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ORIGINAL ARTICLE

Assessment of Sea Water Intrusion in Coastal District of Southern India

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Abstract:
Coastal aquifers are increasingly threatened by seawater intrusion due to increased urbanization, groundwater exploitation, and global sea-level rise. Pattern diagrams, which constitute the outcome of several hydro-geochemical processes, have traditionally been used to characterize vulnerability to seawater intrusion. However, the formats of such diagrams do not facilitate the geospatial analysis of groundwater quality, thus limiting the ability of spatio-temporal mapping and monitoring. This raises the need to transform the information from current pattern diagrams into a format that can be readily used under a GIS framework to define vulnerable areas prone to seawater intrusion. A total of 162 no. of ground water samples were collected during May 2017 and analyzed for ionic properties. Among the 13 blocks of Cuddalore district, only 4 coastal blocks viz., Parangipettai, Kumaratchi, Kurinjipodi and Bhuvangiri blocks were assessed for sea water intrusion. These blocks were located from seashore to 30 km inland distance and around 52 nos. of ground water samples were collected from these coastal areas. Among the 4 coastal blocks studied, Melathirukallipalai and Kavarapattu locations of Parangipettai block and Ammapettai, Erukkankattu padugai and Karuppur locations of Kumaratchi block of Cuddalore district, Tamilnadu were suspected for sea water intrusion based on their hydro geology parameters and molar ratios. Regarding sea water intrusion, the high Mg/Ca ratio (> 5.4) may be indicative of sea water contamination in these locations. According to Cl /CO_3^{2-} +HCO_3^- ratio (> 6.6) the screened locations have highly contaminated ground water (near sea water). Based on Na/Cl ratio (<0.86), the contamination may be due to marine source of origin. Hence, construction of check dams in these areas across the rivers at frequent intervals will assist in mitigating the problems of sea water intrusion by increasing ground water recharge.

Keywords: Coastal areas; Ground water quality, Ionic composition; sea water intrusion

Introduction

Seawater intrusion threatens coastal freshwater resources globally, rendering groundwater non-potable and invariably forcing well abandonment or requiring costly treatment systems. This vulnerability is also expected to exacerbate by future climate change and associated sea-level rise up (Taylor *et al*. 2013). Seawater and freshwater have different hydrochemistry, with the former being characterized by nearly uniform chemistry where chloride (Cl^-) and sodium (Na^+) make up 84% of the total ionic composition. On the other hand, freshwater composition varies widely, where calcium (Ca^{2+}) and bicarbonate (HCO_3^-) ions may commonly dominate. Mixing of these

waters is traditionally depicted by increased Cl^- concentration within the aquifer, which is easily traceable due to the conservative nature of the anion (Panteleit *et al*. 2011). Similarly, the increase in total dissolved solids (TDS) or electrical conductivity (EC) is a common simple indicator to identify an increase in salinity (Singhal and Gupta 2010).While seawater intrusion is recognized as the mixing of seawater into freshwater aquifers, it is a complex process due to influences of hydro geochemical reactions, shoreline geomorphology, biological processes, and aquifer flow. Processes indicative of seawater intrusion include cation exchange reactions, calcite dissolution and carbonate diagenesis, dolomitization, and sulfate reduction. The location of Neiveli mining and Veeranam lake in which ground water extraction is at its maximum fall in the environment (Anandhan 2005). Generally, the ground water qualities remain unchanged in the coastal areas. However, some of the sites showed very high levels of salinity due to the 1 intrusion of sea water into the fresh water systems through Tsunami waves and over exploitation of ground water as well as shoreline changes, geology, geomorphology, rate of sea level rise and current pattern, human impact on coast etc. The Tsunami disaster of December 26, 2004 devastated many areas along the Indian coastline. Due to this, Tamil Nadu was badly altered and leaving a trail of disaster. It is estimated that about 8000 persons perished in the disaster and damaging the properties of many others. While sea water intrusion was a problem in Chennai and Cuddalore district, 99 per cent of fresh water demand can be met out by ground water only in later state. Over exploitation of ground water resources for agricultural domestic and industrial purposes due to insufficient availability of surface water resources and high water demand. The people in North range of Tamil Nadu coast are mainly engaged with harbor works, oil refineries, fishing and industrial activity includes fertilizer manufacturing, thermal power stations, chemicals, pesticides and pharmaceutical manufacturing industries, and SIPCOT industrial complexes are responsible for over exploitation of ground water resources of Cuddalore district, Tamil Nadu. Hence the present investigation was undertaken to assess sea water intrusion if any in coastal areas of Southern Tamil Nadu, India.

Materials and Methods

About the study area

The study area, Cuddalore district in Tamil Nadu lies on the East Coast of Southern India, bound on the north, south and west by Villupuram, Nagapattinam and Perambalur districts and on the east by Bay of Bengal. The average annual rainfall is 1164mm.Cuddalore district is divided into 13 blocks, which further divided into 898 villages. The drinking water source of Cuddalore district is mainly through ground water resources (Fig.1).The district lies between 11° 43'north of latitude and 79° 49' East of longitude. It has an average elevation of 1 meter (3 feet).

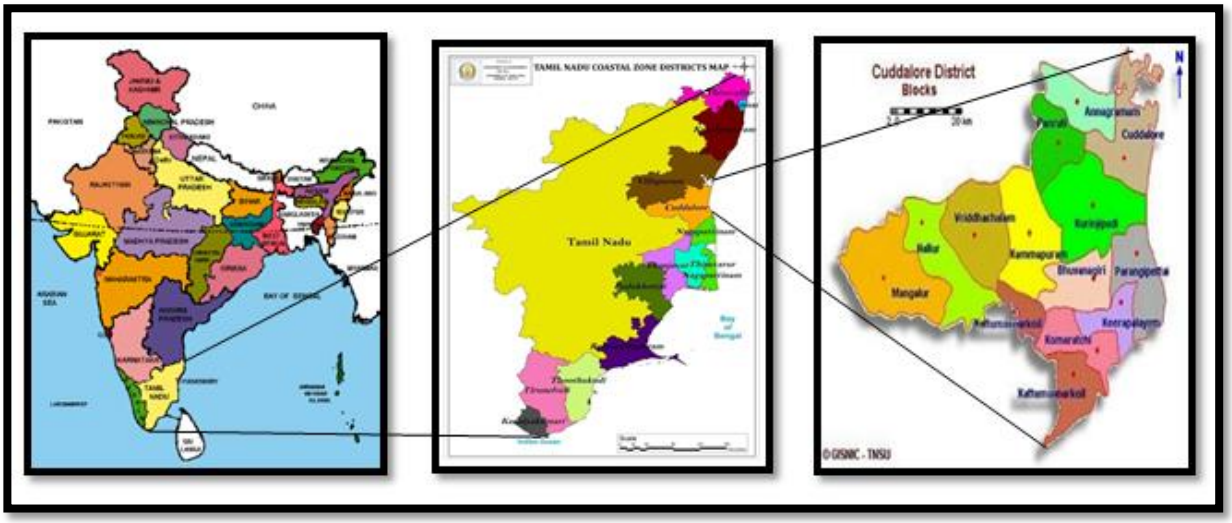

Figure: 1 Location map of study area – Cuddalore district, TamilNadu, India

Grid Surveying and sampling

The entire Cuddalore district map was divided

into grids of 10 sq. km size so that each grid receives at least one bore well location. Samples were stored in airtight bottles. The water samples were analysed for pH, EC, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-}). Quality parameters like SAR and RSC were calculated. Screening of ground water samples for their suitability to irrigation was done on the basis of EC, SAR, RSC values as suggested by Central Soil Salinity Research Institute, Karnal and thematic map pertaining to ground water quality were prepared using RS – Arc GIS software. Based on the ground water quality map prepared, the ground water samples fell under saline and alkali classes alone taken for seawater intrusion studies. out of the 13 blocks studied in Cuddalore district only 4 coastal blocks viz Parangipettai, Kumaratchi, Kurinjipadi and Bhuvanagiri blocks were investigated further for seawater intrusion studies.

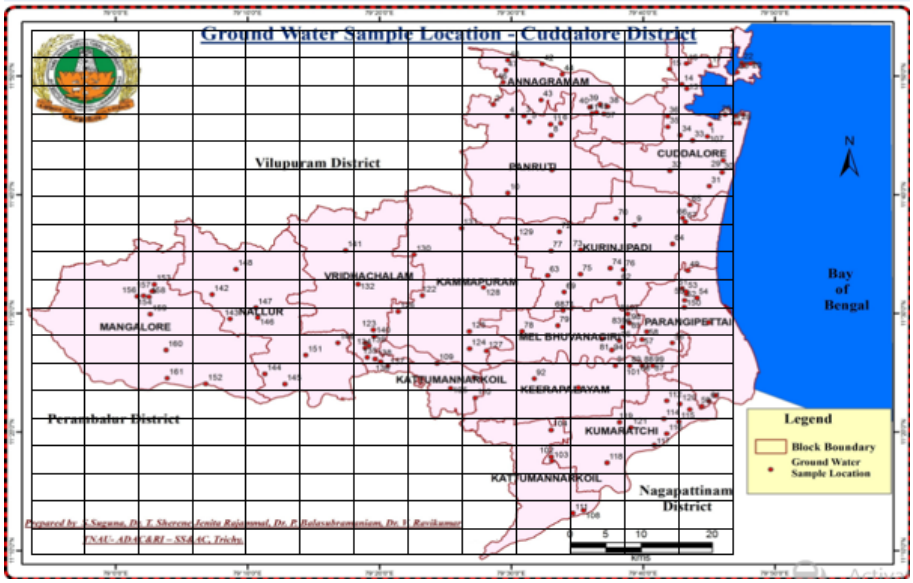

Figure: 2 Grid surveying and ground water sampling location

Analysis of ground water samples

The water samples were analysed for pH, EC, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-}) nitrate and Fluoride contents by following the Versanate method (USDA Hand Book 60), Na^{+} through flame photometry (Jackson, 1958) and anions like CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2} by following the methods of Richards (1954) and Eaton (1950). Quality parameters like SAR and RSC were calculated by using the formulas of (Richards, 1954; Eaton, 1950). Screening of ground water samples for their suitability to irrigation is done on the basis of EC, SAR, RSC values as suggested by AICRP (1989) and thematic map pertaining to ground water quality was prepared using RS – Arc GIS software. From the thematic map, the ground water samples of the 4 coastal blocks (52 Nos.) were selected for sea water intrusion studies. Sea water intrusion signatures like ionic chemistry and molar ratios, were arrived by using standard procedures.

Table 1 Criteria for recognition of sea water intrusion in ground water

Ionic Ratios			
SI.No.	**Parameters**	**Critical limit**	**References**
1.	Cl/HCO_3	> 1- Sea water intrusion	Soni & Pujari, 2010
2.	Na / Cl	<0.86–Salinity due to sea water intrusion 0.86 -1.0 Fresh ground water >1- Anthropogenic activities	Jones *et al*., 1999
3.	$Cl/(CO_3+HCO_3)$	0.05 - Fresh ground water	Mohan Babu *et al*., 2013

		0.05 to 1.30 - Slightly contaminated ground water 1.30 to 2.80 - Moderately contaminated ground water 2.80 to 6.60 - Injuriously contaminated ground water 6.6 to 15.5 - Near sea water>200 -Sea water	
4.	Cl/Br	Cl/Br ratio = 297 mg/l - Seawater (where Cl = 19,500 mg/l, Br = 67.3 mg/l) Hyper saline brine >297 mg/l (from remains of evaporated seawater) up to 800 mg/l - anthropogenic sources (sewage effluents or agriculture-return flows) >1000) - evaporate–dissolution products	Morris & Riley, 1966
5.	Ca/Mg	Ca/Mg ratio low due to Sea water intrusion 'Mg' is the dominant ion in ocean	Mohan Babu *et al*., 2013)
6.	Cl> Na	Sea water intrusion	Mondal et al., 2010 & 2011
7.	Kelly's ratio	<1 – Safe >1 - Unsafe	Kelley, 1951
8.	Mg/Ca	4.5 to 5.2 - Seawater (with an excess of Mg)	Jones *et al*., 1999
Individual ionic concentration			
9.	Ca^{2+}	75 to 200 mg/ l	USDA Handbook, vol.60
10.	Mg^{2+}	50 to 150 mg/l	USDA Handbook, vol.60
11.	Cl^{-}	260 to 1600 mg/L	USDA Handbook, vol.60
12.	SO_4^{2-}	150 to 400 mg/l	USDA Handbook, vol.60
13.	TDS	>2000mg/l – Sea water mixing 500 to 1500 ppm - Normal ground water	USDA Handbook, vol.60
14.	NO_3^{-}	45 mg/l	USDA Handbook, vol.60
15.	F^{-}	0.6 to 1.5 mg/l	
16.	Electrical Conductivity	>5000 µS/cm	Kim *et al*., 2005
17.	Total hardness (TH) mg/l of equivalent CaCO3	< 75 - soft 75 to 150 – Moderately hard 150 to 300 - Hard >300 – Very hard	Sawid & Issa, 2015
18.	Magnesium hazard (MH)	<50 – Suitable >50 - Unsuitable	Eaton, 1950
19.	Permeability Index (PI)	Class I – Good Class II – Permissible Class III - Unsuitable	Richards, 1954
20.	Seawater mixing index(SMI)	SMI - >1 (possibility of sea water intrusion)	Park *et al*., 2005

Sea water Mixing Index (SMI)

SMI was estimated using the relation a, b, c and d are constants and represent the relative concentration proportion of Na, Mg, Cl and SO_4 respectively (a = 0.31, b = 0.04, c = 0.57, d = 0.08). CNa, CMg, CCl and CSO4 represents concentrations of Na, Mg, Cl and SO4 respectively measured in groundwater samples expressed in mg/l and TNa, TMg, TCl and TSO4 represent threshold values of Na, Mg, Cl and SO4 which were estimated from interpretation of cumulative probability curves.

Results and Discussion

The ground water samples collected from coastal blocks of Cuddalore district was analyzed for their suitability to irrigation. Among the 4coastal blocks studied (52 samples),Melathirukallipalai and Kavarapattu locations of Parangipettai block and Ammapettai, Erukkankattu padugai and Karuppur locations of Kumaratchi block of Cuddalore district were suspected for sea water intrusion based on their hydro geology parameters and molar ratios. Bicarbonate and Chloride were the dominant anion, Magnesium and Sodium were the dominant cations found in the above mentioned locations. The ground water chemistry commonly found to be Ca-HCO_3 type. However Nacl is also the dominant water facies in the above mentioned locations.

Regarding sea water intrusion, the high Mg/Ca ratio (> 5.4) may be indicative of salt water contamination in these locations. According to Cl /CO_3^{2-}+HCO_3^- ratio(>6.6) the screened locations have highly contaminated ground water (near sea water). Based on Na/Cl ratio (<0.86), the contamination may be due to marine source of origin. The abundance of cations like Na^+, anions like Cl^- and HCO_3^- over other ions in the ground water samples as well as ionic ratios like Na/Cl (< 0.86) (Nair et al., 2012) Cl /CO3+HCO3 (> 6.6) (Mohan Babu et al., 2013) and Mg/Ca (> 5.4) (Jones et al., 1999) Seawater Mixing Index (>1), Water Quality Index (>100), (Krishnamoorthy & Athimoolam, 2015) of Melathirukallipalai and Kavarapattu locations of Parangipettai block and Ammapettai, Erukkankattupadugai and Karuppur locations of Kumaratchi block of Cuddalore district showed these villages were suspected for seawater intrusion. As these seawater intrusion signatures very well indicated the contamination of ground water quality through seawater intrusion (Fig.3). These were well supported by Park *et al*., (2005) observed as an effective tool for evaluating the relative degree of seawater mixing, the Seawater Mixing Index (SMI) based on the concentrations of Na^+, Mg^{2+}, Cl^-, and SO_4^{2-} . SMI values greater than 1 indicated the ground water was considered to be affected by salinization due to seawater mixing and anthropogenic contamination. Not only the above mentioned reason, the drought and over exploitation of ground water were the main reasons for seawater intrusion in Cuddalore district. This was supported by Kerrou *et al.*,,(2010); (Furuya, 2009); (Wicks and Herman, 1996); (Omonona *et al*., 2014); (Jankowski and Jacobson, 1991). In Cuddalore district, out of 13 blocks the Parangipettai and Kumaratchi block has low water table level due to over exploitation of ground water and the prevalence of severe drought during the past two years. Due to this reason, the above mentioned villages were suspected for seawater intrusion.

Table.2 Screening of Sea water intruded well locations of Cuddalore district, TamilNadu

Blocks / Villages		Geo coordinates	Distance from sea (Km)	Na^+ (m.eq./lit)	Cl^- (m.eq./l)	HCO_3^- (m.eq./l)	Na/Cl	Cl /CO_3^{2-} +HCO_3^-)	Mg^{2+}/Ca^{2+}	WQI	Rating	SMI	Rating
Parangipettai block													
1.	Melathirukallipalai	N11.3845º E079.7584 º	4	90.47	190.0	16.00	0.48	7.92	7.55	177.20	Unfit for drinking	15.11	Sea water intrusion

2.	Kavarapattu	N11.3763 º E079.7499 º	8	84.83	160.0	14.00	0.53	7.27	9.69	160.67	Unfit for drinking	13.06	Sea water intrusion
Kumaratchi Block													
3.	Ammapettai	N11.3769 º E079.6964 º	10	86.93	90.00	16.00	0.51	7.08	8.03	134.42	Very poor	8.55	Sea water intrusion
4.	Erukkankattu padugai	N11.3306 º E079.6961 º	11	99.24	210.0	16.00	0.47	8.75	9.70	225.05	Unfit for drinking	16.53	Sea water intrusion
5.	Karuppur	N11.3149 º E079.6809 º	9	88.92	180.0	18.00	0.49	6.92	7.43	238.16	Unfit for drinking	14.48	Sea water intrusion

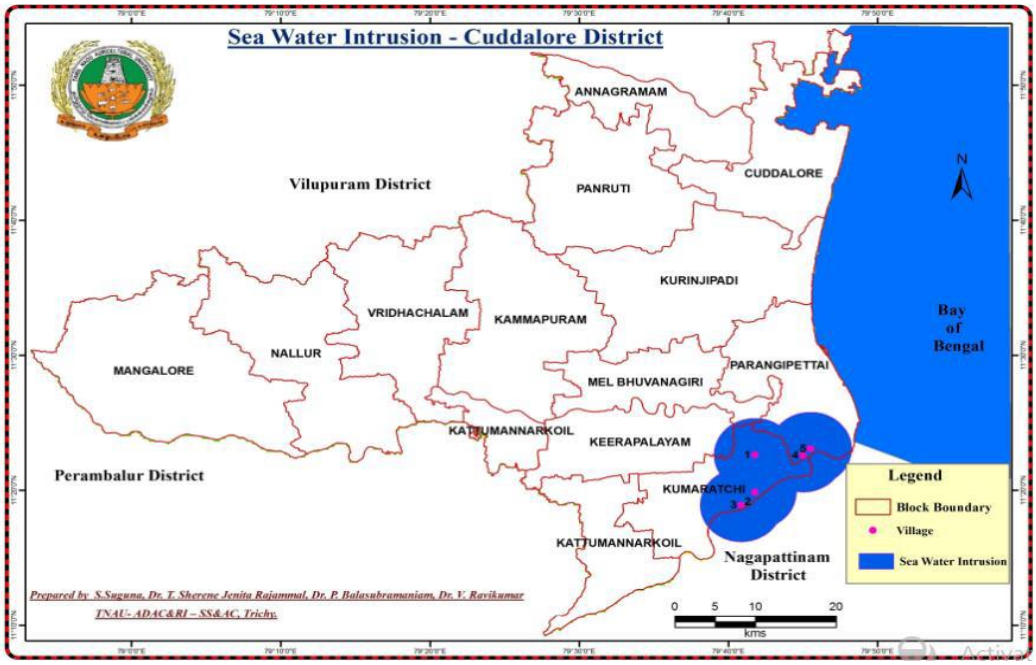

Figure: 3 Sea water intruded areas of Cuddalore district

Conclusion

Seawater Mixing Index of Parangipettai, Kumarachi block was more than 1 whereas the other 2 blocks viz., Kurinjipadi and Bhuvanagiri were less than 1. In Parangipettai block, Melathirukallipalai and Kavarapattu villages and Kumaratchi block, Ammapettai, Erukkankattu padugai and Karuppur villages were identified for sea water intrusion based on Na/Cl (< 0.86), Cl /CO3 2-+HCO3 - (> 6.6), Mg/Ca (> 5.4), Cl- / HCO3 - (>1), Water Quality Index (>100) and Sea water Mixing Index (>1).Hence, construction of check dams in these areas across the rivers at frequent intervals will assist in mitigating the problems of sea water intrusion by increasing ground water recharge.

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