Assessment of groundwater quality in Kanyakumari district, Tamil Nadu, using ionic chemistry

T. Sherene Jenita Rajammal[1,]*, P. Balasubramaniam[1] and M. J. Kaledhonkar[2]

[1]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli 641 003, India

[2]All India Research Project on Management of Salt Affected Soils and Use of Saline Water in Agriculture, ICAR-Central Soil Salinity Research Institute, Karnal 134 001, India

Saline or alkali water also constitutes an important source of irrigation for agricultural production. A study was undertaken at the block level to evaluate major ion chemistry and suitability of water for irrigation purpose in Kanyakumari district, Tamil Nadu, India. A total of 215 groundwater samples were collected and analysed for major ions and the analytical data were interpreted according to established guidelines. The spatial map shows that calcium (Ca^{2+}) is the most dominant cation with bicarbonate (HCO_3^-) and chloride (Cl^-) as the dominant anions. The abundance of cations follows the order Ca > Mg > Na > K and that of anions HCO_3 > Cl > SO_4. The distribution of water samples in different water quality classes based on pH, EC, residual sodium carbonate and sodium adsorption ratio reveals good-quality underground irrigation water in most of the blocks, except Tholavai. In Thucklay, 100% of the groundwater can be used, whereas 89.7% can be used in Rajakamangalam, 81.25% in Munchirai, 80.95% in Thiruvattar and 73.7% in Kuruthencode. The Thovalai block had saline water (73.68%) and marginally saline water (26.32%). Saline water was found in about 25% of the area in the district and *in situ* rainwater conservation for leaching of salts accumulated through saline water irrigation is an important technology. Thus, farmers need to be trained regarding these aspects. Such areas require adequate drainage and also introduction of salt-tolerant crops.

Keywords: Groundwater quality, ionic chemistry, irrigation, salt-tolerant crops, spatial maps.

GROUNDWATER is one of the primary resources of water to meet the requirements of life on earth. At present, the quality of groundwater and surface water is deteriorating. Salinity of both groundwater and surface water is increasing due to sea-level rise, drought, changes in water demand and availability. Tamil Nadu (TN) has a 1076 km long coastline, which constitutes about 15% of the total coastal length of India. Coastal environment is always under threat due to anthropogenic activities, increased human settlement and industrial pollution also causes salinity. Hence, knowledge of hydrochemistry is important to assess the quality of groundwater which is used for both irrigation and drinking. The water quality assessment may give detailed information about the subsurface geologic environments in which the water occurs[1]. Over-exploitation of groundwater has immensely affected its quality and quantity. In several parts of the world, many studies have been carried out to assess the geochemistry of groundwater[2]. In India too, studies have been carried out on groundwater and its quality[3,4]. Some studies on groundwater quality in TN have also been carried out[5–7]. To provide a simple and valuable tool for decision-making on groundwater quality, an integrated approach using ionic chemistry and spatial maps utilizing geographical information system (GIS) was employed. This has yielded good results[8]. Earlier, groundwater quality in the study area was better compared to that in recent years[9]. The present study was carried out to determine the groundwater quality in Kanyakumari district, TN and demarcate areas suitable or unsuitable for agricultural purposes. The process of groundwater quality monitoring is cost-effective. Moreover, collection and monitoring of groundwater quality data for only the index well can provide groundwater quality of the region. The index well can serve as a centre point for quality monitoring and for devising a suitable policy for sustainable management of groundwater. Results obtained in this study can be used for selecting index wells[10].

*For correspondence. (e-mail: shereneraj@yahoo.co.in)

Material and methods

Study area

Figure 1 shows the study area. Average annual rainfall of Kanyakumari district is 1448.6 mm. Most of the rainfall occurs during the northeast (NE) and southwest (SW) monsoon periods. The contributions of SW and NE monsoon are 37.16% and 37.18% respectively[11]. The annual mean minimum and maximum temperatures are 23.78°C and 33.95°C respectively.

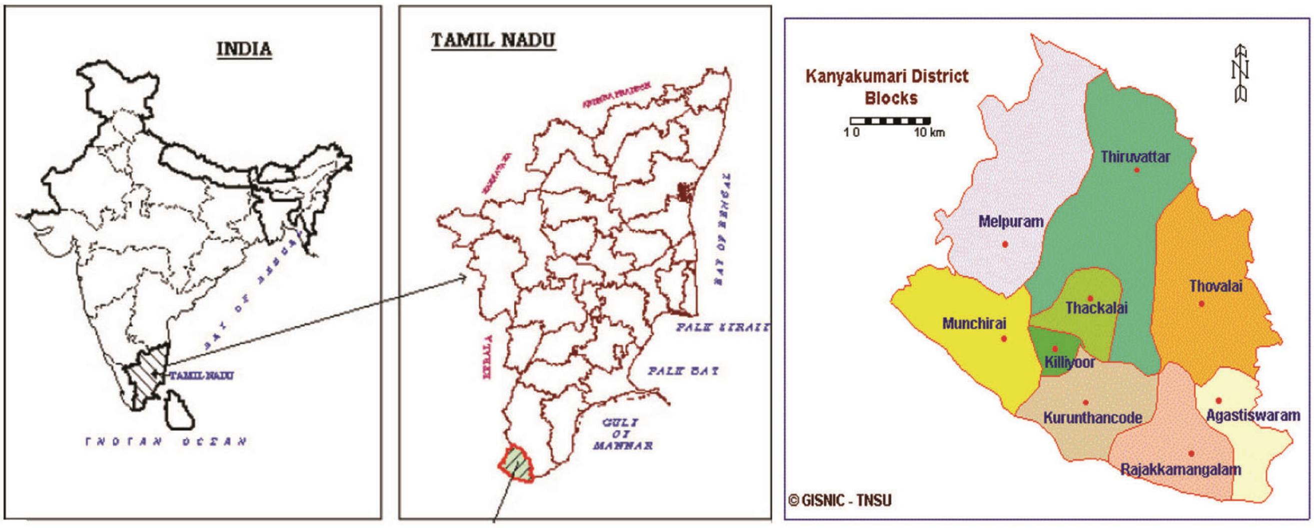

Figure 1. Location map of Kanyakumari district, Tamil Nadu (TN) (adapted from ref. 12).

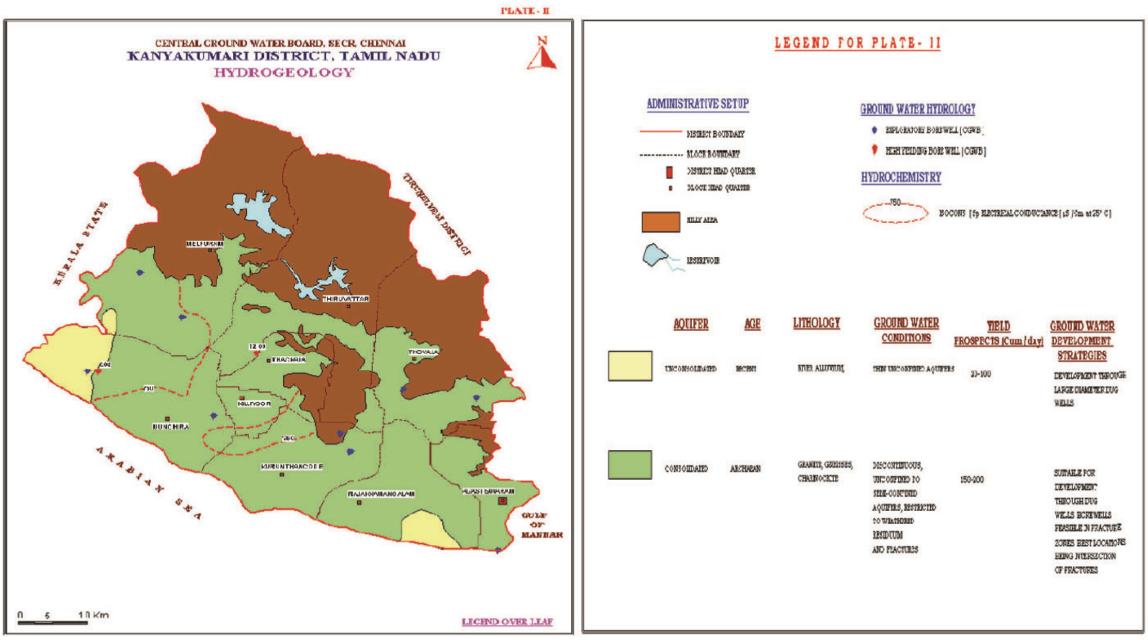

Figure 2. Hydrology map of the study area – Kanyakumari district (adapted from ref. 12).

Hydrology of the study area

Kanyakumari district is underlain by both porous and fissured formations. The important aquifer systems in the district consist of (i) unconsolidated and semi-consolidated formations, and (ii) fractured crystalline rocks. In the areas underlain by crystalline rocks, groundwater is essentially limited to the zone of weathering and fracturing. The groundwater occurs below the water table in semi-confined conditions. The depth to water level ranges from 6 to 10 m bgl, and the discharge ranges from 10 to 20 m^3/day (Figure 2).

Geology and hydrogeology

Geologically, the rock types present throughout the study area are charnockite, leptynite, leptinite gneiss, granite gneiss, laterite, sandstones, variegated clay and river alluvium. The area adjoining the coast is characterized by laterite capping. Soil types within the study area are classified into red loam and red lateritic soil, which are pale reddish in colour. Groundwater occurs in almost all the geological formations in the district. Groundwater recharge is influenced by the intensity of weathering. The depth of the wells in the study area varies from 1 to

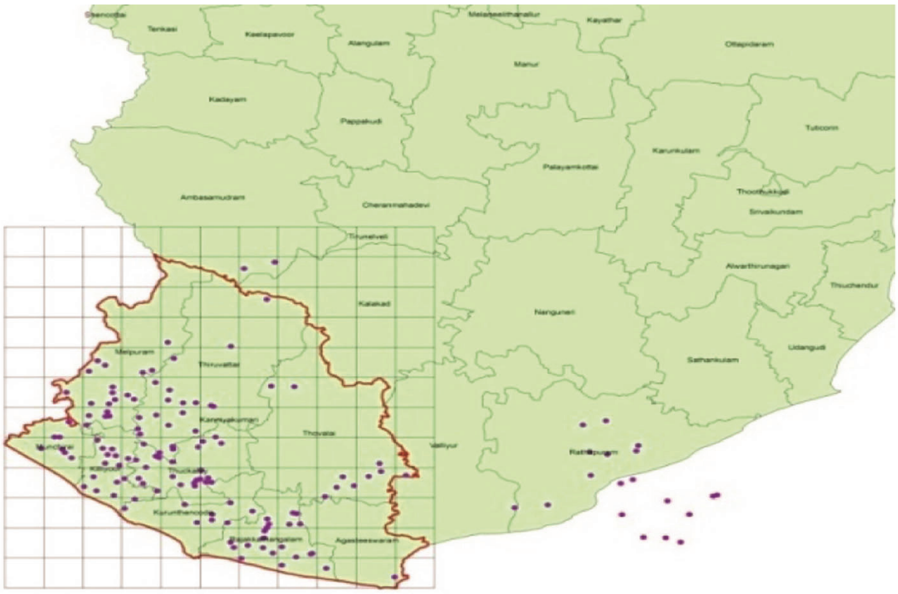

Figure 3. Grid surveying and groundwater sampling locations in Kanyakumari district.

Table 1. Groundwater quality for irrigation in India

Water quality	EC_{iw} (dS/m)	SAR_{iw} (m mol/l)	RSC (me/l)
Good	<2	<10	<2.5
Saline			
Marginally saline	2–4	<10	<2.5
Saline	>4	<10	<2.5
High-SAR saline	>4	>10	<2.5
Alkali water			
Marginally alkali	<4	<10	2.5–4.0
Alkali	<4	<10	>4.0
Highly alkali	Variable	>10	>4.0

Source: Ref. 18. SAR, Sodium absorption rate in irrigation water (IW); EC, Electrical conductivity; RSC, Residual sodium carbonate.

23 m bgl (ref. 12). However, in general water level is decreasing during the past 10 years[13].

Grid surveying and sampling

Grid survey of the study area was conducted and 10 km grids were established. Two hundred and fifteen bore and tube well locations were chosen for the sampling of groundwater and the samples were collected in May 2017. The sampling sites are at a distance of 1–70 km from the seashore in the eight blocks of Kanyakumari district (Figure 3). Groundwater sampling was done such that there was at least one sample from each grid. Samples were stored in airtight bottles.

Analysis of water samples

The samples were collected in thoroughly acid-washed polythene bottle grade no. 1. During sampling and transportation of water samples to the laboratory, all necessary precautions were taken[14]. The water samples were analysed for pH, electrical conductivity (EC), cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-}) following the versanate method[15]; Na^{+} was determined by flame photometry and anions CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2} were determined following the methods of Richards[16] and Eaton[17]. Quality parameters like sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were calculated using the formulae. Groundwater samples for their suitability for irrigation was screened on the basis of EC, SAR, RSC values as suggested by All India Coordinated Research Project (AICRP)[18], and spatial distribution map pertaining to groundwater quality was prepared using RS-Arc GIS software (Table 1).

Ionic charge balance

Ionic charge balance was worked out by calculating the normalized inorganic charge balance[19]. It is defined as $\{\Sigma\ \text{cation} - \Sigma\ \text{anion}/\Sigma^{+} + \Sigma^{-}\}$. It represents the fractional difference between the total cations and anions[20], as exemplified by Huh *et al.*[21]. The measured major ions (Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}) generally give a charge balance. Acceptable water analyses have charge balance error (CBE) less than ±5%.

Results and discussion

pH

Table 2 presents the range of pH, EC, SAR and RSC values. The pH of water is an important indicator of its

Table 2. Quality of groundwater in different blocks of Kanyakumari district, Tamil Nadu, India

	pH		EC (dS m^{-1})		RSC (meq l^{-1})		SAR	
Blocks	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Agastheeswaram	7.35–8.56	7.95	0.6–5.59	1.89	Nil–1.98	0.71	1.41–13.4	5.7
Rajakamangalam	7.52–8.24	8.02	0.2–5.91	1.25	Nil–1.12	0.15	0.12–11.0	4.04
Thucklay (Kozhipulai)	7.46–8.64	8.03	0.25–1.73	0.86	Nil–0.25	0.02	0.81–4.73	2.07
Killiyur	7.17–8.23	7.91	0.12–6.83	1.14	Nil–1.55	0.32	0.24–8.46	1.58
Thiruvattar	7.85–8.36	8.10	0.08–3.61	0.73	Nil–1.15	0.34	0.03–3.87	1.23
Munchirai	7.57–8.23	7.97	0.48–3.21	1.34	Nil–1.25	0.42	0.92–4.28	2.23
Kuruthencode	7.97–8.51	8.16	0.12–4.16	3.70	Nil–1.98	0.75	0.15–5.85	2.60
Thovalai	7.37–8.62	8.19	2.56–5.71	4.36	Nil–1.98	0.97	2.58–7.54	5.35

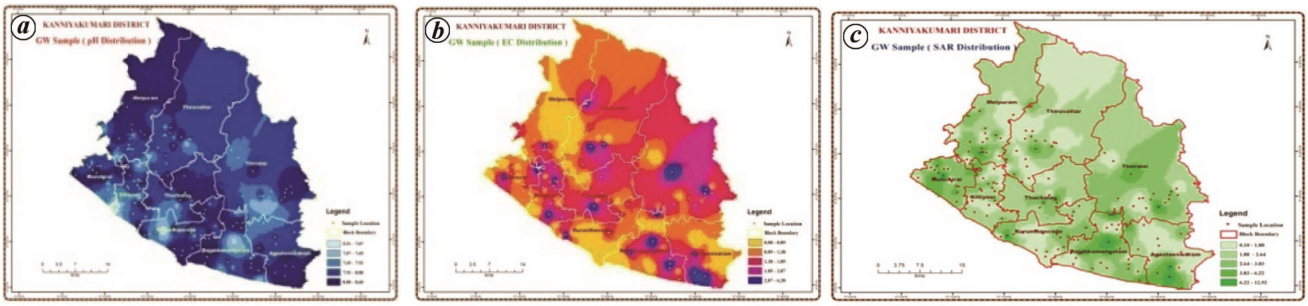

Figure 4. Spatial distribution map of (***a***) pH, (***b***) electrical conductivity (EC) and (***c***) sodium absorption ratio (SAR) of groundwater samples from Kanyakumari district.

quality and the extent of salinity hazard in the study area. The collected water samples were neutral to alkaline in nature as indicated by the pH values of 7.91 to 8.19 (ref. 22), and the groundwater was unpolluted (Figure 4).

Electrical conductivity

EC is a reflection of the state of inorganic pollution and is a measure of total dissolved solids and ionized species in water. Maximum EC of 6.83 dS/m was recorded in Killiyur block followed by 5.91 dS/m in Rajakamangalam block and 5.71 dS/m in Thovalai block in Kanyakumari district. This may be attributed to the mineralogical composition of aquifer rocks and geochemical processes such as ion exchange, reverse exchange, evaporation, silicate weathering, rock–water interaction, sulphate reduction and oxidation processes that take place in the parent rock, in line with the findings of Sarangi *et al.*[23].

Residual sodium carbonate

The RSC value of all the water samples was below 2.5 meq l^{-1}, indicating that there is no alkali water in Kanyakumari district. The trace or negative value of RSC may be attributed to excess Ca and Mg in these samples. The RSC values indicate that the groundwater is either good or falls within the limits (<2.5) prescribed for use in agriculture.

Sodium absorption ratio

The sodium hazard is typically expressed as SAR, which measures the proportion of Na to Ca and Mg ions in the sample. SAR and EC values were used to assess potential soil-related infiltration problems as a result of utilizing this poor quality water. High sodium in the groundwater reduces the soil infiltration potential. Sodium disperses soil particles which readily form a crust, and pose poor water infiltration and permeability problems. The highest SAR of 13.4 m mol/l was observed in only one location, viz. Agastheeswaram block, followed by another bore-well location in Rajakamangalam block (11.0 m mol/l) in Kanyakumari district. However, SAR values of water samples were within safe limits in all other locations.

Figure 5 presents the distribution of groundwater samples in different EC, SAR and RSC classes. According to EC-based classifications, more than 75% of the collected groundwater samples fall in the 0–1.5 dS m^{-1} class. All groundwater samples collected from Kanyakumari district have a safe limit of RSC <2.5 m eq/l. In the case of SAR, more than 90% of groundwater samples belonged to the 0–10 class, which is safe for irrigation purposes. The safe limits for RSC and SAR values in groundwater samples might be due to the presence of underlying parent material consisting of silicate minerals that dissolute in the groundwater. Thovalai block had saline water (73.68%) and marginally saline water (26.32%). Saline water was found in about 25% of the area of the district and *in situ* rainwater conservation for leaching of salts accumulated through saline water irrigation is an important technology. Thus, farmers need to be trained regarding these aspects. Such areas require adequate drainage and also introduction of salt-tolerant crops. The findings of this study illustrate the salt stress on groundwater quality in Thovalai block of Kanyakumari district, as also reported by Hofmann *et al.*[24].

Piper trilinear diagram

The geochemical evolution of groundwater can be understood by plotting the concentration of major cations and anions in the piper trilinear diagram. The groundwater chemistry revealed that around 70% of the samples in Rajakamangalam block fall in domain I, i.e. $CaHCO_3$ water due to secondary salinization, 20% of groundwater samples fall in domain III, i.e. Ca–Na–HCO_3^- combination water and 10% of groundwater samples fall in domain II, i.e. Na–Cl combination water of diamond field of piper diagram which suggested conservative mixing of sea water with freshwater. The findings of the present study are consistent with those of Srinivasamoorthy *et al.*[5], who showed that hydrogeochemical evolution of groundwater in the study area starts from Mg–HCO_3 type to Na–Cl type, indicating cation exchange reaction along with seawater intrusion, as also observed by Vasanthavigar and Srinivasamoorthy[25]. Regarding major cations and anions in solution, an evolution in the hydro-chemical facies from low salinity Ca–HCO_3 type to Na–Cl with increasing salinity was observed (Figure 6). In general, samples with low salinity were located farther away from the coast, whereas samples with higher salinity were located near the coast.

The groundwater chemistry of Agastheeswaram samples conforms to Ca–Na–HCO_3 geochemical facies of groundwater, which reflects freshening ion exchange. Fifty per cent of groundwater samples of Agastheeswaram block belong to the category of Na–K type and 50% to Ca–Mg type, 90% to HCO_3 type. The remaining 10% is of Cl^- type. In Killiyur block, 90% of groundwater samples

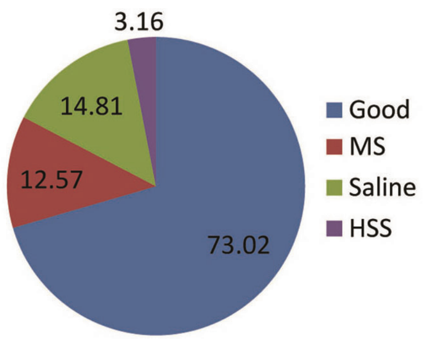

Figure 5. Per cent distribution of groundwater samples in Kanyakumari district. MS, Marginal saline; HSS, High SAR saline.

felt in the range of no dominant type however few samples fall in Ca–Mg type in the piper cation triangle, whereas all the samples fall in HCO_3-type. The ground water chemistry is that of domain I, i.e. Ca–HCO_3^-. In Munchirai, the groundwater chemistry of the samples shows mixed Ca–Mg–Cl combination (HCO_3) water belonging to domain IV in the piper diagram. It represents saltwater intrusion, ion exchange and sulphate reduction.

Among the nine blocks, 100% good quality groundwater samples were observed in Thucklay block. In Rajakamangalm 89.7%, Agastheeswaram 80.0%, Munchirai 81.25% and Thiruvattar 80.95% water samples were found fit for irrigation. Good-quality water was absent in Thovalai block and almost 73.68% of groundwater samples here were saline water. High SAR saline water was found in 15% of samples of Agastheeswaram block and 10.3% of samples in Rajakamangalam block. Alkaline water was almost absent in all the blocks. Out of the total samples collected from Kanyakumari district, 73.02% belong to good quality, 12.57% to marginally saline, 14.81% to saline water and 3.16% to high SAR saline categories. In general, cation abundance follows the order: Ca > Mg > Na > K. Anion abundance follows the order: $HCO_3 > Cl > SO_4$, when the irrigation water quality is good (EC > 2 dS m^{-1}). The distribution of anions followed the order $Cl > HCO_3 > SO_4$ in the EC range 2–4 dS/m and $Cl > CO_3 > HCO_3 > SO_4$ in the EC range >4.0 dS/m (Table 3).

Ionic charge balance of groundwater in Kanyakumari district

The charge balance error (CBE) of groundwater samples was positive. A positive CBE indicates that the samples represent groundwater that has a higher concentration of cations than anions. Conversely, a negative CBE indicates that anions are more abundant. More than 90% of groundwater samples collected from coastal blocks showed an excess of net positive charge. This is consistent with the findings of Anandhan *et al.*[26] for groundwater in Cuddalore district, TN. Calcium was the dominant cation and carbonate was the dominant anion present in the groundwater samples. This might be due to the weathering of carbonate-rich rocks such as kankar, limestone and dolomitic limestone. The available calcium carbonate in these rocks may have dissolved and entered into the groundwater system during irrigation, infiltration and groundwater movement. Acceptable water analyses have CBE less than 5% (Table 4).

Groundwater quality mapping

The distribution of water samples of different water quality classes revealed that good-quality groundwater was found in almost all the blocks. Samples representing

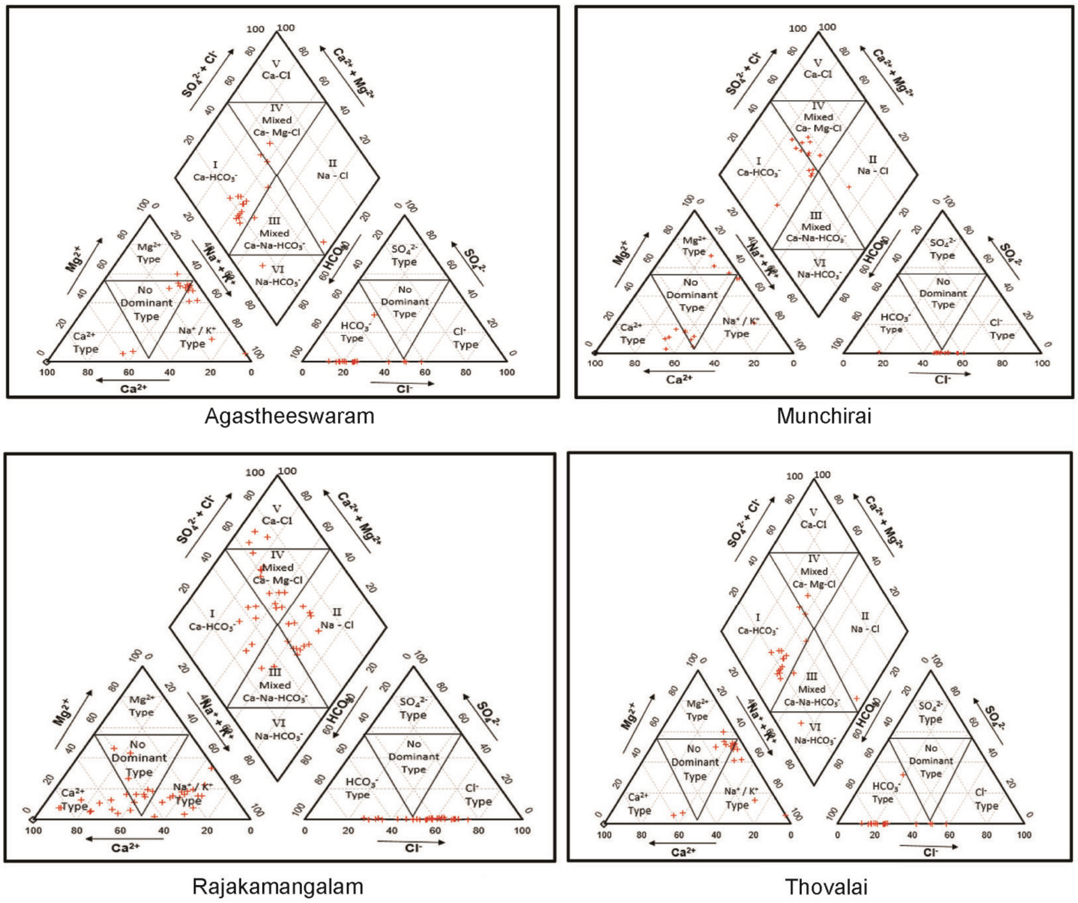

Figure 6. Piper plot showing the dominant ionic type of the study area.

Table 3. Cationic and anionic distribution in groundwater samples from Kanyakumari district

Blocks	Cationic order	Anionic order
Agastheeswaram	Ca > Mg > Na > K	HCO_3 > Cl > CO_3 > SO_4
Rajakamangalam	Na > Ca > Mg > K	HCO_3 > Cl > CO_3 > SO_4
Thucklay (Kozhipulai)	Ca > Na > Mg > K	CO_3 > HCO_3 > Cl > SO_4
Killiyur	Ca > Mg > Na > K	HCO_3 > Cl > CO_3 > SO_4
Thiruvattar	Ca > Mg > Na > K	HCO_3 > Cl > CO_3 > SO_4
Munchirai	Na > Ca > Mg > K	HCO_3 > Cl > CO_3 > SO_4
Kuruthencode	Ca > Mg > Na > K	CO_3 > HCO_3 > Cl > SO_4
Thovalai	Ca > Mg > Na > K	Cl > CO_3 > HCO_3 > SO_4

good-quality water constitute 100% in Thucklay, 89.7% in Rajakamangalam, 81.25% in Munchirai, 80.95% in Thiruvattar and 73.7% in Kuruthencode. Thovalai block had saline water (73.68%) and marginally saline water (26.32%) (Figure 7).

Soil, crop and irrigation management options for saline irrigation water

Good-quality underground irrigation water was found in almost all the blocks, viz. Thucklay (100%), Rajakamangalam (89.7%), Munchirai (81.25%), Thiruvattar (80.95%), Kuruthencode (73.7%), except Thovalai block, which had saline water (73.68%) and marginally saline water (26.32%). Mixing of good-quality water with saline or alkali groundwater, to acceptable level of water quality for various crops, is also useful in reducing salt stress. Cyclic use of good canal water along with saline/alkali groundwater is also recommended. Table 5 provides the Indian Council of Agricultural Research-Central Soil Salinity Research Institute, Karnal guidelines related to saline water use.

Table 6 shows soil and crop management options for poor groundwater quality of Thovalai block in Kanyakumari district. Table 7 shows the crop varieties suitable for

Table 4. Charge balance error (CBE) analysis of groundwater samples from Kanyakumari district

Block	No. of ground-water locations	Total cations (m eq./lit)		Total anions (m eq/l)		Net charge	CBE (%)	
		Range	Mean	Range	Mean		Range	Mean
Agastheeswaram	28	4.71–80.8	22.12	3.2–84.9	21.75	Positive	0.02–0.11	0.05
Rajakamangalam	27	5.33–90.8	16.09	4.2–84.2	15.06	Positive	0.02–0.24	0.04
Thucklay	21	4.22–20.62	12.07	4.1–19.6	10.99	Positive	0.01–0.38	0.05
Killiyur	42	2.21–241.9	24.16	2.5–202.3	19.79	Positive	0.02–0.36	0.06
Thiruvattar	24	4.01–31.61	12.65	3.1–30.8	11.27	Positive	0.01–0.37	0.06
Munchirai	16	4.11–35.25	15.02	3.3–36.6	13.96	Positive	0.01–0.24	0.05
Kuruthencode	34	6.85–94.78	21.88	7.4–82.9	20.44	Positive	0.01–0.07	0.02
Thovalai	23	22.61–159.7	55.81	14.4–74.78	41.49	Positive	0.01–0.39	0.13

Table 5. Guidelines for the use of saline water (RSC < 2.5 m eq/1)

Soil texture (% clay)	Crop tolerance	Upper limits of EC_{iw} (dS/m) in rainfall regions		
		350 mm	350–550 mm	550–750 mm
Fine (>30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately fine (20–30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately coarse (10–20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (<10)	S	–	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

S, ST and T denote sensitive, semi-tolerant and tolerant crops respectively.

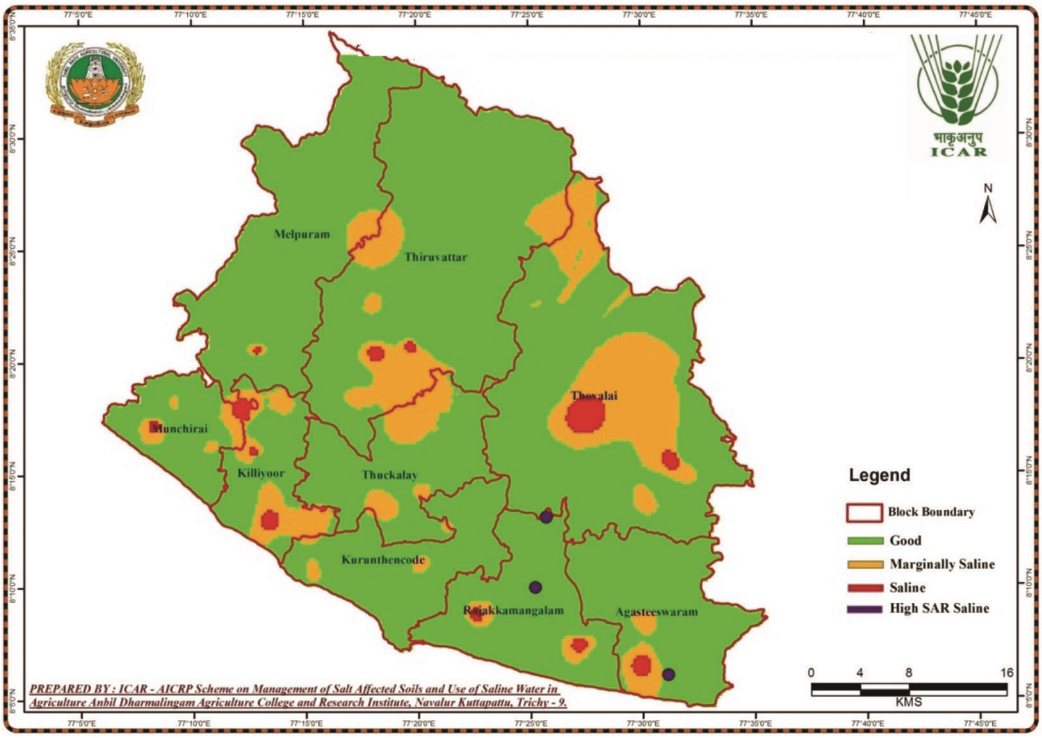

Figure 7. Groundwater quality map of Kanyakumari district.

Table 6. Soil and crop management options for poor quality groundwater

Groundwater quality	Marginally saline	Marginally saline to saline
Crop management	Salt-tolerant crops like vettiver, pearl millet and cashew 25% more seed as well as fertilizer recommendations	Salt tolerant varieties 25% more seed as well as fertilizer recommendations
Soil management	Gypsum application; green manuring along with *in situ*' ploughing	Gypsum application; green manuring along with *in situ*' ploughing
Soil and water conservation	Leaching of surface soil and draining Laying of subsurface drainage pipes with coir pith-wrapped perforated holes Laying out of slotted pipes using well-logging techniques	Mixing bore water with good-quality water

Table 7. Crop varieties for cultivation in saline environment

Crop	Cultivar
Wheat	Raj 2325, Raj 2560, Raj 3077, WH 157
Pearl millet	MH269, 331, 427, HHB-60
Mustard	Pusa Bold, CS52, CS54, CS56, CS58, CS60
Cotton	DHY 286, CPD 404, G 17060, GA, JK276-10-5, GDH 9, G. Cot-23
Safflower	HUS 305, A-1, Bhima
Sorghum	SPV-475, 881, 678, 669, CSH 11
Barley	Ratna, RL345, RD103, 137, K169

saline environment. Thus it is possible to use saline groundwater with scientific management of soil, crop and irrigation[27].

Conclusion

The distribution of water samples in different water-quality classes revealed that the samples of good-quality underground water were found in almost all the blocks, except Thovalai block. No alkali water was found in Kanyakumari district. The topography of this district, particularly in saline groundwater areas, is suited for the construction of various artificial recharge structures such as percolation ponds, check dams and subsurface dykes. However, detailed studies are necessary to formulate a comprehensive scheme for artificial recharge of phreatic groundwater in the district. Also, *in situ* rainwater conservation for leaching of salts accumulated through saline water irrigation is the best management practice. The district is on the coast and there is a steady influx of tourists due to which there may be local excessive groundwater extraction. This may result in local decline in water levels in pockets along the coast. The wells tapping coastal alluvium/tertiary aquifers, and heavy withdrawal create an imbalance in the aquifer system and may lead to salt-water intrusion into freshwater pockets in the peak summer, if not regulated properly. The saline groundwater samples of Thovalai block in Kanyakumari district can be judiciously used with suitable scientific soil, crop and irrigation management practices.

1. Raju, N. J., Shukla, U. K. and Ram, P., Hydrogeochemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. *Environ. Monit Assess*., 2011, **173**, 279–300.
2. Belkhiri, L. and Mouni, L., Hydrochemical analysis and evaluation of groundwater quality in El Eulma area, Algeria. *Appl. Water Sci*., 2012, **2**, 127–133.
3. Kaushik, A. K., Sharma, H. R. and Bhupindar, M., Groundwater quality of Ambala and Nilokheri cities in Haryana in relation to landuse. *Environ. Ecol*., 2000, **18**(3), 616–623.
4. Sarath Prasanth, S. V., Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N. and Gangadhar, K., Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. *Appl. Water Sci*., 2012, **2**, 165–175.
5. Srinivasamoorthy, K. *et al.*, Groundwater quality assessment from a hard rock terrain, Salem district of Tamil Nadu, India. *Arab. J. Geol. Sci*., 2011, **4**, 91–102.
6. Sajil Kumar, P. J. and James, E. J., Physico-chemical parameters and their sources in groundwater in the Thirupathur region, Tamil Nadu, South India. *Appl. Water Sci*., 2013, **3**, 219–228.
7. Krishna Kumar, S., Rammohan, V., Dajkumar Sahayam, J. and Jeevanandam, M., Assessment of groundwater quality and hydrogeochemistry of Manimuktha river basin, Tamil Nadu. *J. Environ. Monit. Assess*., 2009, **159**, 341–351.
8. Dar, I. A., Sankar, K. and Dar, M. A., Spatial assessment of groundwater quality in Mamundiyar basin, Tamil Nadu, India. *J. Environ. Monit. Assess*., 2011, **178**, 437–444.
9. Bhagavathi Perumal, S. and Thamarai, P., Groundwater quality after Tsunami in coastal area of Kanyakumari, South Tamil Nadu, India. *Int. J. Appl. Environ. Sci*., 2008, **31**, 37–55.
10. Bhakar, P. and Singh, A. P., Groundwater quality assessment in a hyper-arid region of Rajasthan, India. *Nat. Resour. Res*., 2019, **28**, 505–522.
11. Bhagavathi Perumal, S. and Thamarai, P., Groundwater level before and after tsunami in coastal area of Kanyakumari, South Tamil Nadu, India. *Int. J. Appl. Environ. Sci*., 2008, **3**(2), 139–147 (ISSN 0973).
12. CGWB, Technical report series of Kanyakumari district. Ministry of Water Resources, Central Ground Water Board, Government of India, South Eastern Coastal Region, Chennai, 2009.
13. PWD, Groundwater perspectives: a profile of Kanyakumari district, Tamil Nadu. Tamil Nadu Public Works Department, 2005.
14. Brown, E., Skougsted, M. W. and Fishman, M. J., Methods for collection and analysis of water sample for dissolved minerals and gases. US Department of Interior, 1974, Book No. 5.
15. Wilcox, L. V., The quality of water for agricultural use. Edit. US Department of Agriculture, Technical Bulletin, Washington, USA, 1948, vol. 962, p. 40.

16. Richards, L. A., *Diagnosis and Improvement of Saline and Alkali Soils*, USDA Handbook, No. 60, 1954.
17. Eaton, F. M., Significance of carbonate in irrigation waters. *Soil Sci*., 1950, **69**, 123–133.
18. All India Coordinated Research Project (AICRP), Management of salt affected soils and use of Saline water in agriculture. Project Manual, ICAR-CSSRI, Karnal, 1989.
19. Lo, C. P. and Yeung, A. K. W., *Concepts and Techniques of Geographic Information Systems*, Prentice-Hall of India Pvt Ltd, New Delhi, 2003, p. 49.
20. Edmond, J. M., Palwer, M. R., Measures, C. F., Grant, B. and Stallard, R. F., The fluvial geochemistry and denudation rate of the Guayana Shield in Venezuela, Colombia and Brazil. *Geochim. Coscochim. Acta*, 1995, **59**, 3301–3323.
21. Huh, Y., Tsoi, M. Y., Zaitiser, A. and Edward, J. N., The fluvial geochemistry of the rivers of Eastern Siberia: III. Tributaries of the Lena and Anabar draining the basement terrain of the Siberian Craton and the Trans-Baikal. *Geochim. Cosmochim. Acta*, 1998, **62**, 1657–1676.
22. Balasubramanian, R. and Kannan, L., Microbial diversity and density in the coral reef environment of the Gulf of Mannar. *Int. J. Ecol. Environ. Sci*., 2005, **31**, 265–271.
23. Bandyopadhyay, B. K., Burman, D., Sarangi, S. K., Mandal, S. and Bal, A. R., Analysis of stability of $G \times E$ interaction of rice genotypes across saline and alkaline environments in India. *J. Indian Soc. Coast. Agric. Res*., 2009, **27**(1), 13–17.
24. Hofmann, J., Watson, V. and Scharaw, B., Groundwater quality under stress: contaminants in the Kharaa River basin (Mongolia). *Environ. Earth Sci.*, 2015, **73**(2), 629–648.
25. Vasanthavigar, M. and Srinivasamoorthy, K., Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamil Nadu, India. *Environ. Monit. Assess*., 2010, **171**, 595–609.
26. Anandhan, P., Chidambaram, S., Srinivasamoorthy, K., Manivannan, R., Sarathidhasan, J. and Ganesh, N., Hydrogeochemical quality of groundwater in coastal region of Cuddalore Taluk, Cuddalore district, Tamil Nadu – a case study. *Int. J. Appl. Pure Sci. Agric*., 2016, **2**(6), 1–11.
27. AICRP on SAS and USW, Biennial Report 2016–18. ICAR-AICRP on management of salt affected soils and use of saline water in agriculture, ICAR-CSSRI, Karnal, 2019, p. 282.

ACKNOWLEDGEMENT. We thank the Indian Council of Agricultural Research-Central Soil Salinity Research Institute, Karnal, for providing financial support.

Received 14 May 2020; revised accepted 23 February 2021

doi: 10.18520/cs/v121/i5/676-684