Effects of land-use change on groundwater quality in a coastal habitat of south India

R. RAMESH
Institute for Ocean Management, Anna University, Chennai 600 025, India
e-mail: ramesh@annauniv.edu

Abstract Groundwater samples were collected from 22 locations for a one-year period to evaluate the spatial and temporal variability in water quality. The period included pre-monsoon, monsoon, post-monsoon and summer seasons and the groundwater was collected from both open and dug wells, covering an area of 50 km^2 in the Cauvery Delta (Sirkazhi) region, India. Electrical conductivity and pH were measured *in situ*. The major ions (HCO_3, Cl, SO_4, Ca, Mg, Na and K) and nutrients (NO_3, NO_2 and H_4SiO_4) were analysed. The mobility, concentration, and geo-accumulation of these elements were assessed. The spatial distributions of these elements are indicators of the different pathways of these elements entering the hydrological system during different seasons. Concentrations of total dissolved solids (TDS) and some elements, including Cl and Na, exceed the maximum permissible limits at some locations due to seawater intrusion. The concentration range of NO_3 and NO_2 was 5–48 mg l^{-1} and 0.23–2.13 mg l^{-1}, respectively. The elevated concentration of NO_3 in drinking water, are attributed to non-point sources, such as seepage from agricultural areas and effluent discharge from shrimp farms. In addition, the land-use change has been evaluated particularly with respect to rapid increase in aquaculture activities in the Cauvery Delta region.

Key words aquaculture; groundwater quality; land-use change; pollution

INTRODUCTION

Land-use change is currently very rapid and its consequences are more evident in tropical regions, in part because human population growth there is the most rapid of all geographical regions. In India, nearly 70% of the population is directly dependent on agriculture for sustenance. Of the total 320 Mha land area, nearly 180 Mha is cultivable. From 1970 to 2000, non-agricultural land use in India expanded from 16.2 to 26 Mha, an increase of about 60%. This study focuses on the change in groundwater quality due to land-use change in the Sirkazhi region (11°14′N, 79°44′E) of the Cauvery Delta in India (Fig. 1). The Sirkazhi region primarily depends on the Cauvery River for irrigation. Recently, farm-cultured shrimp and other commercially important fisheries have grown rapidly in this region. The continued inter-state water dispute, which deprives the Cauvery Delta of its share of freshwater for agriculture, has resulted in decreased agriculture as farmers have either sold their prime agricultural land or converted it for aquaculture. This paper investigates a few key drinking water parameters, emphasizing the occurrence, land-use change pattern, concentrations, and spatial distribution.

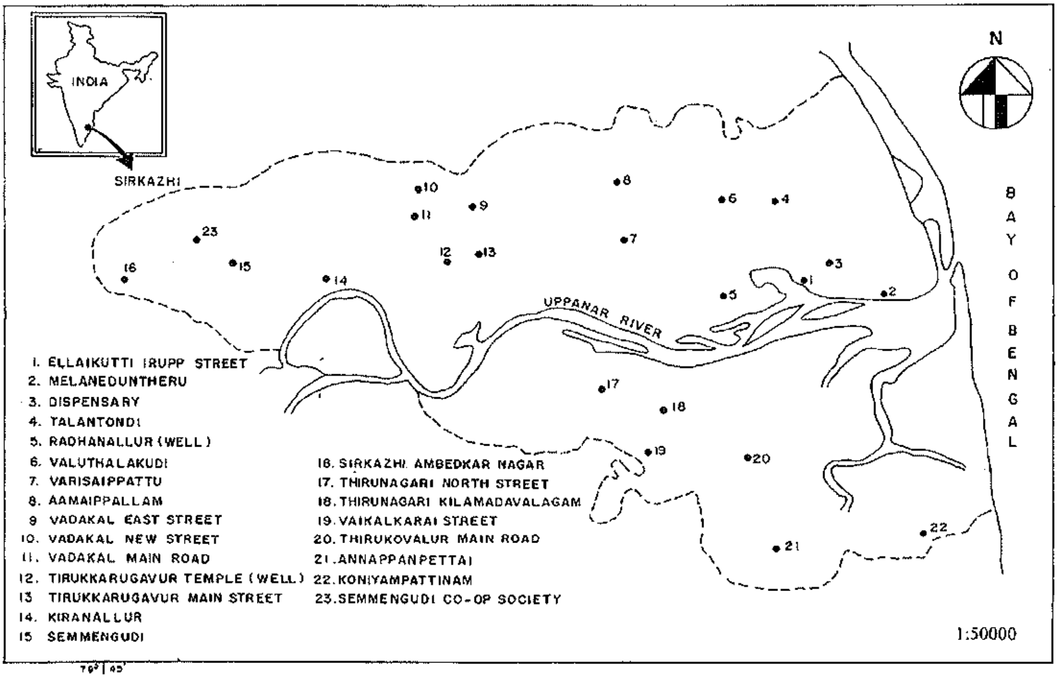

Fig. 1 Map showing the Cauvery Delta region and the groundwater sampling locations.

METHODOLOGY

Groundwater samples were collected from 22 locations (Fig. 1) in 14 villages for a one-year period during pre-monsoon (July–September), monsoon (October–December), post-monsoon (January–March) and summer (April–May) seasons. Acid washed 1-l polyethylene bottles were used for sample collection and storage. Water samples were collected from both bore and open dug wells. Electrical conductivity and pH were measured *in situ*. Water samples were filtered immediately after collection in the laboratory using 0.45 μm Millipore filters and analysed for major ions including Cl, SO_4, HCO_3, Ca, Mg, Na and K, and nutrients including NO_3, NO_2 and H_4SiO_4, using standard methods (Ramesh & Anbu, 1996). The ion balance, i.e. the difference between the sum of cations and anions, is within ±5%.

RESULTS AND DISCUSSION

Groundwater quality

The movement of inorganic and organic chemical species underground is partly governed by their occurrence as free ions, complexes, or molecules, and partly by the physical, chemical, and hydrogeological features of the groundwater environment. The study of such a complex system requires the acquisition of several types of information such as hydrogeological, geochemical, and human influences on the landscape (Bencini *et al.*, 1993). The average groundwater major ion and nutrient concentrations of the Cauvery Delta (Sirkazhi region) are listed in Table 1. The groundwater of this region is generally colourless and the pH ranges from 6.3 to 9.2. Groundwater can be classified based on the total dissolved solids (TDS) concentration as: freshwater 0–1000 mg l^{-1}; brackish water 1000–10 000 mg l^{-1}; saline water 10 000–100 000 mg l^{-1}; and brine water >100 000 mg l^{-1} (Freeze & Cherry, 1979). Most samples are freshwater except at locations 14, 20, 21 and 22, which may be due to the seawater intrusion into the aquifer system (Fig. 2 and Table 1). The seasonal distribution of TDS and Cl was evaluated to determine the extent of salinity encroachment into the inland basin (Fig. 2). The Cl in two groundwater samples of the Cauvery Delta region exceeds 1000 mg l^{-1} during pre-monsoon and monsoon seasons, indicating seawater intrusion. A Cl content of 600 mg l^{-1} is the highest acceptable salinity level for human consumption (Rosenthal, 1994; Ramesh *et al.*, 1995). In other parts of the basin, the Cl concentration is less than 1000 mg l^{-1} indicating marginal mixing. Similarly, the maximum concentration of Na occurs along the coast and Cl concentrations gradually decrease inland. Over-exploitation of groundwater in areas adjoining the coastline and pumping of seawater for aquaculture may be major factors affecting the migration of seawater inland. In contrast, *Penaeus monodon* (shrimp) culture requires a lower salinity than that of seawater. Large amounts of freshwater are pumped into shrimp farms to decrease the salinity of seawater, which is used as the growth medium. The annual water used in semi-intensive and intensive shrimp culture is 11 000–21 000 m^3 t^{-1} and 29 000–43 000 m^3 t^{-1}, respectively (Sonak, 2000), which results in a large-scale depletion of groundwater. Because most of the aquaculture farms are located in coastal areas within 500 m of the high tide line, a decrease in groundwater level will result in seawater intrusion of the aquifer (Alagarswami, 1993; Beveridge *et al.*, 1997). Groundwater flowing through a normal and active hydrological gradient is characterized by Na:Cl ratios of 0.86–1.00 (Rosenthal, 1994). The Na:Cl ratio of the Sirkazhi aquifer is 0.29–0.71. The lower than normal ratio indicates mixing of seawater and freshwater within the aquifer.

Nitrate (NO_3) is the main inorganic N species in groundwater. The average concentrations of NO_3 and NO_2 were 5–48 mg l^{-1} and 0.23–2.13 mg l^{-1}, respectively (Table 1). The average NO_3 concentration exceeded the permissible health limit 45 mg l^{-1} only in two groundwater samples (WHO, 1984). During monsoon and pre-monsoon, the NO_3 concentration exceeded the permissible limit in 27% and 14% of the samples, respectively (Fig. 2). The consumption of water with high NO_3 concentration can decrease the O_2 carrying capacity of the blood, which is particularly important for the health of infants (McNeely *et al.*, 1979; WHO, 1984; Rajagopal & Tobin, 1989). NO_2 is much more toxic to humans and animals than is NO_3. WHO drinking water guidelines specify that the NO_2 concentration should not exceed 3.3 mg l^{-1}, as NO_2 (WHO, 1984). NO_2 concentration in the groundwater samples in this study did not exceed the recommended maximum concentration limit (Table 1).

Land-use change

Development of aquaculture in the coastal areas has led to the destruction of vast areas of mangroves. The total area of the wetland of the Vellar-Pichavaram-Colleroon estuarine complex (Cauvery Delta) is about 2335 ha, of which only 241 ha are presently

Table 1 Average concentration (mg l^{-1}) of major elements and nutrients in the groundwater of the Cauvery Delta region.

Site	HCO_3	Cl	SO_4	Ca	Mg	Na	K	H_4SiO_4	NO_2	NO_3	F	TDS
1	116±20	254±94	75±19	35±14	22.45±6	130±26	88±10	42±40	0.23±0.37	5±7	0.34±0.17	559±89
2	99±48	178±114	56±24	50±20	27.41±9	92±28	48±13	54±49	0.34±0.41	5±4	0.30±0.16	438±131
3	96±39	129±74	90±9	40±18	29.10±7	82±17	32±14	58±50	0.29±0.43	5±6	0.52±0.24	368±44
4	50±33	115±27	59±15	35±14	22.50±9	72±8	10±1	56±47	0.93±0.34	27±17	0.33±0.19	269±92
5	200±99	451±176	16±6	46±9	42.60±14	243±153	35±4	33±13	2.13±0.74	48±20	0.38±0.34	808±136
6	106±42	121±64	23±4	37±11	40.20±18	76±17	10±2	55±47	0.44±0.60	12±11	0.27±0.11	292±26
7	130±48	139±40	28±23	29±11	32.25±16	80±28	79±68	50±54	0.44±0.38	10±10	0.22±0.09	355±221
8	110±62	267±168	75±38	43±13	38.40±10	93±14	110±53	50±55	0.83±1.03	18±24	0.54±0.25	571±223
9	85±46	368±192	202±49	81±13	64.80±43	189±73	18±3	49±37	1.13±1.21	55±58	0.31±0.18	726±204
10	213±75	331±112	183±44	44±11	67.95±26	235±70	22±4	46±36	1.39±1.87	33±42	0.26±0.15	806±101
11	138±42	415±320	211±98	44±19	61.15±20	187±84	22±13	79±103	2.01±1.00	37±19	0.45±0.24	753±347
12	49±14	122±88	24±11	46±5	19.65±8	35±17	12±4	72±82	0.42±0.48	7±6	0.32±0.18	222±103
13	183±92	280±126	103±28	57±13	46.75±7	102±29	92±11	70±81	0.80±0.90	19±25	0.24±0.20	669±87
14	181±28	570±324	149±34	71±31	62.25±6	201±50	108±13	72±80	0.27±0.43	5±5	0.51±0.33	1080±223
15	124±41	240±60	135±40	47±13	105.43±141	126±19	14±3	75±85	0.54±0.80	14±13	0.30±0.13	609±60
16	207±86	394±134	119±24	46±12	45.65±5	212±100	12±1	29±11	0.51±0.55	18±17	0.52±0.03	797±171
17	201±94	212±70	35±1	48±12	44.80±23	100±19	76±15	67±72	0.85±1.10	20±30	0.33±0.23	549±66
18	159±95	327±107	70±31	56±10	43.70±11	134±18	74±6	73±85	0.71±1.00	16±26	0.11±0.01	770±89
19	107±38	152±22	44±15	34±10	39.00±23	90±34	42±21	68±74	0.55±0.54	15±15	0.15±0.04	397±188
20	156±32	1160±791	64±12	53±15	113.55±28	739±105	33±7	27±9	0.80±0.63	13±13	0.27±0.05	1419±387
21	153±66	681±261	73±13	45±12	74.20±46	314±132	93±7	23±13	0.31±0.41	8±8	0.49±0.20	1149±240
22	174±96	999±755	72±43	43±6	66.30±39	301±384	70±117	24±9	1.30±1.51	17±19	0.24±0.13	1238±1419

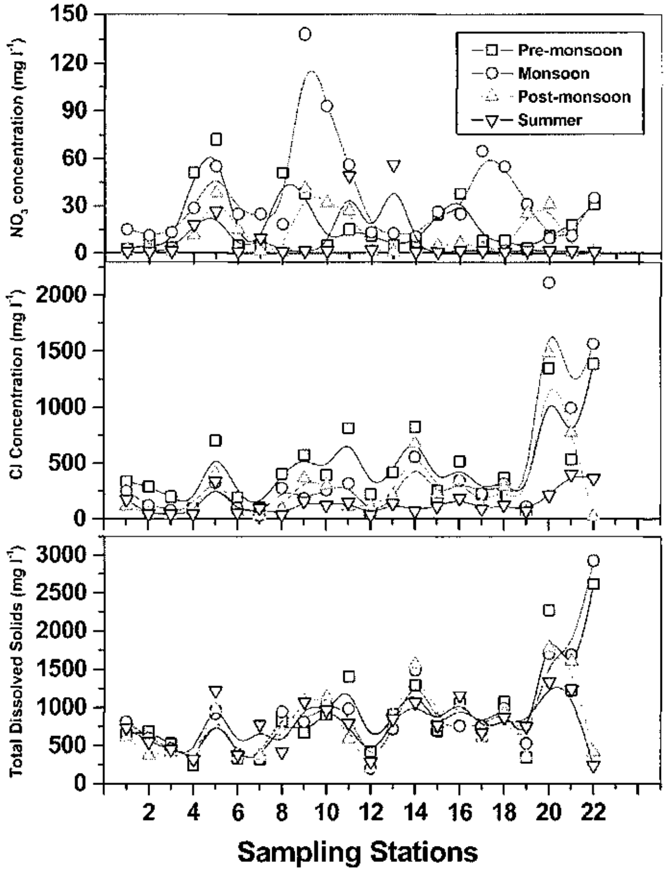

Fig. 2 Seasonal variation of TDS, Cl and NO_3 concentration in groundwater of the Sirkazhi region.

occupied by dense mangrove vegetation (Pichavaram mangroves). Krishnamoorthy (1996) calculated the total loss of mangrove extent in this mangrove using satellite data. His study showed that the mangrove cover has decreased from 650 ha in 1971 to 495 ha in 1987, to 477 ha in 1998, and to 241 ha at present.

However, the rate of decline in mangrove cover has slowed in recent years, due to the extensive replanting measures. Nevertheless, nutrient concentrations have increased in the mangrove waters (Purvaja & Ramesh, 2000) over the past decade. This increase is due to the untreated effluent discharges from the aquaculture farms surrounding the mangrove area.

CONCLUSIONS

The heterogeneous distribution of elements in the Sirkazhi region of the Cauvery Delta, India is mostly due to indiscriminate use of groundwater in aquaculture farms, which causes groundwater levels to decline and salinization of freshwater aquifers. The land-use change associated with intensive aquaculture activities results in groundwater abstraction and pollution due to effluent discharge. Pollution and land-use change is of concern and because the environment, development, and public health are interlinked, it is essential to adopt sustainable utilization of the available water resources.

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REFERENCES

Alagarswami, K. (1993) *Sustainable Management and Development of Coastal Aquaculture* (ed. by M. S. Swaminathan & R. Ramesh). MSSRF, Chennai, India.

Bencini, A., Ercolanelli, R., Sbaragli, A. & Verrucchi, C. (1993) Groundwaters of Florence (Italy): trace element distribution and vulnerability of the aquifers. *Environ. Geol.* **22**, 193–200.

Beveridge, M. C. M., Ross, L. G. & Stewart, J. A. (1997) The development of mariculture and its implications on biodiversity. In: *Marine Biodiversity: Patterns and Processes* (ed. by R. F. G. Ormond, J. D. Gage & M. V. Angel), 56–69. Cambridge University Press, Cambridge, UK.

Freeze R. A. & Cherry J. A. (1979) *Groundwater*. Prentice Hall Inc., Englewood Cliffs, New Jersey, USA.

Krishnamoorthy, R. (1996) Remote sensing of mangrove forests in Tamil Nadu Coast, India. PhD Thesis, Anna University, Chennai, India.

McNeely, R. N., Neimanis, V. P. & Dwyer, L. (1979) *Water Quality Sourcebook: A Guide to Water Quality Parameters*. Inland Waters Directorate, Water Quality Branch, Ottawa, Canada.

Purvaja, R. & Ramesh, R. (2000) Natural and anthropogenic effects on phytoplankton primary productivity in mangroves. *Chemistry & Ecology* **17**, 41–58.

Rajagopal, R & Tobin, G. (1989) Expert opinion and groundwater quality protection: the case of nitrate in drinking water. *Groundwater* **27**, 835–847.

Ramesh, R. & Anbu, M. (1996) *Chemical Methods for Environmental Analysis: Water and Sediment*. Macmillan Publ., India.

Ramesh, R., Shiv Kumar, K., Eswaramoorthi, S. & Purvaja, G. R. (1995) Migration and contamination of major and trace elements in groundwater of Madras City, India. *Environ.Geol.* **25**, 126–136.

Rosenthal, A. V. E. (1994) Saline groundwater in Israel: its bearing on the water crisis in the country. *J. Hydrol.* **156**, 389–430.

Sonak, S. (2000) Aquaculture in India. In: *Proc. on Land Use, Land Cover Changes and Modeling in Coastal Areas* (ed. by S. Ramachandran), 20–32. Anna University, Chennai, India.

WHO (1984) *Guidelines for Drinking Water Quality*, vol. 2, *Health Criteria and Other Supporting Information*. WHO, Geneva.