Aquifer vulnerability assessment of Eloor Municipality using Solute Transport Model

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ABSTRACT

Eloor Municipality is the industrial hub of Ernakulam District, Kerala. It is an island formed between two tributaries of Periyar.Groundwater quality of this area is getting deteriorated due to the effect of various industrial pollutants. This study is an attempt to assess the vulnerability of Aquifer in Eloor industrial belt using Visual Modflow and MT3DMS. Total Dissolved Solids (TDS) were taken as an indication to pollution and well samples were tested for the same. A point source of pollution was identified and TDS value of the source was determined through field investigation.Most of the industries discharge effluents directly into periyar and hence the TDS concentration of at different sampling points were also considered for Modelling. Solute Transport Model was formed using MT3DMS and Modflow. By simulating the groundwater flow and solute transport of Total Dissolved Solids in Eloor municipality, vulnerability assessment of the aquifer was carried out.The solute transport model was predicted for 20 years and parts of the study area which are under risk were identified.

Keywords: Solute Transport Modelling, Visual Modflow, MT3DMS, Aquifer Vulnerability, TDS.

I. INTRODUCTION

Water is the most important natural resource which is vital for all forms of life on earth. Tremendous increase in the agricultural, industrial and domestic activities in recent years has increased the demand for good quality water to meet the growing needs. Groundwater is mostly preferred to meet this growing demand because of its lower level of contamination and wider distribution. Groundwater is becoming an increasingly essential resource in this world with diminishing freshwater supplies. Groundwater supplies are frequently contaminated by a variety of human activities associated with cities, industry, and agriculture. While prevention of groundwater contamination is preferable, groundwater treatment techniques are necessary for the remediation of current hazardous waste sites and for sites that will become contaminated in the future. Among the various problems associated with groundwater, pollution is a serious and severe threat to society. Pollution of groundwater due to infiltration of industrial effluents has been a serious issue in many industrial areas. In areas where zoning is missing and people are bound to live around industries, these industrial pollutions pose to be a threat to human health and life. When hazardous wastes from industries are not treated and disposed properly, these contaminants can eventually make their way down through the soil and into the groundwater. [1][2]

Groundwater models describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock within the aquifer, the contaminant transport mechanisms and chemical reactions. Because of the simplifying assumptions embedded in the mathematical equations and the many uncertainties in the values of data required by the model, a model must be viewed as an approximation and not an exact duplication of field conditions. Groundwater models, however, even as approximations, are a useful investigation tool that groundwater hydrologists may use for a number of applications.[1][3]

II. STUDY AREA

The area of study is Eloor Municipality in Ernakulam which is a part of The Greater Kochi Area (GKA) which ranks 24th (with CEPI score of 75.08) amongst the critically polluted areas (CPA) in the country. [1]Eloor, the industrial hub of Kerala, is an island spread over an area of 14.21 km^2 as shown in Fig 3.1, located in Ernakulam district, between north latitudes 9º 3´ and 10º 6´ and east longitudes 76º 20´ and 76º 28´. Eloor was formed between two distributaries of river Periyar and houses more than 247 industries of different kinds. It is also rated as one of the toxic hotspots of the world by Green Peace International.[1]

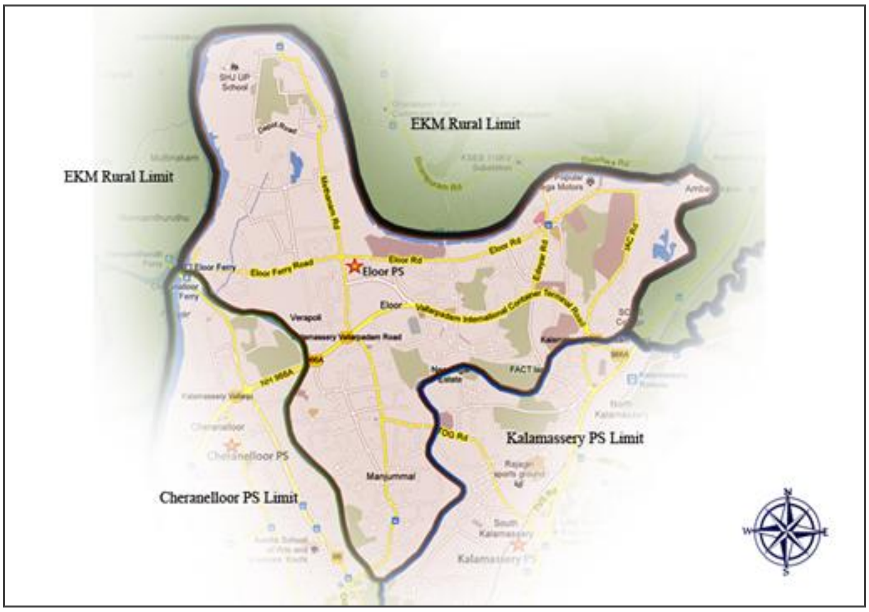

Fig.1 Administrative boundary of Eloor Municipality

III. METHODOLOGY

3.1Groundwater Flow Modelling

Modelling environment chosen for the flow modelling process was Visual MODFLOW. MODFLOW is a computer program that numerically solves groundwater flow equation for a porous medium by using finite difference method. The program also combines extensions such as MT3DMS (Mass transport 3D multi species), MODPATH, ZONE BUDGET etc.

Defining grid cells was done for discretizing the model using finite difference method. The finite difference method involves fitting the conceptual model to one or more finite difference grids. Flow equation for each of the grid cells will be solved by MODFLOW solver, thus delineating the flow direction.The site map of the study area was inserted as model domain. Finite difference grid cells were developed by dividing the model domain into 50 rows and 50 columns. Refining the grid cells was done in the areas of interest by increasing number of rows and columns. The reason for refining the grid was to get more detailed simulation in the area of interest. [4]

The study area was bounded by Periyar river. The grid cells which are outside the river boundary were treated as 'inactive' or 'no flow' cells. These inactive grid cells were ignored by the model and were not used in any of the calculations of flow, particle tracking or contaminant transport. Fig 2 shows active and inactive cells.

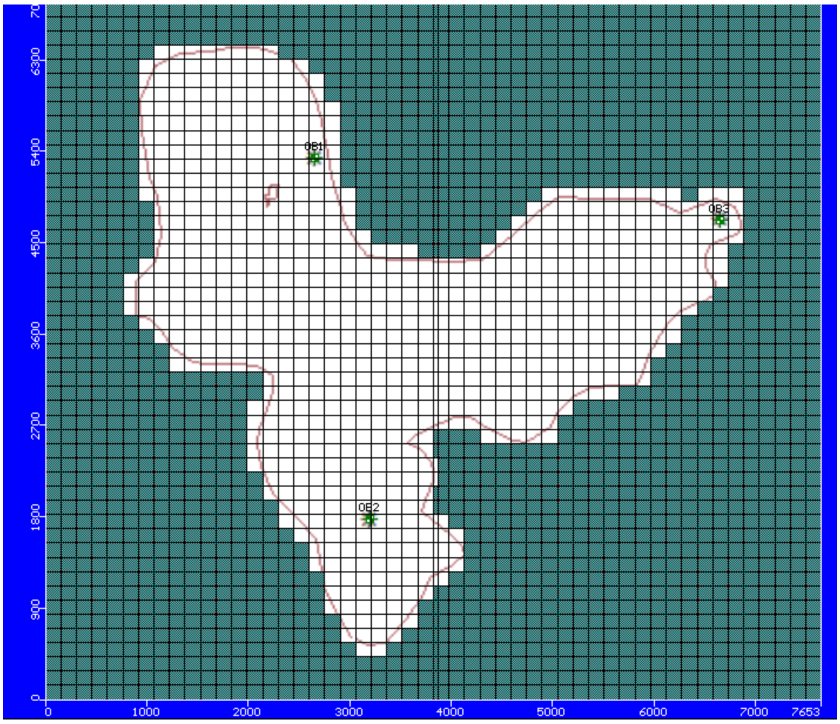

Fig 2: Grid Design

In Visual MODFLOW hydrogeological and hydrochemical characteristics of the model are classified as flow properties and transport properties. Flow properties include conductivity, storage, initial head and vadose zone. Conductivity values were assigned, which can be altered later in calibration stage. It was assumed hydraulic conductivity in x and y direction to be equal .The constant value property zone approach was used for the modeling process. It requires the development of conceptual model, whereby each hydrostratigraphic unit of the model was assigned a uniform set of property values.[5]

Every model requires appropriate set of boundary conditions to represent the system's relationship with the surrounding systems. In groundwater flow boundary conditions will describe the exchange of flow between the model and the external system. Boundary conditions applied to the model were recharge boundary conditions, river boundary conditions and general head boundary conditions. Recharge boundary condition was typically used to simulate surficially distributed recharge to the groundwater system. Here recharge was given as precipitation that is percolating into the groundwater system. Recharge value was taken as 10% of monthly rainfall. Seasonal recharge was entered by changing the start time and stop time. Since natural recharge enters the groundwater system through ground surface, the recharge values were assigned to Surface layer.River

ISBN: 978-93-86171-56-6

boundary condition was applied to the boundary line of study area. River boundary condition was used to simulate the influence of a surface water body on groundwater flow. [6]

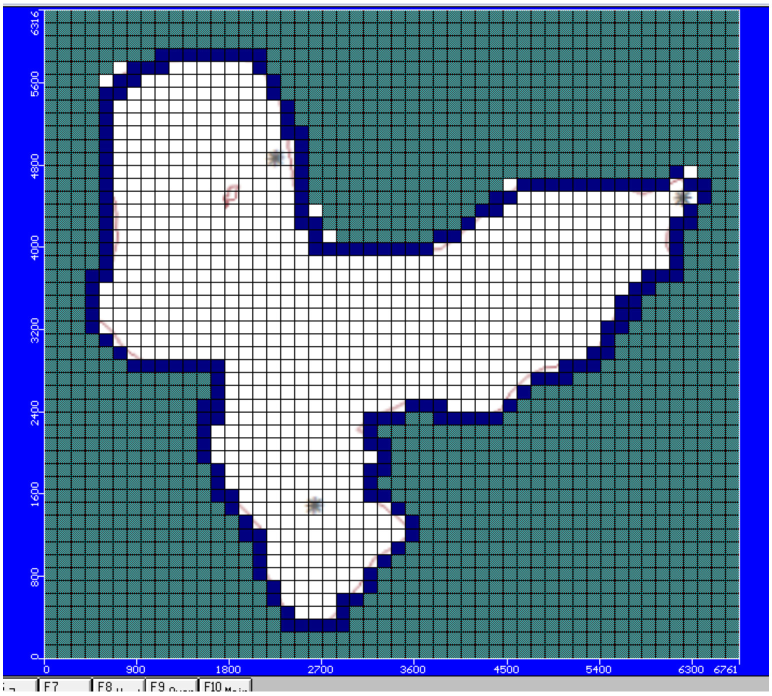

Fig 3: River Boundary

Observation Well Data for 10 years were imported to Modflow. 3 observation wells were considered. Data was obtained from CGWB Trivandrum.

3.2Solute Transport Modelling

Field visits to the study area was done a number of times to identify a point source and to study the effect of pollution. 20 well samples were collected from various parts of Eloor municipality and was tested for Total Dissolved Solids (TDS) using a TDS meter. Fig 4 shows a sampling well and testing of well sample using TDS Meter.

Fig 4 : Testing Well sample for TDS

Contours of concentration for TDS were prepared using ArcGIS. The interpolation was done by inverse distance weighted (IDW) interpolation method. The latitude- longitude values of the sampling locations and the concentration of TDS in the samples were provided as inputs for the contour preparation. Fig 5 shows concentration contour map prepared using ArcGIS.

Acceptable limit of TDS according to IS 10500 - 2012 is 500 mg/l. By comparing the TDS contours with the Ward map (Fig 6) obtained from Eloor municipality office, it was seen that ward number 6 is having undesirable concentration of TDS in its wells.

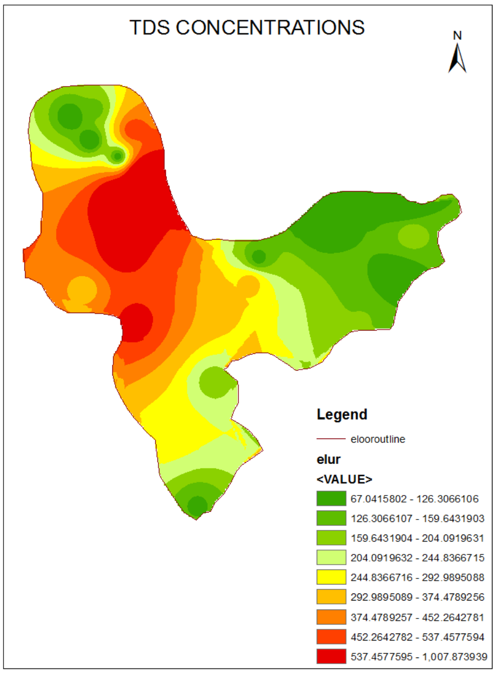

Fig 5 :TDS concentration contour

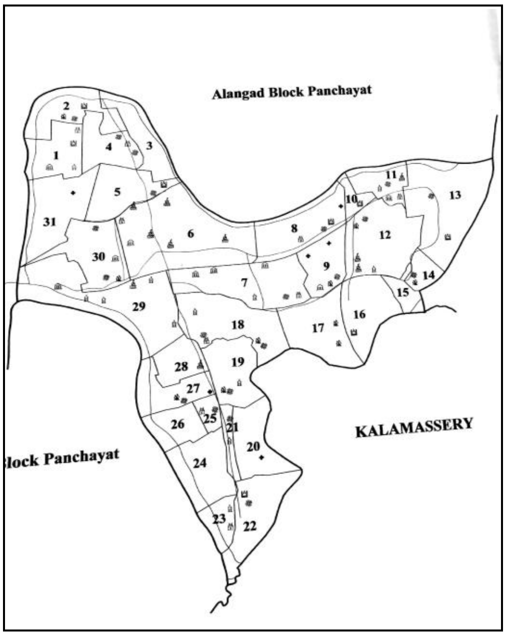

Fig 6 : Ward map of Eloor Municipality

From Water quality analysis it was found that ward number 6 named "Head quarters" is the most polluted. So the field investigation was concentrated to this ward. The ward houses maximum number of industries including

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large scale industries such as FACT (Fertilizers and chemicals Travancore) and HIL (Hindustan insecticides limited). Through site investigation and information from local people it was found that a part of effluent from HIL was discharged through a creek to a nearby paddy field. Fig 7 shows the creek starting from underneath of the compound wall of HILdischarging into paddy field and Fig 8 shows the waste disposed and effluent spread over the paddy field. From local people it was understood that this paddy field was under cultivation years back before these companies came into existence.

Fig 7 : Start of creek

Fig **8** : Paddy Field with Effluent

TDS was measured using samples from 3 points. One at the start of the creek and 2 others at the 2 ends of paddy field. The average of three values was found as 3480 ppm (or mg/l) . This value was used as initial concentration to start solute transport modelling. **S**ince most of the industries discharge their effluents directly into periyar, the TDS concentration at different discharge locations in the river was also needed for the study. It was obtained from a study titled "An Assessment of Water Quality in River Periyar, Kerala, South India Using Water Quality Index" [7] . Fig 5.9 shows the sampling points the author have considered for study. The average values of TDS for a period of one year was obtained from this reference which was sufficient for river concentration input. The TDS values at different sampling points ranged from 356 mg/l to 5560 mg/l. considering these initial concentration and dispersion coefficients along with flow model inputs, solute transport modelling was carried out using MT3DMS.

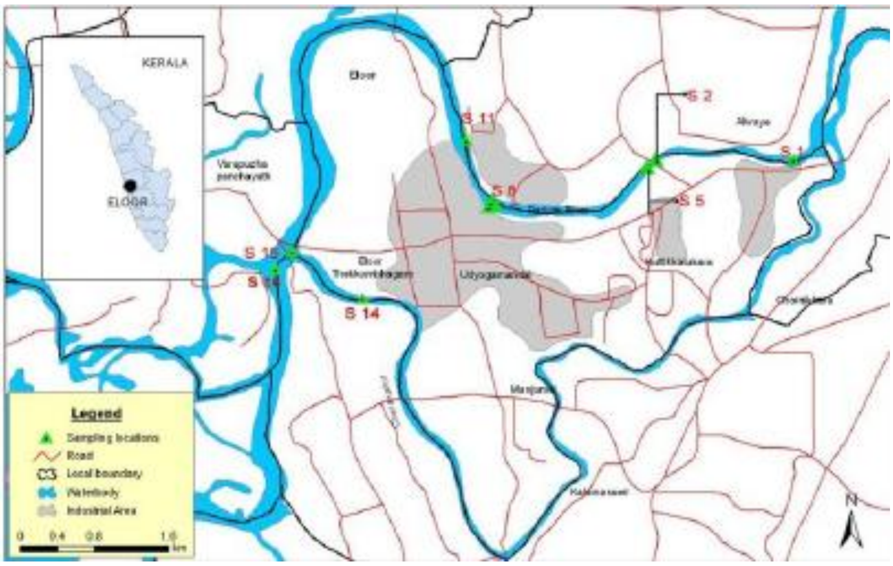

Fig 9 : Map showing sampling locations in Periyar [7]

IV RESULTS AND DISCUSSIONS

4.1 Groundwater Flow Modelling

Groundwater flow model was run in steady state and transient state and calibration and validation was done.Water table elevation data taken from 3 observation wells in the site were used for the calibration process. Calibration was done by trial and error adjustment of input parameters such as hydraulic conductivity and recharge until the observed values reasonably matches with the calculated values.

After 10 year calibration using observation well data from 2003 to 2013, the model was validated observation well data of year 2014 and 2015. Calibration and validation plot for all the time steps for all the three observation wells is shown in fig 10. The plot between observed and calculated head showed close relation at all time steps. Hence the model was proved valid.

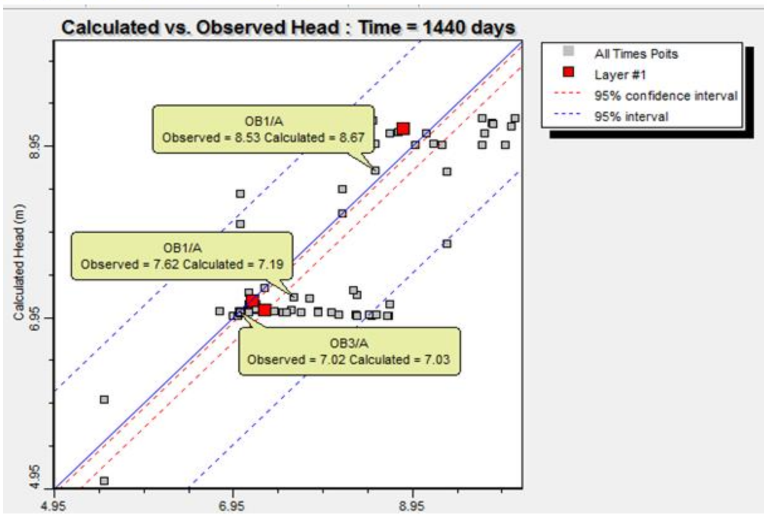

Fig 12: Head Calibration at all time steps

4.1.2 Water table and flow direction

Water table elevation was obtained as shown in fig 11. Water table depth contour is a line passing through points of equal water table depth. It showed a maximum depth of 10.1 m and minimum depth of 0 m below ground level.

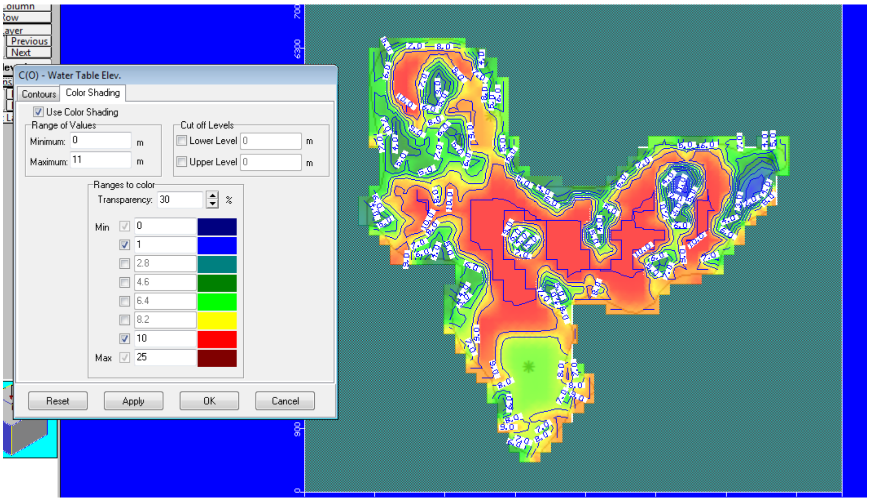

Fig 11 : Water table contour

Flow directions were obtained as shown in figure 1. Flow direction indicates the direction in which groundwater flows. The arrow head indicates the direction and the length of arrow represents the velocity. Longer the arrow higher will be the velocity.

ISBN: 978-93-86171-56-6

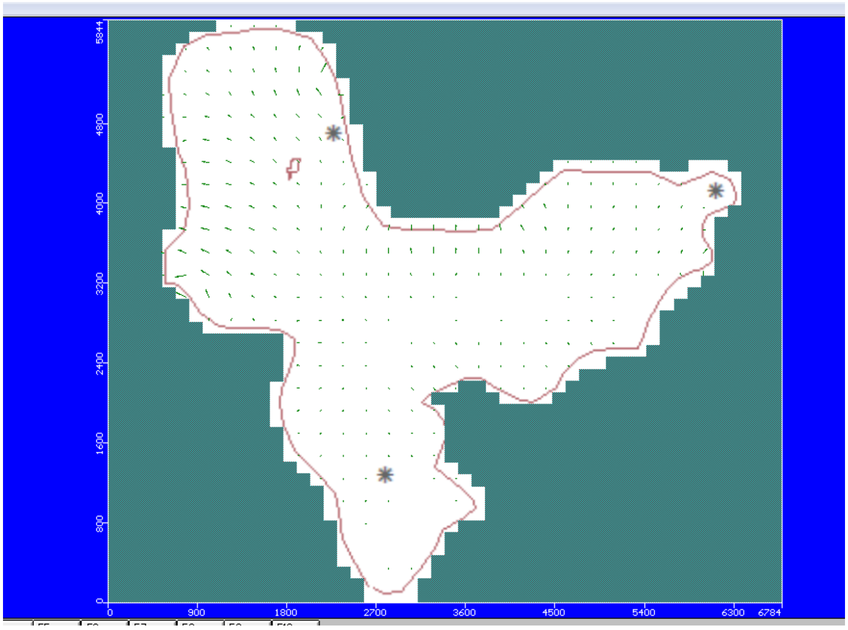

Fig 12: Flow direction

4.2 SOLUTE TRANSPORT MODELLING

Model simulation for 10 years and prediction for 20 years was carried out. Model was run using MODFLOW and MT3DMS engine. Calibration was done using concentration observation values (CGWB) for 10 years. Plot of calculated and observed concentration values for all time steps for all the three observation wells are shown in fig 13. Predicted model was validated using the TDS concentration obtained from field test wells. The transport of pollutants and vulnerable zones of the aquifer was identified from the output of transport model.

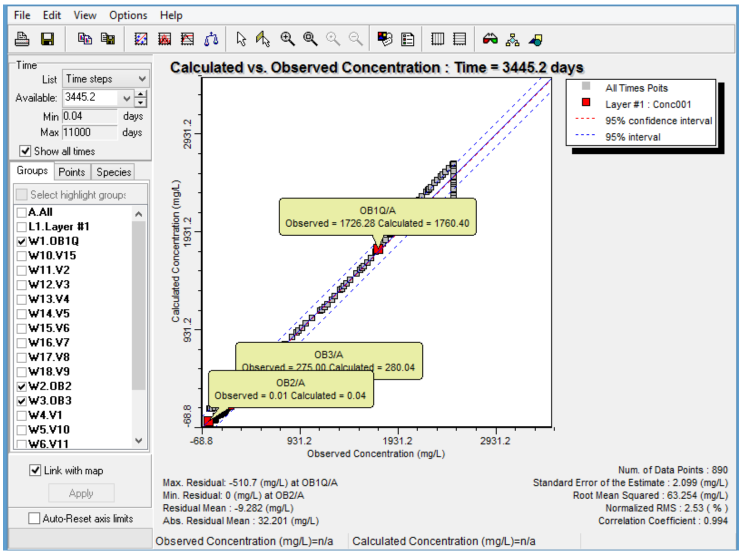

Fig 13: Concentration Calibration at all time steps

Calibration result shows plot between actual observed values of concentration and calculated concentration of model. It was found that the model results closely matches with the field conditions.

For validating the model, TDS concentration values obtained from field observation was used. 15 wells were selected for validation.

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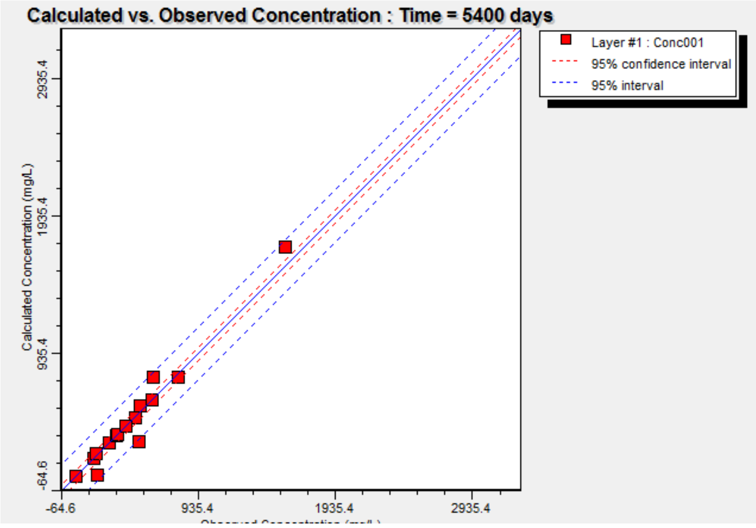

Fig 14 : Validation

All the 15 wells showed close relation to the model output. Hence the solute transport model was validated.

The TDS plume migration at different stages of simulation was visible from Fig 15. There is evident increase in radius of plume as the time steps increases.

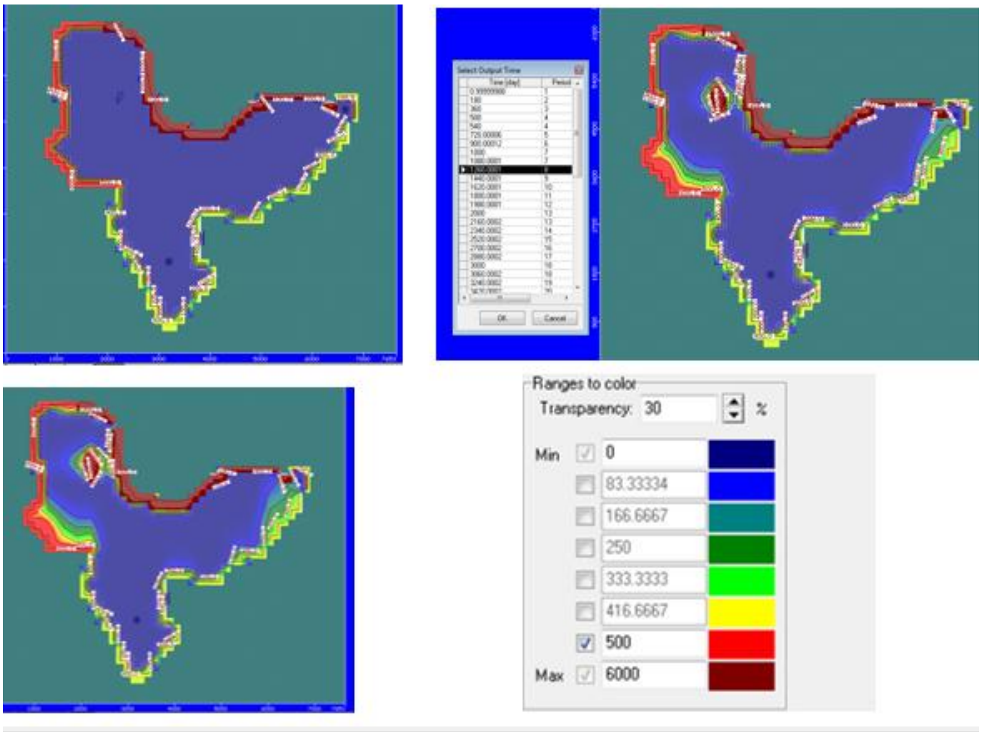

Fig 15: Stages of Plume Migration

At the end of calibration the plume has spread and contaminated 1.41 km^2 of area as shown in fig 16. Area was measured by overlaying the contour map onto Google Earth and calculating area by drawing polygon.

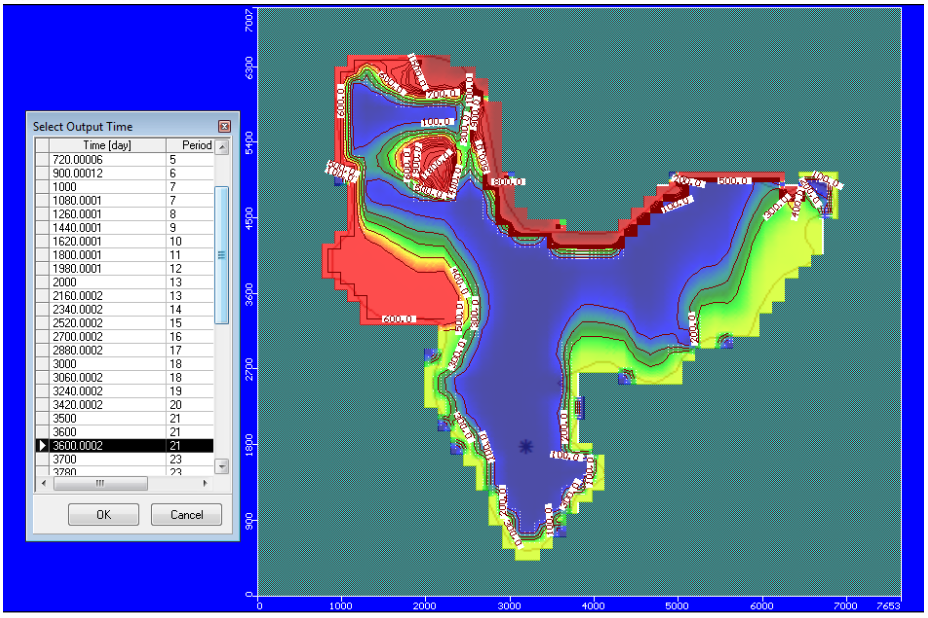

Fig 16: Plume migration at the end of calibration period

The model was then predicted for 20 years. And results at the end of prediction is shown in Fig 17. It was evident that the area of pollution has increased. On measuring the area it was found to be 4.45 square kilometres. It included 7 wards completely and 3 wards partially.

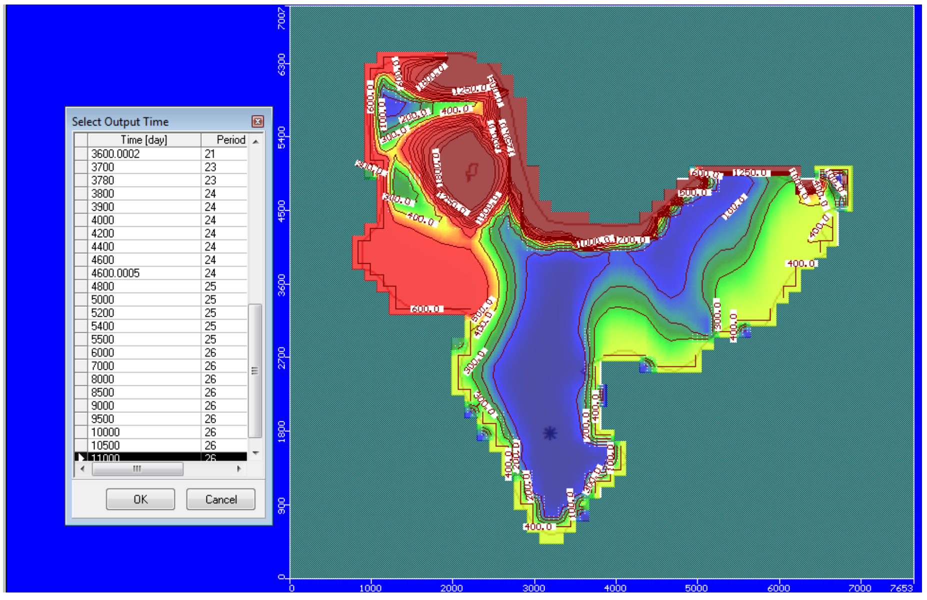

Fig 17: Plume migration at the end of prediction

V CONCLUSIONS

MODFLOW and MT3DMS have been used to study the transientgroundwater flow and solute transportation process of Eloor Municipality. Flow and Transport model were calibrated and validated using Field observation values. Solute transport prediction indicated that after 20 years the area vulnerable to TDS pollution will increase from 1.41 to 4.45 square kilometers. The Northern part of Eloor was found more vulnerable to pollution. If the current scenario of effluent disposal continues, it will be a great threat to people living in and around Eloor North. The model can be further used to assess the vulnerability of aquifer to other contaminants such as heavy metals.

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