Groundwater Quality Investigations and Modeling in Bhadravathi Town, Karnataka

B. K. Purandara, T. Chandramohan, M. K. Jose and B. Venkatesh
Scientist, National Institute of Hydrology, Hard Rock Regional Center, Belgaum, Karnataka, India

Abstract- **In India, there is an increasing desire to conserve and restore the ecological health and functioning of the rivers and their associated wetlands for human use and biodiversity. In order to achieve this goal, the primary requirement is to assess the minimum flow requirement to keep the ecological balance of the river ecosystem. In this connection, an attempt has been made to evaluate the existing conditions of the water flow in the Bhadrariver. It is reported by earlier researchers that the natural flow of Bhadra river has been altered considerably, resulting in loss of riparian zones, aquatic habitat and water quality. Further, it is stated that the Mysore paper mill and Visvesvaraya Iron and Steel industries which are functioning in Bhadravathi town may also add pollutants to both surface and ground water resulting in water quality deterioration. Therefore, in the present study an attempt has been made to understand the impact of wastewater from the industrial and domestic sewage on ground water. Groundwater samples were collected from the selected locations and analysed for major anions and cations.Groundwater quality indices developed for Bhadravathi town showed considerable variation in water quality parameters from post-monsoon to pre-monsoon. 20% of the samples during pre-monsoon and 50% of the samples during post monsoon fall under very good quality category. 50% of the pre-monsoon and 60% of the post-monsoon samples are categorized as good quality. It is also noticed that, 20% of the samples show index values more than 100, indicating that the water is unfit for use. This could be due to the dumping of wastes from various sources in the vicinity of the wells. Therefore, it is very important to take appropriate measures to maintain the river flow in good condition or otherwise there is a possibility of quality reduction over the years. This is particularly true in Bhadravathi town and adjoining areas, where the impact of Mysore Paper mills and Visveswaraya Iron and Steel Industries are working. HYDRUS-1D model was applied to simulate the chloride concentration passing through the unsaturated zone. Simulated profile was compared with the observed data which showed a reasonably good match indicating the applicability of the model for the simulation of solute transport process in an unsaturated zone.**

Keywords-Groundwater, unsaturated zone, modeling, water quality index

I. INTRODUCTION

The modern agricultural practices give rise to large quantities of water soluble contaminants which in turn are applied frequently to the soil surface for irrigation. The impact of industrial effluents is also responsible for the deterioration of the physical, chemical and bio-chemical parameters of groundwater [1]. It is known that part of the contaminant remains in the root zone, and remaining part is carried underground by the flowing water. To understand the impacts of some of these chemicals, it is important to investigate their movement from the soil surface through the root zone down to the groundwater table. The rate of movement of a given solute moves in the soil system depends on the average flow pattern, on the rate of molecular diffusion, and on the ability of the porous material to spread the solute as a result of local variations in the average flow. For proper modeling and understanding of the manner of solute transport in a natural soil profile, these phenomena must be considered simultaneously. Understanding these processes will make it possible to develop optimum management schemes for environmental control with the purpose of preventing soil and water pollution. The environmental impacts on the groundwater contaminations may seriously affect the socio-economic conditions of the country. Therefore, knowledge on chemistry is important to assess the quality of aquatic resources for understanding its suitability for various purposes [2].

The present study is an attempt to combine field investigations and laboratory analysis with quantitative approach.Groundwater quality investigations have been carried out in an industrial town, viz. Bhadravathi, in Shivamogga district of Karnataka. An attempt is also made to understand the solute transport mechanism through the unsaturated zone using HYDRUS-1D [3].

II. STUDY AREA

Bhadrariver originates at Gangamoola, Kudremukha, Karnataka, Western Ghats range and flows east across the Deccan plateau. It is joined by its tributaries the Somavahini,Thadabehalla, and Odirayanahalla. The river flows through the Bhadra Wildlife Sanctuary. A dam was built across the river near Lakkavalli. The Bhadra meets the TungaRiver at Koodli, a small town near Shivamogga. The combined river continues east as the Tungabhadra, a major tributary of the Krishna, which empties into the Bay of Bengal. Bhadravathi lies in the central part of the Karnataka State and in the southeast corner of the Shivamogga District. The latitude and longitude coordinates of Bhadravathi town are 13°50′24″ N and 75°42′07″ E / 13.840; 75.702 (Bhadravathi) / 13.840; 75.702 (Bhadravathi) respectively. Bhadravathi is at an altitude of 597 m above Mean Sea Level (MSL). Bhadravathi is an industrial town and taluk in the Shivamogga District of Karnataka State, India. The BhadravathiTaluk has a total area of 675.08 square kilometres. Bhadravathi town is spread over an area of 67 square kilometres. Based on the 2001 census, the total population of the BhadravathiTaluk is 3,38,989. Bhadravathi Town has a population of 1,60,662. The Mysore Paper Mills and the Mysore Iron and Steel Works are situated on the left bank of the Bhadrariver in the township of Bhadravathi in Shivamoggadistrict[4].

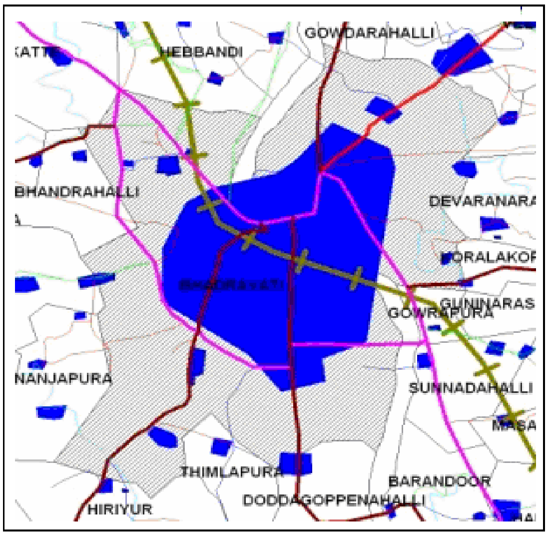

Fig.1 Location map of study area

The average temperature in the summer is between 25°C (77°F) and 37°C (99°F). The average winter temperature is between 20°C (68°F) and 30°C (86°F). The annual precipitation in the city is around 950 mm.Taluk wise rainfall data for the last 10 years suggest that average annual rainfall is around 769.4 mm at Bhadravathi.

The major types of industries in the study area are iron and steel, paper and pulp, chemical and sugar. Across the river Bhadra, the major industries are Kudremukh iron ore company Ltd (presently closed). Mysore Paper Mills and Visvesvaraya iron and steel industries. In addition, there are number of small scale industries.

III. MATERIALS AND METHODS

A. Field Investigations

Measurement of saturated hydraulic conductivity using Guelph Permeameter[5] and soil samples were collected from two sections at an interval of 5 days, for a period of 30 days.

B. Laboratory Investigations

Groundwater samples were collected from selected wells during pre-monsoon and post-monsoon period of year 2011and analysed in the laboratory for various anions and cations[6]. Soil moisture content was determined by gravimetric method and soil moisture retention characteristics were estimated using the Pressure Plate Apparatus.Chemical analysis of soil samples were also carried out by adopting standard procedures.

C. Modelling of solute transport process was done using the HYDRUS 1D model. Daily rainfall and evaporation data for available stations within the catchment were used for the study. Field observed and simulated solute concentration profiles were compared.

IV. RESULTS AND DISCUSSION

The chemical quality of groundwater is expressed in terms of pH, EC, TDS, major cations and anions. Since long, it has been reported that the river Bhadra is affected by pollution due to various reasons such as mining (Kudremukh Iron Ore Company Limited), presence of major industries like Visvesvaraya Iron and Steel Industries and paper mill effluents. A study by Karnataka State Pollution Control Board (KSPCB) has highlighted pollution as a result of dumping of agricultural residues/pesticides at Balehonnur in 2005 where ginger is the major crop grown which uses huge amounts of pesticides. Pollution due to industrial activities is mainly observed in downstream of BRP, from Bhadravathi to Kudli. It is estimated that around 15 villages in the area have been affected by industrial pollution [7].Raikar et al. [8] carried out surface and ground water quality investigations in parts of Bhadravathi taluk.Based on the information available from the reported study,further investigations have been made to understand the groundwater quality variations and solute transport characteristics of the study area.

The temperature has a direct effect on certain chemical and biological activities of the organism in aquatic media. The ground water temperature in the study area varied from 18ºC to 23ºC. The mean pH ranges from 7.2 to 8.9. Maximum pH of 8.9 was observed at Ujjainpura open well during post-monsoon season and a minimum pH of 7.2 was observed at MGM complex bore well in Santhemaidana. However, during the pre-monsoon season, pH showed a declining trend, both in Ujjainpura OW (8.2) and at MGM complex bore well (6.9).

The Electrical Conductivity is an index to represent the total concentration of soluble salts in water. In the study area, EC ranges from 65.7µmho/cm to 1470.1µmho/cm during the post-monsoon season and from 105.00µmho/cm to 1343.1µmho/cm in the pre-monsoon season. The maximum value of EC (1470.10µmho/cm& 1343.1 µmho/cm) was noticed at Ujjainpura main road bore well both during pre-monsoon and post-monsoon season and minimum of 65.70 µmho/cm was observed at MGM complex bore well (Santhemaidana). The maximum TDS (1030 mg/l during post-monsoon & 1170 mg/l in pre-monsoon) was observed at Ujjainpura (BW). The minimum values observed were at Hindu Mahasabhaborewell (419 mg/l) during post-monsoon and surprisingly, during pre-monsoon, the minimum value of TDS was noticed in the Ujjainpura bore-well indicating a high fluctuation between two seasons.

Chloride occurs naturally in all type of waters. High concentration of chloride is considered to be the indicators of pollution due to organic wastes of animal and industrial origin. The chloride concentration varied between 48 mg/l (Veerashaivasabhabhavan) and 227.00 mg/l at Ujjainpura main road (BW). On the other hand, during pre-monsoon season, the maximum value of 211 mg/l was found at LaxmiNarasimha temple (OW) and minimum 81.50 mg/l at Veerashaivasabhabhavan (BW). Both during pre-monsoon and post-monsoon samples demonstrated that there was no significant change in the concentration during the study period.

The fluoride causes various health hazards to human beings if found excess in drinking water. Therefore, fluoride estimation is highly essential to guide the public with regard to water contamination. In the present study, it was noticed that the concentration of fluoride is within the range of prescribed limits. The maximum value observed during the post-monsoon was 0.4 mg/l (Ganapathi temple, Ujjainpura and Hindu mahasabha temple well) and minimum was 0.2 mg/l inHaladamma templeopenwell. Further, during pre-monsoon season, maximum value of fluoride was 0.7 mg/l at Ujjainpuraopen well and minimum 0.27 mg/l at Haladamma temple open well and bore well.

Iron is one of the major constituents of rocks. The maximum value of iron in groundwater during post-monsoon season was found to be 0.39 mg/l at Haladamma temple OW and minimum of 0.15 mg/l at Ujjainpura OW. However, in the pre-monsoon season, maximum value of 0.57 mg/l was noticed at Haladamma temple OW and the minimum was 0.11 mg/l at Veerashaivasabhabhavan BW. During the post-monsoon season the iron content was less than the pre-monsoon season. Though the level of iron content is slightly higher than the acceptable limit, it can be used for drinking with filtration and standard treatments.

Total alkalinity ranges from 27.57 mg/l to 643 mg/l during the post-monsoon season while it varies from 53.65 mg/l to 690 mg/l in the pre-monsoon season. The maximum value of 643 mg/l was observed at Ujjainpura (BW) during post-monsoon season, while minimum of 27.57 mg/l was noticed in an open well of Hindumahasabha. During pre-monsoon season, the alkalinity value increased to 710.25 mg/l at Ujjainpura and a minimum of 170.35 mg/l, which is lower than the post-monsoon value, was observed in anopen well located in the Hindu mahasabha temple premises. Total hardness in groundwater samples ranges from 34.87 mg/l to 835 mg/l duringthe post-monsoon, while from 60.61 mg/l to 929.27 mg/l in the pre-monsoon season. The maximum total hardness observed in groundwater was 835 mg/l atUjjainpura main road (BW) during post-monsoon season, while minimum of 34.87 mg/l in an open well at Hindu mahasabha temple premises. In the pre-monsoon season, maximum value of 929.27 mg/l was observed in the bore well of Ujjainpura main road and a minimum of 60.61 mg/l at Hindu mahasabha temple (OW).

The maximum concentration of calcium observed was 266.90 mg/l in a bore well located atUjjainpura and minimum was 40.39 mg/l at Veerashaivasabhabhavan BW during post-monsoon season. In the pre-monsoon season, maximum value of 248.15 mg/l was observed at Ujjainpura main road BW and minimum 40.65 mg/l at Hindu mahasaba temple OW. In the groundwater, the concentration of calcium varies widely from place to place. During the post-monsoon, maximum magnesium concentration (80.52 mg/l) was observed at LaxmiNarasimha temple OW and minimum of 33.70 mg/l at Haladamma temple bore well. In the pre-monsoon season, 72.72 mg/l was the maximum concentration that was noticed at Veerashaivasabhabhavan and minimum 25.15 mg/l, at Hindu mahasabha temple (OW). The concentration of magnesium was high, exceeding the limits in all observation points (except at Hindu mahasabha temple). In the pre-monsoon season, slight improvement in the concentration was noticed at Ujjainpuraand Hindu mahasabha temple well (25.15 mg/l). In groundwater, the difference in calcium and magnesium content are in accordance with their relative abundance in rocks but contrary to the relative solubility of their salts. Therefore, it is essential to identify the process of solubility and source to account for the magnesium enrichment.

High concentration of sodium was noticed in groundwater of Bhadravathitaluk during the study period. During post-monsoon, 215 mg/l of sodium was observed at Ujjainpura OW and a minimum of 54.15 mg/l was noticed at Hindu mahasabhabore well. However, during pre-monsoon season, maximum value of 181.90 mg/l was found atUjjainipura open well and minimum 81.35 mg/l at Hindu Mahasabhabore well. The results show that sodium concentration was higher during the post-monsoon and declined during the pre-monsoon season. This indicates that there could be more than one source of sodium due to which there was a reduction during pre-monsoon season. The wide variations in water table fluctuations may also lead to such kind of variations during different seasons.

The potassium concentration showed variation between 2.8 mg/l (Ujjainpura) and 38 mg/l (Hindu mahasabha open well) during the post-monsoon and 3.98 mg/l (Hindu mahasabha OW) to 60.11 mg/l (Ujjainpura) during pre-monsoon season. This high concentration of potassium could be attributed to various reasons. The primary cause could be the source rocks in addition to the large quantities of fertilizers used for agriculture purposes. In general, less quantity of potassium is expected in groundwater due to its resistance to weathering conditions. Therefore, the high concentration in the groundwater indicates excessive agriculture activities prevailing in the area.

A. Water Quality Index

Water quality index (WQI) is defined as a rating reflecting the composite influence of a number of water quality parameters. It provides a convenient means of summarizing complete water quality data. Water quality index developed for the groundwater samples indicate that there is a wide variation in the indices from station to station. WQI of all the locations are shown in Table 1.

Ground water quality indices of Bhadravathi taluk indicated considerable variation in water quality parameters from post-monsoon to pre-monsoon. 20% of the samples during pre-monsoon and 50% of the samples during post monsoon fall under very good quality category. 50% of the pre-monsoon and 60% of the post-monsoon samples are categorized as good quality water having an index 50 – 100. 20% of the samples show index values more than 100, which is at Haladamma temple premises where both open well and bore-well samples found to be unfit for use. This could be due to the dumping of wastes from various sources in the vicinity of the wells. Therefore, water quality index provides a means to assess the suitability of water for drinking and other domestic purposes.

Table 1: Ground Water Quality Indices of Bhadravathi town

Locations	Pre-monsoon	Post-monsoon
Ujjainipura OW	50	42
Ujjainipura BW	51	41
Ganapathi Temple OW	45	42
Haladamma Temple OW	139	94
Haladamma Temple BW	111	60
LaxmiNarasimha Temple OW	67	57
Veerashaivasabhabhavan BW	43	39
Hindu Mahasabha Temple BW	60	45
Hindu Mahasabha Temple OW	72	55
Santhemaidan BW	89	62

V. MODELING (HYDRUS – 1D MODEL)

HYDRUS model numerically solves the Richards Equation for variably saturated water flow and conversion-dispersion type equation for solute transport. The Galerius finite element method [9] with linear basis functions is used to obtain a solution for the water flow equation. In this method, the solutions obtained by iterative process using Gaussian elimination. Similarly the same Galerkin finite element method is also used to solve the solute transport equations. To obtain numerical solution of the solute transport process, first, an iterative procedure is used to obtain the solution of the Richard Equation. These methods of solution are relatively standard and have been explained in detail by [3]. In this study, modeling of solute transport for the study site was carried out for the unsaturated zone of 1.5m thickness, as water table occurs at this depth. Solute transport was considered to be one dimensional vertical flow in a column of unit width and a length of 1.5m. As irrigation return is the major source of flow in the unsaturated zone, one dimensional vertical flow was assumed.

A. Soil Layers and Properties

The number of soil materials and number of layers were decided based on field data. The soil core collected from the top one meter of the unsaturated zone and its grain size analysis indicate that there are two set of materials. Two soil layers were considered, based on the variation in soil characteristics (up to 1 m).Analyses of the soil core for the contents of sand, silt and clay were used as an input to the model for the estimation of hydraulic properties through modeling. The unsaturated soil hydraulic properties were determined by the percentage of sand, silt and clay in different layers [10].

B. Solute Properties

Dispersivity and diffusion co-efficient are important in solute transport process. Dispersivity of solutes in a particular soil will vary with respect to the property of the soil. The dispersivity of chloride is used in the models. The diffusion co-efficient for chloride in water is assumed to be0.20 sq.m/day[11].

C. Boundary Conditions

Atmospheric boundary was assumed at the top of the column. The atmospheric boundary condition varies depending up on the amount of rainfall, irrigation and evaporation. The actual variation in rainfall and water depth in the irrigation land were collected from the field observations and were used in the model .The evaporation is assumed as 40% of irrigation water. In addition, two limiting values of the surface pressure head are also provided. The maximum allowed pressure head at the soil surface is zero and minimum allowed surface Pressure head is assumed as 10m. Variable head was considered at the lower boundary.Initially the model was simulated for one crop period and compared with field data for chloride. The computed chloride trend in the unsaturated zone is in good agreement with the field data. The chloride concentration in the unsaturated zone varies significantly during irrigation period due to intense agricultural activities. The temporal variation in mass of chloride is higher in the upper layers than in the lower layers. The mass of chloride varies from 42mg/kg to 22 mg/kg in the top layer and in the bottom layer it varied between 39 mg/kg to 23 mg/kg. Chloride was estimated at an interval of 5 days for a period of 30 days. The model developed with the field data, was used to predict the movement of chloride in the unsaturated zone.

D. Model Conceptualization

The HYDRUS-1D model was applied to understand the solute transport characteristics that pass through the unsaturated zone in parts of Bhadravathitaluk with special reference to agriculture land. As the model considers point values for simulation, an agriculture plot with sugarcane has been selected for the modeling studies. Detailed field investigations were carried out for soil physical and chemical characteristics. The solute will enter the soil profile with irrigation. There is also some solute present initially. Sugarcane is the vegetation type. Exponential root growth with depth and linear interpolation with time was considered. The depth of the soil considered is 100 cm with eleven nodes and the bottom boundary conditions are applied at 100 cm. There is also some solute present initially. Solute production and first order decay processes are active. In the model, solute production/uptake and first order decay processes are expressed in terms of source or sink terms. There is no solute exclusion from plant water uptake, i.e. and a surface conductance function. The matric potential gradient of zero i.e., `unit gradient' has been considered as bottom boundary condition throughout the simulations. No bypass flow is included. There is no solute input with rain or irrigation. All solute dissolved in the uptake water is also taken up by the plant. Plant uptake of solute is assumed to take place only by mass flow. In this case, vapor conductivity is not taken into account nor is the effect of osmotic potential. There is one hydraulic property set for each plot and one solute property set that applies to all 11 nodes of this 100 cm deep profile. Hysteresis is not taken into account. Solute gets adsorbed with linear isotherm. Initially, there is no water ponded on the surface and hence solute concentration of `ponded water' is zero. Runoff is governed by simple power law function.

E. Data input for HYDRUS -1D model

Rainfall: Annual average rainfall data for the period 2001 - 2010 were collected from the Water Resources Development Organization, Karnataka for rain gauge located close to Bhadravathi. The average rainfall is950 mm.

Evaporation: Evaporation data of Belgaum was obtained from Water Resources Development Organization, Karnataka. Minimum evaporation of 90 mm was noticed during November December months and maximum of 240 mm during the month of May.

Saturated Hydraulic Conductivity: Hydraulic properties which are the basic input data for HYDRUS model were determined in the field using disc permeameter. Depth-wise saturated hydraulic conductivity was estimated using textural data (Table 2).

Table 2 Soil Moisture content and hydraulic conductivity

S.No.	Depth in cm	Sat. Moist. Cont (θ_n)	Res. Moist Cont. (θ_r)	Hydraulic Conductivity cm/hr
1	0-30	0.33	0.18	1.10
2	30-60	0.22	0.17	1.51
3	below 60	0.30	0.21	1.20

Soil Moisture Retention Characteristics

The soil moisture retention characteristics show a very high moisture holding capacity of the soil. One of the most interesting observations is that there is an increase in soil retention capacity of the soil with depth. The higher moisture holding capacity could be attributed to the wide distribution of fine grained soils and also due to the mineralogical composition derived from source rocks. Table 3 shows the soil moisture retention characteristics of the soil with depth.

Table 3: Soil Moisture Retention characteristics of Bhadravathi (agriculture plot)

Depth cm	Pressure in bars				
	0.3	3	7	10	15
0-60	0.38	0.35	0.33	0.31	0.27
below 60	0.37	0.33	0.30	0.28	0.282

VanGenuchten parameters: To model the retention and movement of water and chemicals in the unsaturated zone, it is necessary to know the relationship between soil water pressure (h), water content (θ), and hydraulic conductivity (K). From the retention data van Genuchten parameters were obtained. The averaged van Genuchten parameters for the soil layer were obtained by non-linear regression analysis (Table 4). The van Genuchten parameters α varies between 0.0036 and 0.024 and the n parameter varies between 1.21 and 1.58

Table 4: van Genuchten Parameters for the soils of Bhadravathi (agriculture plot)

Sl. No.	Depth in cm	Van Genuchten Parameters	
		A	n
1	0-60	0.0036	1.21
2	Below 60	0.0240	1.58

Vegetation: One vegetation type is present. Exponential root growth with depth and sigmoid with time were assumed for the study. The following vegetation parameters were adopted for the simulation.

F. Application of HYDRUS- 1D Model

The model was initially run with the above mentioned input parameters for modelling the movement of chloride in the soil column. The concentration computed by the model was compared with field data. Then the model was run by varying certain input parameters such as evaporation, bulk density, coefficient of diffusion and dispersivity. All these parameters were varied within the reasonable limit of 10% and the sensitivity of these parameters were studied. The model is sensitive to the variation in dispersivity and hydraulic conductivity. The model, however, is not very sensitive to other physical parameters. Thus by varying these input parameters within the reasonable limit, concentration of chloride ion was simulated and compared with observed field data.

After calibration and testing, the model was used to simulate the concentration of chloride in the unsaturated zone. The model results were obtained for a period of 30 days. The results were compared with the observed concentration of chloride in the selected agriculture field.Simulation was carried out for a single crop season and shows that there is a good agreement between the results of the model and the observed field trend (Fig.2&3). It is found that both in top and bottom soil layers the chloride concentration decreases gradually with time. However, it is noticed that in the bottom layer the variation in the chloride concentration was quite minimum as compared to top layer.It is also noticed that there is no significant overall downward trend in the concentration of ions in the unsaturated zone thereby contributing to the groundwater zone. The results of the model indicate that there is no threat to ground water quality due to the present level of use of agrochemicals. Therefore, it is understand that the HYDRUS-1D model will be highlyuseful tool to compute the probable concentration of solutes in unsaturated zone and groundwater over a time period of a few years. Similar observation was made in an agriculture land (Tamil nadu) [11].

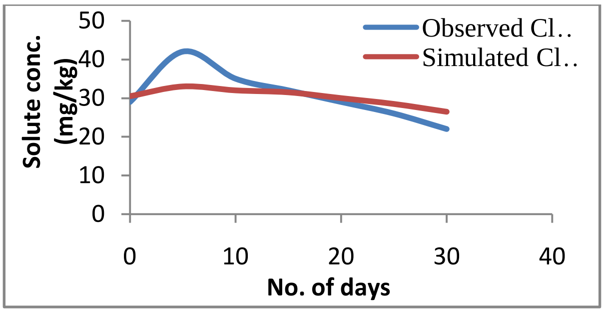

Fig. 2 Observed and Simulated solute concentration in an agriculture land (top layer).

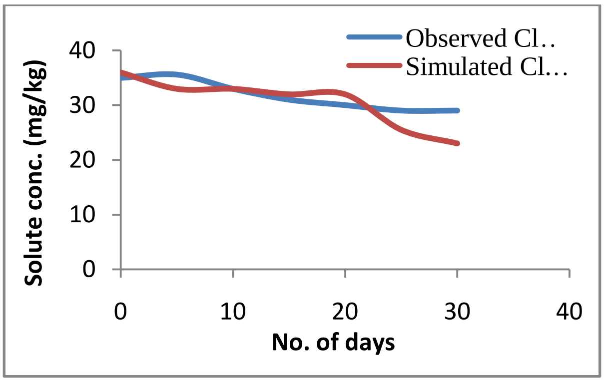

Fig. 3 Observed and Simulated solute concentration in an agriculture land (bottom layer).

VI. CONCLUSIONS

Groundwater quality observations show that Bhadravathi town faces water quality deterioration both in open and bore wells in and around the industrial belt of Bhadravathi town. One of the major reason for water quality variation could be due to the industrial waste waters which may seep through joints and fractures in to the adjoining aquifers. However, to ascertain the actual cause it is necessary to understand the geogenic properties of the study area. Modeling study indicated that the solute concentration is comparatively higher in the top layer (up to root depth) and below that, there is significant decline which is attributed to higher clay content and possibility of adsorption of certain chemicals in the unsaturated zone.

ACKNOWEDGMENT

Authors are highly thankful to Sh. R. D. Singh, Director, NIH, for his encouragement and granting permission to publish the paper. Dr. Sudhirkumar, Scientist G & Head, Hydrological Investigation Division, NIH, Roorkee is acknowledged for his continuous support and encouragement. Authors are also grateful to M & G Dept. and NRDMS center Shivamogga for providing maps and data related to the study.

REFERENCES

[1] K.Sivasankar, R. Gomathi, “Fluoride and other quality parameters in the ground water samples of Pettaivaithalai and Kulithalai areas of Tamil nadu, Southern India, Water Quality Exposure Health”, Vol. 1, pp. 123-134, 2009.

[2] T. E. Subramani, A. Deshpande, “Can Fuzzy Logic Complex Problems into factors in Environmental Policy”, Environmental Science and Technology, Vol. 39, pp.42A-45A, 2005.

[3] J. Simunek, M. Sejna and Genuchten V. Th. Hydrus -2D/Meshgen 2D: Simulating Water flow and solute transport in two-dimensional variably saturated media. U.S. Salinity Laboratory, Agriculture research service, Riverside, California, 1999.

[4] [4] B. S. Bhimachar, and A. David, “ A study of the effects of factory effluents on the Bhadrariver fisheries at Bhadravathi”, Proc. Ind. Sci. Congr., Abstracta, pp. 130, 1946.

[5] W. D. Reynolds, Saturated hydraulic conductivity: field measurement. InM.R. Carter (ed.) Soil Sampling and Methods of Analysis. Canadian Society of Soil Science.Lewis Publishers, Boca Raton, USA, 1993,pp. 599-613.

[6] APHA (American Public Health Association), AWWA, WEF. [For the Examination of Water and waste water] standard methods Book 19th Edition Washington, DC,1995.

[7] S. Manjappa. Studies on the heavy metal pollution in river Bhadra near Bhadravathi town, Karnataka, Ph.DThesis, KuvempuUniversity, Shimoga, Karnataka 2002.

[8] Raikar, R. V and Sneha, M. K. “Water quality analysis of Bhadravathi taluk using GIS – a case study”, International Journal of Environmental Sciences, Vol. 2, No. 4, pp 2443-2453, 2012.

[9] S. P. Neuman, R. A. Feddes and E. Bresler . Finite element simulation of flow in saturated –unsaturated soils considering water uptake by plants. Third Annual Report, Project No. A10-SWC-77, Hydraulic Engineering lab, Technion, Haifa, Israel, 1974.

[10] V. M. Th. Genuchten, “A Closed form equation for predicting the hydraulic conductivity of unsaturated soils”, Soil Soc. Am. J., pp. 892-898, 1980.

[11] N. Rajmohan and L. Elango, Modeling the movement of Chloride and Nitrogen in the unsaturated zone, Modelling in Hydrogeology, pp. 209-226.