

Identification of salinization by bromide and fluoride concentration in coastal aquifers near Chennai, southern India

Indu S. Nair ^a, K. Brindha ^b, L. Elango ^{a,*}

^a Anna University, Department of Geology, Chennai 600025, Tamil Nadu, India

^b International Water Management Institute, Vientiane, Lao People's Democratic Republic

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Abstract

This study aims to use fluoride as an additional indicator for seawater intrusion apart from the known effective geochemical indicators such as EC, TDS, sodium, chloride and bromide. Groundwater in a coastal part of Arani-Koratalaiyar river basin located north of Chennai, Tamil Nadu, India was assessed to determine its suitability for domestic purpose and to delineate the region affected by seawater intrusion. Fluoride concentration in groundwater samples from forty nine locations varied from 0.02 mg/l to 2.9 mg/l with an average of 0.5 mg/l. As per the Bureau of Indian Standards, the permissible range of fluoride in drinking water is 0.6–1.5 mg/l. Fluoride concentration in groundwater of this area exceeds 1.5 mg/l in 6% of the groundwater samples and is below 0.6 mg/l in 74% of the groundwater samples. There is no known geological source for fluoride in this area. Spatial variation in fluoride concentration in groundwater indicates that the coastal areas have comparatively high fluoride due to seawater intrusion which was similar in comparison with EC and bromide concentration measured in groundwater. This study indicates that fluoride can be used as an indicator of seawater intrusion in coastal areas.

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Keywords: Coastal area; Electrical conductivity; Bromide; Fluoride; Sea water intrusion

1. Introduction

Groundwater salinization is a common threat in coastal parts of the world (Giménez-Forcada, 2014; Camp et al., 2014). Many researchers have identified seawater intrusion along the coastal regions and proposed different indicators that can help to easily identify the groundwater quality degradation by geochemical analysis of groundwater including isotopic signatures (Khaska et al., 2013; Yamanaka et al., 2014), geophysical investigation (Choudhury et al., 2001) and

* Corresponding author.

E-mail address: elango34@hotmail.com (L. Elango).

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also sophisticated numerical modelling (Narayan et al., 2007; Cobaner et al., 2012). Of these methods, the simplest, cost-effective and rapid determination is through the measurement of electrical conductivity (EC) of groundwater in the coastal regions. Other geochemical indicators for seawater intrusion known historically are the presence of high concentration of sodium, chloride and bromide concentration in groundwater.

Presence of high fluoride in groundwater used for drinking purpose is a serious issue which is recognized worldwide. However, low fluoride in drinking water i.e. <0.6 mg/l (WHO, 2004; BIS, 2012) is also a concern as it may cause tooth decay. Groundwater used for drinking purpose having fluoride concentration above the maximum permissible limit of 1.5 mg/l (WHO, 2004; BIS, 2012) may cause dental and skeletal fluorosis. Many times the sources of fluoride are natural i.e. from the rocks that are rich in fluoride bearing mineral which weathers during rock and water interaction (Reddy et al., 2010; Brindha and Elango, 2011). The other sources of fluoride in groundwater include agrochemicals (Motalane and Strydom, 2004; Farooqi et al., 2007) and combustion of coal (Jha et al., 2008). The presence of high concentration of fluoride i.e. above the maximum permissible limit of 1.5 mg/l has been reported earlier in many parts of the world (Ahn, 2012; Reyes-Gómez et al., 2013). In India too, fluoride poses a challenge to groundwater quality (Brindha et al., 2011; Sharma et al., 2012; Brindha and Elango, 2013). All these studies emphasize on the importance of studying the occurrence of fluoride in groundwater as it is a potential contaminant that causes health impacts in humans. It is essential to determine the fluoride in groundwater of the areas where it is used by the people for drinking and domestic purposes without proper treatment.

This study was carried out in an area which forms a part of Arani-Korattalaiyar river basin located north of Chennai, Tamil Nadu, India with an objective to ascertain the suitability of groundwater for domestic purpose based on the fluoride concentration in groundwater and using fluoride as an indicator to determine the area affected by seawater intrusion. EC, total dissolved solids (TDS) and bromide which have served as established indicators for seawater intrusion has also been studied for comparison.

2. Materials and methods

The base map was prepared from Survey of India toposheets (1:50,000) and the geology map was prepared from the maps obtained from Geological Survey of India (1:125,000). Initially, a survey was carried out to understand the types of wells, pumping pattern and the local hydrogeology. Based on this, forty nine representative wells (Fig. 1) were chosen for monitoring the groundwater quality. Groundwater samples were collected from these 25 bore wells and 24 open wells in clean polyethylene bottles of 500 ml capacity during June 2011. Prior to the collection, water was

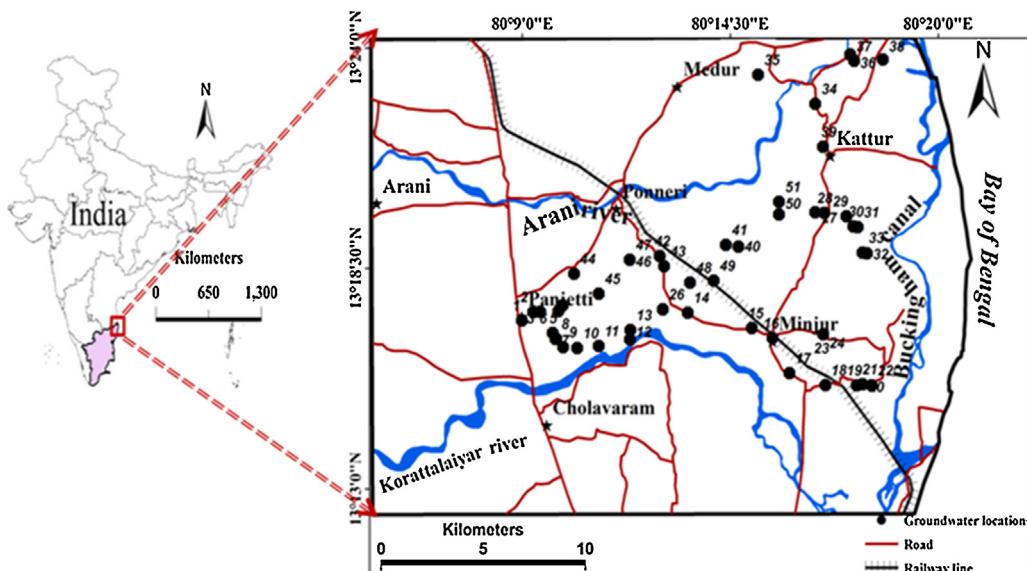


Fig. 1. Location of the study area and monitoring wells.

pumped for sufficient time depending on the sampling location and depth of the well so as to collect the water from the aquifer formation. In dug wells, a depth sampler was used to collect the water below 2–3 m from the groundwater table. Care was taken to collect samples from wells which are used for domestic as well as agricultural purposes. The pH and EC of the samples were measured in the field immediately after sampling using a portable multi parameter probe (YSI 556) which was calibrated before the analysis. The samples were brought to the laboratory and filtered using 0.22 µm Millipore filter paper before analysing for fluoride and bromide concentration using Metrohm 861 advanced compact ion chromatograph. Analytical grade reagents were used and the detection limit of the instrument is <2 ppb for anions. TDS was calculated using the measured EC values using the relationship, TDS (mg/l) = EC (µS/cm) × 0.64 (Lloyd and Heathcote, 1985). Arc GIS 9.3 was used to prepare the base maps and the spatial variation in various parameters.

3. Description of study area

The study area forms a part of the Arani and Koratalaiyar river basin located north of Chennai, Tamil Nadu, southern India (Fig. 1). This area experiences a tropical climate. The weather is hot most of the time in a year. May to June has maximum temperature ranging between 38 °C and 42 °C. Minimum temperature is around 18–20 °C during the months of December and January. The average annual rainfall is about 1200 mm. North east and south west monsoon contribute to 60% and 35% of the annual rainfall. Many times, the city also receives rainfall when cyclones hit the Bay of Bengal. The Arani River is on the northern part of the study area while the Koratalaiyar River is in the south. The eastern side of this area is bounded by the Bay of Bengal. Buckingham canal runs parallel to the coast which carries saline water. There are numerous lakes in this area which are filled with water only after severe monsoon rains. The reservoirs dry up by April. The Arani and Koratalaiyar Rivers are non-perennial and normally flow only for a few days during north east monsoon i.e. from October to December. During summer months, the river becomes dry and the saline waters from the sea enter the river and these backwaters extend inland up to 4 km. This area gently slopes towards the east and the drainage pattern is mainly dendritic (Fig. 2a).

This area comprises of landforms of fluvial, marine and erosional sediments (United Nations Department of Technical Co-operation for Development, 1987). It includes alluvial planes, beach ridges, mudflats and abandoned paleochannels in the eastern region (Fig. 2b). The studies based on borehole data collected show the thickness of the coastal alluvium is about 40 m. Groundwater occurs in alluvium generally in unconfined condition. The thick clay lenses in some parts result in semi-confined aquifer system. Geomorphological features are given in Fig. 3a. The groundwater level in the unconfined aquifer ranges from 2 to 6 m bgl and in semi-confined aquifer it ranges from 14 to 20 m bgl. The general groundwater flow is towards the east. Groundwater recharge relies mainly on rainfall which feeds the non-perennial streams at the same time. The open/dug wells in this area have a depth up to 25 m and the bore wells extend up to 52 m deep. Groundwater is the major source for domestic and irrigational purposes. Apart from the piped drinking water being supplied for few hours in a day, people depend on the groundwater as a source for their everyday domestic uses. Most of the settlements are located on the south eastern region. In about 75% of this area, agriculture is practiced (Fig. 3b). Many well fields are located in this area which supplies water to the Chennai city.

4. Results and discussion

Groundwater quality of this area is analysed based on the pH, EC, TDS, bromide and fluoride concentration and the statistical summary of these parameters measured are given in Table 1. As groundwater is directly used for drinking purpose in this area, the desirability of groundwater for the directed purpose is compared with the drinking water quality standards.

4.1. Chemical characteristics and quality

Groundwater is alkaline based on pH and of the 49 groundwater samples analysed, 14% were not within the suitable range of 6.5–8.5 for drinking purpose. Spatial variation in pH given in Fig. 4a shows the groundwater samples exceeding the limit in the northern and western parts of the study area. EC of groundwater gives an idea about the general groundwater quality. Groundwater in this area is permissible for drinking in 39% of the sampling areas with

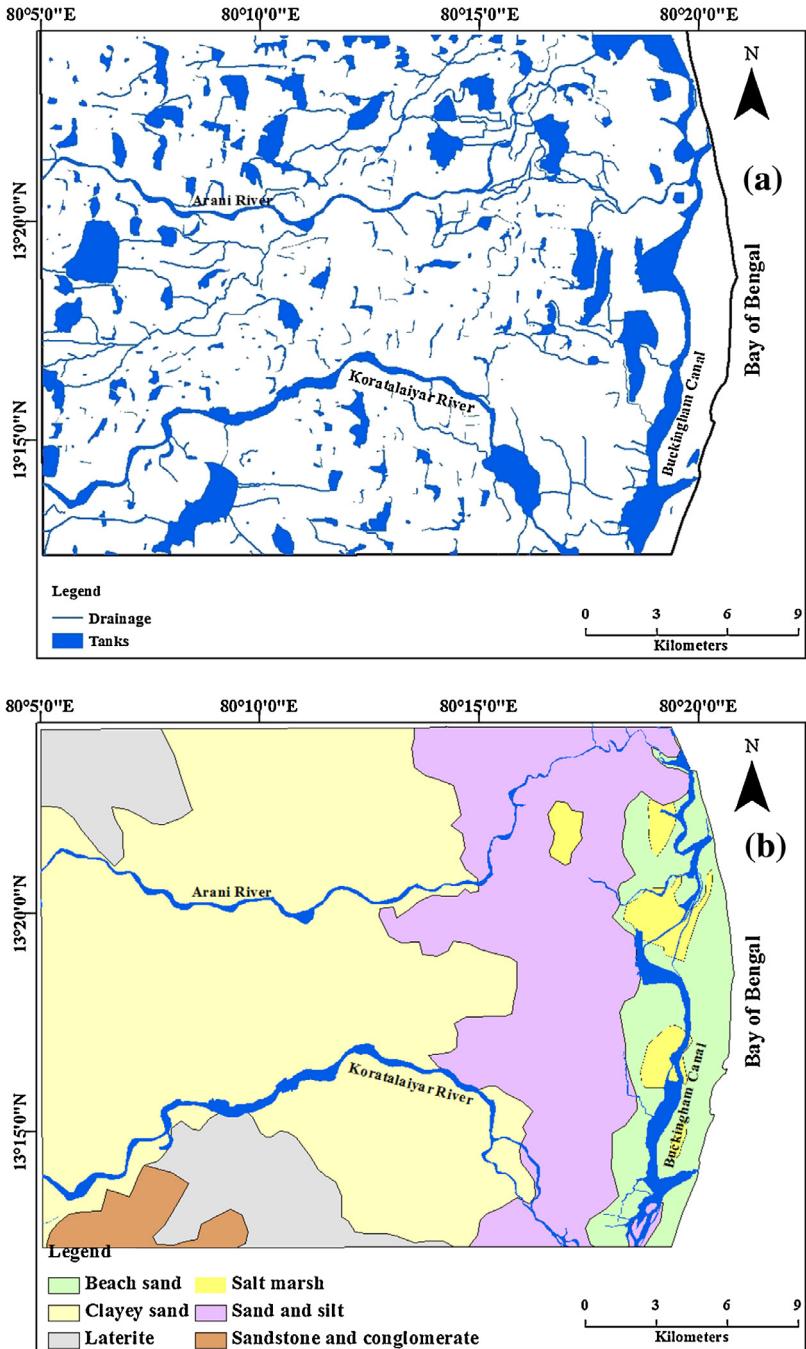


Fig. 2. (a) Drainage and (b) geology of the study area.

EC less than 1500 $\mu\text{S}/\text{cm}$ and unfit for drinking in 37% of the area i.e. EC between 1500 $\mu\text{S}/\text{cm}$ to 3000 $\mu\text{S}/\text{cm}$. Remaining 24% of the groundwater samples are hazardous for consumption ($>3000 \mu\text{S}/\text{cm}$). Most of the groundwater in this area is of brackish nature (Table 2, Freeze and Cherry, 1979) and 21% of the groundwater samples were desirable and permissible for drinking use on the basis of TDS (Table 3, Davis and DeWiest, 1966). Bromide concentration in groundwater of this area varied from 0.2 to 23.7 mg/l. This ion has a low degree of toxicity, but, large doses of bromide cause nausea and vomiting, abdominal pain, coma and paralysis (WHO, 2009). Threshold limit for bromide in drinking

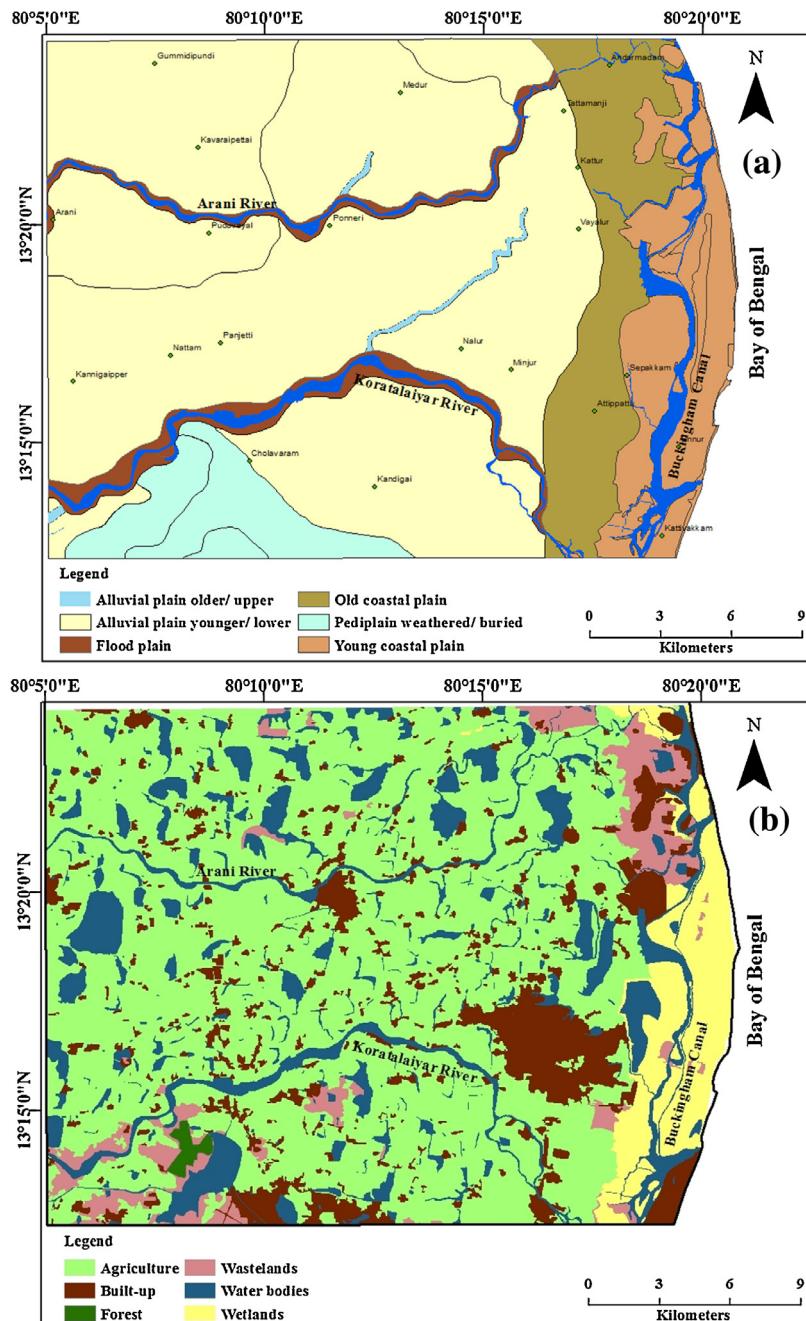


Fig. 3. (a) Geomorphology and (b) landuse features in the study area.

water is not specified by any health organization. Based on the limit of 1 mg/l proposed by Flury and Papritz (1993), 71% of the groundwater samples had higher bromide concentration (Table 4). Concentration of fluoride in groundwater varied from 0.02 to 2.9 mg/l. As per the BIS and WHO standards, the suitable range of fluoride in drinking water is 0.6–1.5 mg/l (WHO, 2004; BIS, 2012). Fluoride content was below 0.6 mg/l in 36 (74%) groundwater samples and above 1.5 mg/l in 3 (6%) groundwater samples (Table 4). Only 20% i.e. ten groundwater samples were within the suitable range as prescribed by BIS. Overall, most part of this area has less fluoride in groundwater.

Table 1

Statistical details of various parameters in groundwater.

Parameter	Unit	N	Minimum	Maximum	Mean
pH	No unit	49	6.4	9.6	7.9
EC	$\mu\text{S}/\text{cm}$	49	303	23,808	3177
TDS	mg/l	49	194	15,237	2033
Bromide	mg/l	49	0.2	23.7	4
Fluoride	mg/l	49	0.02	2.9	0.5

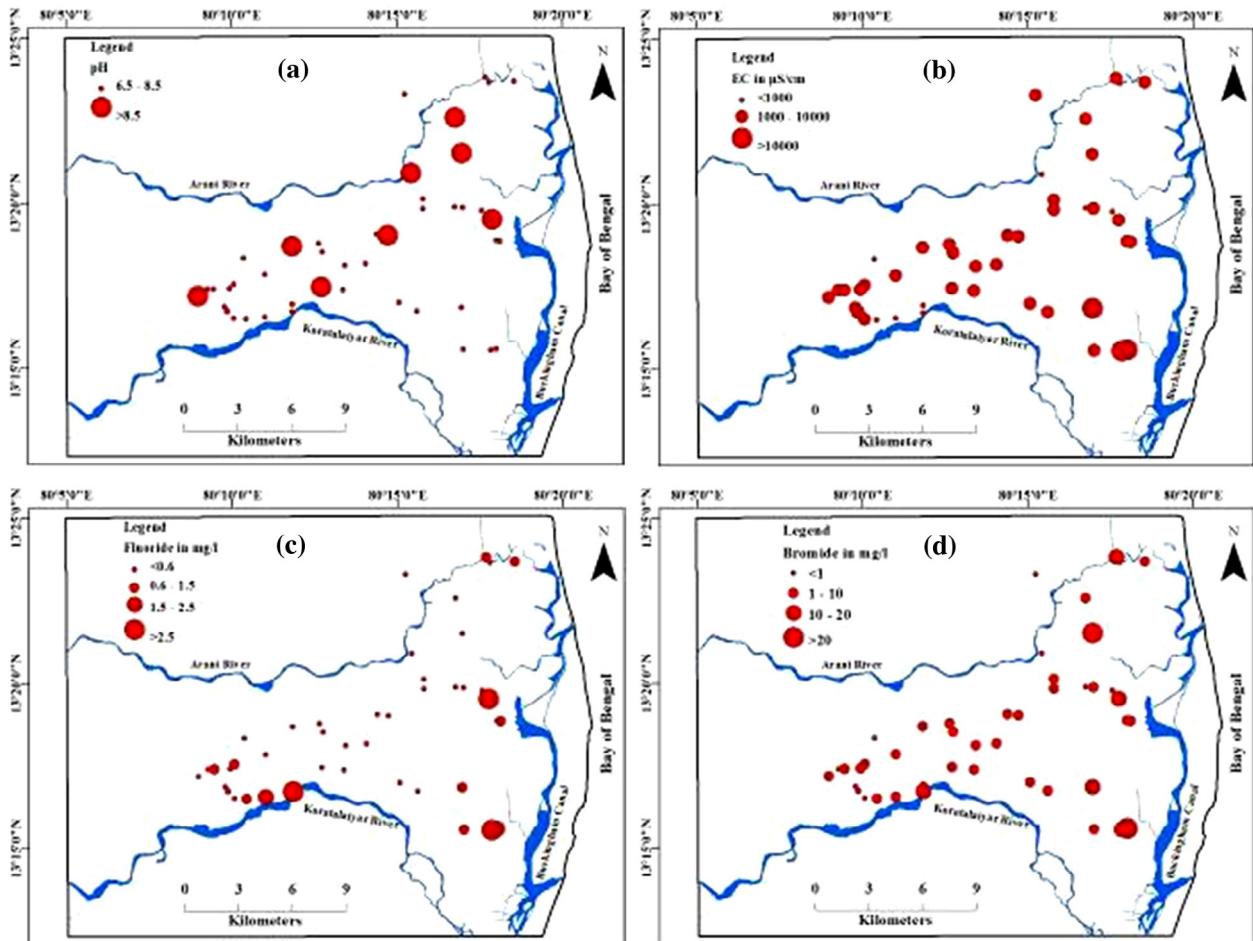


Fig. 4. Spatial variation in (a) pH, (b) EC, (c) fluoride and (d) bromide in groundwater.

Table 2

Freeze and Cherry classification of groundwater based on TDS.

TDS (mg/l)	Water type	Number of samples	Percentage
<1000	Fresh	21	43
1000–10,000	Brackish	25	51
10,000–1,00,000	Saline	3	6
>1,00,000	Brine	Nil	Nil

Table 3

David and DeWeist classification of groundwater based on TDS.

TDS (mg/l)	Classification	Number of samples	Percentage
<500	Desirable for drinking	6	12
500–1000	Permissible for drinking	15	31
1000–3000	Useful for irrigation	21	43
>3000	Unfit for drinking and irrigation	7	14

4.2. Salinization

Spatial variation in EC (Fig. 4b) indicates that most of the study area has brackish water showing the salinization of groundwater. A plot of EC versus the distance of the sampling locations from the coast (Fig. 5) show that the EC is highest near the southern part of the coast i.e. above 15,000 $\mu\text{S}/\text{cm}$, but, also high contents of about 5000 $\mu\text{S}/\text{cm}$ has been recorded inland. The three locations seen distinctly in Fig. 4b in the southern part near the cost with EC above 15,000 $\mu\text{S}/\text{cm}$ are attributed to seawater intrusion due to over pumping of groundwater. However the spatial variation of EC (Fig. 4b) showing above 1500 $\mu\text{S}/\text{cm}$ in most part of the area suggests other sources for salinization apart from seawater intrusion.

Variation in fluoride concentration in groundwater shows that it is higher in the coastal as well as inland areas (Fig. 4c). Geologic formation in this area does not contain any fluoride bearing minerals and so the increase in fluoride concentration in groundwater due to rock water interaction which is the most obvious source for high concentrations of fluoride in groundwater worldwide is not possible. Concentration of fluoride in groundwater being high near the coast in the south eastern part of the area (Fig. 5) implies that the seawater intrusion can be a reason for its occurrence. Fluoride concentrations ranging from 0.86 to 1.4 mg/l has been reported in seawater by Warrington (1995). The other possible source for fluoride being agrochemicals used for irrigation was also assessed. Presence of fluoride in fertilizers and their impact on groundwater has been reported in other regions by Rao (1997), Motalane and Strydom (2004), Farooqi et al. (2007), and Brindha and Elango (2013). But, agriculture is practiced in most parts of the area (Fig. 3b) and hence the reason of high fluoride in the southern part alone cannot be grouped as due to agrochemicals. It is possible that the high concentration of fluoride in the south eastern coastal regions is attributed to seawater intrusion which is also confirmed by the EC measured above 1500 $\mu\text{S}/\text{cm}$ in these locations. Infiltration of saline water from the salt pans used for producing salt as well as the saline water from the Buckingham canal is also responsible for high fluoride in groundwater especially in the north eastern parts. Further, eastern part of this region has sediments of marine origin, which might also be partly responsible for the salinity in this area (United Nations Department of Technical Co-operation for Development, 1987). Traces of paleo seawater were reported in the western parts of the region at about 16 km from the coast by Nair et al. (2015). It is possible that the

Table 4

Groundwater samples in various range of EC, bromide and fluoride in groundwater.

Parameter	Range	Number of samples	Percentage
EC ($\mu\text{S}/\text{cm}$)	<1500	19	38.8
	1500–3000	18	36.7
	>3000	12	24.5
Bromide (mg/l)	<1	14	28.6
	10	28	57.1
	20	5	10.2
	>20	2	4.1
Fluoride (mg/l)	<0.6	36	73.5
	0.6–1.5	8	16.3
	>1.5	5	10.2

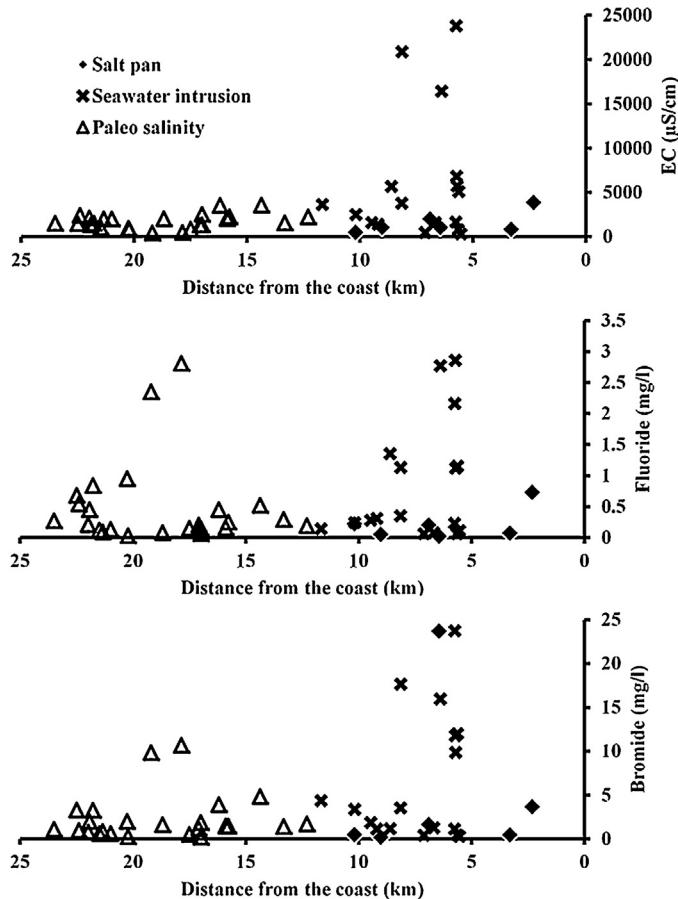


Fig. 5. Variation in different parameters with distance from the coast.

agrochemicals together with paleo salinity were the primary reason for the presence of high fluoride in locations in the west.

This is also supported by the spatial variation in bromide concentration (Figs. 4d and 5) in groundwater which is a key indicator for seawater intrusion as seawater contains bromide concentration ranging from 65 mg/l to above 80 mg/l (Al-Mutaz, 2000). Generally bromide concentration in fresh water ranges from trace amounts to about 0.5 mg/l (WHO, 2009). High concentration of bromide in groundwater has thus been used to indicate seawater intrusion by many researchers. Spatial distribution figures of EC, fluoride and bromide (Fig. 4b, c and d) does not show coincidence of high concentrations geographically as regions of high EC will be mainly attributed to the high concentration of sodium and chloride from seawater intrusion and effect of salt pans. As fluoride and bromide are minor ions in natural waters, their concentration cannot be expected to coincide with the spatial variation of EC. However, resemblances in variation of fluoride and bromide can be witnessed in the study. Thus seawater intrusion/ salinization of groundwater in this area are mainly due to three factors: (1) paleo seawater (2) effect of salt pans and (3) over pumping (Fig. 6). Northern part of the area is saline mainly due to mineralogy and effect of salt pans while the south eastern part is affected by seawater intrusion due to over-pumping. Salinity in the inland areas is attributed to paleo salinity. Apart from these some contribution by agrochemicals is also possible.

In general, the groundwater quality is not suitable for domestic use in the coastal areas based on pH, EC, TDS, bromide and fluoride. As people in this area depend on groundwater for their daily needs and as the well fields located in this area supply water to the Chennai city every day, it is essential that the water is treated and quality is maintained within the permissible limit for drinking and domestic use.

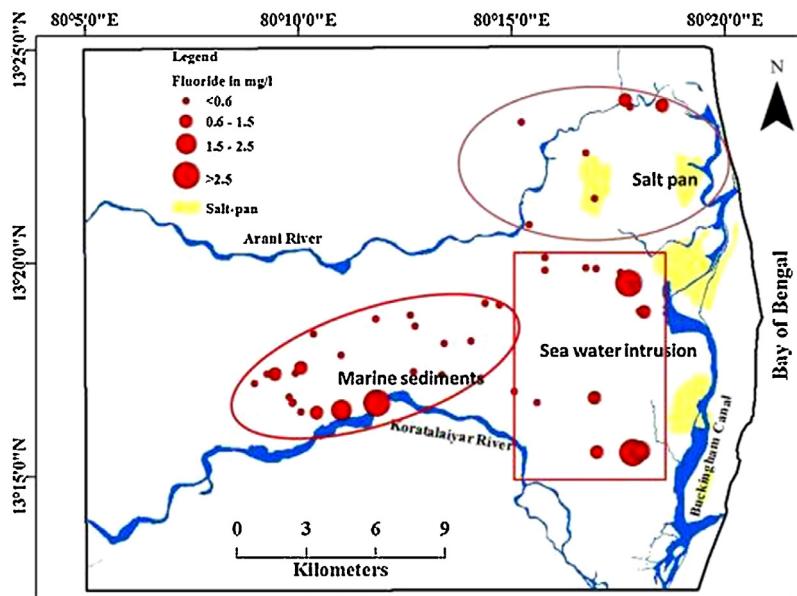


Fig. 6. Reasons for salinization of the coastal aquifer.

5. Conclusion

Groundwater quality for drinking purpose mainly with respect to fluoride was studied in a part of Arani-Koratalaiyar river basin located north of Chennai, Tamil Nadu, India. Samples were collected from 25 bore wells and 24 open wells in July 2011 and analysed for pH, EC, fluoride and bromide in groundwater. Maximum EC of up to 23,808 µS/cm was recorded near the coastal areas due to seawater intrusion. The general groundwater quality based on EC was unsuitable for domestic use in 61% of the locations i.e. EC greater than 1500 µS/cm. Fluoride in groundwater varied from 0.02 mg/l to 2.9 mg/l with 16% of the groundwater samples falling within the permissible range for drinking purpose. Similarity in the spatial variation of high concentration of fluoride and bromide as well as EC implies salinization of the aquifer indicating that the concentration of fluoride in groundwater can also serve as an index for seawater intrusion. Sources of salinity vary from salt pans in the north to over pumping in the south eastern parts with contribution from agrochemicals and paleo salinity in the west.

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