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Mass transport modelling for assessement of groundwater contamination : case studies

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Abstract

Groundwater contamination due to discharge of domestic sewage and industrial effluents is increasing day by day in different parts of the country. Mass transport modelling is a tool to assess the status of groundwater contamination as well as predict the contaminant migration in groundwater. A groundwater flow model is required to compute the hydraulic heads, which in turn is used to compute the groundwater velocity. The processes of advection and dispersion are accounted in mass transport modelling. Three examples of mass transport modelling have been presented to demonstrate the utility of groundwater flow and mass transport modelling for assessment and management of groundwater contamination. These models will provide quantitative results for groundwater management decisions. The case studies include quantification of contaminant migration in groundwater due to discharge of industrial effluents from Hindusthan Polymers plant in Venkatapuram area near Visakhapatnam, the problem of contamination of drinking water supply well in the Sabarmati river bed near Ahmedabad and contamination of groundwater in Patancheru industrial development area from discharge effluents of chemical and pharmaceutical industries.

INTRODUCTION

Water carries pollutants through invisible and visible landscapes. On the local scale, water soluble compounds used in agriculture (fertilisers), industrial refuse, solid waste deposits etc., may be caught by water and produce groundwater contamination, which will remain undetected until the polluted water passes through a local well. Groundwater modelling has become an important tool for planning and decision making process involved in groundwater management. For managers of water resources, models may provide essential support for regulations and engineering designs affecting groundwater. This is particularly evident with respect to groundwater protection and aquifer restoration. Assessment of the validity of modelling-based-projections is difficult and often controversial. The success or failure of a model depends on the availability of field information and the type and quality of the mathematical tools. These mass transport processes determine the extent of plume spread and the geometry of the concentration distribution. Advection is by far the most dominant mass transport process in shaping the plume. Hydrodynamic dispersion is usually a second order process. The advective transport is controlled by

the configuration of water table or piezometric surface,
the presence of sources or sinks,
the permeability distribution within the flow field, and
the shape of flow domain.

Above parameters are important in controlling the groundwater velocity, which drives advective transport. Adding dispersion to advective transport can cause important changes in the shape of a plume. Other important process is sorption and irrespective of the model describing sorption, the process is of paramount importance in controlling contaminant transport.

MATHEMATICAL MODELLING

The partial differential equation describing three-dimensional transport of contaminants in groundwater (Javandel et al, 1984) can be written as

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i}\left[D_{ij} \frac{\partial C}{\partial x_j} \right] - \frac{\partial}{\partial x_i}(v_i C) + \frac{q_s}{\theta} C_s + \sum_{K=1}^{N} R_k \qquad (1)$$

where

C	the concentration of contaminants dissolved in groundwater
t	time
x_i	the distance along the respective Cartesian co-ordinate axis
D_{ij}	the hydrodynamic dispersion coefficient
v_i	the seepage or linear pore water velocity
q_s	the volumetric flux of water per unit volume of aquifer representing sources (positive) and sinks (negative)
c_s	the concentration of the sources or sinks
θ	the porosity of the porous medium
R_k	chemical reaction term

Assuming that only equilibrium controlled linear or non-linear sorption and first order irreversible rate reactions are involved in the chemical reactions, the chemical reaction term can be expressed as (Grove and Stollenwerk, 1984).

$$\sum_{k=1}^{N} R_k = -\frac{\rho_b}{\theta} \frac{\partial \overline{C}}{\partial t} - \lambda \left[C + \frac{\rho}{\theta} \overline{C} \right] \qquad (2)$$

where

ρ_b	the bulk density of the porous medium
$\overline{C}$	the concentration of contaminants sorbed on the porous medium
λ	the rate constant of the first-order rate reactions

rewriting

$$\frac{\rho_b}{\theta} \frac{\partial \overline{C}}{\partial t} = \frac{\rho_b}{\theta} \frac{\partial C}{\partial t} \frac{\partial \overline{C}}{\partial C} \qquad (3)$$

Rewriting equation (1) by substituting equation (2) and (3) as

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i}\left[D_{ij}\frac{\partial C}{\partial x_j}\right] - \frac{\partial}{\partial x_i}\left(v_i C\right) + \frac{q_s}{\theta}c_s - \frac{\rho_b}{\theta}\frac{\partial \overline{C}}{\partial C}\frac{\partial C}{\partial t} - \lambda\left(C + \frac{\rho_b}{\theta}\overline{C}\right) \tag{4}$$

Rearranging terms we get

$$R\frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i}\left[D_{ij}\frac{\partial C}{\partial x_j}\right] - \frac{\partial}{\partial x_j}\left(v_i C\right) + \frac{q_s}{\theta}c_s - \lambda\left(C + \frac{\rho_b}{\theta}\overline{C}\right) \tag{5}$$

where R is called the retardation factor, defined as

$$R = 1 + \frac{\rho_b}{\theta}\frac{\partial \overline{C}}{\partial C} \tag{6}$$

Equation (5) is the governing equation underlying the solute transport model.
The transport equation is linked to the flow equation

$$v_i = -\frac{K_{ii}}{\theta}\frac{\partial h}{\partial x_i} \tag{7}$$

where

K_{ii} a principal component of the hydraulic conductivity tensor

h hydraulic head

The hydraulic head is obtained from solution of three dimensional groundwater flow equation through MODFLOW software (McDonald and Harbaugh, 1988).

$$\frac{\partial}{\partial x_i}\left[K_{ii}\frac{\partial h}{\partial x_j}\right] + q_s = S_s\frac{\partial h}{\partial t} \tag{8}$$

where S_s is the specific storage of the porous material. The hydrodynamic dispersion tensor for isotropic media is defined by (Bear, 1979) and Burnett and Frind (1987) as

$$D_{xx} = \alpha_L\frac{v_x^2}{|v|} + \alpha_{TH}\frac{v_y^2}{|v|} + \alpha_{TV}\frac{v_z^2}{|v|} + D^*$$

$$D_{yy} = \alpha_L\frac{v_y^2}{|v|} + \alpha_{TH}\frac{v_x^2}{|v|} + \alpha_{TV}\frac{v_z^2}{|v|} + D^*$$

$$D_{zz} = \alpha_L\frac{v_z^2}{|v|} + \alpha_{TH}\frac{v_x^2}{|v|} + \alpha_{TV}\frac{v_y^2}{|v|} + D^*$$

$$D_{xx} = D_{yx} = \left(\alpha_L - \alpha_{TH}\right)\left[\frac{v_x v_y}{|v|}\right]$$

$$D_{xz} = D_{zx} = \left(\alpha_L - \alpha_{TV}\right)\left[\frac{v_x v_z}{|v|}\right]$$

$$D_{yx} = D_{xy} = \left(\alpha_L - \alpha_{TV}\right)\left[\frac{v_y v_z}{|v|}\right]$$

where

α_L is the longitudinal dispersivity

α_T is the transverse dispersivity

D^* is the effective molecular diffusion coefficient

v_x, v_y, v_z are components of the velocity vector along the x,y,and z-axes

$|v| = \left(v_x^2 + v_y^2 + v_z^2\right)^{\frac{1}{2}}$ is the magnitude of the velocity vector

Numerical Approaches

The numerical approaches for solving the mass transport equations are based on computer based particle tracking methods. They are approximate forms of the advection-dispersion equation (5) as a system of algebraic equations or alternatively simulating transport through the spread of a large number of moving reference particles. These numerical approaches deal with variability of flow and transport parameters (hydraulic conductivity, porosity, dispersivity etc.). One of the first steps in developing computer model is to sub-divide the region in terms of cells. This process makes it possible to account for variable nature of parameters involved in controlling groundwater flow and mass transport. Second step is to provide boundary conditions at a large number of node points and assign values of concentration or loading rates defining various boundary conditions for all nodes located along boundary of the domain. Continuity consideration of numerical solutions of solute transport requires a smooth and accurate representation of velocity field, which can be obtained by simulation with a flow model. Velocity values are computed by applying Darcy's equation with calculated hydraulic heads and porosity values. The transport model is coupled to the flow model by the velocity terms. There is no requirement to solve the flow and transport equations simultaneously and in many cases concentration does not influence the flow by changing the fluid density. Flow is then assumed to be independent of mass transport.

The finite difference method replaces the governing differential equations of groundwater flow and solute transport by a set of difference equations applicable to the system of nodes. The difference equations approximate the first and second -order derivatives in the transport equation by concentration differences between node points. When each node in the grid is considered, the result is a system of algebraic equations, which can be solved with matrix methods. The method of characteristics (MOC) takes the advection-dispersion equation and breaks it down into a set of simpler differential equations. This formulation in effect provides a frame of reference that is moving with the mean groundwater velocity. The transport of contaminants is simulated by adding reference particles and moving them in a prescribed manner. By varying the number of particles added at the source during any one-time step, it is possible to simulate complex loading functions. Advection is accounted by moving each particle by a distance in the direction of flow that is determined by the product of the magnitude of the groundwater velocity and the size of the time step. With a small time step, this particle motion traces a pathline through the system (Konikow and Bredehoeft, 1978). Dispersion is accounted for in the particle motion by adding to the deterministic motion a random component, which is a function of the dispersivities. The mean concentration for each grid block is calculated as the sum of the mass carried by all the particles located in a given block divided by the total volume of water in the block.

Reliability of groundwater model predictions typically depends on the correctness of the conceptual model, availability and quality of model data and the adequacy of the prediction tools. Conceptualisation and characterisation are sufficiently understood to meet project objectives, and then the conceptual model may be translated into a mathematical model. Such a mathematical model typically consists of a set of governing equations and boundary conditions for groundwater flow and transport simulation. Relating such a mathematical model to a particular system requires specific values for system parameters, stresses and boundary conditions as well as rate coefficients. The application of geochemical and transport models requires making simplifying assumptions with respect to system processes, stresses and geometry, a procedure referred to as model schematisation. Efficient model schematisation starts early during conceptualisation and characterisation process and continues into the code selection, model design or construction and model attribution and calibration phases of a modelling project. Determination of site boundaries is based on (a) natural site characteristics (topography, soils, geology, hydrology, biota, and chemistry) (b) current and past land use and (c) known or suspected extent of site-related contaminants. Investigations of groundwater contamination should include areas of potential source up-gradient and potential migration paths down-gradient from a vulnerable source location. Data from existing sources are gathered by identifying data sources and collecting and organising relevant data into a manageable database.

Transferring data into a conceptual model is rather intuitive process consisting of (1) qualitative and quantitative data interpretation of individual data elements and grouped data within a particular data type, (2) analysis of spatial and temporal relationships between various data types and (3) relating data types and interpreted data to elements of specific system (i.e. processes, structure, state and stresses). The source, transport, fate and resulting distribution of each targeted chemical (e.g. inorganic and/or organic chemical constituents, tracers or isotopes) in the transport phenomenon are conceptualised in the second step. In the case of unknown sources, source locations and strengths are hypothesised from the conceptualised transport and fate processes and actual distribution of chemicals. The conceptual models are described and visualised using cross-sections and regional maps. Surface characterisation at the near ground-surface is made considering vegetation related (including plant releases and uptake) and rainfall related chemical exchanges with subsurface system.

The groundwater system is characterised and quantified by determining the type, amount, temporal variation and spatial distribution of groundwater recharge and discharge using surface, subsurface and hydrogeological analysis. Further more, reaction and flow paths of indicative chemical species are analysed for information regarding the groundwater flow system. The groundwater system is quantitatively defined in terms of boundary conditions, flow paths and potentiometric surfaces and groundwater regime budget. Transport system characterisation analyses the presence, transport and fate of the chemical species in both space and time. At this stage relevant physical and chemical processes of the transport system are mathematically described and quantitatively attributed. Transport processes include advection, dispersion, adsorption, volatilisation, ion exchange and bio-transformation. The final result of this analysis is a characterised and required mass transport process model. An adequate computer code is chosen to simulate groundwater flow and mass transport processes.

The distribution of contaminants in the sub-surface is a manifestation of mass transport processes. Establishing this link is vital because from it follows understanding of how a particular contaminant plume has been developed, how it can be expected to behave in future and finally how effective a remedial measure might be if implemented. The main attributes distinguishing sources of groundwater contamination are

the degree of localisation,
the loading history, and
the kinds of contaminants emanating from them.

GROUNDWATER FLOW MODEL

Slice successive over relaxation is a method for solving large systems of linear equations by means of iteration is implemented in the SSOR package of MODFLOW by dividing the finite difference grid into vertical slices and grouping the node equations into discrete sets, each set corresponding to a slice. In every iteration, these sets of equations for each slice are processed. They are first expressed in terms of the change in computed head between successive iterations. The set of equations corresponding to the slice is then solved directly by Gaussian elimination treating the terms for adjacent slice as known quantities. The values of head change computed for the slice are then each multiplied by an acceleration factor, ω generally taken between 1 and 2. The computed heads are taken as the final values of head change in that iteration for the slice. This procedure is repeated for each slice in sequence until all slices in the three-dimensional array have been processed, thus completing a domain iteration. The entire sequence is then repeated, until differences between the computed head values in successive iterations is less than the chosen criterion at all nodes in the grid. The solver checks for the maximum change in the solution at every cell after completion of every iteration. If the maximum change in the solution is below a set convergence tolerance then the solution has converged and the solver stops. Otherwise a new iteration is started (McDonald and Harbaugh, 1988).

MASS TRANSPORT MODEL

Mass transport in three dimensions (MT3D) is a computer model for simulation of advection, dispersion and chemical reactions of contaminants in three-dimensional groundwater flow systems (Zheng, C., 1990). The model is used in conjunction with a block-centred finite difference flow model MODFLOW and is based on the assumption that changes in concentration field will not measurably change the flow field and uses a mixed Eulerian-Lagrangian approach to the solution of the advection-dispersion equation, based on a combination of method of Characteristics (MOC) and the modified method of characteristics (MMOC). Longitudinal dispersivity is specified as a characteristic of the soil type (related to the tortuosity of interconnected pores) which tends to spread out contaminant mass along the advective path of the plume. The horizontal transverse (plume width) and vertical transverse (plume thickness) dispersivities are assigned as ratios (fractions) of the longitudinal dispersivity as required by MT3D. The molecular diffusion coefficient value is also to be given as input. The hydrodynamic dispersion coefficient is computed as the product of the dispersivities and velocity (mechanical dispersion) plus the molecular diffusion coefficient. The MOC uses a conventional particle tracking technique based on a mixed Eulerian-Lagrangian method for solving the advection. The dispersion, sink/source mixing and chemical reaction terms are solved with the finite difference method. (Zheng, C.,1990).

Contaminant migration in groundwater due to industrial effluent in Venkatapuram area, Andhra Pradesh

Untreated industrial effluents from the Hindusthan Polymers is being discharged into a stream which joins two small tanks in Venkatapuram, Visakhapatnam, Andhra Pradesh (Fig. 1). The groundwater and water quality monitoring has been carried out since 1981 in 33 observation wells covering an area of 15 sq. km. The water quality measurements during 1991-92 indicated elevated Total Dissolved Solids (TDS) concentration (as high as 4500 mg/l) in a few observation wells as compared to 1981-82. The TDS concentration of the effluents was observed as 6500 mg/l at the outlet of the plant during the same period. The transmissivity and storativity of the Khondalitic aquifer system were estimated from 3 pumping tests carried out on large diameter wells. The lithologs indicated a 30 - 40 m thick unconfined aquifer. The regional water table configuration of May 1981 was used for steady state model calibration. Transient model was calibrated for three year period from 1981.

Conceptualisation of the groundwater regime from above information formed the basis for mathematical modelling of groundwater flow. Two groundwater flow models were prepared using MODFLOW (McDonald and Harbaugh, 1988) and FLOWPATH computer codes (Franz and Guiger, 1990). Both models used a block centred finite difference grid. Initial conditions, flow parameters as obtained flow model were fed as input to the mass transport model. Solute transport modelling was carried out using the MOC computer code. The effective porosity and dispersivity values were assigned conforming to the values estimated for similar hydrogeological formations elsewhere. The effective porosity of 0.2, longitudinal dispersivity of 40 m and transverse dispersivity of 10 m were used uniformly for the entire area. The source concentration of 4000 - 4500 mg/l at the water table was estimated from the analysis of surface water and groundwater quality data. It was assumed that the effluent reaching the water table source nodes are located just below the stream course and two tanks. Thus sources concentration was distributed at 8 nodes in the model. It was assumed that the quantum of fluid effluent seeping to the groundwater system was about 20 - 30% of that discharged at the surface and solute reaching the water table would be about 70 - 80% of TDS concentration of the effluent at the surface (Subbarao and Gurunadha Rao, 1999).

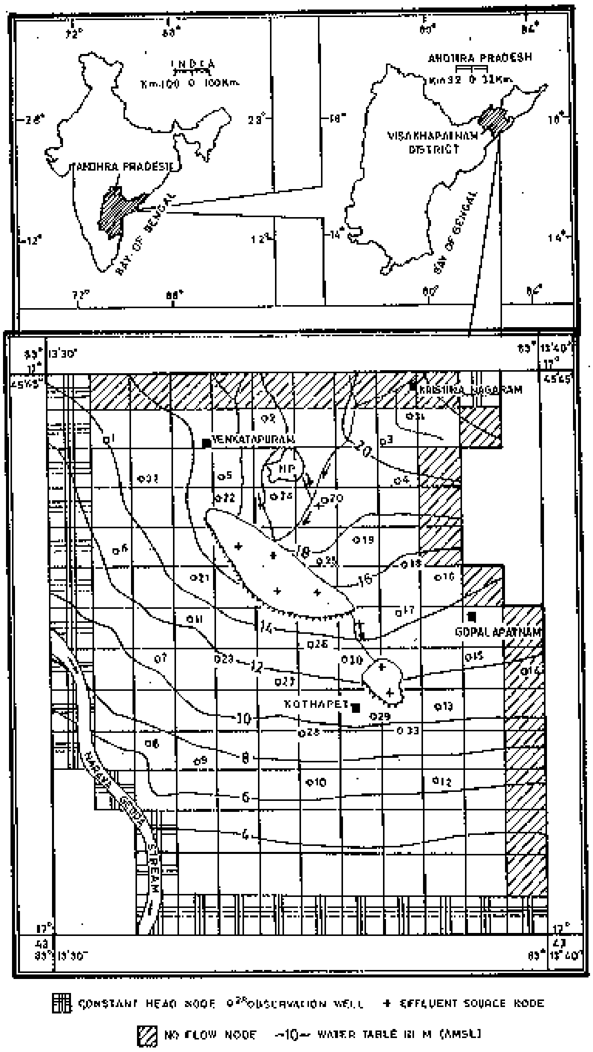

Figure 1. Grid map of Venkatapuram area, Visakhapatnam and boundary conditions.

Flow paths and advective travel times for specified periods of time were determined with the help of particle tracking computer code FLOWPATH by computing particle movement through a velocity field. The groundwater velocity field consists of velocity vectors resolved from inter-cell flow rates computed for individual grid cells in a mathematical flow model. The computed pathline of a particle can be displayed graphically as a trace of discrete points (x,y,z,t) viewed in the x-y, x-z and y-z planes of a Cartesian co-ordinate system. Imaginary particles forward released at source node points track the movement of particles in groundwater as pathlines. Pathlines in this case were predicted for 30 years

(Fig. 2). Calibration and prognosis of the solute transport model was also made for the same period for quantifying the migration of TDS concentration. Areal migration of TDS concentration for 30 years was computed from transport model and compared with predicted pathlines from FLOWPATH model (Fig. 3). The computed TDS concentration of contaminant is found matching satisfactorily with the observed TDS concentrations during 1992. Prognosis of migration of contaminants indicated that the effected area increases by 20% of the present level with elevated concentrations in the range of 200 to 1500 mg/l in a period of 10 years (Subbarao et al, 1998).

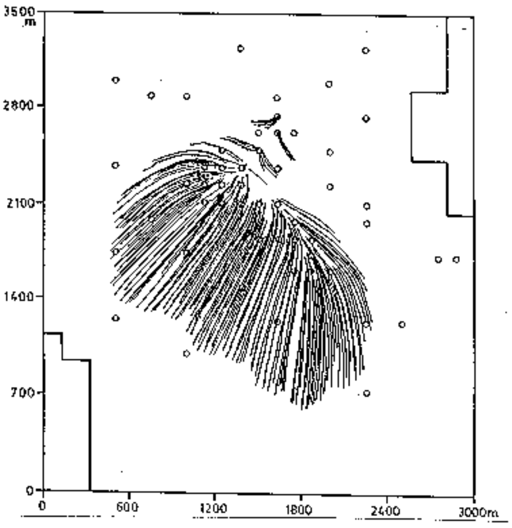

Figure 2. Pathlines of contaminant migration for 2002 (30 years).

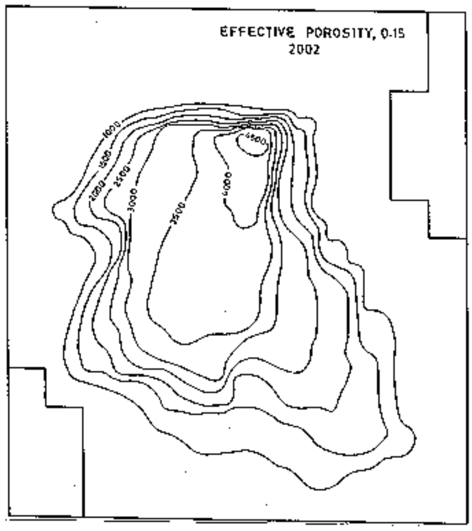

Figure 3. Computed is0-concentration of TDS in groundwater (in mg/l) for 2002 (30 years).

Contamination of a drinking water supply well in Sabarmati river bed aquifer, Ahmedabad

French wells are radial collector wells with several horizontal radial infiltration pipes emanating from a central caisson (also called jack well) and under favourable hydrogeologcial conditions are convenient means of groundwater recovery. Five such wells are supplying drinking water from the Sabarmati river bed aquifer during last decade. Each well was pumping at a rate of 4000 m^3/day. Bacterial and fungal contamination was detected in the French well water near Sabarmati railway bridge in Ahmedabad during September,1992 (Fig. 4). National Environmental Engineering Research Institute (NEERI), Nagpur and Physical Research Laboratory (PRL), Ahmedabad had jointly investigated the contamination problem (Draft Final Report (DFR), 1994). The contamination problem could have been due to infiltration of the river water containing sewage effluent discharged in this reach of Sabarmati river. They have carried out three types of investigations

a tracer test designed to ascertain if there existed a rapid channel type of flow between the sewage discharge points and any of radials of the collector wells a step draw-down pumping and recovery test to understand process of the French well-river bed aquifer interaction, and

physico-chemical and bacteriological analyses of the river bed aquifer soil samples to ascertain the extent of river bed contamination.

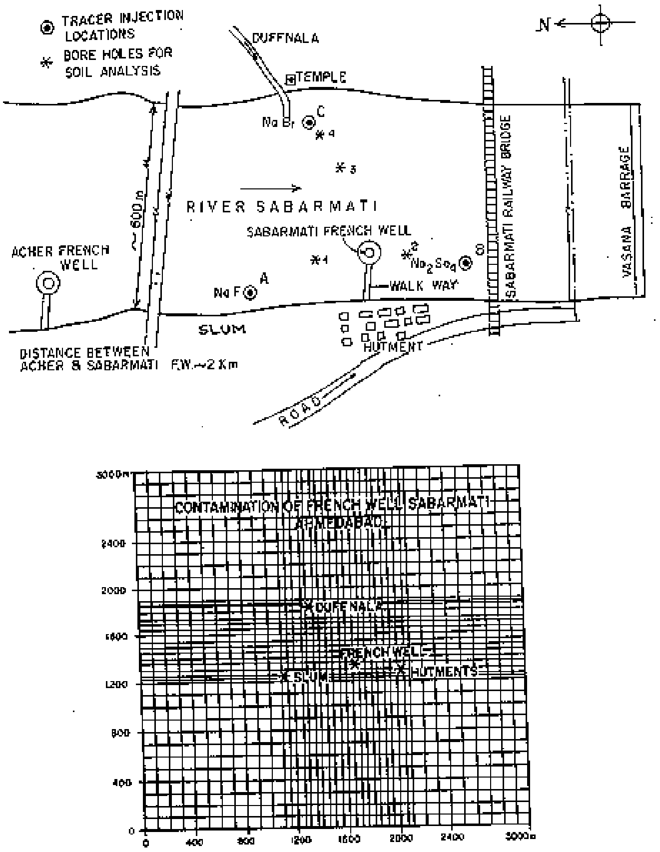

Figure 4. Water supply wells and sources of contamination in Sabarmati river bed, Ahmedabad.

It was reported that observed contamination of water pumped from the collector well was not caused by any channel type of flow. It may be due to slow and steady migration of contaminants through years of persistent sewage effluent discharge from river banks. The groundwater flow, pathline and mass transport models were developed to analyse reported concepts and to verify results of field experiment carried out by computing groundwater velocities and studying migration of contaminants from sources in the river bed aquifer. The hydraulic gradient in the river bed aquifer was assumed as 0.5 m/km and porosity as 0.2. The permeability of formations on either side of Sabarmati river course was assumed 20 m/day. The thickness of first layer was 18.3 m and second layer as10 m. Sewage effluent TDS concentration was in the range of 800 - 1000 mg/l and at the source locations groundwater TDS concentration has reached about 500 mg/l. Groundwater TDS concentration at the source nodes was kept constant at 500 mg/L throughout mass transport simulation. The longitudinal dispersion coefficient of 30 m and a horizontal transverse dispersion coefficient of 10 m was assumed to account dispersion processes. Predictions were made to determine capture zone of the French well under two Scenarios

when the river bed was dry with only later groundwater inflow /outflows across the river bed cross-section under Scenario I

under controlled release of surface water from upstream Dharoi reservoir to keep a minimum water column of 0.2 m in the Sabarmati river (Scenario II).

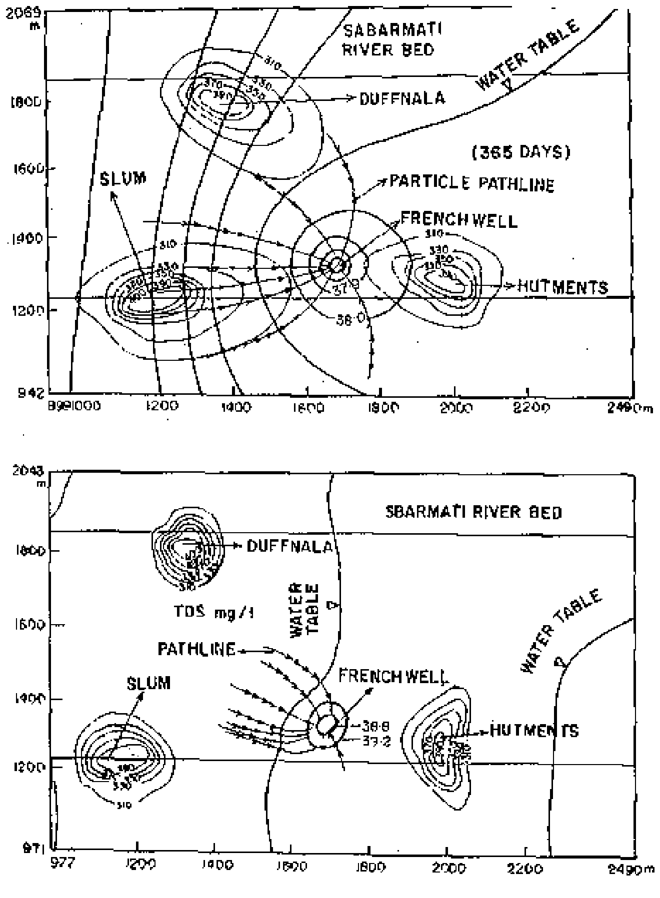

Figure 5. Cpmputed contaminant migration from sewage sources and capture zone of French well under (a) scenario I- dry river bed; (b) scenario II- flow in river.

Comparison of pathlines and iso-concentration contours of TDS under both scenarios indicate that capture zone of the French well under Scenario II was much less than under Scenario I (Fig. 5). The scenario II clearly indicated necessity of providing controlled release of surface water from Dharoi reservoir to maintain a minimum level of 0.2 m surface water around the French well. The scenario could be implemented through appropriate planning of controlled release of surface water from Dharoi reservoir. The significant role of river-aquifer interaction controlling pollutant migration from sewage sources was also evident. Thus, it became imperative for the government to implement a scheme of controlled release of surface water from Daharoi reservoir throughout the year to reduce contaminant migration from sewage sources in this reach of Sabarmati river (Gurunadha Rao and Gupta, 1999). The computed radius of influence of French well as 150-200 m in the model when there is flow of surface water in the river and it confirmed pumping test results.

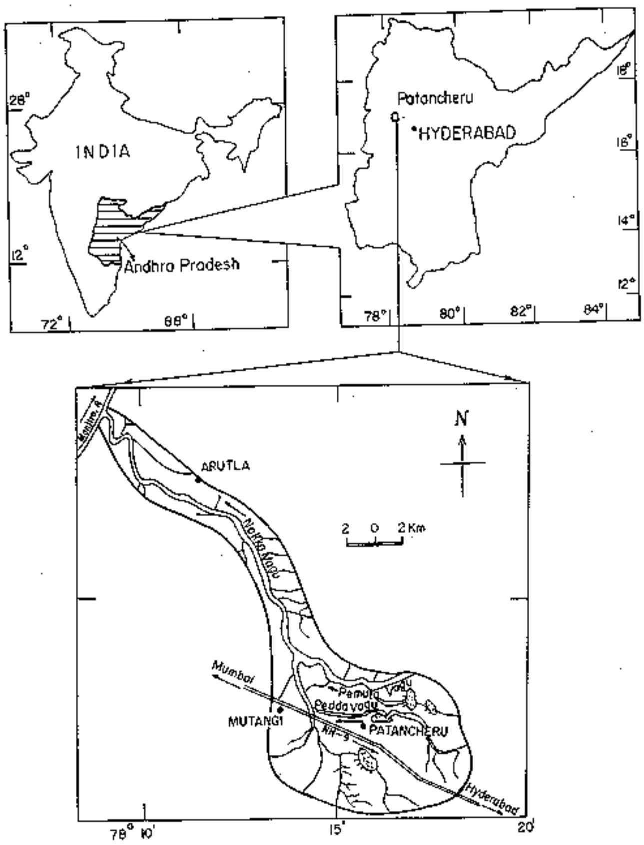

Figure 6. Patancheru industrial development area near Hyderabad, A.P.

Patancheru Industrial Development Area and its Environs, Medak District, Andhra Pradesh

The Patancheru Industrial Development Area (IDA) forms part of catchment of Nakkavagu, a tributary of Manjira river. The area covers about 120 km^2 under Patancheru, Mandal of Medak district, Andhra Pradesh India (Fig. 6). The industries are located around Patancheru village on both sides of National High way from Hyderabad to Mumbai. More than 400 industries are functioning dealing in production of pharmaceuticals, paints and pigments, metal treatment and steel rolling, cotton and synthetic yarn and engineering goods since 1977. Most of these industries use various inorganic and organic chemicals as raw material in the manufacturing and processing units. The effluents naturally contain appreciable amounts of these chemicals and their bye products. These effluents (mostly untreated) are discharged into various unlined channels and streams. The Common Effluent Treatment Plant (CETP) of Patancheru was situated adjacent to Peddavagu and treats various untreated effluents from a number of industries. The waste water from the CETP is let out into Peddavagu. The wastewater discharged from the CETP was found having total dissolved solids (TDS) concentration ranging from 4000 to 5000 mg/L.

The Pamulavagu, Peddavagu and Nakkavagu streams while carrying effluent contributes as a diffuse source of contamination all along its course up to confluence with Manjira river near Gowdcherla village. The alluvium around Nakkavagu is a result of paleo-channel course of Manjira river and forms a potential groundwater bearing zone. Contaminants on reaching groundwater table through stream-aquifer interaction migrate in the aquifer system mostly through advective dispersion. The rate of movement and consequent spread of pollutants depends upon the hydraulic gradient and groundwater velocity. To determine the groundwater velocity distribution a groundwater flow model was constructed. The computed velocity distribution was used to analyse advective and dispersive transport to determine contaminant migration in the area.

Estimation of aquifer parameters is essential for quantifying the groundwater resources and also to determine well characteristics. Pumping tests were carried out on 10 wells including bore wells, filter points and dug wells. High transmissivity values were obtained in alluvial formations, in spite of limited aquifer thickness. The pumping test data was interpreted using GWW computer software. The transmissivity was found to vary from 140 m^2/day in granites to 1300 m^2/day in alluvium. The permeability values as high as 50-75 m/day are found in the alluvium around Arutla village. Intensive groundwater irrigation has resulted in stream aquifer interaction around this village.

The surface water while seeping through bed of Nakkavagu carries effluent to groundwater regime thereby contaminating groundwater up to a distance of 600-800 m on the East of Nakkavagu. The well inventory and lithologic data collected from tube wells indicated that top weathered aquifer having 10-12 m thickness was underlined by a fractured layer. The most important process contributing to the mass transport in groundwater is advection. Longitudinal dispersion is relatively significant but transverse dispersion could be negligible. The total dissolved solids (TDS) concentration in contaminant was selected for a detailed model study because (a) it’s concentration was remained relatively constant in effluent ranging between 1000-4000 mg/L along different reaches of Nakkavagu and (b) it showed a uniform background level of about 300 mg/L in native groundwater. The initial stage in developing the flow and TDS concentration solute transport models was to define the region of interest and establish boundary conditions for flow and solute transport.

The simulated model domain of Patancheru IDA and environs consists of 51 rows and 88 columns and 2 layers covering an area of 22000 m x 8000 m. The top layer mostly consists of 10-15 m thick alluvium along Nakkavagu or a weathered zone in granites and was underlain by 10-15 m fracture zone. The simulated vertical section has a total thickness of 30 m in the model. The outflow from groundwater flow model was estimated in terms of one constant head node at the confluence of Nakkavagu with Majira river by assuming outflow towards Manjira river. The groundwater recharge at rate of 110 mm/year has been fed to simulate distributed recharge to aquifer system from the first layer in the recharge package. Continuous seepage from Peddavagu, Pamulavagu and Nakkavagu streams was simulated as additional input in the model as there was always some effluent flow noticed in Nakkavagu at Ismailkhanpet bridge even during summer months.

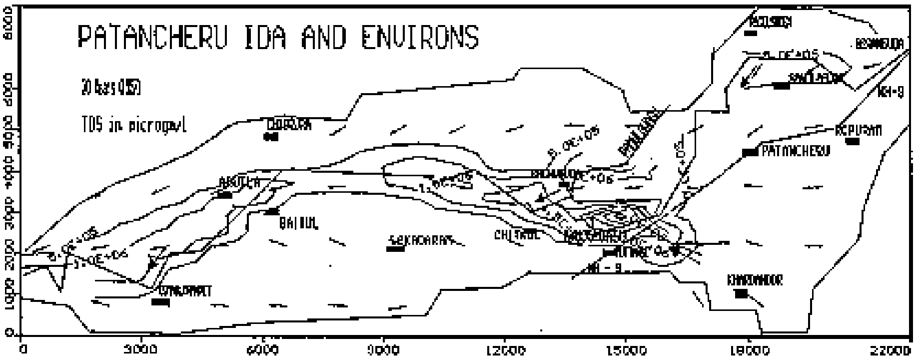

Figure 7. Computed TDS concentration (microgm/L) and velocity vectors of groundwater in Patancheru IDA for 1997.

The values of dispersivity in longitudinal and two transverse directions (Y and Z) were assumed to be 50 m, 5m and 0.05 m respectively. The tendency for α_L to be about 10 times larger than α_{TH} and for α_{TZ} to be much smaller than either of them is in line with the concentrations determined in the area. The relatively smooth decline of TDS concentration away from the Nakkavagu suggests a relatively constant rate of loading. Thus a constant TDS concentration at different nodes on Nakkavagu was assigned varying from 3500 mg/L at source near Patancheru and 1000 mg/L away from the source at about 18 km downstream of Nakkavagu near Ismailkhanpet. The computed iso-concentration contours indicate that the plume is expanding and follows the hydraulic gradient implying that advection is the dominant mechanism of spreading. Qualitatively shape of the plume indicates that longitudinal dispersion is more significant than transverse dispersion. The contaminant migration was found extending up to 500-600 m from Nakkavagu on the eastern part during last 20 years (1997) (Fig. 7). The modelling study has helped gain better insight of the hydrogeologic set up and assessment of contaminant migration due to mass transport processes. Over-exploitation of groundwater in the alluvial parts of Nakkavagu has resulted in decline of water table resulting in further contamination of groundwater through stream aquifer interaction. Remedial measures like reduction of concentration of effluent in waste water let out into streams from CETP and individual industries has been suggested to contain elevated concentration of TDS (Gurunadha Rao et. al., 1999).

CONCLUSION

The groundwater modelling is a prognostic tool for assessment and management of groundwater contamination due to discharge of effluents on ground surface. The case studies presented illustrated the applicability of mass transport models for assessing the contaminant migration. The studies will help plan creation of organised geohydrologic and water quality data base for construction of reliable mass transport models for understanding and prediction of likely contamination of groundwater from effluent sources and designing of necessary remedial measures. Data collection and monitoring in a study area tend to be curtailed after the project has ended. This inevitably results in deficiency of future data relating to prediction period. The collection of new data after a prediction was made provides the basis for a strict test of model accuracy - post audit. If a model is to be used for prediction of responses in a system, subject to continuing water management constraints, it should be periodically post audited and re-calibrated to incorporate new information such as changes in imposed stresses or revisions of the assumed conceptual model.

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