Chapter 20
Interaction Between Groundwater and Surface Water and Its Effect on Groundwater Quality

S. K. Pramada and Sowmya Venugopal

Abstract The unscientific disposal of wastes into rivers and canals can cause surface water pollution. The surface water and groundwater are fundamentally interconnected and thus one can contaminate the other. In some cases, surface water systems gain water and solutes from groundwater and in others the surface water body is a source of groundwater recharge and causes changes in groundwater quality. For managing the water resources, it is essential to study, how the surface affects the groundwater systems. Mathematical models have been widely used in planning and management of water resources. This paper presents a study where a surface water and groundwater interaction model is developed and applied to a case study. A finite-difference code was developed for the modeling of river water quality. A program is written in MATLAB using the explicit finite difference method. In this study, MODFLOW is used to model the groundwater flow and MT3DMS is used to model the contaminant transport flow in groundwater. Finally, the interaction between the surface water and groundwater was studied from the surface and groundwater quality models.

Keywords MODFLOW · MT3DMS · Groundwater · Contaminant transport · River water quality

20.1 Introduction

Water pollution is a major problem in the global context. When waste materials enter lakes, rivers, oceans, and other water bodies, they get dissolved or suspended in water or get deposited on the bed. This causes the pollution of surface water bodies. Naturally, surface water contains a wide variety of substances, and human activities inevitably add to this mixture. There are many sources of surface water pollution.

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The main sources of pollution are the sewage and industrial waste. The facilities to treat wastewater are not adequate in many cities in India. Presently, only about 10% of the wastewater generated is treated; the rest is discharged into our water bodies (Radha 2008). Due to this, pollutants enter groundwater, rivers, and other water bodies. Groundwater contains mineral ions naturally. Human activities can affect the natural mineral composition of groundwater through the disposal waste matter at the land surface or through surface water. Since one of the sources of groundwater is surface water, high concentrations of chemical parameters in surface water can cause pollution to groundwater. Since both surface and groundwater are the sources of drinking water, this polluted water can seriously affect the health of the people consuming it. Thus, it is essential to study both surface water and groundwater pollution.

Since surface water and groundwater are fundamentally interconnected, one can contaminate the other. The ability to link groundwater to surface water bodies makes it possible to predict the migration of contaminants from surface water to groundwater or vice versa. Inadequate and incompetent management of water resources causes water-borne diseases and related health problems. Thus, water quality management is an important issue of relevance in the context of present times. Hence the interaction of surface water and groundwater has to be deeply studied for better management of water resources. Many researchers carried out work on stream aquifer interactions (Yan and Smith 1994; Hussein and Schwartz 2003; Sophocleous 2002; Serdar Korkmaz et al. 2009; Rodríguez et al. 2006; Kim et al. 2008; Zhou et al. 2019). In this paper, the stream water quality model is developed using finite difference approach and groundwater quality is modeled using MT3DMS. The objectives of the present study are set as follows (1) To develop a surface water quality model (2) To develop a groundwater quality model, and (3) To analyze the interaction between surface water and groundwater through the above models.

20.2 Study Area and Data Collection

The study area is located along the Canoly Canal in Kozhikode, Kerala. The Kozhikode district falls within latitudes 11° 08′ and 11° 42′ and longitudes 75° 31′48″ and 75° 49′30″ and is situated along the southwest coast of India. The coast of the district is about 71 km and it covers an area of 91 km^2. This district has a humid tropical climate and an annual rainfall is estimated to be about 3000 mm.

The Canoly Canal is a manmade canal constructed in 1848. This canal connects the Korapuzha River in the north and the Kallai River in the south. The canal is 11.4 km long. The width of the canal ranges from 6 to 20 m and the water depth in the peak rain period varies from 0.5 to 2 m. The canal is a part of the West Coast Canal System. There are a lot of industrial activities such as coir retting, log setting and other kinds of timber industries around the southern end of the canal. Most residential areas and several hospitals along the canal are letting out their wastewater into the canal or the sea via ditches without any treatment. In addition to the liquid waste, there are also

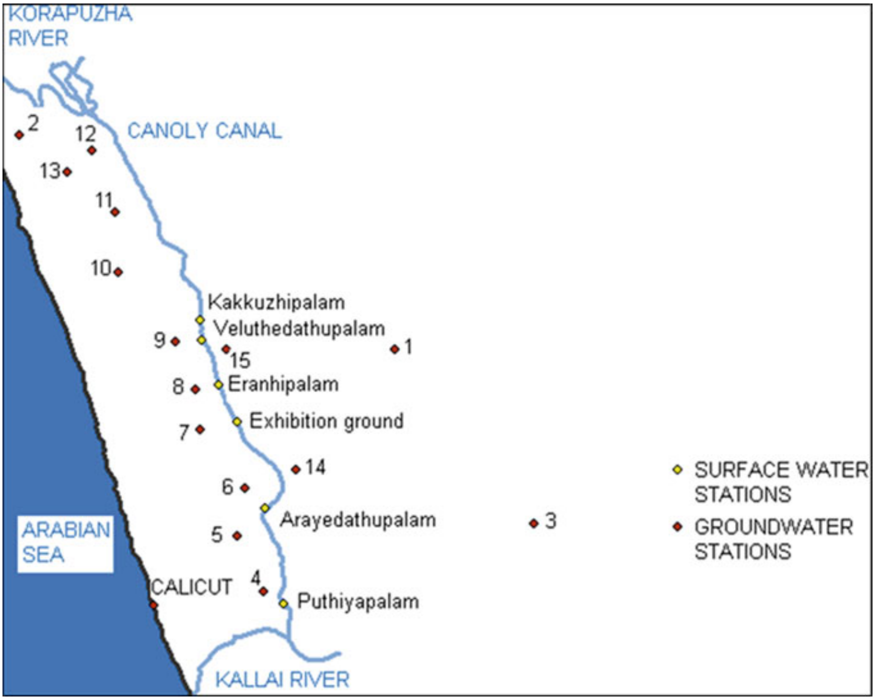

Fig. 20.1 Map showing wells in the study area

considerable amounts of solid waste dumped into the Canoly Canal, both domestic as well as industrial waste. There is lining made of stones along the sides of the canal but incomplete and collapsed at some locations. Toward the junction of Canoly Canal with Kallai River in the south, there are some sections where there has not been any lining constructed. In many places, trees and bushes are also present in the canal together with a lot of water living plants such as water hyacinths on the surface. Thus, the water flow is low in the middle stretch of the canal. The data required for the study were collected from Centre for Water Resources Development and Management, Kozhikode (CWRDM, Kozhikode) and Groundwater department, Kozhikode during the period 2002–2008. The surface water sampling site and groundwater observation wells in the study area are shown in Fig. 20.1.

20.2.1 Surface Water Quality

The Canoly Canal is heavily polluted from all the surrounding activities that let out their sewage into the canal water. Among the present activities are hospitals, hotels, garages, timber industries, coir retting, slaughterhouses as well as big residential

Table 20.1 Surface water quality data (2005)

S. No.	Parameters	1	2	3	4	5	6
1	pH	7.8	7.96	7.77	7.03	8.04	8.1
2	EC (micro siemens/cm)	8521	4039	4466	8361	10,744	3953
3	Turbidity (NTU)	26	18	35	13	15	19
4	TDS (mg/l)	5283	2504	2769	5184	6661	2451
5	Total alkalinity (mg/l)	132	109	104	92	120	136
6	Total hardness (mg/l)	400	120	240	670	340	140
7	Sodium (mg/l)	1590	1000	1800	1370	2090	1200
8	Potassium (mg/l)	125	68	70	165	45	47
9	Magnesium (mg/l)	240	390	109	267.3	230	104
10	Calcium (mg/l)	128	156	260	192	96	200
11	Iron (mg/l)	Nil	Nil	Nil	Nil	Nil	Nil
12	Chloride (mg/l)	3200	890	530	3190	4200	900
13	Phosphate (mg/l)	Nil	Nil	Nil	Nil	Nil	Nil
14	DO (mg/l)	7.05	7.13	6.87	6.9	5.9	6.2
15	BOD (mg/l)	30	22	23	18	12	20
16	COD (mg/l)	390	389	400	320	423	230
17	Sulfate (mg/l)	155	209	512	145	366	201
18	Total coliform (MPN/100 ml)	2400	2400	2400	2400	2400	2400

areas. Many drainage outlets are connected to the canal and all together they drain almost the whole city from stormwater, household gray water and also sewage. This wastewater has not been treated so far. These activities contribute to the poor condition of the surface water. The city has problems with epidemics of typhoid, hepatitis, cholera, and other water-borne diseases regularly due to the lack of potable water. Table 20.1 shows the surface water quality parameters for 6 sampling sites during 2005 collected from CWRDM, Kozhikode.

20.2.2 Groundwater Level and Quality

The topography in Kerala is generally sloping from the Western Ghats in the east toward the Arabic Sea in the west making the groundwater flow being orientated in a westerly direction. The available water level data and quality data over the period 2002–2008 were collected from Groundwater Department, Kozhikode. The water level plots for representative three wells are given in Figs. 20.2, 20.3 and 20.4. The groundwater quality data obtained from Groundwater Department, Kozhikode is depicted in Table 20.2. The water in a large number of wells is not potable due to high bacteriological content.

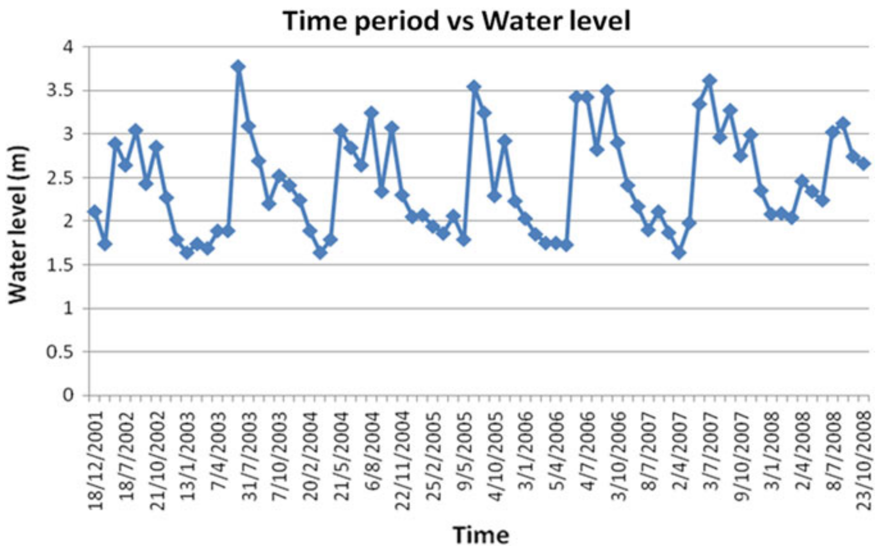

Fig. 20.2 Water level data—well no. 1

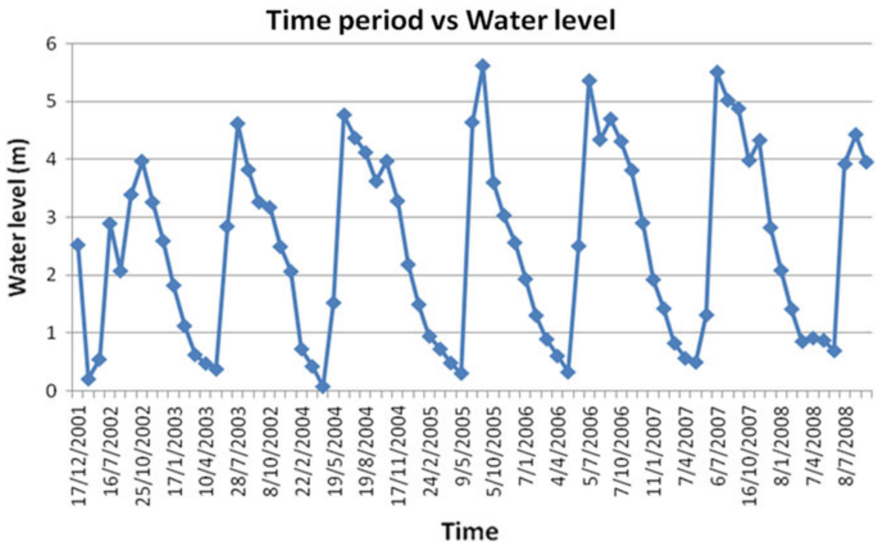

Fig. 20.3 Water level data—well no. 2

20.2.3 Rainfall Data and Lithology

The lithology data was available for the four wells and is given in Table 20.3. The rainfall data during the period 2002–2008 is given in Table 20.4.

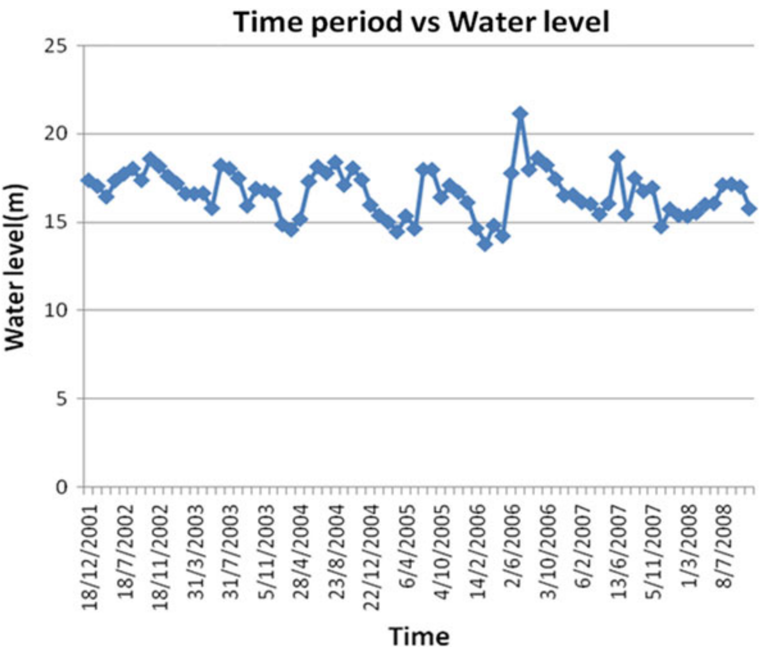

Fig. 20.4 Water level data—well no. 3

20.3 Methodology

The methodology consists of three phases. The first phase of the work consists of data collection. The second phase includes modeling of surface water quality. A finite-difference code was developed for the modeling of river water quality. A program was written in MATLAB (The MathWorks Inc. 2003) using the explicit finite difference method. In the third phase, MODFLOW is used to model the groundwater flow and Modular Three Dimensional Transport Multi Species (MT3DMS) is used to model the contaminant transport flow. And finally the interaction between the surface water and groundwater was studied from the surface and groundwater quality models.

20.4 Modeling of Surface Water Quality

The surface water quality of Canoly Canal is modeled using the explicit finite difference method. To apply finite difference method, the problem domain is divided into a finite difference grid.

The governing equation for one-dimensional solute transport can be expressed as

Table 20.2 Groundwater quality (2002)

Well No	pH	EC (μS/cm)	TDS (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	Phosphate (mg/l)
Well 1	8.1	694	416	121	2.4	22.5	1.8	37	16	0.002
Well 2	7.8	953	572	137	7.6	52.4	2.3	63	23	0.016
Well 3	8	171	103	17	6	7.6	0.5	7.1	6	0.055
Well 4	8.1	2700	1900	113.6	37.9	380	30	800	86.6	0.069
Well 5	8	186	130	20.8	2.9	19.6	8.4	50	22.4	0.018
Well 6	7.9	370	250	34.4	7.8	40	5.8	90	24.68	0
Well 7	8	520	380	98.2	18.7	35.2	16.2	45	67.52	0.011
Well 8	8.1	600	360	121	4.3	22.5	3.9	70	51.68	0.238
Well 9	8.1	320	190	124	7.6	52.4	3.6	4	12.36	0.202
Well 10	7.2	750	450	117	6.3	7.6	4.8	100	88.2	0.025
Well 11	7.4	720	430	113.6	37.9	37.4	7.7	110	97.2	0.026
Well 12	6.9	285	170	29.4	2.9	19.6	6.7	60	52.8	0.024
Well 13	7.8	953	572	137	7.6	52.4	2.3	63	23	0.016
Well 14	8	1925	1155	17	6	7.6	0.5	7.1	6	0.055
Well 15	8.1	320	190	124	7.6	52.4	3.6	4	12.36	0.202

Table 20.3 Lithology

Well	Depth up to (m)	Soil type
Well no. 1	34.75	Laterite
	35.10	Granite weathered
Well no. 3	3.25	Top soil
	6.20	Laterite
Well no. 6	12.19	Laterite with clay and sand
	15.24	Gneissic rock weathered
Well no. 14	18.29	Laterite with clay and sand
	22.25	Gneiss weathered

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} - v_x \frac{\partial C}{\partial x} + q_s C_s \tag{20.1}$$

where

C aqueous concentration of the solute
D dispersion coefficient
v average linear velocity of flow
q_s velocity
C_s concentration of solute.

The first term on the right-hand side represents the dispersion of the solute, the second term is the advection term, the third term is the source/sink term and the term on the left-hand side denotes rate of change solute mass within the control volume.

On applying Taylor's series expansion to Eq. 20.1

$u(x_i, t_j + \Delta t)$ gives $u(x_i, t_j + \Delta t) = u(x_i, t_j) + u_t(x_i, t_j)\Delta t + \mathrm{O}((\Delta t)^2)$.

The forward approximation is given by

$$(u_t)_{i,j} \approx \frac{u_{i,j+1} - u_{i,j}}{\Delta x} \tag{20.2}$$

The backward approximation is given

$$(u_t)_{i,j} \approx \frac{u_{i,j} - u_{i,j-1}}{\Delta x} \tag{20.3}$$

The central approximation is given by

$$(u_x)_{i,j} \approx \frac{u_{i+1,j} - u_{i-1,j}}{2\Delta x}$$

The spatial and temporal derivatives in the governing equation are written in the finite difference form as

Table 20.4 Rainfall data in mm (2002–2008)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	Nil	0.4	6.1	27.5	4500.7	666.9	666.9	343.6	418.4	128.4	Nil	Nil
2003	Nil	5.1	1.9	198.6	90.3	919.3	515.8	210.1	165	243.8	114.2	Nil
2004	1.8	0.4	2.8	97.6	863.6	850.8	438.9	429.8	125.8	33.1	35.6	0.4
2005	18.3	Nil	Nil	56.3	56.1	697	610.9	207.6	334.9	190.7	155.2	17.7
2006	Nil	Nil	14.5	20.8	636.6	983.6	599.9	531.9	707.1	331.6	996	Nil
2007	Nil	0.4	12.4	81.2	379.4	1030.1	1078	596.3	671.1	353.3	141.3	Nil
2008	Nil	Nil	266.5	151.1	80.4	698.3	485.5	247	414.3	Nil	Nil	Nil

$$\frac{\partial C}{\partial t} = \frac{C_{i,j+1-}C_{i,j}}{\Delta t}$$
$$\frac{\partial C}{\partial x} = \frac{C_{i,j-}C_{i-1,j}}{\Delta x}$$
$$\frac{\partial^2 C}{\partial x^2} = \frac{C_{i-1,j-}2C_{i,j+}C_{i+1,j}}{\Delta x^2}$$

Substituting in the advection—dispersion equation, for a fully explicit temporal discretization, leads to the following form:

$$C_i^{j+1} = a(C_{i-1}^j - 2C_i^j + C_{i+1}^j) - b(C_i^j - C_{i-1}^j) + C_i^j + q_s C_s \Delta t \qquad (20.4)$$

where

$$a = \frac{D_x \Delta t}{\Delta x^2}$$
$$b = \frac{v_x \Delta t}{\Delta x}$$

Equation 20.4 is written for each active node, with initial and boundary conditions leading to an equation with one unknown. A program is written in MATLAB for explicit finite difference solution. The unknown concentration at any node i at present time level depends on the concentration at the adjacent nodes at the previous time level. Initial and boundary conditions of the model were assigned based on the field data. The finite difference model, when applied to the case study by considering total dissolved solids (TDS) and indicator of contamination, the concentration of TDS was found to be 6661 mg/l for the surface water at Puthiyapalam.

20.5 GroundWater Quality Modeling

In order to study the effect of surface water contamination on groundwater, a groundwater flow and transport model were developed. The groundwater flow model (MODFLOW) (Harbaugh et al. 2000) is used for the development of groundwater flow model and MT3DMS (Zheng et al. 1999) was used for contaminant transport model. The dimension of the study area was selected as 11,000 m × 12,000 m. The grid size is 50 m × 50 m. Based on the lithological data obtained, the geology of the study area is divided into two layers. The pumping rate from fifteen wells in the area is obtained from Groundwater Department, Kozhikode.

Thirteen observation wells were identified for the calibration of model parameters. The available water levels of the wells were imported to the model. The water level data of January 2002 were interpolated in the study area and were assigned as the initial head. For contaminant transport model, total dissolved solids (TDS) was taken as an indicator. The TDS concentration data observed in January 2002 around the

Table 20.5 Aquifer parameters

Parameter	Layer 1	Layer 2
Conductivity-Kx	20 (m/day)	10 (m/day)
Conductivity-Kz	2 (m/day)	1 (m/day)
Specific storage	1×10^{-5} (1/m)	5×10^{-5} (1/m)
Specific yield	0.15	0.1
Porosity	0.2	0.2

study area was interpolated and assigned as initial concentration. The seaside is represented with constant head of 0 m and constant TDS concentration of 35,000 mg/l. The Canoly Canal is represented as the river boundary condition. The data during 2002–2008 were considered for model calibration. During calibration, the aquifer parameters were slightly modified to match the observed head and concentration to that of simulated values. Table 20.5 shows the finally adopted aquifer parameters for two layers of the aquifer system. For contaminant transport model, dispersivity was varied to match the simulated and observed TDS values. The calibrated longitudinal dispersivity was found to be 50 m. Figure 20.5 shows the comparison between observed and computed heads for an observation well 2. Figure 20.6 shows the calibration plot for TDS concentration for all wells for a time period. Figure 20.7 shows the head and velocity contour during 2009. Figure 20.8 shows the concentration contour during 2009. It can be seen that there is reasonable agreement between the

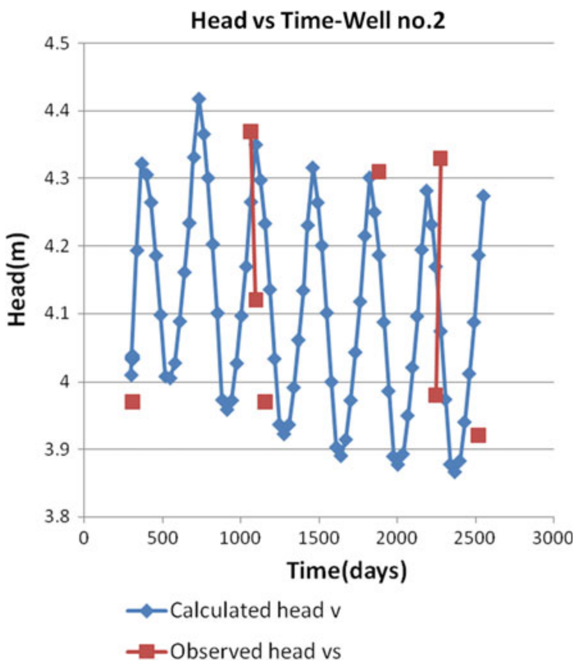

Fig. 20.5 Simulated and Observed water level in well no. 2

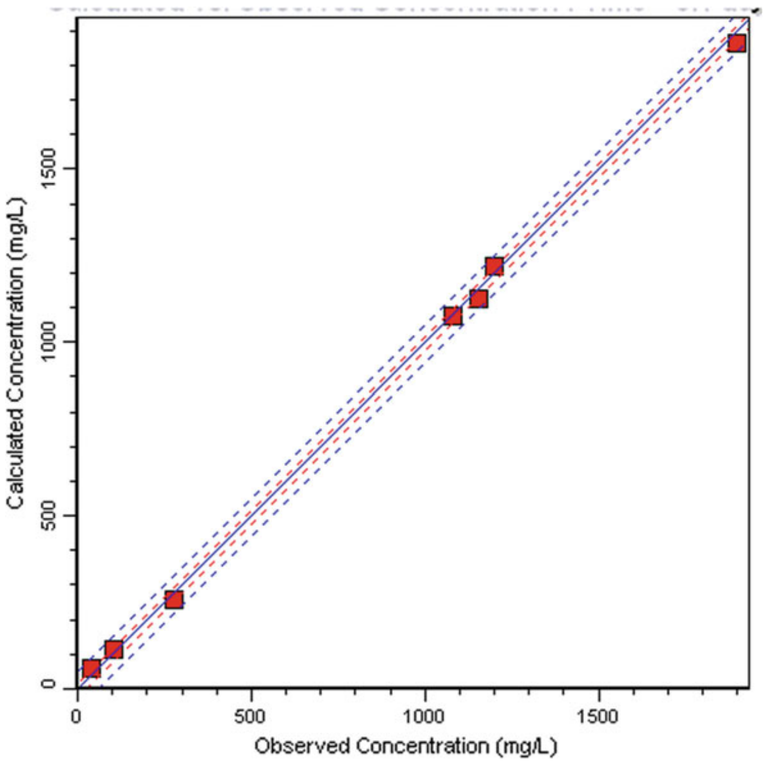

Fig. 20.6 Calibration plot for concentration

observed and computed values of head and concentration. From the obtained plots, it can be seen that the area around Puthiyapalam and Arayedathupalam shows higher concentration of total dissolved solids, and it was found to be varying from 1000 to 1800 mg/l. The groundwater monitoring wells in between Korapuzha River and Eranhipalam satisfied drinking water standards.

20.6 Conclusions

The effective water management requires a clear understanding of the linkages between groundwater and surface water. The primary goal of this study was to assess the interaction of both surface and groundwater. The surface water quality was modeled using finite difference method by writing a code in MATLAB. The groundwater flow and contaminant transport were modeled using MODFLOW and MT3DMS. The models developed are applied to a case study.

The finite difference model, when applied to the case study, the concentration of TDS was found to be 6661 mg/l for the surface water at Puthiyapalam. The

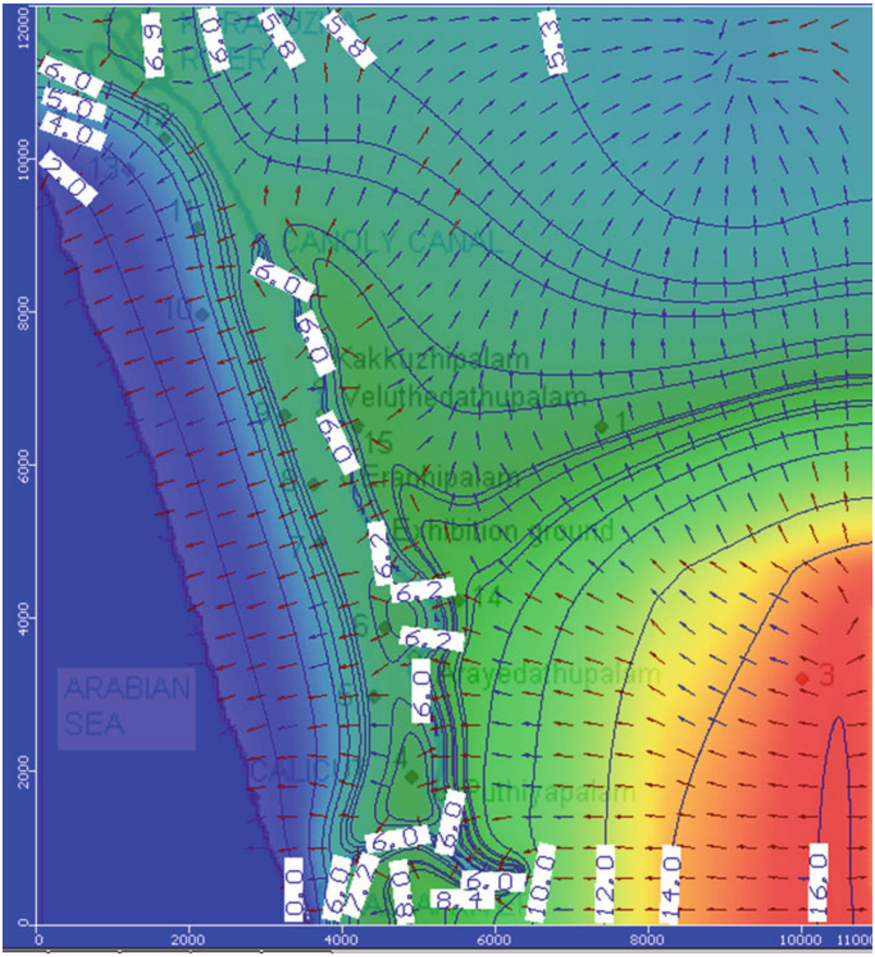

Fig. 20.7 Head and velocity contour during 2009

concentration of TDS for groundwater in the area around Puthiyapalam was obtained as 1500 mg/l, which revealed that the groundwater was also polluted. From the results obtained, it is evident that Canoly Canal is highly polluted. It can be concluded that the surface water—groundwater interaction is significant in this area. It is high time that this pathetic picture of the canal to be noticed. Strict vigil is required to prevent people from dumping the wastes into the canal. The developed models can be used for decision making, specifically to decide how much treatment is required before discharging the waste into surface water system and also the treatment required for groundwater for specific uses.

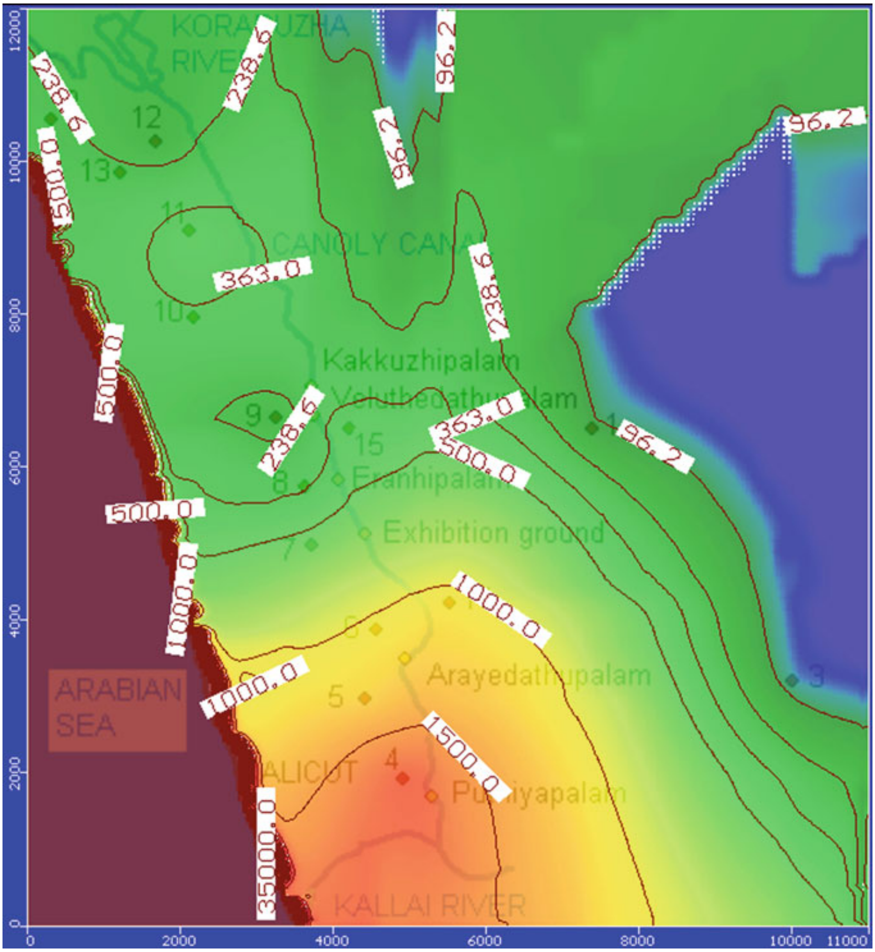

Fig. 20.8 Concentration contour during 2009

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