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Geoinformatics for Groundwater Characterization in Coastal Areas of Thoothukudi District

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Abstract: ***A study was undertaken with a view to assess the groundwater quality in the coastal areas of Thoothukudi district. 200 groundwater samples were collected from borewells, openwells and tubewells located five to ten kilometres from coastal line at regular intervals. The groundwater samples were analysed for pH, EC, TDS, TSS, anions (HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}) and anions (Ca^{2+}, Mg^{2+}, Na^+, K^+) by adopting standard procedures. Experimental results showed that the pH was slightly acidic to alkaline in nature varying from 6.38 to 8.65 and the electrical conductivity values of the samples ranged from 0.17 to 18.08 dS m^{-1} i.e., good to alkali condition. The correlation studies revealed that the pH was negatively correlated and EC was positively correlated with all the other parameters. From the study, it is concluded that the dominating ions in the groundwater samples of Thoothukudi district were Na^+ and Cl^-. According to AICRP classification, 22.5 per cent of samples were good, 14 per cent were marginally saline, 15.5 per cent were saline, 4.5 per cent were high SAR saline, 23.5 per cent were marginally alkali and 20 per cent were alkali.This indicates that the groundwater in the study area were of Na-Cl type, indicating that they were largely intruded with seawater and are of poor quality.***

Keywords: Groundwater quality; Spatial distribution; Coastal areas; Thoothukudi district.

Introduction

Water is a prime requisite among all the natural resources. It is a basic and fundamental need for the sustenance of every living organism (Das, 2013). Water covers about two-thirds of the earth surface. The freshwater only contributes about 3 percent which supports all forms of life on earth and the remaining 97 percent of water is saline. Amongst water resources, groundwater is the major source and is widely dispersed in

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India. It is utilized for all the purposes including domestic, agricultural and industrial purposes. The quality of ground water is degraded with increasing population (Selvam *et al.*, 2013). Indian agriculture mainly depends on groundwater for irrigation and it plays a foremost role in increasing the yield and productivity of crops. The over use of groundwater and quality deterioration led India towards a serious crisis, in spite of having 30 million groundwater structures. Groundwater is threatened by several factors related to its mismanagement. The main characteristics of water quality which defines its compatibility for different purposes are the chemical compounds present in water. The groundwater quality is normally characterized by using certain parameter which includes physio-chemical characteristics and its composition. The major anions and cations present in water are Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-} and Ca^{2+}, Mg^{2+}, Na^+, K^+, respectively. Water quality depends on various parameters such as pH, Electrical conductivity, Total Dissolved Solids, Total Suspended Solids, anions and cations. The agricultural development in India especially in Tamil Nadu mainly depend on the surface irrigation as well as ground water irrigation. The total water potential of Tamil Nadu is about 5.65 M ha i.e., 2.5 M ha from surface water and 3.15 M ha from groundwater resource. The area irrigated by ground water source in Tamil Nadu in the last five decades has increased from 0.5 M ha which is 23.6 per cent of total irrigated area of 2.12 M ha in 1950's to 1.45 M ha which is 48.8 per cent of the total irrigated area of 2.97 M ha in 2000. The study aims at the characterization and mapping the spatial variability of groundwater present in the study area in GIS environment. Geographical Information System (GIS) is one of the effective scientific tool for the spatial variability studies of groundwater (Kumar *et al*., 2014). The main objectives of the study is to characterize and map the spatial variation in water quality parameters for coastal areas of Thoothukudi district using Geographical Information System (GIS).

Study Area

The Thoothukudi district of Tamil Nadu is located in the foot of Western Ghats between 0.8º and 45º Northern latitude and 78º and 11º Eastern longitude with an area of 4,621 Km^2. The coastal length of the district is about 163.5 kms. Its maximum temperature is 41ºC and the minimum is 26ºC. The district had a climate that promotes agriculture and horticulture. Thoothukudi comes under low rainfall region. The normal rainfall of the district is 662.2 mm. The river Tamiraparani is one of the important perennial rivers of the Southern Peninsular India and the river basin area lies in the Tirunelveli and Thoothukudi districts. The southern part of the

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peninsular India is influenced by two monsoons: the South-west monsoon that originates from the Arabian sea and the North-east monsoon that originates in the Bay of Bengal. The South-west monsoon prevails during June to August, while the North-east monsoon follows September to December. Thoothukudi depends mainly on north east monsoon rains. The irrigation sources are canals, tanks, wells and tubewells. The Tuticorin coastal zone has been classified with major landforms such as fluvial, fluvo-marine and marine origins.

Materials and Methods

A study was carried out in coastal areas of Thoothukudi district (Fig. 1) during March 2018. Two hundred samples were collected from different sampling location. Each samples were collected in a clean Polyethylene containers and labelled. All the samples were analyzed using standard procedures (APHA, 1985). pH and Electrical Conductivity (EC) was analyzed using glass electrode method. Major ions like chlorides, carbonates, bicarbonates, calcium and magnesium were analyzed using titration.

Sodium and potassium were measured by a flame photometer. Sulphates were estimated by the UV-visible spectrophotometer. The geostatistical analyst tool ArcGIS 9.3 was used to create the spatial distribution map of different water quality parameters. Geostatistical studies aims at assessing the spatial variability and depicting continuity of variables in a particular study area. In spatial continuity studies, variability increases with increasing distance between points i.e., closer the location similar in characteristics. Ordinary Kriging was selected as the interpolation method in this study (Kumar *et al*., 2014). A semivariogram will be created in Kriging method and the average degree of dissimilarity will be evaluated between the unknown point and the nearby known value. From the analysis of the experimental variogram, a suitable model (e.g., spherical, exponential and gaussian) is fitted by weighted least squares. The parameters like Nugget, sill and range are used to describe the data structure.

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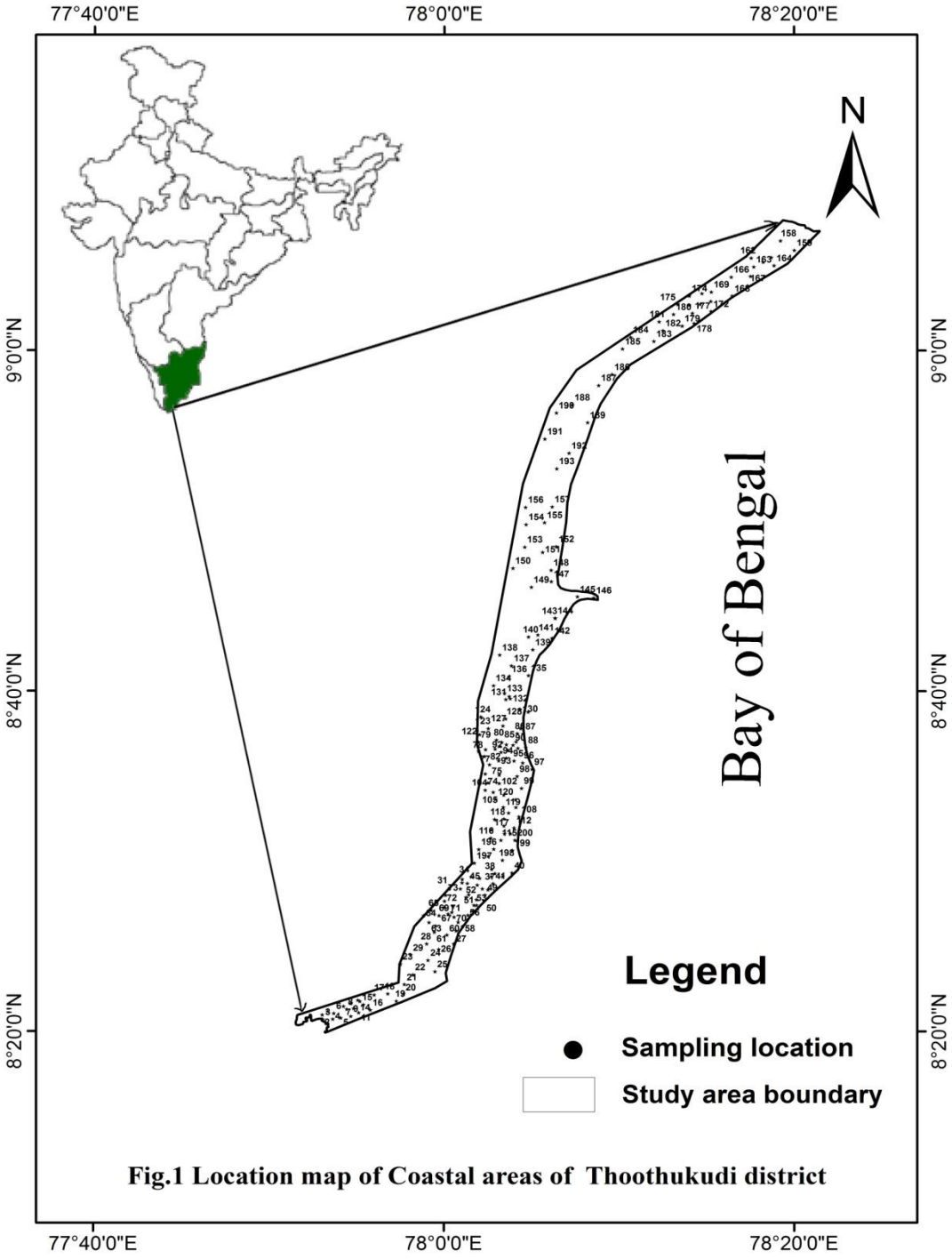

Fig.1 Location map of Coastal areas of Thoothukudi district

Results and Discussion

Groundwater hydrochemistry

The descriptive statistics for the water quality parameters are given in Table 1. The pH of the water samples ranged from 6.38 to 8.65. This indicates that the nature of the water is slightly acidic to alkaline (Fig. 2a). The increase in pH is mainly due to the mixing of salt water with the groundwater and high activity of biological organisms (Arasu and Murugan, 2013). The Electrical Conductivity (EC) of the groundwater samples ranged between 0.17 and 18.08 dS m^{-1} (Fig. 2b). The total dissolved solids in water is indicated by EC. The variation of EC is larger in groundwater of coastal areas because of the manmade activities, dissolution of minerals and the intrusion of salt water (Srinivasamoorthy *et al*., 2011). The content of Total Dissolved Solids (TDS) in the water samples ranged from 107.14 to 11377.40 mg L^{-1} (Fig. 2c). The TDS consists mainly of bicarbonate, carbonate, sulphate, chloride, nitrates and other substances (Awoyemi *et al*., 2014). The increase in enrichment of salinity from seawater is due to over-exploitation by urbanization which results in higher range of TDS values (Kumar *et al*., 2014). The content of Total Suspended Solids (TSS) in the water samples ranged from 200.00 to 81200 mg L^{-1} (Fig. 2d). The calcium content in the water samples varied from 0.52 to 55.31 me L^{-1} (Fig. 3a). The cations such as calcium and magnesium mainly decides the hardness of water. Limestone, Dolomite or Gypsum are the major sources of high calcium content and its dissolution leads to increase in calcium in groundwater. The magnesium content in the water samples varied from 0.26 to 29.42 me L^{-1} (Fig. 3b). The dissolution of dolomites and weathering of silicates are generally the sources for magnesium. However, the Magnesium content in the coastal areas are higher due to seawater intrusion because the seawater contains higher magnesium in it. The Sodium content of the water samples ranged from 0.73 to 85.95 me L^{-1} (Fig. 3c). The weathering of silicates, halites dissolution and overexploitation can result in higher concentration of sodium. The mixing of salt water from the sea is also one of the major reason for high sodium content in the coastal areas (Pandian *et al*., 2016). The potassium content of the water samples ranged between 0.44 and 62.15 me L^{-1} (Fig. 3d). In the coastal aquifers, the weathering of clay minerals and the potash feldspar will increase the potassium content in water. Sometimes, the potassium chloride present in water also contributes to potassium content. The chloride content in the groundwater samples varied from 1 to 192.80 me L^{-1} (Fig. 4a). The formation of salt in water is mainly due to the presence of chloride. Infiltrated seawater, brines, salt blown by wind, wastes from industries and water softening plants might be the reason for higher concentrations of

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chloride. The range of carbonate and bicarbonate contents in the water samples varies from 0 to 4.00 me L^{-1} and 1.00 and 19.00 me L^{-1}, respectively (Fig. 4b, 4c). The carbonate content is found to be absent in several sampling sites. The reasons for carbonate and bicarbonate concentrations in the groundwater can be ascribed to carbonate weathering as well as from the dissolution of carbonic acid in the coastal aquifers (Pradhan *et al*., 2011 and Kumaresan and Riyazuddin, 2006). The sulphate content in the groundwater samples ranged from 0.18 to 13.97 me L^{-1} (Fig. 4d). The occurrence of sulphate in groundwater results from the oxidation of sulphur in igneous rocks and the dissolution of sulphur bearing minerals. The leaching action and anthropogenic activities will also contribute to sulphate content. Based on the ionic concentration, sodium and chloride are the dominant cation and anion, respectively in the study area. Therefore, the higher concentration of sodium and chloride in the groundwater of coastal area indicates a significant effect of saltwater intrusion (Kumar *et al*., 2014).

Table 1. Descriptive statistics of water quality parameters

Parameters	Min	Max	Mean
pH	6.38	8.65	7.62
EC (dS m^{-1})	0.17	18.08	2.60
Na^{+} (me L^{-1})	0.73	85.95	11.92
Ca^{2+} (me L^{-1})	0.52	55.31	7.97
Mg^{2+} (me L^{-1})	0.26	29.42	4.20
K^{+} (me L^{-1})	0.44	62.15	7.36
Cl^{-} (me L^{-1})	1.00	192.80	22.09
HCO_3^{-} (me L^{-1})	1.00	19.00	6.84
CO_3^{2-} (me L^{-1})	0.00	4.00	0.46
SO_4^{2-} (me L^{-1})	0.18	13.97	2.00
TDS (mg L^{-1})	107.14	11377.40	1637.79
TSS (mg L^{-1})	200.00	81200.00	3266.90
SAR	1.13	13.21	4.08
RSC (me L^{-1})	-77.53	7.41	-4.86

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Spatial distribution of major ions

The pH and EC was well fitted with exponential and gaussian model with a nugget of 0.12 and 1.01, respectively. The TDS and TSS values were well fitted with gaussian model. The sodium, magnesium, bicarbonate values were well fitted with gaussian model, whereas calcium, potassium, sulphate and carbonate were well fitted with spherical model. The ratio of nugget variance to sill was ranged between 0.16 and 10.59 indicating strong to weak spatial dependence. A detailed description of the semivariogram parameters are presented in Table 2.

Table 2. Semivariogram parameters (ordinary kriging interpolation) of water quality parameters

Water quality parameters	Semivariogram Model	Nugget (C)	Partial sill (Co)	Sill (C+Co)	Nugget (%)	Spatial class
pH	Exponential	0.12	0.04	0.16	72.10	M
EC (dS m^{-1})	Gaussian	1.01	0.34	1.35	74.69	M
Na^{+} (me L^{-1})	Gaussian	1.02	0.35	1.37	74.64	M
Ca^{2+}(me L^{-1})	Spherical	0.91	0.40	1.31	69.64	M
Mg^{2+}(me L^{-1})	Gaussian	1.01	0.34	1.35	75.11	W
K^{+}(me L^{-1})	Spherical	0.99	0.42	1.40	70.34	M
Cl^{-}(me L^{-1})	Exponential	0.46	1.10	1.57	29.55	M
HCO_3^{-}(me L^{-1})	Gaussian	6.59	4.00	10.59	62.27	M
CO_3^{2-}(me L^{-1})	Spherical	0.42	0.00	0.42	100.00	W
SO_4^{2-}(me L^{-1})	Spherical	0.73	0.25	0.97	74.66	M
TDS(mg L^{-1})	Gaussian	1.00	0.35	1.34	74.33	M
TSS(mg L^{-1})	Gaussian	0.71	0.40	1.11	63.72	M
SAR	Gaussian	0.2633	0.0878	0.3512	74.99	M
RSC (me L^{-1})	Exponential	0.0000	279.8107	279.8107	0.00	S

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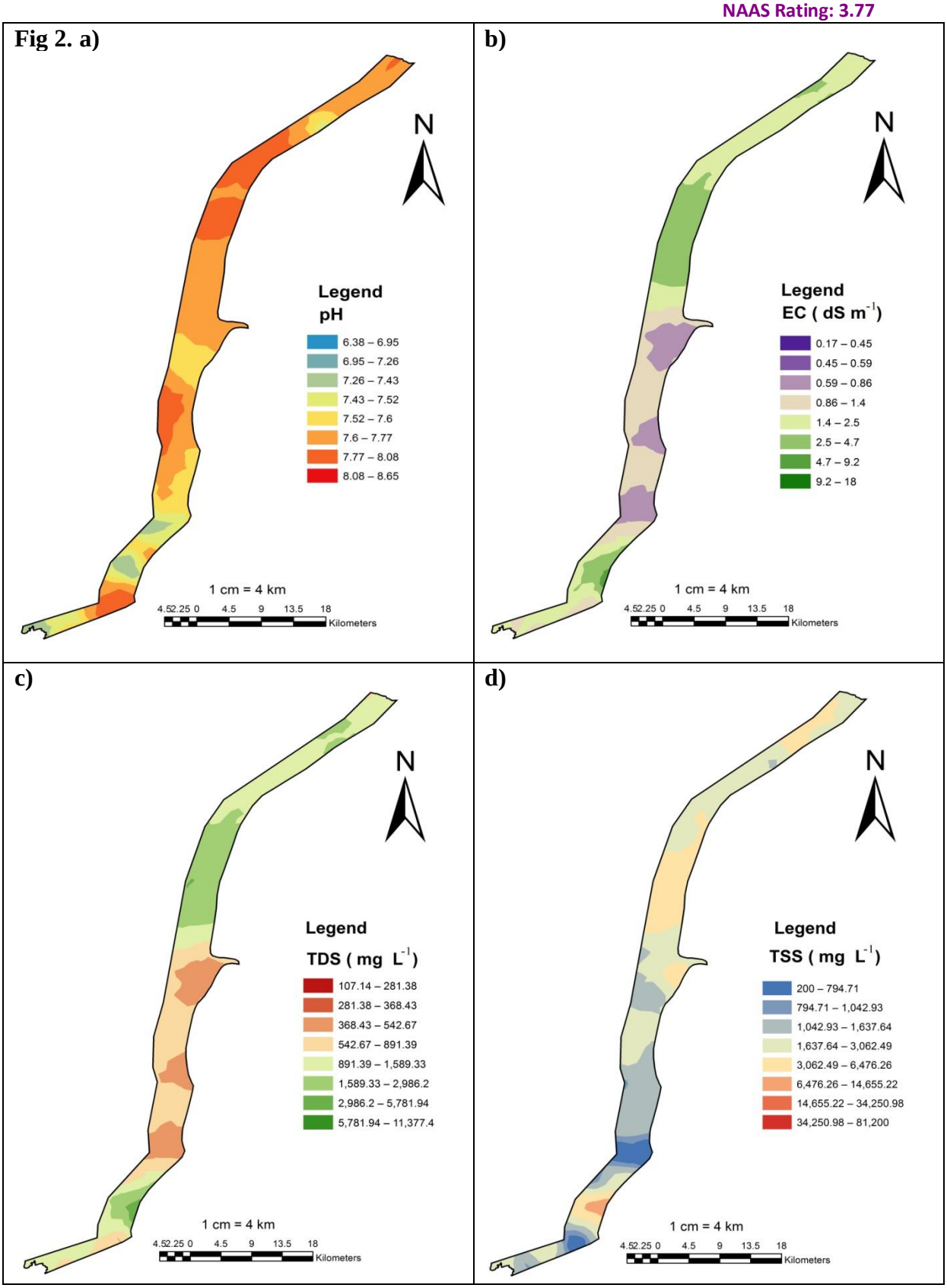

Fig 2. Spatial distribution of pH (a), EC (b), TDS (c) and TSS (d) in the groundwater samples

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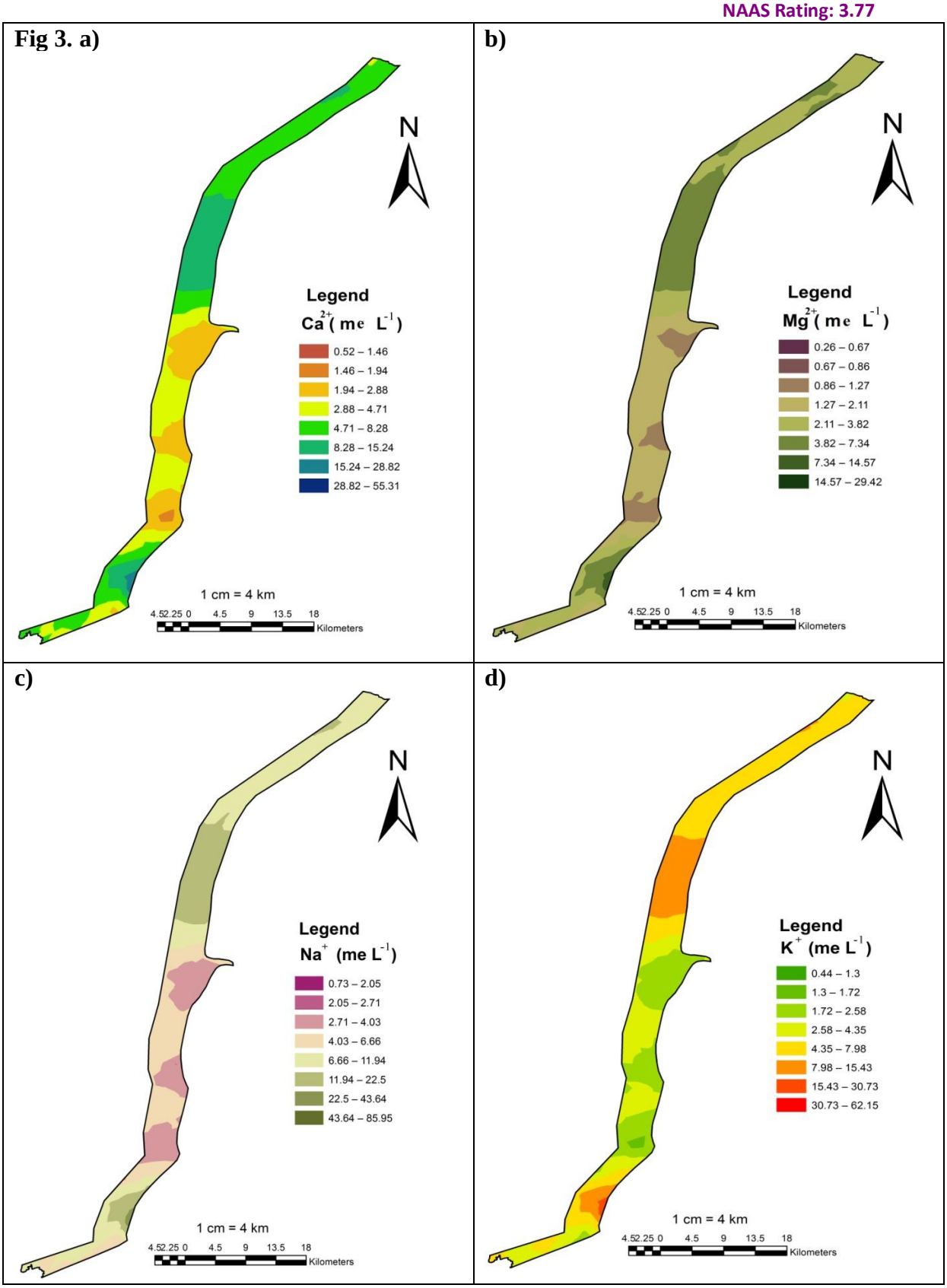

Fig 3. Spatial distribution of Ca (a), Mg (b), Na (c) and K (d) in the groundwater samples

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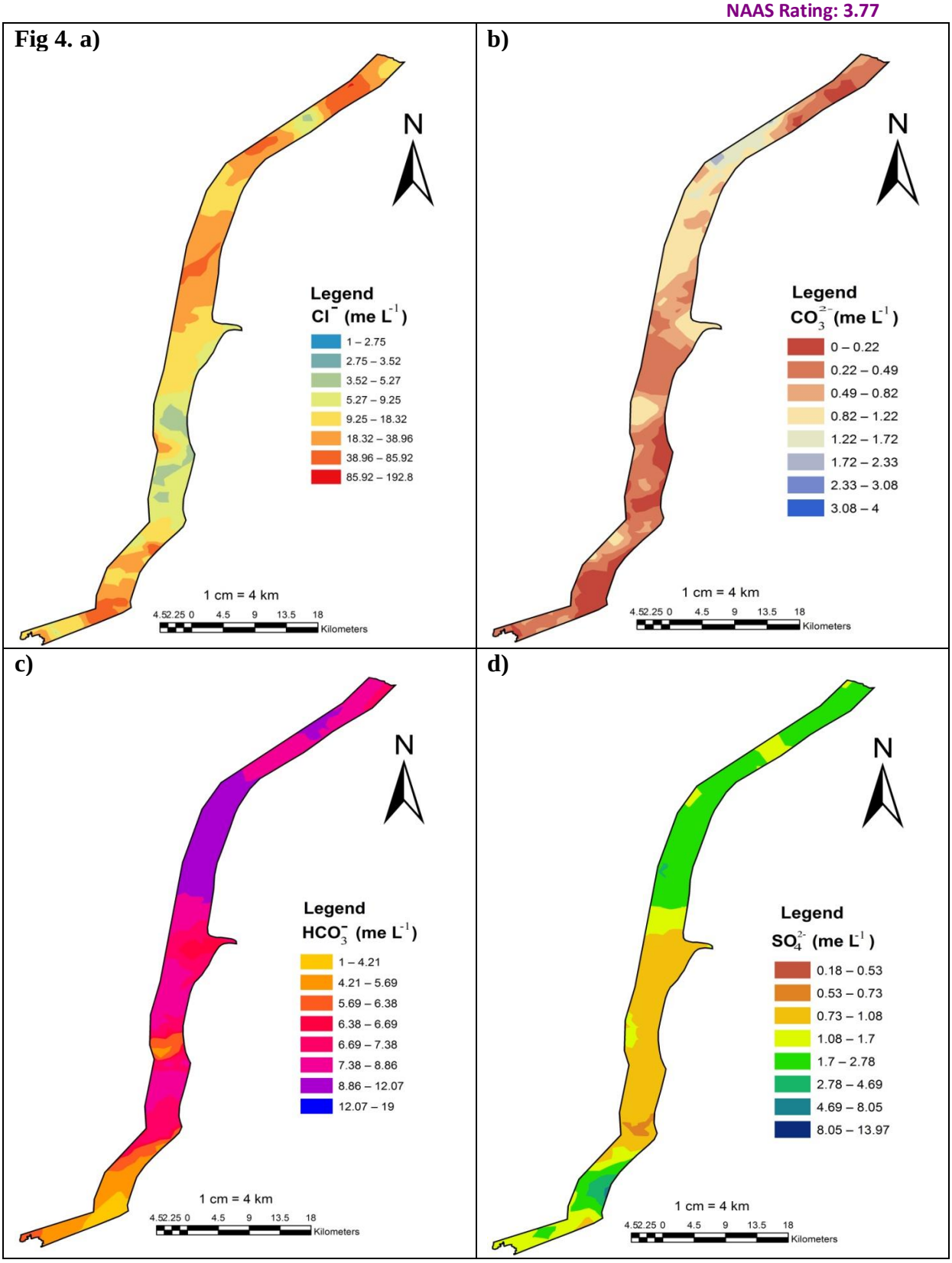

Fig 4. Spatial distribution of Cl (a), CO_3 (b), HCO_3 (c) and SO_4 (d) in the groundwater samples

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Sodium Adsorption Ratio (Richards, 1954)

It is commonly used as an index for evaluating the sodium hazard associated with irrigation water supply. The formula for SAR is

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where, all cations are expressed in Me L^{-1}.

The Sodium Adsorption Ratio values of groundwater samples were ranged from 1.13 to 13.21 (Fig. 5a). As per the classification of USSL staff (1954), none of the water samples exceeds the SAR values of 18.00 and hence the groundwaters in the study area are moderately safe for irrigation purpose.

Residual Sodium Carbonate (RSC)

Eaton (1950) proposed this criteria for evaluating water quality.

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Where, all cations are expressed in Me L^{-1}.

The maximum and minimum values of Residual Sodium Carbonate in the groundwater samples ranged from -77.53 to 7.41 me L^{-1} with an average of -4.86 me L^{-1} (Fig. 5b).

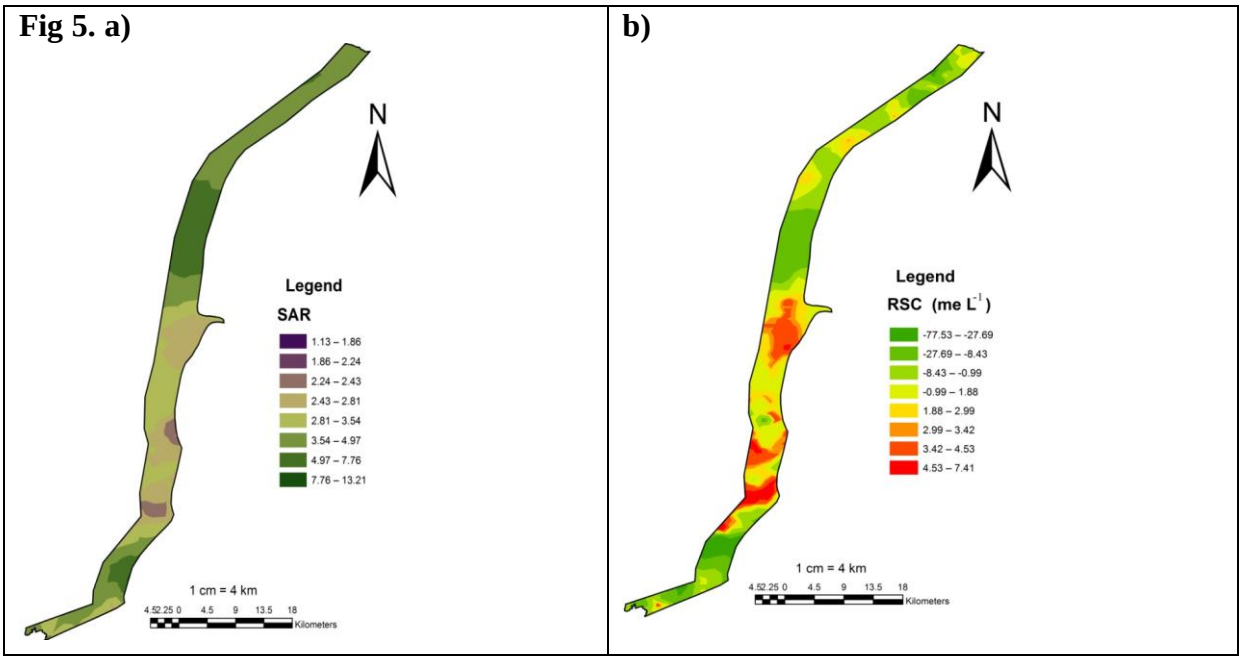

Fig 5. Spatial distribution of SAR (a) and RSC (b) in the groundwater samples

Classification based on EC, RSC and SAR

Based on EC, SAR and RSC, water samples were classified into different categories as per the classification of All India Coordinated Research Project (AICRP) (Table 3). According to AICRP classification (Gupta *et al*., 1994), it was found that water samples of 45 locations good with the per cent distribution of 22.5 and 28 samples marginally saline with the per cent distribution of 14; 31 locations were saline with per cent distribution of 15.5; 9 locations were high SAR saline with the per cent distribution of 4.5; 47 locations were marginally alkali with per cent distribution of 23.5 and 40 locations were alkali with per cent distribution of 20 (Sanjay *et al*., 2009).

Table 3. AICRP suitability classification of groundwater for irrigation in Coastal areas of Thoothukudi district

Water Quality	Class	No. of Samples	Percentage
Good	A	45	22.5
Saline			
Marginally Saline	B1	28	14
Saline	B2	31	15.5
High SAR Saline	B3	9	4.5
Alkali water			
Marginally Alkali	C1	47	23.5
Alkali	C2	40	20.
Highly alkali	C3		
Total		200	100

Conclusion

The dominating ions in the groundwater samples of Thoothukudi district were Na^+ and Cl^- and an increasing trend have been observed with EC in the samples nearer to the coast. This indicates that the groundwater in the study area were of Na-Cl type, indicating that they were largely intruded with seawater and are of poor quality. As per the AICRP suitability classification of groundwater for irrigation, 22.5, 34 and

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43.5 per cent of water samples of the study area were classified under good, saline and alkali categories, respectively. Spatial distribution maps of major cations and anions showed that the groundwater quality is markedly deteriorated near the coast.

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