

DIAGNOSING SALT WATER INTRUSION IN VAIPPAR ESTUARY OF THE CHOLAMANDAL COAST, INDIA

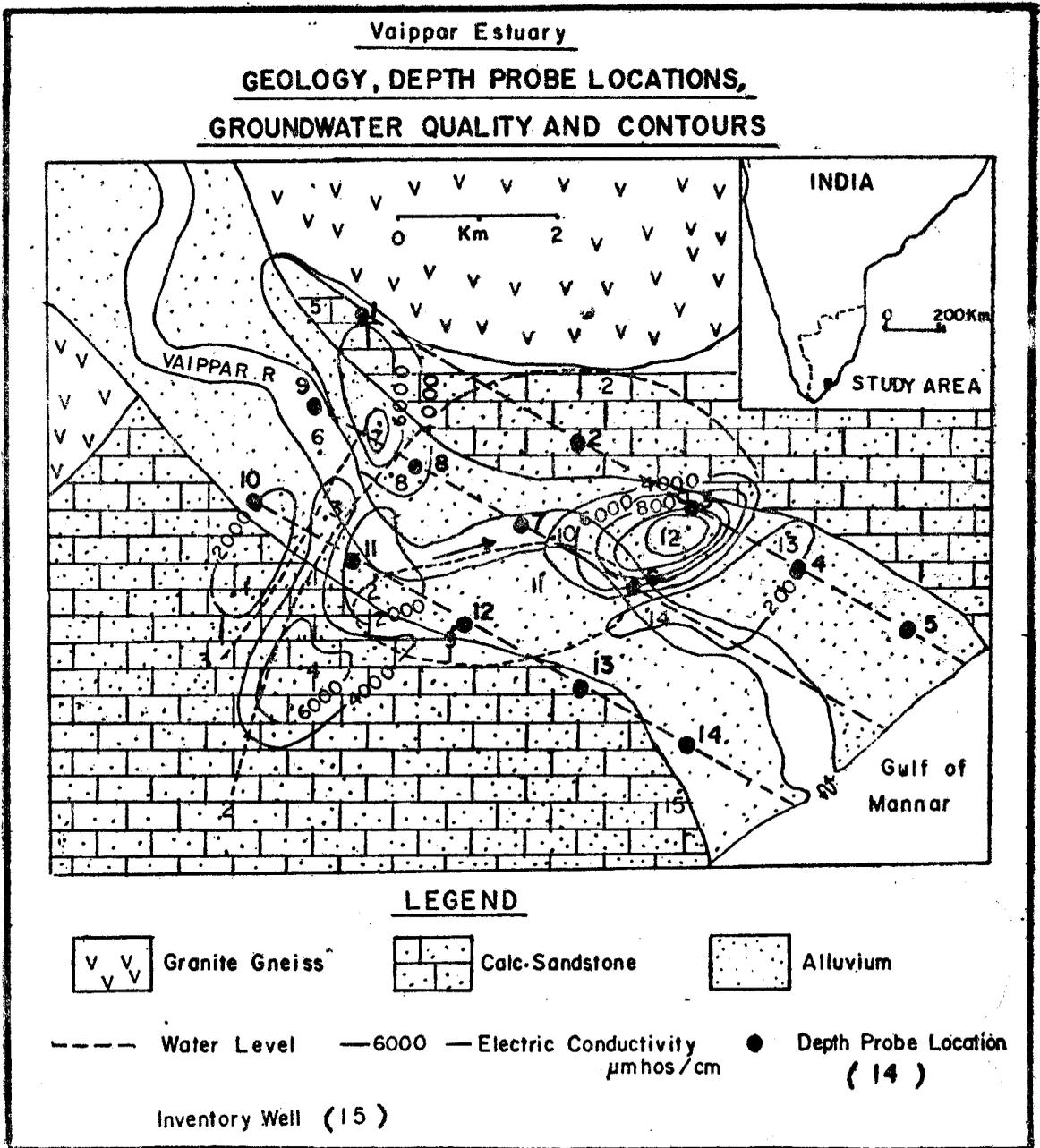
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ABSTRACT: Geohydrological, geochemical and geophysical studies were undertaken to assess the degree of salt water intrusion within fresh water aquifers in the Vaippar estuary of the Cholamandal Coast. Water users in the Vaippar estuary are aware of salt water intrusion in the groundwater but no scientific work has been done to define the extent of the problem. The results of this study indicate that 1) salt water intrusion is present where thin soil and sand layers are above clay or calcareous sandstone, 2) electrical conductivity values, cation-anion ratios— $\text{Ca}+\text{Mg}/\text{Na}+\text{K}$ and $\text{Na}+\text{K}/\text{Cl}+\text{NO}_3$, and SAR, TDS and Total Hardness (as CaCO_3) values are indicative of salt water contamination in the groundwater reservoir and 3) electrical earth resistivity depth profiles depict the fresh-salt-water interface at depths of 10 and 20-30 meters. There is an urgent need for additional scientific work to define the extent of salt water intrusion so that effective remedial measures can be undertaken to reduce the potential threat of the problem.

Coastal geohydrology is especially significant in semi-arid monsoon tracts of India where the withdrawal of groundwater is excessive and the local people depend more on surface/groundwater for their livelihood. Only in the water surplus period, the fresh water aquifers in coastal zones discharge groundwater into the sea. The natural groundwater system is disrupted when withdrawal of fresh groundwater lowers the potentiometric surface and accelerate the movement of fresh/salt water interface inland. This process, called salt water intrusion, is generally slow and takes many years to disturb the entire groundwater system permanently. Continued and excessive pumping of fresh water eventually reverses the hydraulic gradient, and as a result sea water migrates rapidly inland causing displacement of the fresh water component of the system.

The problem of salt water intrusion has been reported from various parts of the world including the United States (Task Committee of Salt Water Intrusion, 1969), Thailand (Das Gupta and Yapa, 1982), Italy, Mexico, USSR (Goldberg, 1973) and United Kingdom (Lloyd et al. 1977). The excessive use of groundwater, especially for irrigation, in the coastal areas of India and the resultant intrusion of sea water into fresh water aquifers has also been well documented (Government of India, 1976; Sharma and Mehta, 1979; Indian National Committee for IHP, 1981; Handa, 1989).

The coastal plain of Chidambaranar District of Tamil Nadu, a part of Cholamandal Coast, is well known for the excessive use of groundwater for wet crop cultivation. People living in the coastal zone are aware of salt water intrusion but



(Fig. 1)

no scientific studies have been made to define this problem. This paper brings together the geological and hydrological information to describe the spatial extent and intensity of salt water intrusion in Vaippar estuary.

HYDROGEOLOGY:

The Vaippar estuary covers an area of about 60 km² extending 6 km wide along the coast and 10 km long from the point of confluence of river Vaippar to the in-

terior (Fig. 1). Rainfall is approximately 600 mm annually (Station: Vilathikulam). Water flows in the river only during October and November when 50 per cent of the rainfall occurs. The estuarine zone is a river plain containing alluvium all along the flood plain and its vicinity. The alluvium is composed of coarse sand, gravel and black soil. The black soil contains traces of calcareous sandstone which is found beyond the bluffs. Away from the alluvium tract, granite gneiss and red soil with pockets of black soil are common.

There are few storage tanks to retain the seasonal flow of water for irrigation and drinking purposes. Water shortages are more common in this area where the fresh groundwater is the major source of water supply for various purposes. For the 7 villages located in the study area, there are 153 irrigation wells of which 86 are energized and the others are bullock bailed. Since other types of economic resources are not well developed, the land is intensively used for agriculture and the fresh groundwater is over exploited.

A detailed inventory of both water level and water quality for 15 observation wells was undertaken by the Groundwater Division of Public Works Department, Government of Tamil Nadu. The observation wells are located mostly in the alluvial tract of the study area (Fig. 1). The depth of the dug wells range between 2.2 and 9.0 m below the ground level (Table 1). The water level depth is -0.35 to -2.0 m above MSL along the lower river course and above 3.0 to 4.6 m on the western part of the study area. Pump tests have been conducted in the alluvial and calcareous sandstone tracts to assess the groundwater withdrawal in the area. The average extraction per well

per year is calculated as 2.05 ha.m. Groundwater extraction by four bullock bailed wells is approximately equal to one energized well's extraction. The average extraction is about 5.4 million gallons/well/year. From this it is estimated that 212 ha.m. of groundwater is being extracted per year in the study area.

GROUNDWATER QUALITY:

Chemical analyses of Electrical conductivity, EC; Hydrogen ion concentration, pH; Calcium, Ca; Magnesium, Mg; Sodium, Na; Potassium, K; Chloride, Cl; Carbonate, CO_3 ; and Bi-carbonate, HCO_3 , were conducted on groundwater samples collected from the 15 observation wells. In addition, Sodium Adsorption Ratio, SAR; Total Dissolved Solids, TDS; and Total Hardness (as CaCO_3) were determined. These analyses were used to determine the extent of salt water intrusion in the study area. Higher EC, SAR, TDS, Total Hardness and $\text{Cl}/\text{CO}_3 + \text{HCO}_3$ and lower pH, $\text{Ca} + \text{Mg}/\text{Na} + \text{K}$ and $\text{Na} + \text{K}/\text{Cl} + \text{NO}_3$ indicate the presence of saline water in the coastal area (Ravelle, 1941; Love, 1944; Todd, 1981; Rodda et al. 1976; Lloyd et al. 1982; Howard and Lloyd, 1983). The Chloride-bicarbonate ratio ($\text{Cl}/\text{CO}_3 + \text{HCO}_3$) and cation-anion ratios ($\text{Ca} + \text{Mg}/\text{Na} + \text{K}$ and $\text{Na} + \text{K}/\text{Cl} + \text{NO}_3$) were also calculated to evaluate the usefulness of water quality in the area (Table 2).

The chemical characteristics of the water samples vary widely. Electrical conductivity, SAR, TDS, Total Hardness and $\text{Cl}/\text{CO}_3 + \text{HCO}_3$ had appreciable variations. The water samples from the wells 1, 7, 12 and 13 show a varying degree of contamination by salt water intrusion. Groundwater quality show contamination by some parameters and

Table 1 : Lithology and Groundwater Level

Well Number	Depth (m) Well	Lithology (m)		Water Level (MSL) (m)
1	8.65	0 — 4.5 4.5 — 8.65	BS CSS	4.77 (3.88)
2	5.10	0 — 1.5 1.5 — 5.10	BS CoS	4.10 (1.00)
3	5.50	0 — 1.2 1.2 — 5.50	BS CS	3.13 (2.37)
4	6.85	0 — 3.8 3.8 — 6.90	RS CSS	5.51 (1.34)
5	7.70	0 — 2.5 2.5 — 7.70	BS GrS	3.07 (4.63)
6	2.20	0 — 0.7 0.7 — 2.20	CS CoS, G	-1.52 (3.72)
7	7.35	0 — 2.5 2.5 — 7.40	BS CoS	4.46 (2.89)
8	9.00	0 — 1.0 1.0 — 9.00	BS GrS	7.44 (1.56)
9	5.70	0 — 2.0 2.0 — 5.70	BS GrS	4.94 (0.76)
10	3.20	0 — 1.0 1.0 — 3.20	CS CoS, G	2.20 (1.00)
11	5.90	0 — 2.0 2.0 — 5.90	BS GrS	6.25 (-0.35)
12	5.50	0 — 1.8 1.8 — 5.50	BS CSa, O	4.04 (1.46)
13	3.85	0 — 3.9	BS, O	1.53 (2.32)
14	2.90	0 — 0.7 0.7 — 2.90	BS CoS	1.83 (1.07)
15	3.70	0 — 1.0 1.0 — 3.70	BS CoS, G	3.89 (-0.19)

BS — Black soil; RS — Red soil; CS — Clayey soil; O — Organic Material;
 CSS — Calcareous sand stone; CoS — Coarse sand; GrS — Gravellary Sand;
 G — Gravel; CSa — Clayey Sand.

Table: 2 Chemical Characteristics of Groundwater Samples

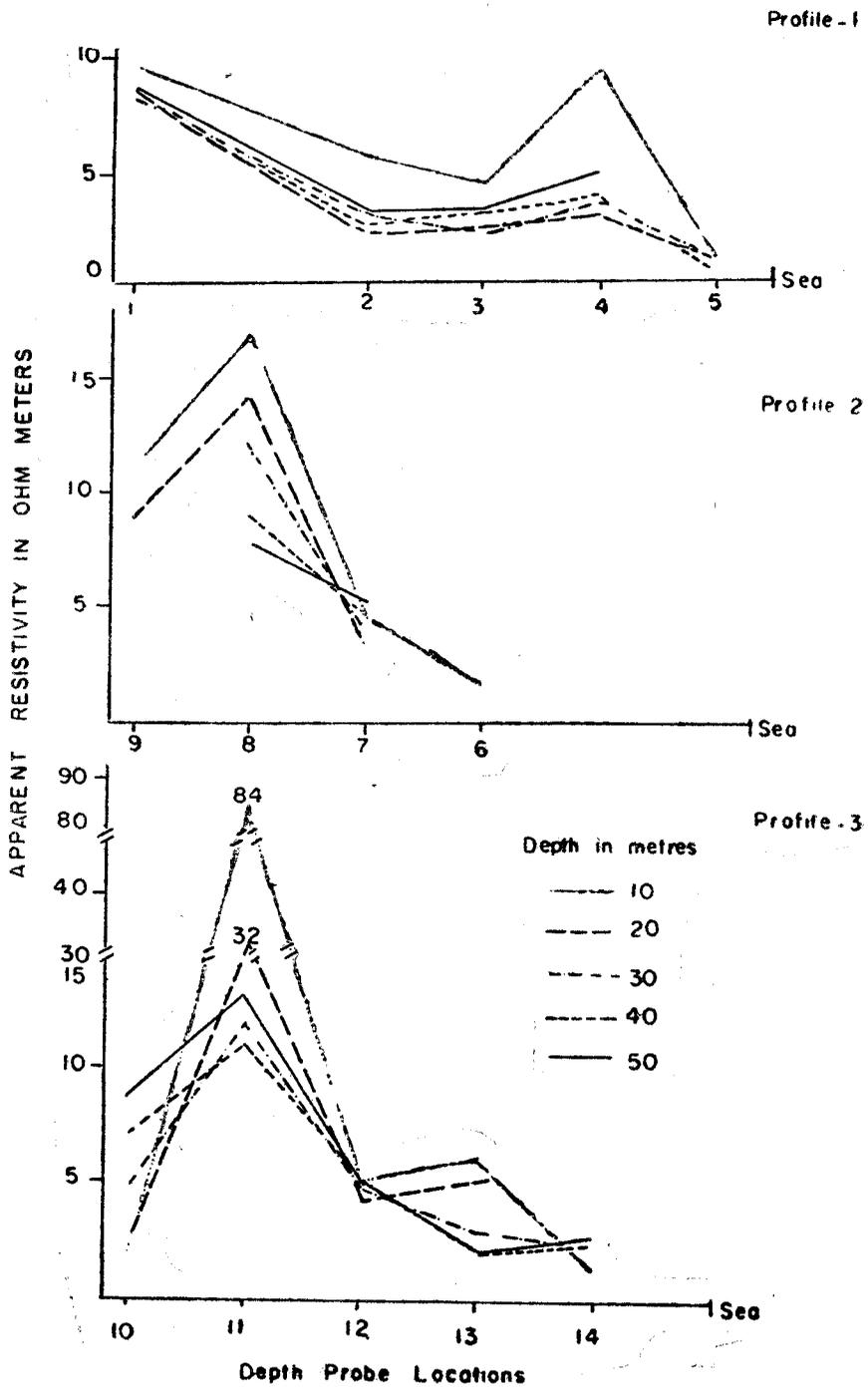
Well Number	Electrical conductivity (mmhos/cm at 25°C)	pH	Sodium adsorption ratio	Total dissolved solids (mg/l)	Total hardness at CaCO ₃ (mg/l)	Cl		
						Ca + Mg Na + K	CO ₃ + HCO ₃	Na + K Cl + NO ₃
1	345	8.2	1.0	230	153	2.54	0.15	2.16
2	1290	8.1	5.0	800	268	0.65	1.33	1.39
3	4870	8.3	11.7	3070	875	0.50	5.95	1.06
4	7100	8.1	25.5	4350	590	0.19	9.05	1.12
5	4770	7.9	12.2	2650	665	0.42	4.50	1.20
6	3050	7.4	8.5	1660	475	0.51	7.83	1.03
7	8420	8.0	25.0	5320	1635	0.57	12.55	0.92
8	3240	7.5	10.6	1830	445	0.40	3.00	1.61
9	3080	7.4	8.7	1980	618	0.57	2.98	1.15
10	3340	8.1	7.0	1865	683	0.74	4.93	0.92
11	3320	8.4	7.2	1775	623	0.70	6.51	0.93
12	15000	8.0	30.0	8910	1700	0.27	17.47	0.91
13	740	9.0	2.0	360	205	1.42	0.31	1.80
14	1820	8.3	5.6	1080	398	0.72	2.45	1.10
15	3980	8.2	9.1	2360	798	0.62	5.52	0.84

others show evidences of contamination in all parameters except pH (Table 2). Data from well 7 indicates mixing of saline water with the fresh groundwater to undesirable (injurious) proportions. Well 4 also indicates mixing of saline water but EC, TDS and the cation-anion ratio have much lower values than what is being recorded for well 7. Wells 3, 5 and 15 show traces of saline water, but at moderate levels. Moreover, these three

wells have variable chemical characteristics. Wells 1 and 13 contain relatively fresh groundwater while wells 2 and 14 show minor effects of saline water contamination. All the other wells (4, 6, 8, 9, 10 and 11) have recorded moderate levels of saline water contamination as indicated by one parameter or another.

Wells 12 and 7 are located about 1000 m away from the northern side of the

GEOPHYSICAL PROFILES



(Fig. 2)

Vaippar river (Fig. 1). These locations have only shallow top soil (Table 1). Wells 4 and 5, which show traces of saline water, are also located where the top soil is thin and the underlying parent rock (calcareous sandstone) exerts its influence on groundwater quality. These two wells are located off the river course, but have thick top soil than other wells in the area. The fresh groundwater gradient from the peripheral zones may be the reason for the lower salt content in the wells (1 and 13) located in the alluvial tract (Fig. 1).

ELECTRICAL RESISTIVITY :

Depth Probe (DP) surveys were conducted up to a depth of 70 meters in 3 profiles approximately parallel to the river course (Fig. 1). The results of the geophysical profiles in terms of apparent resistivity are shown in Fig. 2. Uniformly, DP locations 2, 3, 4 (Profile 1), 12, 13 and 14 (Profile 3) show lower apparent resistivity (less than 5 ohm-m) indicating the stronger possibility of fresh water-salt water mixing between 20 and 50 m depth. These locations are in the transition zone between river alluvium and calcareous sandstone.

Depth probes 5, 6 and 14 have less than 5 ohm-m apparent resistivity at 10 m depth indicating the possible presence of saline water. The DP profiles 1 and 3 at 10 m depth depict a continuous declining trend (1 to 5 and 11 to 14 DPs), except for the conspicuous higher value at DPs 4 and 13.

The elevated resistivities at DPs 4 and 13 are attributed to the seepage of fresh water either from the tank located near by or from the natural fresh water gradi-

ent. Depth Probe 11 has the highest variation in apparent resistivity suggesting the possibility of small salinity increase with depth. Depth Probe 8 shows the possibility of mixing of salt water with fresh water at increasing depth with small variations in apparent resistivity values.

DISCUSSION AND CONCLUSIONS :

Estimates of the extent of saline groundwater may contain significant errors if they are based on a single measurement parameter. This problem is overcome by selecting multicriteria for determining salt water intrusion. As a first step, the parameters (simple as well as ratio measures) to measure the intrusion of the 15 observation wells are intercorrelated (Table 3). Some variables are strongly interrelated with each other (EC-TDS-SAR); some with strong correlations (SAR-Cl/CO₃+HCO₃ - Total Hardness). The negative parameters of intrusion (pH, Ca + Mg/Na+K and Na+K/Cl+NO₃) have weaker correlations among themselves as well as with other variables indicating the risk in defining the salt water intrusion based on these parameters alone.

The overall estimate based on the eight criteria used in the present study indicates that wells 4, 7 and 12 are located near the fresh water / salt water interface. It shows that the interface is projecting along the river alignment. If unabated, the wedge will migrate inland and enlarge the saline water contaminated area of the Vaippar estuary.

The results of the present study indicate that contamination in the study area has not yet reached severe proportions at 10 m depth in most of the area

Table 3 : Relationships between intrusion indicators

Variable	TDS	SAR	$\frac{\text{Cl}}{\text{CO}_3 + \text{HCO}_3}$	Total Hardness (Ca CO_3)	pH	$\frac{\text{Ca+Mg}}{\text{Na+K}}$	$\frac{\text{Na+K}}{\text{Cl+NO}_3}$
EC	0.99	0.77	0.58	0.46	-0.39	-0.22	-0.11
TDS		0.76	0.55	0.43	-0.39	-0.28	-0.14
SAR			0.79	0.59	-0.11	-0.01	-0.26
$\frac{\text{Cl}}{\text{CO}_3 + \text{HCO}_3}$				0.80	-0.15	0.23	-0.29
Total Hardness (Ca CO_3)					-0.11	0.31	-0.40
pH						0.06	-0.09
$\frac{\text{Ca + Mg}}{\text{Na + K}}$							-0.05

Significance of P

P < 0.01 df 13=0.68

P < 0.05 df 13=0.48

and at 20-30 m. depth in fewer areas. Salt water which is apparently at 30-70 m below the ground level will rise as a cone and enter into fresh water aquifers if unabated in time. Drawdown of one or two metres of fresh water between 10-30 m of depth may not pose a problem of salt water intrusion mainly because of the hydraulic gradient of the basin.

It is apparent that saline water has intruded vertically as well as laterally in

the fresh water aquifers of Vaippar estuary. This is the case in many estuarine tracts of the Indian Coast. It is a potential danger to the Indian economy which is mainly dependent on agriculture for its development. Thus there is an urgent need for additional scientific work to understand the patterns of salt water intrusion so that remedial measures can be undertaken to reduce the intensity and spread of this problem in the coastal areas.

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