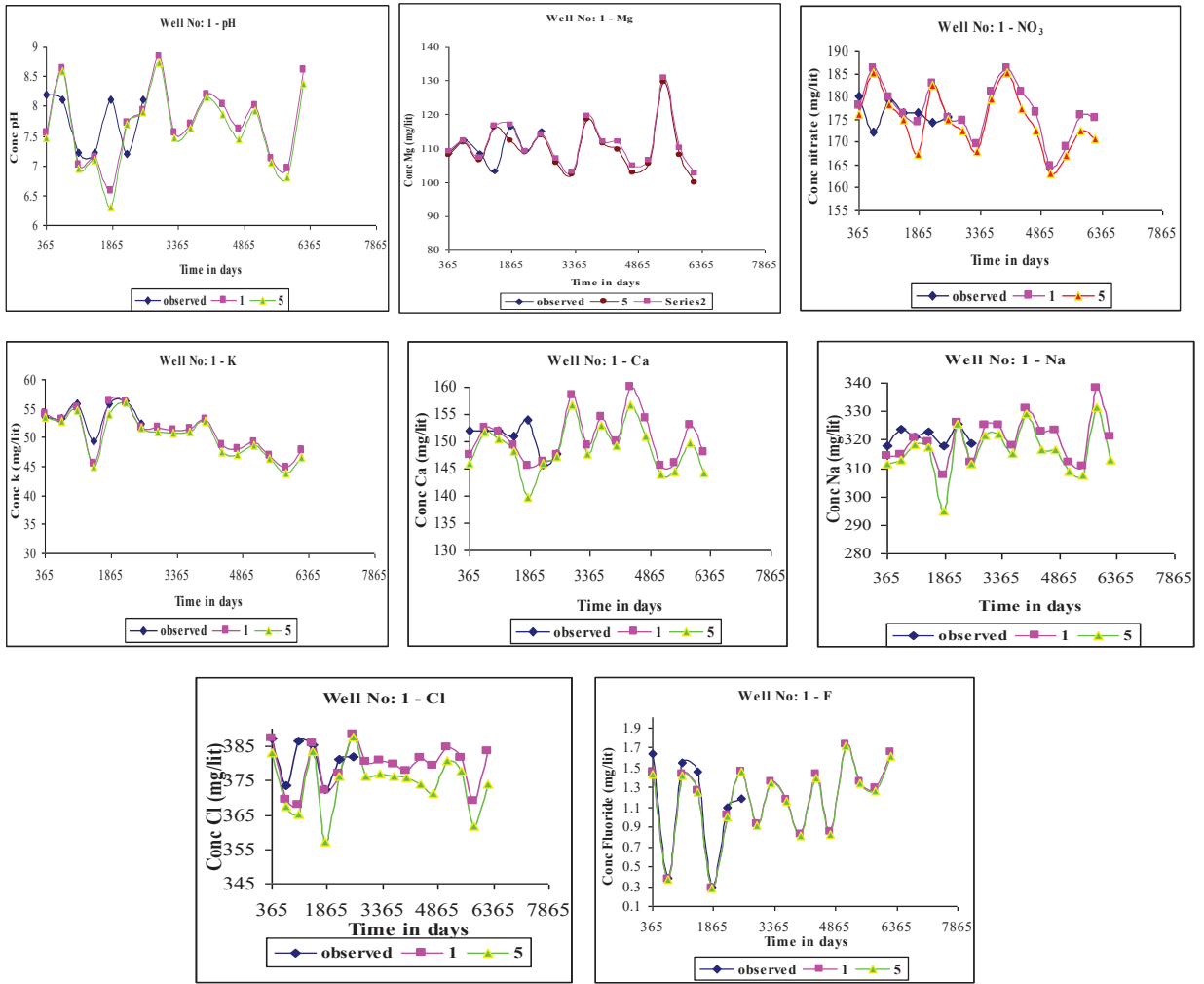


Fig. 18: Responses to concentration level at observation well number 1, for the scenarios 1 and 5.

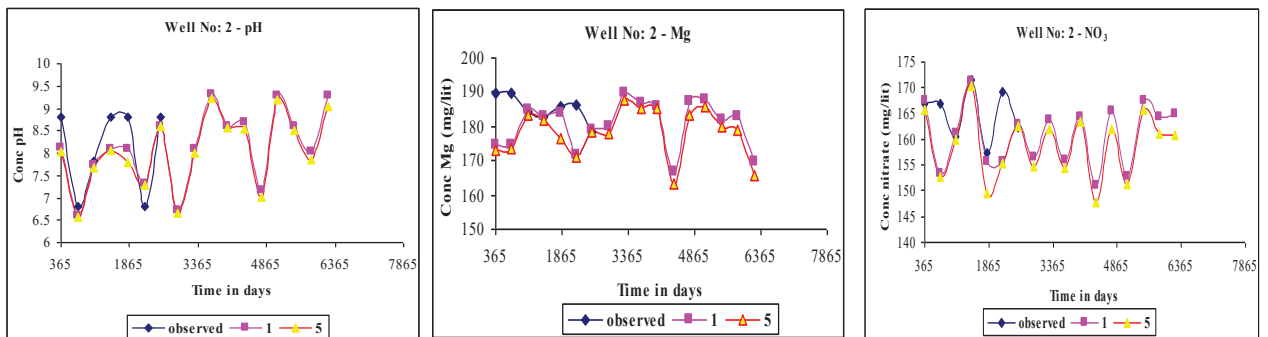


Fig. 19 Cont....



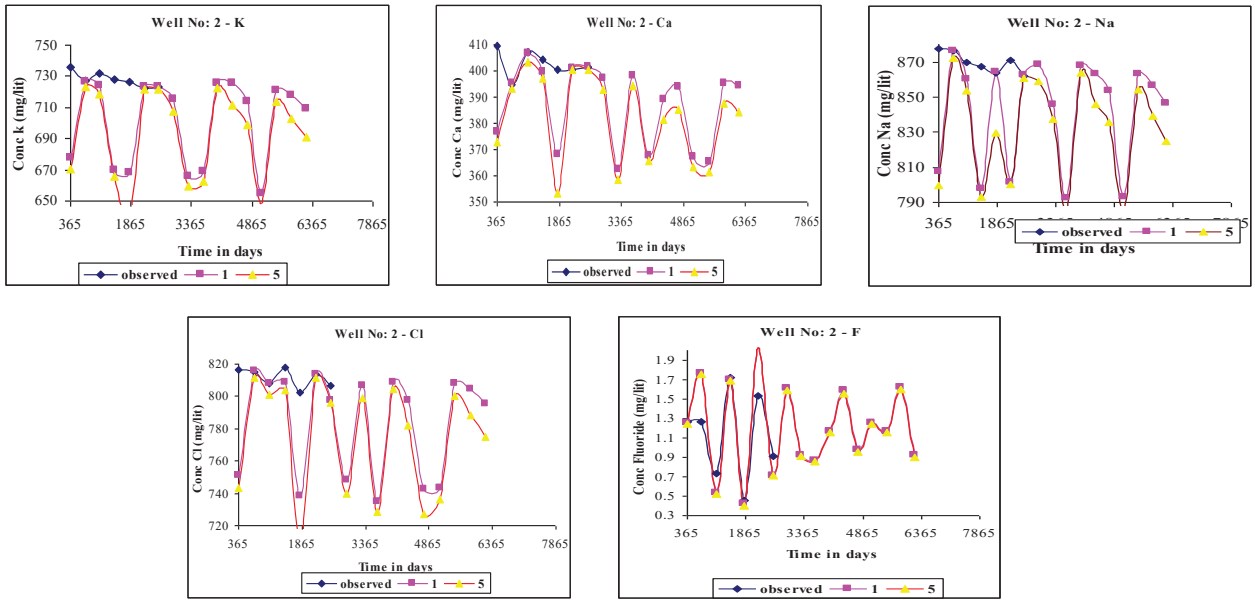


Fig. 19: Responses to concentration level at observation well number 2, for scenarios 1 and 5.

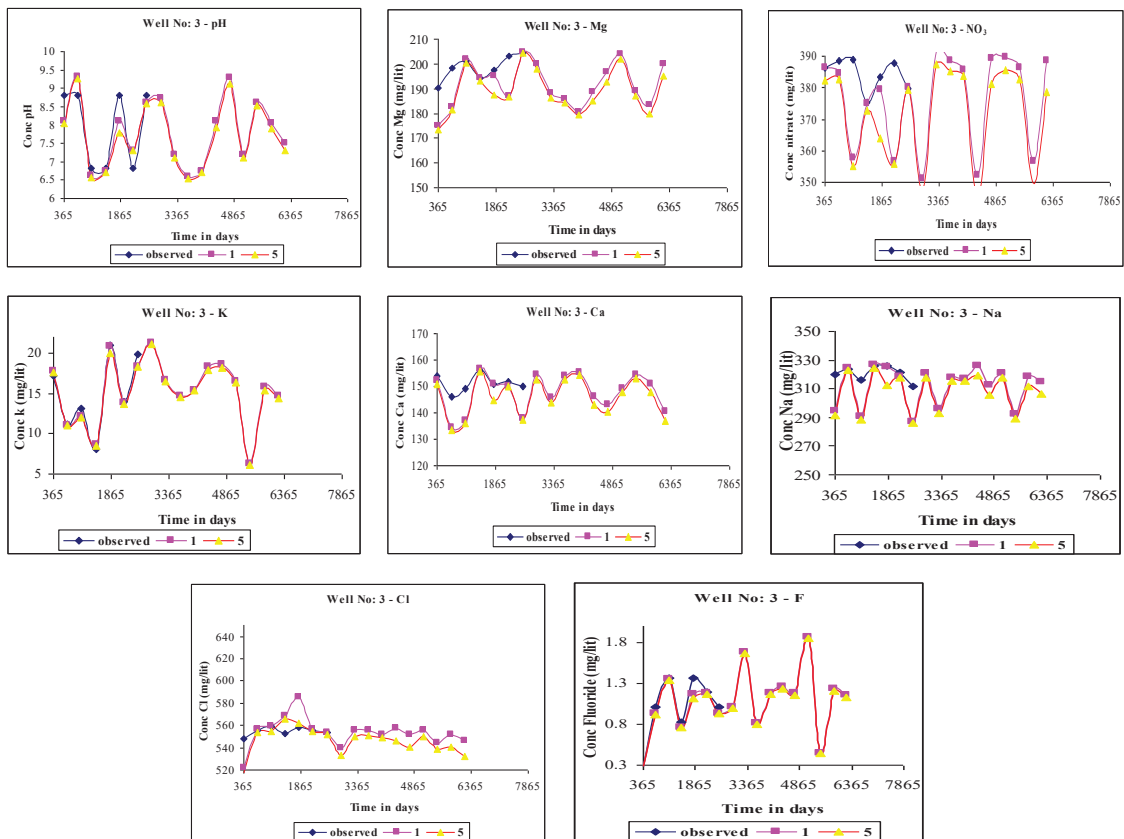


Fig. 20: Responses to concentration level at observation well number 3, for scenarios 1 and 5.

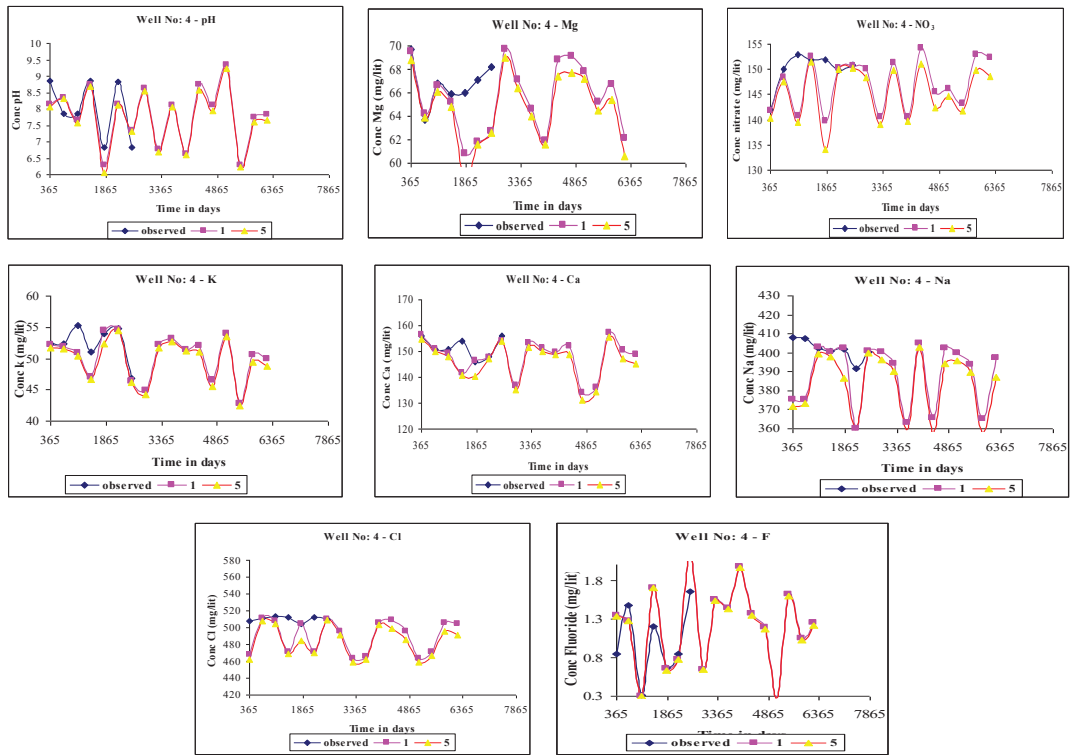


Fig. 21: Responses to concentration level at observation well number 4, for scenarios 1 and 5.

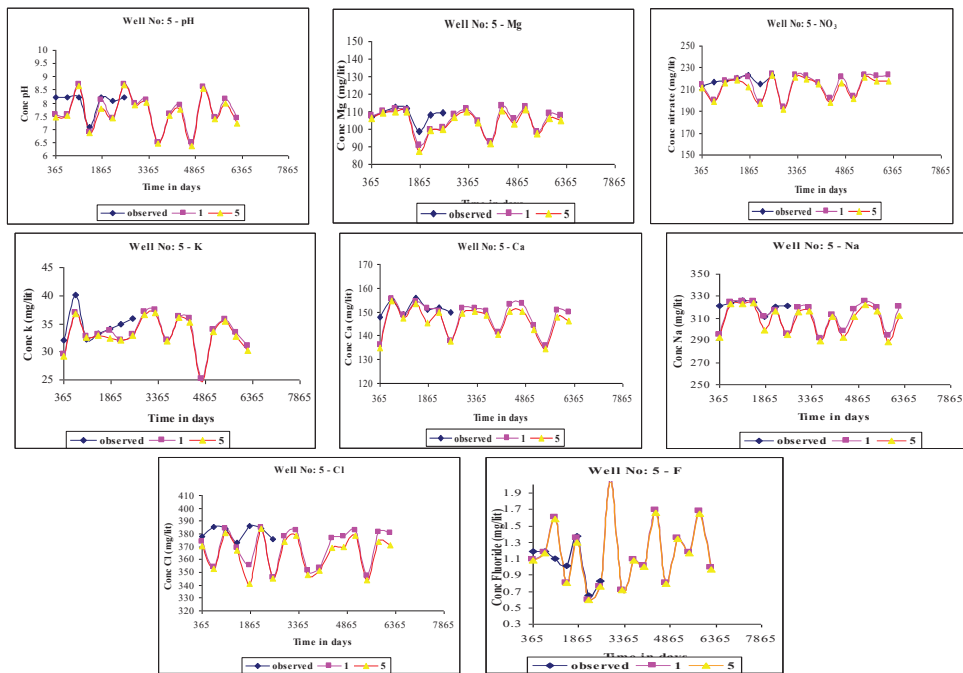


Fig. 22: Responses to concentration level at observation well number 5, for the scenario1 and 5.

The groundwater level is not much disturbed owed to different scenarios except scenario 2, in which the pumping velocity is condensed by 20 per cent results in the elevation of the groundwater level in all the observation wells. The forecasted groundwater level too reflects the same trend of water level for the data of the past seven years.

## CONCLUSION

The model response to scenario 1 for water quality forecasting for the next ten years from 2021 to 2030 indicates the real risk in the groundwater quality. Unfortunately, it is not suitable for both domestic and irrigation purposes. Uniform nature of the trend is followed in all the observation wells. The model exactly predicted the quality level in the well 1, 2 and 5 satisfactorily. In the wells 3 and 4, the model response to scenario 2 to 4 is very negligible. So, the exact value is much less comparing to the previous scenario. It indicates that the present condition in the Noyyal River does not change by reducing the concentration to some percentage. The model response to scenario 5 is negligible. Less than 2% reduction is observed in the wells 1, 2 and 5. In the wells 3 and 4, there is less than 0.5% change in concentration level. It is concluded that the present condition in Tirupur region will change if there is no injection of industrial effluent.

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