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Water quality aspects of ground water recharge modelling for sustained effluent irrigation

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Abstract: Water quality aspect of ground water recharge modelling of M/s SIV Industries effluent irrigated farm in Coimbatore, Tamil Nadu, which is polluted due to the disposal of Viscose pulp plant effluents is carried out to know the impact of Sodium, Calcium and Magnesium in the ground water. The model was developed using the VISUAL MODFLOWpackage. At first, the flow modelling of the area is developed to find out the water table fluctuation and direction of ground water flow. The calculated values are retrieved in the mass transport package MT3D to find the concentration of Na, Ca and Mg in the ground water for various options. The result of this study indicated that the ..concentration values are on the increasing trend at all the observation points irrespective of options. However, the effect is minimized if diluted effluent irrigation was carried out. At 25per cent and 50 per cent dilution, the reduction in the rate of accumulation was observes as 2-3 times and 7 times respectively. The application of this developed model with VMF has created a new platform for the design of eco-friendly management of effluent irrigation schemes.

Key words: Effluent irrigation, contaminant transport, groundwater recharge

Introduction

Ground water is an important source of drinking water, irrigation and industrial use. At present nearly one fifth of the available water in the world is obtained from ground water. Although the use of groundwater resources in India started only during the past three decades, it is estimated that 40 per cent of the irrigated area in India is from ground water and more than 50 per cent of the public water supplies are obtained from wells (Raghunath 1985).The country has been constantly encouraging exploitation of groundwater but has done little to recharge. As a result, groundwater table continuously falls all over the country. So, finding alternate strategies that could surmount this alarming situation is the need of hour. But for the goodness, groundwater too is facing serious illness due to the indiscriminate discharge of wastewater from the industries and communities, that either have inadequate or no treatment facilities. A strategy can be designed for safe release of pollutant and usage of treated effluent as source of irrigation and artificial recharge to augment ground water potential. Effluent irrigation is the cheapest option for both safe disposal and artificial recharge of groundwater. Lee and Jones 1992,1993,1994 have reviewed these issues and provided guidance on the approach that should be taken in reuse of reclaimed wastewaters as they may impact groundwater and aquifer quality and storm water runoff.

The development of groundwater recharge project should require in depth assessment of the characteristics of the recharge waters and their impact on the quality of the water recovered from the aquifer and on longevity of the recharge project. Due to the complex field environment, it is difficult to solve the ground water flow and contaminant transport directly. The simplification is introduced in the form of models that express our understanding of the

Table 1. Recharge rate and Concentration

Well Number	Initial Concentration (mg/l)			Initial Water Table (m)
	Sodium	Calcium	Magnesium	
C5	94	120	62	8.74
C7	71	88	29	8.48
CII	88	88	91	6.15
C14	106	80	82	7.72
CIS	125	112	106	6.25
C17	113	112	125	5.68
C26	135	104	106	6.21
C32	113	88	96	7.99
C33	75	56	62	7.95
C34	85	52	96	8.66
C36	80	40	67	5.03
C45	87	56	65	8.14

Table 2. Error Analysis

S.No.	Parameters	Mean Error	Mean Absolute	Standard Error of the Estimate	Root Mean Square	Normalized RMS
			Concentration (mg/l)			
1.	Sodium	0.39821	0.40218	0.0572	0.8304	6.7341 %
2.	Calcium	-2.89371	3.98042	0.09743	5.51870	6.231%
3.	Magnesium	0.31732	0.52361	0.06173	0.6771	6.01 %
			Water Table (m)			
4.		0.298105	0.462108	05201621	0.643077	5.846163%

nature of the system and its behavior. Many researchers have adopted mathematical modelling techniques for finding the behaviour of aquifer against environmental and human interventions. Konikow and Bredehoeft, (1974); Golick *et al.* (1983); Rashid Al-Layla *et al.* (1988); Biver (1991); Francis(1986); Shamurkh *et al.*(2001); Gates *et al.* (2002) etc. are some among them. This paper presents an overview of issues that should be considered in protecting groundwater aquifer system from recharge of contaminant (Na, Ca and Mg) in wastewater.

Objective of the study

This investigation was initiated to evaluate the long term impact on groundwater quality and sustainability of effluent irrigation. SIV pulp plant effluent irrigated area was chosen as the study site for this investigation. VISUAL MODFLOW software was used to address the

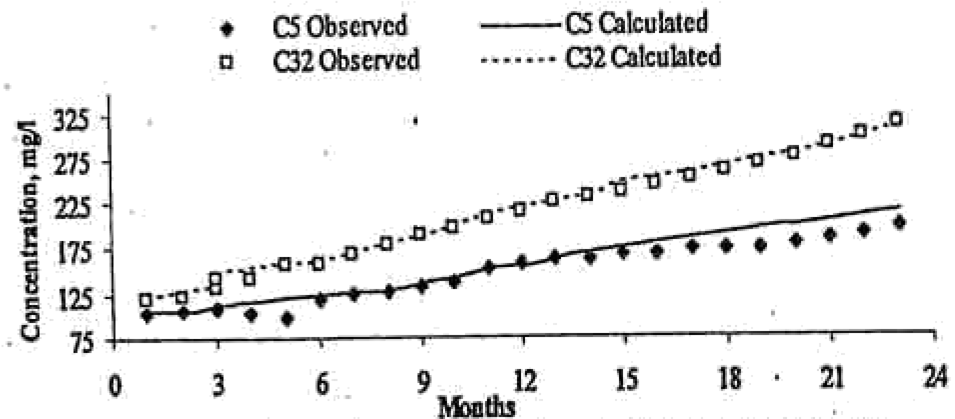

Fig. 1. Comparision of observed and calculated sodium concentration, mg/l

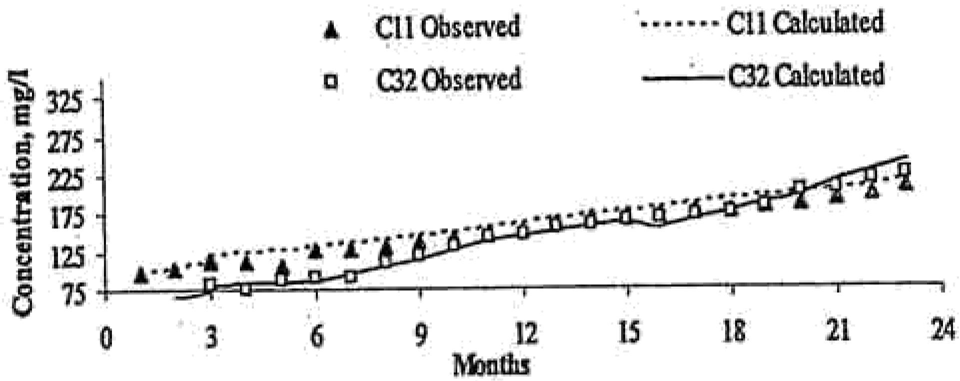

Fig. 2 Comparision of observed and calculated calcium concentration, mg/l

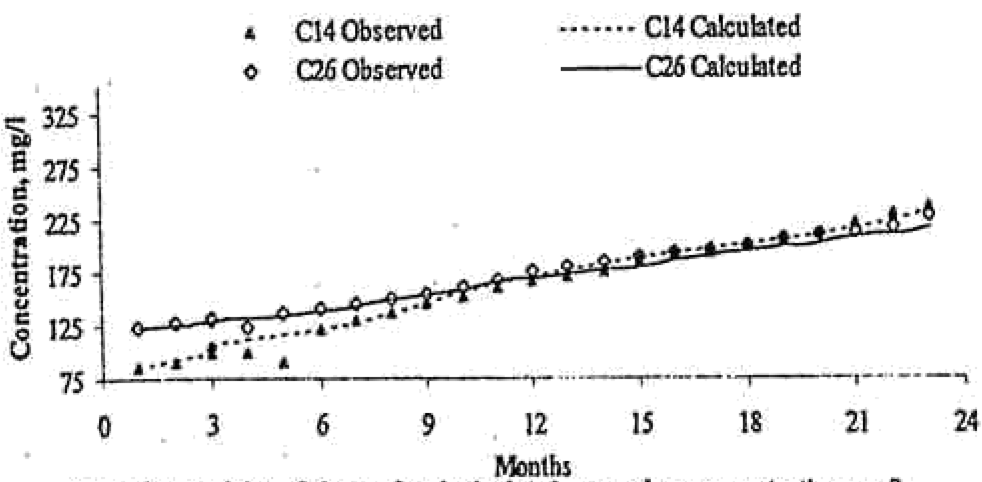

Fig. 3. Comparision of observed and calculated magnesium concentration, mg/l

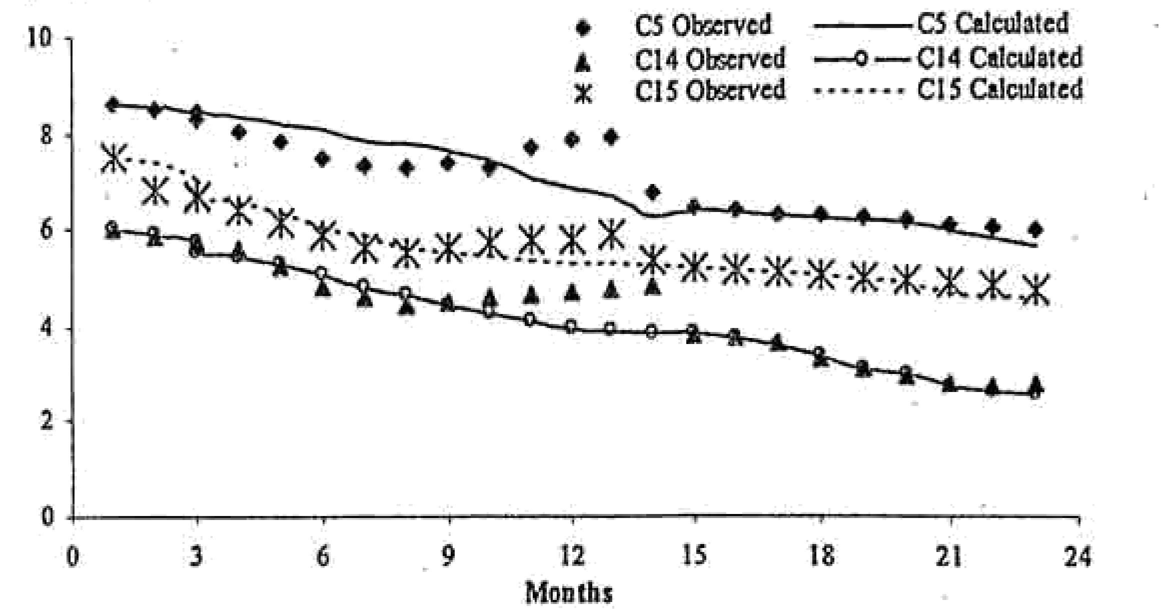

Fig.4. A nalysis of observed a nd calculated water t able depths, m

groundwater flow and contaminant transport simulations.

Description of study area

The study area falls within the Bhavani river basin, located on the south bank of Bhavani on the foreshore of Lower Bhavani Project (LBP) reservoir. It is located very nearer to the water spread area of LBP reservoir separated by 2km of Reserved Forest Area. The effluent from the pulp mill is treated in the factory located at Sirumugai village and then pumped to the farms located 6k.m away for irrigation. The farm is located at an elevation between 290m and 305m above MSL and is drained by a stream, which passes through adjoining forest area to river Bhavani, which lies between 11°25' latitude and 77°0' longitude. Geologically, the area is covered by crystalline rocks of Archean age. The rock type includes complex geniss formation covered by top red sandy soil and its thickness ranges from 0.1m to 3.0m. The thickness of weathered zone extends upto 45m depth. The total area of the effluent irrigation project is 565.10 acres. The major crop cultivated is sugarcane, planted in the furrow system.

Modeling Framework

General Considerations

Ground water contamination from effluent irrigation can be predicted by employing a solute transport model. Since sodium, calcium and magnesium are the major components, the design of transient contaminant transport models for the end product species is necessary. The use of a groundwater flow model is also indispensable, since this provides the flow velocities for the contaminant transport model. The ground water flow and contaminant transport simulations were conducted only for the saturated zone of the aquifer. VISUAL MODFLOW makes it easy to modelers to design the model, run the simulations codes and visualize the simulation results. The use of ground water flow and contaminant transport models requires the determination of hydraulic, transport and chemical parameters.

Modeling Ground Water Flow

Ground water flow models are used for numerous hydrologic investigation purposes such as vulnerability assessments, remediation designs and water quality and quantity estimation. Depending on particular study, the model can range in complexity, from simple one dimensional flow analyses at the local scale (Gerla and Matheny 1996), to regional groundwater flow studies in three dimensions (Brodie 1999, Kennett-smith *et al.* 1996, Vermulst and De Lahge 1990). In addition, either steady state or transient modeling strategies may be employed based on objectives of investigation.

Fully saturated models, such as MODFLOW are very popular and commonly applied to many ground water contamination problems. Transient three-dimensional saturated ground water flow is described as

$$\frac{\partial}{\partial x} K_{xx} \frac{\partial h}{\partial x} + \frac{\partial}{\partial y} K_{yy} \frac{\partial h}{\partial y} + \frac{\partial}{\partial z} K_{zz} \frac{\partial h}{\partial z} - W = Ss \frac{\partial h}{\partial t}$$

(Kennett-smith *et al.* 1996)

Where Ss is the specific storage, K_{xx}, K_{yy}, K_{zz} are the values of hydraulic conductivity along x, y and z areas, 'h' is the piezometric head and 'W represents the volumetric flux per unit volume.

The migration and mixing of chemicals dissolved in ground water will be obviously affected by the velocity of the flowing ground water. To calculate the actual seepage velocity of ground water flow, we must account for the cross-sectional area through which flow is

$$V_i = \frac{q_i}{\varepsilon} = k_{ji} \frac{\partial h}{\partial x_i}$$

(Konikow and Bredanoeft 1974)

Where Vi is the seepage velocity, q_i represents a volumetric flux per unit cross-sectional area and E is the effective porosity of the porous medium.

Contaminant Transport Modelling

In this study, MT3DMS three dimensional multispecies transport model was used to simulate the contaminant transport in the aquifer. Calibration of ground water flow model was obtained by using MODFLOW. MT3DMS employ a mixed Eularian-Lagrangian approach to solve the adjective-dispersive- reaction equation (Zheng 1999). The partial differential equation describing the rate and transport of contaminant, of species in three dimensional, transient groundwater flow system can be written as follows.

$$\frac{\partial \varepsilon C^k}{\partial t} = \frac{\partial}{\partial x_i}\left(\partial \varepsilon Dij \frac{\partial c^k}{\partial x_i}\right) - \frac{\partial}{\partial x_i}\left(\varepsilon v_i \; C^k\right) + q_s \; c_s^K + \Sigma \, Rn$$

where C^K is the dissolved concentration of species, E is the porosity of the subsurface

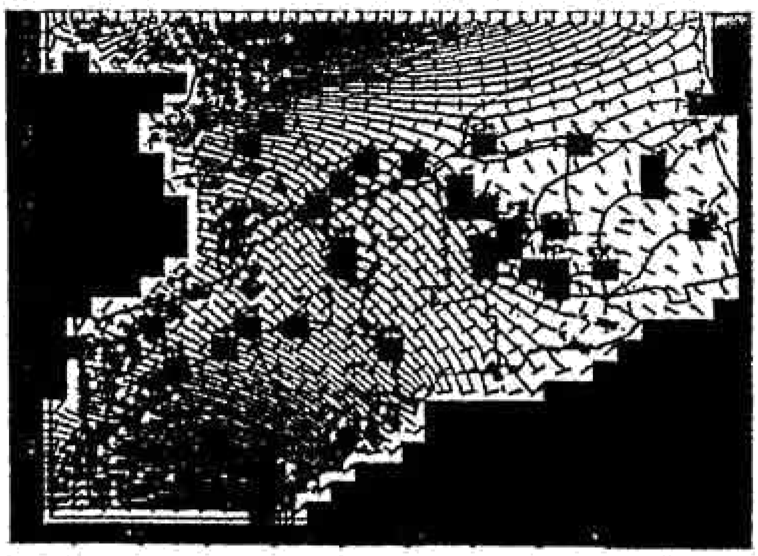

Fig. 5. Ground Water Flow Direction

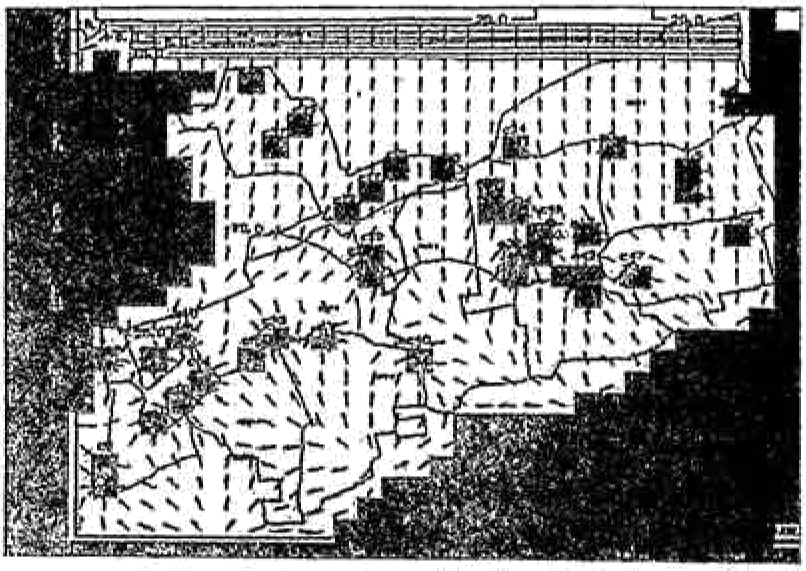

Fig.6 Ground Water Flow Direction when the well water Pumping

medium, t is time, X_i is the distance along the respective Cartesian co-ordinate axis; D_{ij} is the hydrodynamic dispersion co-efficient tensor; v_i is the seepage velocity; q_s is the volumetric rate per unit volume of aquifer representing fluid source and sink; C^K_S is the concentration of source or sink flux for species k; ΣR_n is the chemical reaction term.

The numerical solution of the transport equation in MT3DMS code was under taken by using the method of characteristics. Solutions produced using-this method are free from numerical dispersion and artificial oscillation errors.(eg., Garder *et al.* 1964, Konikow and Bredehoeft, 1978; Neuman 1981 and 1984; Farmers 1987; Zheng 1993; Konikow *et al.* 1996).

Model Input Parameters

Aerial discretization was done in to 300 rows and 400 columns, origin of the model was taken at 11°25' latitude and 77° 0' longitude. The size of the each cell is 4m (Haitjema *et al.* 2001). The study area map was prepared in DXF format using CAD Soft. The elevation of top layer was given based on detailed electronic theodolite field survey data. Aquifer parameters such as transmissibility and storage coefficient data were used according to the observations made by PWD, Govt. of Tamil Nadu (Hydraulic conductivity m/sec 0.000026, storage co-efficient 0.000136 and specific yield 0.005). Monthly water table depth and pumping rate of each observation well were given from observed data. The water levels and concentration levels observed for the year March 1999 were taken as initial water level and initial levels of concentration in the observation wells (Table 1). The monthly values of elements (sodium, calcium and magnesium) data of the 12 study wells were used from well water analysis and monthly water level the above wells were measured and used as the monthly observed water level (From June 1999 to May 2001).

The amount of effluent used for irrigation in this study area is 10,000m^3/day and its chemical constituent levels are sodium 150 mg/l, calcium 172 mg/l and magnesium 28 mg/l. The recharge rate for the study area was estimated as a function of total applied water and evapotranspiration (Konikow, 1974).

Table 3. Summary of the Simulation Result on Chemical Concentration in Groundwater

S. No	Management option	Increasing Rate Sodium concentration (mg/l per year)	Increasing Rate calcium concentration (mg/l per year)	Increasing Rate magnesium concentration (mg/l per year)
1.	Same level of effluent irrigation (without dilution)	45-130	40-87	25-62
2.	25per cent dilution of effluent irrigation	28-75	24-38	11-34
3.	50per cent dilution of effluent irrigation	6-14	12-22	2-8

Recharge rate = Total applied water - Evapotranspiration

Total applied water = Effluent load + Well water pumping + Precipitation.

The concentration of chemical contaminants of recharge water was calculated by assuming that the total mass of dissolved solids in the recharge water is the same as that in the total applied water. The increase in concentration in the recharge water is then proportional to the decrease in volume of water due to evapotranspiration loss.

Calibration of parameters

Calibration of the model involves parameter estimation. It deals with the computation of values for the parameters that appears in the model equation. In the values of the parameters such as porosity, longitudinal and transverse dispersivity were used for simulation, with these values the simulation was carried out in 24 time step for each 30 days and the results compared with the observed data (Fig. 1,2,3 & 4)

The simulation runs were respected with increments in dispersivity and porosity. It was found that a uniform effective porosity of 25 per cent produced the best result for both flow and contaminant transport. Longitudinal dispersivity and ratio of transverse to longitudinal dispersivity were taken as 120m and 0.05 respectively from literature (Shamrukh *et al.* 2001). The simulation results were relatively insensitive to adjustments of dispersivity values. Since there is no transition zone between contaminated and non-contaminates area. Subsequently the longitudinal and transverse dispersivity were assigned as a constant value.

Model Validation

With calibrated parameters, the model was applied to selected wells in the study area. The calibrated parameters were used for simulating the entire study area. Verification was made between the computed and observed values of water table levels and concentration of sodium, calcium and magnesium. The comparison between observed and computed values indicate that the sodium, calcium and magnesium concentration levels were matching in 93 per cent of the cases with a deviation of ± 5 per cent. Whereas, in the use of water levels, 95 per cent of the observed and computed values showed a deviation of ± 5 per cent.

The infirmities in the computed values of the model seem to stem from the difference in the direction of groundwater flow, irrigation practices and variations in recharge rate of aquifer within the study area. One such source of error is the time difference between the data determination for the calculated data of which was end of each month and actual data of sample collection for the observed data.

All the above factors, contribute to the considerable difference between the observed and computed values. Such type of variation was also encountered by Konikow and Bredanoeft (1974), when they evaluated the chemical quality changes in an irrigated stream-aquifer system.

Water table

As noted earlier, the flow model was calibrated by matching the measured value in the study area. Input parameter, porosity was adjusted in order to match the known configuration of head and to minimize the water balance difference in the model. The model was considered for calibration when all the simulated heads were matching 95 per cent of cases within the deviation ± 5 per cent (Fig. 4). In this study region, the dryland crop like groundnut/ redgram are normally cultivated. The water table in the wells were 9.38 to 22.45m below the ground level and there may not be any water in summer. After implementing the project, groundwater availability has improved, within a year the water table has increased to 3-4m and the farmers around the effluent irrigated area are cultivating their entire land with irrigating banana, sugarcane and coconut. The farmers cultivate their land throughout the year.

Groundwater flow

The study of ground water flow helps to improve the understanding of hydrologic system and they incorporate virtually all the available information about the behavior of the system. It is used as a management tool to evaluate the effect of alternative method of controlling or developing the ground water resource in an area of interest.

The water table contour indicates the area having uniform groundwater potential. The region having wider water table spacing indicates that there is a lesser hydraulic gradient for ground water flow. It is seen from the fig.5 that close contour lines are observed in the northwest direction (Bhavani River). The LBP reservoir is located very nearer on the northwest side of effluent irrigated farm. While LBP reservoir is located 2 km away from the farm in the Reserved Forest Area. This circumstance may lead to the contamination of reservoir water quality in the LBP. It is also found from fig.6 that pumping wells altered the natural water flow direction of ground by drawing water from all the direction. Working against the natural gradient, a well can induce groundwater that would normally flow towards the well (Allan Crow and Piggoh 1999).

Ground Water Quality

In order to keep the ground water as well as reservoir water quality within the permissible level, different irrigation water management options were thought of. In the present paper, simulation model was used to predict the ground water quality under different management options namely i) same level of irrigation (without dilution), ii) 25 per cent dilution of effluent irrigation iii) 50 per cent dilution of effluent irrigation. The current effluent loading rate is 10,000 m^3/day. To achieve the different management options on the field, only concentration of the effluent was changed by keeping all other parameters as constant including the quantity of effluent.

Table 2 lists the simulation results running under different concentration of effluent irrigation. The data indicate that the increasing rate of concentrations of sodium, calcium and magnesium in ground water decreases as the concentration of effluent decreases. The concentration values are on the increasing trend at all the observation points irrespective of options. However, the effect is minimized if diluted effluent irrigation was carried out. Comparing the treatment without dilution with the treatments of 25 per cent and 50 per cent dilution, the reduction in the rate of accumulation by 2-3 times and 7 times were noticed respectively. Now, the question becomes to what level the concentration of the raw effluent should be reduced.

The permissible concentration of effluent sodium, calcium and magnesium for sustainable irrigation should be minimum so that the sodium, calcium and magnesium concentration of ground water can be kept within its limited value. In the present case, it is found that 50 per cent dilution of effluent irrigation is safe for ground water. Hence, the effluent from the factory should be treated to reduce the sodium, calcium and magnesium concentration of effluent to 50 per cent before irrigation.

Summary and Conclusion

The sustainability status of effluent irrigation scheme is reflected by their environmental impacts that are caused by contaminant exported from the disposal site. The application of the concept with a simulation model has created new platform for engineering design of effluent irrigation schemes. The platform can be used to investigate the discharge parameters that make the effluent irrigation more sustainable in the future. The results indicate that the groundwater contamination can be a controlling factor. The practical use of this study can be enhanced by a systematic research i.e. improved or new techniques are needed to determine field value of certain aquifer properties such as effective porosity and dispersion, which cannot readily be evaluated. In some areas, the spatial and temporal variation of these parameters may be important and that should be incorporated in the simulation model.

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