Assessment of groundwater quality in and around Vedaraniyam, South India

Article *in* Environmental Earth Sciences · March 2014

DOI: 10.1007/s12665-013-2626-2

6 authors, including:

Krishna Kumar
Rathinam technical campus, coimbatore
7 PUBLICATIONS **70** CITATIONS

LAKSHUMANAN CHOKKALINGAM
Bharathidasan University
56 PUBLICATIONS **333** CITATIONS

M. Sundararajan
National Institute for Interdisciplinary Science and Technology
45 PUBLICATIONS **306** CITATIONS

Chidambaram Sabarathinam
Kuwait Institute for Scientific Research
202 PUBLICATIONS **3,287** CITATIONS

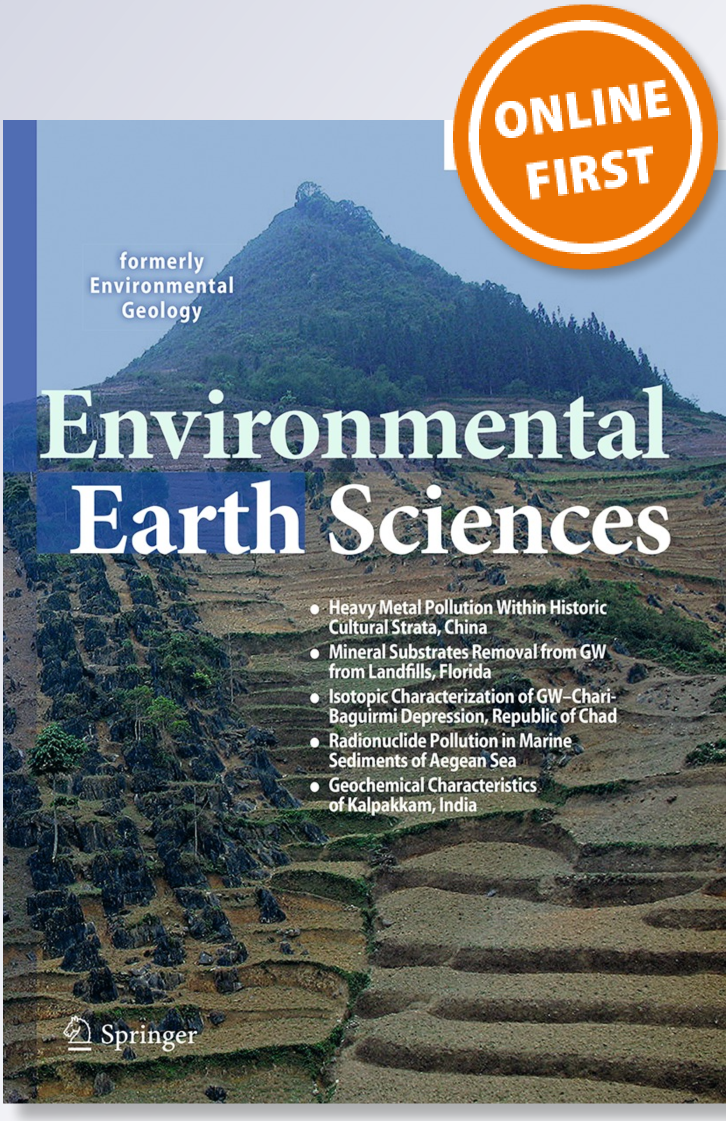
Assessment of groundwater quality in and around Vedaraniyam, South India

P. Krishnakumar, C. Lakshumanan, V. Pradeep Kishore, M. Sundararajan, G. Santhiya & S. Chidambaram

Environmental Earth Sciences

ISSN 1866-6280

Environ Earth Sci
DOI 10.1007/s12665-013-2626-2



Environ Earth Sci
DOI 10.1007/s12665-013-2626-2

ORIGINAL ARTICLE

Assessment of groundwater quality in and around Vedaraniyam, South India

P. Krishnakumar · C. Lakshumanan · V. Pradeep Kishore · M. Sundararajan · G. Santhiya · S. Chidambaram

Received: 24 August 2012 / Accepted: 24 June 2013

Abstract Groundwater from 47 wells were analyzed on the basis of hydrochemical parameters like pH, electric conductivity, total dissolved solids, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, CO_3^{2-}, HCO_3^{-}, NO_3^{-}, PO_4^{3-} and F^{-} in the Cauvery delta of Vedaraniyam coast. Further, water quality index (WQI), sodium percentage (Na %), sodium absorption ratio, residual sodium carbonate, permeability index and Kelley's ratio were evaluated to understand the suitability of water for drinking and irrigation purposes. The result shows significant difference in the quality of water along the coastal stretch. The order of dominance of major ions is as follows: $Na^{+} \geq Mg^{2+} \geq Ca^{2+} \geq K^{+}$ and $Cl^{-} \geq HCO_3^{-} \geq CO_3^{2-} \geq PO_4^{3-} \geq F^{-}$. Na/Cl, Cl/$HCO_3$ ratio and Revelle index confirmed that 60–70 % of the samples were affected by saline water intrusion. WQI showed that 36 % of the samples were good for drinking and the remaining were poor and unsuitable for drinking purpose. The degradation of groundwater quality was found to be mainly due to over-exploitation, brackish aquaculture practice, fertilizer input from agriculture and also due to domestic sewage.

Keywords Groundwater · Land use · Hydrochemistry · Coastal · Spatial analysis · South India

Introduction

Basically, groundwater is an integral part of the environment, and hence it is a major life-sustaining resource for all living beings. In India, as also in certain parts of the world, water crisis is becoming a regular phenomenon, perhaps due to improper scientific management of water resources leading to continued environmental degradation. In the last few decades, there has been a tremendous increase in the demand for freshwater resource due to rapid population growth and industrialization (Ramakrishnaiah et al. 2009). It is estimated that approximately one-third of the world population depends on groundwater for drinking (Nickson et al. 2005). At the same time, geographical location and land use pattern have a significant influence on the quality and quantity of groundwater. Since it plays an important role in determining the various hydrological phenomena such as infiltration rate, overland flow, evaporation and interception, a number of researchers (Gilliom et al. 1995; Fianko et al. 2009; Kim 2010; Jiang and Yan 2010) have determined the link between land use and groundwater quality. There are various ways by which groundwater may be contaminated, such as from discharge of treated and untreated sewage, aquaculture, salt pans, solid waste and industrial activity (Vengosh and Keren 1996; Kumar et al. 2010). Further, overextraction of groundwater in the coastal areas is a reason for the seawater migrating inland into the coastal aquifer. The quality of groundwater deteriorates as the salt concentration increases (Giménez-Forcada et al. 2010). Therefore, understanding the groundwater quality is important to determine its suitability

P. Krishnakumar · C. Lakshumanan · V. P. Kishore · G. Santhiya
Centre for Remote Sensing, Bharathidasan University, Khajamalai Campus, Thiruchirappalli 620 023, India

M. Sundararajan (✉)
National Institute for Interdisciplinary Science and Technology, Council of Scientific and Industrial Research, Industrial Estate (P.O), Pappanamcode, Trivandrum 695019, Kerala, India
e-mail: rajanmsundar77@yahoo.com

S. Chidambaram
Department of Earth Science, Annamalai University, Chidambaram 608002, India

Published online: 26 July 2013

for drinking, agricultural and industrial use (Subramani et al. 2005; Chidambaram et al. 2011). Measures to prevent and control groundwater pollution at the source and along pathways need to be advocated. Multivariate statistical technique provides significant information on critical aspects of water quality and indicates the need to secure water quality and also promote microlevel planning and management in a particular area (Das et al. 2010; Belkhiri et al. 2010; Chapagain et al. 2010). Few studies were attempted to evaluate the groundwater chemistry in Vedaraniyam region (Mary et al. 2012; Ramkumar et al. 2010). A systematic study is required to evaluate the water quality and to determine the factors affecting the water chemistry of the region. Hence, an attempt has been made to assess the same and evaluate the hidden hydro-geochemical process.

Study area

Vedaraniyam is located in Nagapattinam District and lies between 10°15′ and 11°30′N latitude and 79°30′ and 79°55′E longitude. It has medium tropical transition climate, characterized by monthly average temperature of above 27 °C. The major activities are agriculture, salt pan, fishing and aquaculture, which engage almost 75 % of the workforce of the study area. The major rivers are Mulliyar, Koraiyar and Valvanar which pass through the long agricultural belt before draining into the Vedaraniyam wetlands (Fig. 1). The study area occupies an area of about 1,066 km^2 which includes the great Vedaraniyam wetland swamp (Muthupet mangrove and Seruthalaikadu creek) and dry evergreen Kodiyakarai reserved forest, which falls under the Ramsar convention site. Numerous small-scale aquaculture farms have been established along the Cauvery River tributaries and adjacent to the Vedaraniyam canal during the 1990s (Ravichandran 2005). A number of domestic and industrial salt works operate around the Vedaraniyam wetlands.

Land use/land cover

The Vedaraniyam coast consists of the following land use categories such as settlement, agriculture land, mangroves, river, land with and without scrub, plantation, scrub forest, salt-affected land, waterlogged area, marshy/swampy land, creek, mud/tidal flat, aquaculture and salt pan (Fig. 2). The study on the P6 LISS III satellite image of 2007 shows that the dominant land use category was agricultural land, occupying 319.64 km^2, followed by plantation (172.30 km^2) and settlement (63.96 km^2). Further, aquaculture and salt pan cover an area of 17.58 sq. km and 44.75 km^2, respectively, which also contribute to the increase of salt-affected land (33.2 km^2).

Materials and methods

Groundwater samples were collected randomly from bore wells from 47 locations of the study area during February 2009 (Fig. 1; Table 1). Before taking a sample, water was pumped for 10–15 min to ensure complete homogeneity. Then the extracted water samples were collected in pre-cleaned polythene bottle and analyzed for various water quality parameters as per standard procedure. pH, EC and TDS were measured in the field itself using water analysis kit (Deep Vision -191). Na^+ and K^+ were analyzed using flame photometer (Systronic 128). Ca^{2+}, Mg^{2+}, Cl^- and HCO_3^- were determined by volumetric titration method. Nitrate, phosphate and fluoride were determined using a spectrophotometer (Shimadzu UV-1800). The charge balance of the analyzed cations and anions are well within ±10 %. Descriptive statistics were carried out using the SPSS package (Khan 2011). Spatial distributions of geochemical parameters were prepared on Arc-GIS software by interpolation method called inverse distanced weighted (IDW) method (Lee et al. 2006).

Result

The minimum, maximum, mean and standard deviation of physicochemical parameters of groundwater quality such as pH, EC, TDS and major elements (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, CO_3^{2-}, HCO_3^-, NO_3^-, PO_4^{3-} and F^-) are presented in Tables 1 and 2. Among this, pH is a very important indicator of its quality and controlled by the amount of dissolved CO_2, carbonate and bicarbonate in groundwater (Ghandour et al. 1985). In the studied samples, the pH value ranged from 7.3 to 8.2 indicating that the groundwater was of alkaline nature due to bicarbonate form of dissolved carbonate (Nagarajan et al. 2010). Generally, carbonate concentrations are low in groundwater at near neutral pH, and at pH values above 8, carbonate exists in groundwater. However in the present study, carbonate was present in some sample locations even with high pH value due to the presence of carbonate rocks (Rizk et al. 1988; Ramkumar et al. 2010). The EC value of groundwater varies from 530 to 6,300 µS/cm with a mean value of 1,500 µS/cm. A higher EC value is noticed in the eastern part of the study area. The TDS value ranged from 340 to 4,120 mg/L and the highest TDS was found in sample 27. According to Davis and DeWiest (1966), TDS is classified into four different categories based on drinking and irrigation suitability (Fig. 3). Table 3 shows that

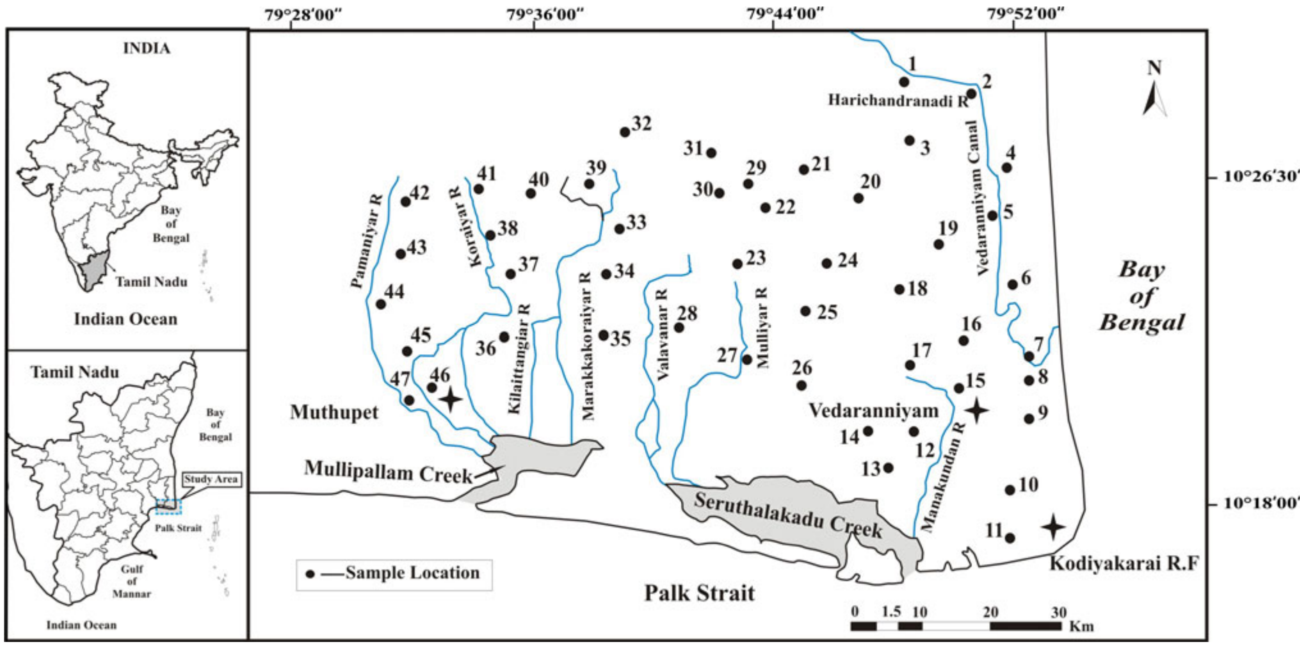


Fig. 1 Study area and sample location map. The numbers in the map indicate different sample locations

Fig. 2 Land use/land cover of the study area (LISS-III-2007)

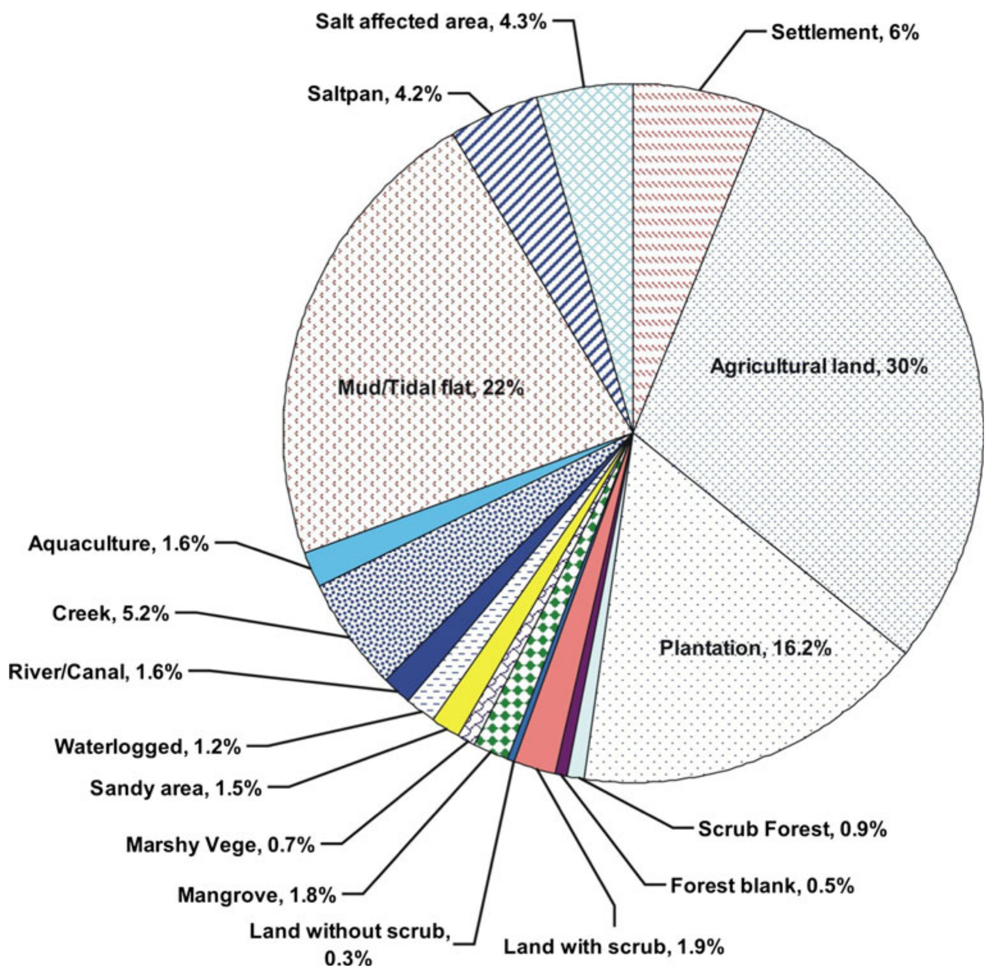


Table 1 Chemical composition of groundwater samples collected from the study area

Sample number	pH	EC (µS/cm)	TDS (mg/L)	Na^{2+} (mg/L)	K^{+} (mg/L)	Ca^{+} (mg/L)	Mg^{2+} (mg/L)	NO_3^{-} (mg/L)	PO_4^{-3} (mg/L)	CO_3^{-2} (mg/L)	HCO_3^{-} (mg/L)	Cl^{-} (mg/L)	F^{-} (mg/L)	Error (%)
1	7.54	2,870.00	1,880.00	312.80	1.60	72.00	113.70	1.50	2.40	24.00	219.60	936.00	0.50	−7.25
2	7.80	4,470.00	3,070.00	536.00	46.00	48.00	105.00	7.40	0.60	0.00	451.40	1,131.60	0.60	−5.13
3	7.64	1,840.00	1,210.00	391.00	32.00	56.00	88.50	0.40	1.30	0.00	366.00	617.00	0.50	8.83
4	7.88	970.00	640.00	179.40	5.90	44.00	35.00	0.70	0.80	0.00	307.40	229.00	0.50	6.15
5	7.63	1,700.00	1,120.00	184.00	0.60	60.00	65.60	0.10	0.40	0.00	196.40	427.00	0.50	3.76
6	7.53	980.00	640.00	65.86	0.40	64.00	52.50	3.80	0.80	0.00	213.50	199.00	0.50	6.15
7	7.48	750.00	490.00	80.20	7.80	60.00	45.00	7.60	0.40	0.00	234.00	179.00	0.40	6.96
8	7.68	1,170.00	770.00	138.00	0.60	48.00	43.00	19.50	3.10	36.00	115.90	229.00	0.50	8.61
9	7.70	3,510.00	2,310.00	199.00	0.50	60.00	111.80	0.20	7.30	0.00	231.80	694.80	0.50	−5.88
10	7.64	1,330.00	870.00	358.80	28.10	28.00	66.10	12.30	1.70	48.00	356.00	426.00	0.40	8.02
11	7.68	4,020.00	2,640.00	312.80	58.50	36.00	124.90	25.40	0.70	0.00	353.80	913.20	0.40	−8.11
12	7.25	810.00	530.00	70.15	9.90	44.00	3.90	5.40	1.30	0.00	312.00	29.80	0.50	−2.57
13	7.26	530.00	340.00	76.00	1.20	36.00	30.10	3.20	3.10	0.00	364.20	69.50	0.50	−2.97
14	7.55	3,190.00	2,100.00	17.48	0.30	108.00	101.00	1.80	0.30	0.00	244.00	456.40	0.20	−7.40
15	7.60	2,020.00	1,330.00	161.00	1.40	52.00	86.00	0.30	0.80	0.00	268.40	376.00	0.40	5.53
16	7.46	1,460.00	960.00	138.00	46.80	36.00	66.60	0.10	0.60	0.00	246.80	286.50	0.50	8.94
17	7.67	2,910.00	1,910.00	75.90	0.60	44.00	113.20	18.70	0.80	0.00	268.40	466.50	0.30	−9.25
18	7.69	4,620.00	3,160.00	659.74	0.10	32.00	93.00	27.60	0.50	0.00	36.60	1,081.90	0.50	9.04
19	7.75	3,810.00	2,500.00	531.10	19.50	64.00	52.50	1.30	0.40	24.00	250.10	843.70	0.40	4.07
20	7.72	1,770.00	1,180.00	133.40	1.60	32.00	26.20	4.20	2.10	24.00	213.50	129.00	0.40	8.56
21	7.62	1,620.00	1,070.00	147.20	1.60	28.00	57.00	0.30	0.30	0.00	256.20	248.20	0.50	5.70
22	7.62	1,010.00	660.00	61.27	1.00	36.00	29.00	0.10	2.30	54.00	115.90	89.30	0.40	4.57
23	7.52	3,560.00	2,340.00	598.00	95.20	72.00	78.30	82.60	1.20	0.00	445.30	804.00	0.30	9.56
24	7.62	1,430.00	940.00	239.20	19.90	28.00	43.40	1.80	0.20	0.00	164.70	467.00	0.40	0.02
25	7.80	3,860.00	2,530.00	184.00	49.90	64.00	140.00	0.10	2.20	0.00	250.10	704.70	0.50	0.22
26	7.75	3,950.00	2,590.00	285.20	50.70	68.00	170.60	68.20	1.20	0.00	555.10	684.90	0.50	2.20
27	7.62	6,300.00	4,120.00	487.60	78.00	96.00	236.70	40.10	17.00	0.00	207.40	1,340.00	0.50	5.75
28	7.58	970.00	640.00	896.00	101.40	40.00	75.30	13.50	0.70	0.00	329.40	1,299.00	0.50	8.13
29	7.50	1,100.00	720.00	24.15	0.20	40.00	70.50	0.10	1.40	0.00	366.00	139.00	0.50	−5.57
30	7.54	780.00	510.00	119.60	24.00	28.00	14.40	0.10	0.10	0.00	140.30	219.60	0.50	−0.60
31	8.20	2,660.00	1,740.00	404.80	11.10	32.00	45.70	0.10	0.50	12.00	329.40	526.10	0.60	5.97
32	7.80	910.00	590.00	847.00	201.20	40.00	45.00	0.10	0.70	0.00	353.80	1,201.00	0.40	9.22
33	7.53	3,200.00	2,100.00	119.60	0.60	64.00	169.10	8.90	0.50	0.00	457.50	536.00	0.40	−0.72
34	7.69	5,600.00	3,880.00	692.00	25.70	44.00	91.40	0.40	9.40	0.00	219.60	1,191.10	0.40	4.00
35	7.43	530.00	340.00	154.10	0.60	52.00	38.40	0.10	4.60	0.00	250.10	239.00	0.40	6.52
36	7.53	1,310.00	860.00	179.50	0.10	28.00	19.90	11.90	0.40	30.00	164.70	188.60	0.30	7.74
37	7.78	2,420.00	1,580.00	124.50	4.10	36.00	64.20	2.20	0.80	0.00	152.50	387.10	0.30	−3.15
38	7.95	890.00	580.00	68.93	0.50	32.00	48.10	3.30	0.60	0.00	250.10	199.00	0.80	−6.61
39	7.77	1,120.00	740.00	138.00	3.50	32.00	45.70	0.10	0.60	0.00	250.10	196.50	0.50	8.58
40	7.88	1,300.00	850.00	145.52	10.90	36.00	53.30	0.80	0.30	0.00	335.50	186.70	0.40	8.63
41	7.50	1,120.00	730.00	144.90	13.10	32.00	63.20	0.10	0.20	0.00	274.50	239.50	0.30	9.01
42	7.93	2,170.00	1,420.00	171.30	3.60	32.00	60.30	11.40	0.20	0.00	359.90	337.50	0.40	−5.10
43	8.10	2,190.00	1,440.00	368.00	0.80	24.00	47.60	0.10	0.40	30.00	475.80	415.00	0.60	1.56
44	7.50	1,630.00	1,040.00	108.10	1.80	28.00	95.30	0.10	0.20	18.00	640.50	188.60	0.40	−7.71
45	7.59	4,120.00	2,840.00	279.15	22.80	56.00	168.60	81.80	0.30	0.00	280.60	764.30	0.50	2.76
46	7.62	1,050.00	690.00	24.15	1.00	44.00	69.50	10.30	0.10	0.00	323.30	109.20	0.50	2.45
47	7.47	1,880.00	1,230.00	135.70	0.10	40.00	67.20	0.10	0.40	0.00	207.40	307.70	0.40	5.47

36.2 % of samples are within the permissible limit for drinking and 46.8 % of samples useful for irrigation purpose. However, 8.5 % of samples are unfit for drinking as well as irrigation. Freeze and Cherry (1979) also classified the TDS, based on fresh, brackish, saline and brine water type (Table 3). This classification shows about 44.7 % of the groundwater to be under freshwater condition and the remaining samples as brackish water type (Fig. 4).

Table 2 Minimum, maximum, mean and standard deviation of physicochemical parameters

S. no	Parameters	Min	Max	Mean	Std. deviation
1	pH	7.25	8.2	7.6	0.2
2	EC (μS/cm)	530.0	6,300.0	2,200.0	1,500.0
3	TDS (mg/L)	340.0	4,120.0	1,455.7	959.8
4	Ca^{2+} (mg/L)	24.0	108.0	46.3	18.0
5	Mg^{2+} (mg/L)	3.9	236.7	84.1	46.3
6	Na^{+} (mg/L)	17.48	956.8	200.6	205.8
7	K^{+} (mg/L)	0.1	201.2	21.0	37.0
8	Cl^{-} (mg/L)	29.8	1,340.0	388.8	345.9
9	CO_3^{-2} (mg/L)	0.0	54.0	27.3	15.3
10	HCO_3^{-} (mg/L)	36.6	640.5	277.9	117.8
11	NO_3^{-} (mg/L)	0.1	82.6	10.2	19.8
12	PO_4^{-3} (mg/L)	0.1	17.0	1.6	2.9
13	F^{-} (mg/L)	0.2	0.8	0.5	0.1

The relative tendency of major ions in groundwater is in the following order $Na^{+} \geq Mg^{2+} \geq Ca^{2+} \geq K^{+}$ and $Cl^{-} \geq HCO_3^{-} \geq CO_3^{2-} \geq PO_4^{3-} \geq F^{-}$. The sodium concentration in the present samples ranged from 17.5 to 958.8 mg/L. The BIS (1998) guideline shows the maximum permissible limit for sodium in drinking water to be 200 mg/L. In most of the samples, Na^{+} concentration was within the permissible level and only 13 samples exceeded the permissible limit (Fig. 5a–h). The magnesium concentration of the studied samples ranged from 3.9 to 236.7 mg/L. As per the standard, 30 mg/L is the maximum permissible and 100 mg/L is the allowable limit of magnesium for drinking purpose, but Mg^{2+} concentrations in the studied samples showed that about 27.7 % exceeded the allowable limit. Higher concentration of Mg^{2+} is toxic and affects the crop yields (Joshi et al. 2009); also it combines with sulfate to produce laxative effect. The calcium value of groundwater samples ranged from 24 to 104 mg/L; all the samples were within the permissible limits (75–200 mg/L) of BIS (1988) for drinking purpose. The potassium ion concentration varied from 0.1 to 202.2 mg/L with mean value of 37 mg/L; about 57 % of the samples were within the permissible limit (10 mg/L) and the remaining samples (43 %) exceeded the limit.

Among the anionic (Cl^{-}, NO_3^{-}, PO_4^{3-}, CO_3^{2-}, HCO_3^{-} and F^{-}) concentrations, chloride plays a predominant role in the studied groundwater samples. The chloride value ranged from 29.8 to 1,340 mg/L, but 46 % of samples exceeded the permissible limit (250 mg/L). Nitrate is another important anionic groundwater parameter, and the concentration range is 0.1 to 82.6 mg/L. According to the BIS (1998) guideline (45 mg/L), all the samples are within the permissible limit, except those from the following stations: 23, 26, 27 and 45. Higher concentration of nitrate may produce methanoglobenemia and gastric cancer (Naidu et al. 1998; Olaniya et al. 1978). Figure 6 indicates that the Cl^{-} versus NO_3^{-} trend line represents the mixing with saline water and the progressive pollutant load of NO_3^{-} enrichment (Re et al. 2011). Phosphate concentration ranged from 0.1 to 17.0 mg/L; higher concentration of PO_4^{-3} is indicative of pollution and the major sources are

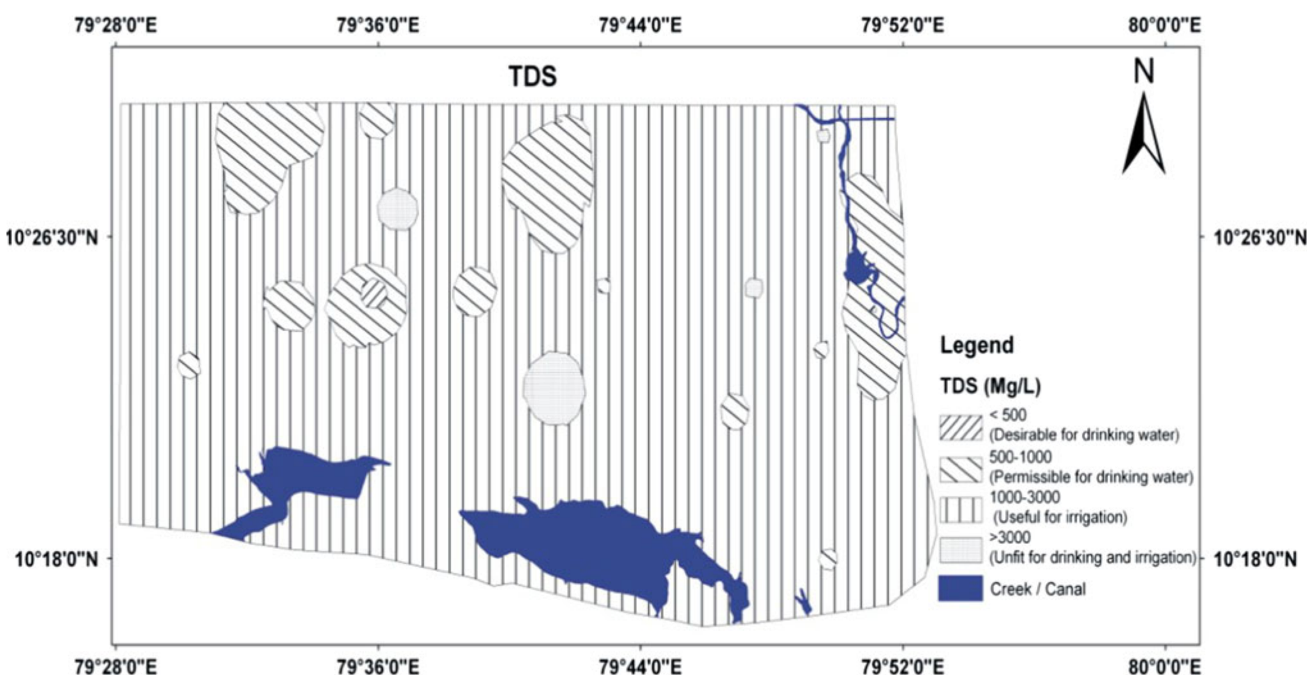


Fig. 3 Spatial distributions of TDS (Davis and DeWiest 1966)

Table 3 Groundwater quality based on TDS

Parameter	Range	Classification	Sample numbers	No. of samples	% of samples
Davis and DeWiest (1966)					
TDS (mg/L)	<500	Desirable for drinking water	7, 35	2	4.3
	500–1,000	Permissible for drinking water	4, 6, 8, 10, 12, 13, 16, 22, 24, 28, 29, 30, 32, 36, 38, 39, 40, 41, 46	17	36.2
	1,000–3,000	Useful for irrigation	1, 3, 5, 9, 11, 14, 15, 17, 19, 20, 21, 23, 25, 26, 31, 33, 37, 42, 43, 44, 45, 47	22	46.8
	>3,000	Unfit for drinking and irrigation	2, 18, 27, 34	4	8.5
Freeze and Cherry (1979)					
TDS (mg/L)	<1,000	Freshwater	7, 4, 6, 8, 10, 12, 13, 16, 22, 24, 28, 29, 30, 32, 35, 36, 38, 39, 40, 41, 46	21	44.7
	1,000–10,000	Brackish water	1, 2, 3, 5, 9, 11, 14, 15, 17, 18, 19, 20, 21, 23, 25, 26, 27, 31, 33, 34, 37, 42, 43, 44, 45, 47	26	55.3
	10,000–100,000	Saline water	Nil	–	–
	>100,000	Brine water	Nil	–	–

Table 4 Factor analysis-rotated component matrix-varimax with Kaiser normalization

Component	1	2	3	4	Communalities
pH	0.15	0.08	**0.82**	0.11	0.714
EC	**0.97**	0.03	0.13	−0.01	0.955
TDS	**0.97**	0.03	0.13	−0.01	0.955
Ca^{2+}	**0.60**	0.12	−0.44	−0.14	0.597
Mg^{2+}	**0.84**	0.04	−0.16	0.09	0.742
Na^{+}	0.02	**0.95**	0.12	0.09	0.928
K^{+}	0.13	**0.94**	−0.03	0.09	0.908
Cl^{-}	**0.94**	0.07	0.15	−0.05	0.921
HCO_3^{-}	0.10	0.23	0.07	**0.78**	0.672
NO_3^{-}	**0.55**	0.21	−0.21	0.42	0.573
PO_4^{-3}	**0.53**	0.21	−0.04	−0.62	0.714
F^{-}	−0.05	0.03	**0.72**	−0.06	0.522
Eigenvalues	4.63	1.98	1.49	1.09	
Cumulative %	37.34	53.68	66.42	76.67	

Bold values indicate the factor loadings higher than 0.5, which are significant contributors to the variance in the groundwater chemistry

domestic sewage, detergents, agricultural effluents and fertilizers. The concentration of fluoride observed in this study ranged from 0.2 to 0.8 mg/L with a mean value of 0.5 mg/L.

Discussion

Saline water intrusion

Groundwater salinization in coastal aquifer was observed based on the chloride with carbonate–bicarbonate and sodium–chloride interaction. The Cl^{-}/HCO_3^{-} ratio is classified into three, such as <0.5 for no intrusion, 0.5–6.6 for slight to moderate intrusion and >6.6 for strong intrusion. Based on this Cl^{-}/HCO_3^{-} ratio, it is inferred that 70 % of the samples are affected with slight to moderate seawater intrusion and only three samples are affected with strong seawater intrusion (Fig. 7). According to the Revelle index (RI) ($Cl^{-}/CO_3^{2-} + HCO_3^{-}$), the studied samples ranged from 0.2 to 50.9, which indicates 70 % of samples exceeded the RI ratio (>1) due to possible seawater mixing. Further, Na^{+}/Cl^{-} weight ratio (0.85) was used to confirm the mixing of freshwater and seawater (Re et al. 2011). Figure 8 shows that half of the studied samples have less than the Na^{+}/Cl^{-} reference value maybe due to possible seawater mixing.

Factor analysis

Factor analysis is very useful to interpret the groundwater quality data and to understand specific hydro-geochemical processes. The R-mode factor analysis is a most widely used statistical method. Hence, varimax with Kaiser normalization rotated factor loading matrix was performed. In the analysis, four principal components were extracted accounting for 76.67 % of variance, which shows the major effective controlling agents in the groundwater (Table 4). Factor 1 accounted for about 37.34 % of variance, which is positively contributed by EC, TDS, Cl^{-}, Ca^{2+}, Mg^{2+}, PO_4^{3-} and NO_3^{-}. EC and TDS have loadings of 0.97, and control the overall mineralization, while Cl^{-} has a loading of 0.94. It is derived from saline water intrusion, salt pan deposits or agricultural return flow into groundwater (Ramkumar et al.

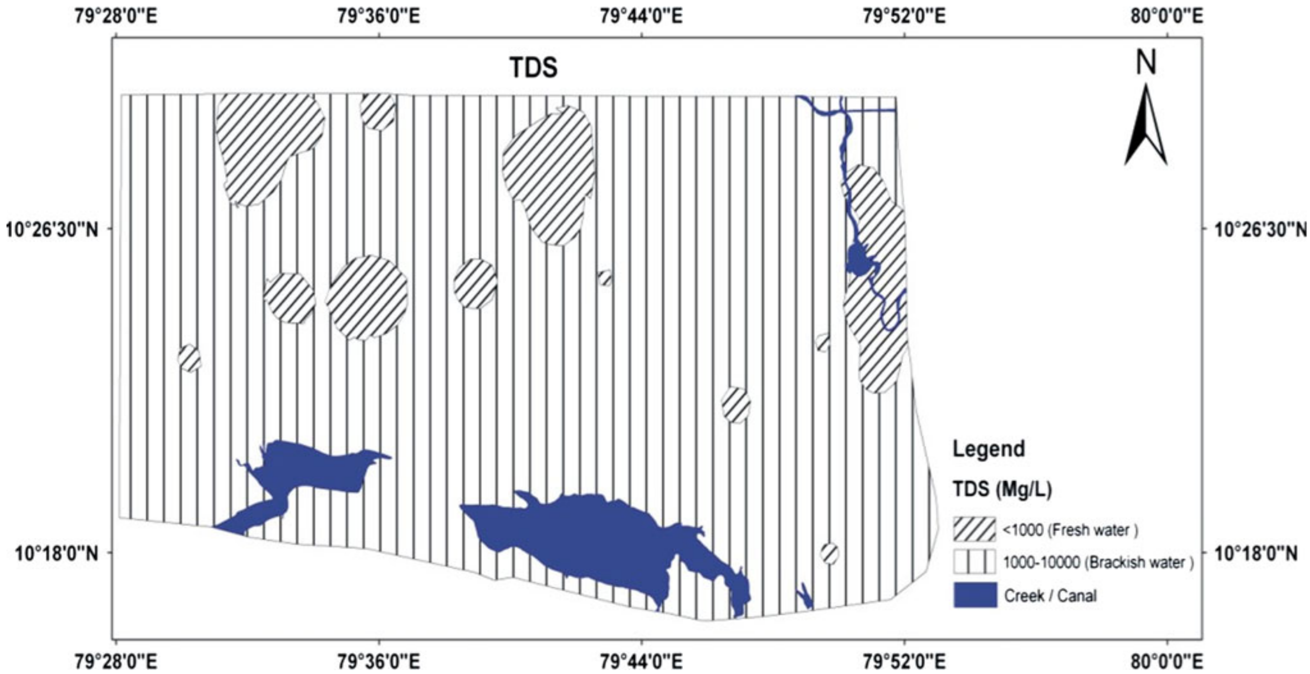


Fig. 4 Spatial distributions of TDS (Freeze and cherry 1979)

2010). The positive loadings on chloride with Ca^{2+} and Mg^{2+} may also represent the salinity of groundwater (Akoteyon and Soladoye 2011). PO_4^{3-} and NO_3^- have moderate loadings (0.55 and 0.53) in factor 1 and may attribute to anthropogenic activities. Application of potassium fertilizers Potash and NPK (nitrogen–phosphorus–potassium, mixed fertilizer) and gypsum seems to be contributed well in potassium and sulfate concentrations in addition with domestic wastewater (sewage, septic tank effluent, etc.) (Nagarajan et al. 2010). Represention of PO_4^{3-}, Ca^{2+} and Mg^{2+} in the first factor is indicative of anthropogenic impact from agricultural practices (Prasanna et al. 2009, 2010). The second factor explains about 16.34 % of the variance and contains Na^+ and K^+. This may be due to the process of ion exchange between the aquifer matrix and the groundwater (Chidambaram et al. 2007). The third factor is represented by pH and F; the representation in this factor indicates the lowering of pH values or the addition of H^+ to the system along with K and Mg. This may be due to the normal mica weathering process which releases these ions and H^+ into the system (Chidambaram et al. 2007). Factor 3 extracted about 12.74 % of the total variance represented by pH and F^-. In addition, calcium was negatively loaded in the third factor, which is consistent with fluoride influence. Normally, fluoride ions help in dissolution of the calcium ion concentration in groundwater (Dutta et al. 2010; Kumar et al. 1992). Fluoride is a strong electronegative ion and it easily attracts Ca^{2+} from the mineral matrix. The fourth factor is positive loading of HCO_3^- due to carbonate dissolution, accounting for 10.25 % of the total variance.

Cluster analysis

Cluster analysis is also another data reduction method that is used to classify entities with similar properties (Pathak et al. 2008). Through hierarchical cluster analysis (HCA), the associations among the stations were obtained using Ward's method with Euclidian distance as a similarity measure with dendrogram plots (Fig. 9). The physicochemical parameter concentrations were used as variables to show the spatial heterogeneity among the stations as a result of sequence and their relationship in the level of contamination. There were two major groups of cluster obtained from the sampling, while sample yielded groups are summarized below. Group I, clustered with a limited number of stations, interprets the spatial similarity in the physicochemical composition, as influenced by human interference and extent of pollutants received by salt pan and aquaculture activity. Group I is further subdivided into two subgroups, Ia and Ib (Table 5). Ia is typically represented by the first factor (Group I—Ca^{2+}, Mg^{2+}, Cl^-, PO_4^{3-} and NO_3^-) group of samples; the stronger relation between the groups are due to anthropogenic impact and also agricultural practices (Prasanna et al. 2009, 2010). Ib under this subgroup is represented by the 27th sample site grouped alone; F^- dominance is due to the weathering of minerals. Fluoride from this region is mainly obtained from

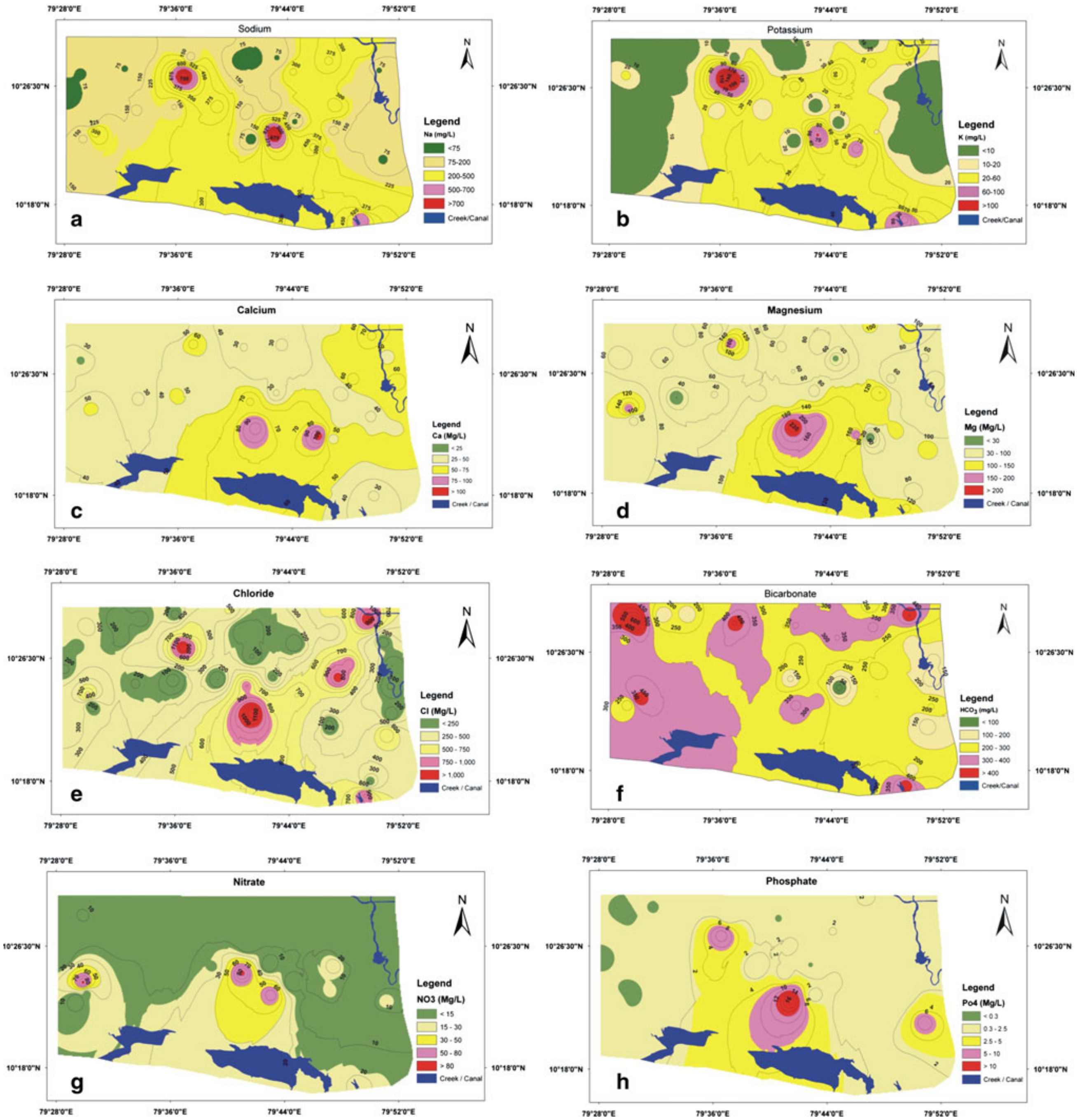


Fig. 5 a–h Spatial distribution of physicochemical parameters

the weathering of mica present in the alluvium sand. Hence it is inferred that dominance of F^- is due to the weathering of minerals. This fact is also supported by spatial distribution of the result (Figs. 11, 12). The Group II cluster samples showing ion exchange of Na and K (Chidambaram et al. 2007) consists of 66 % of samples distributed around the western part of the study area. Also, Group II cluster could be categorized as less polluted compared to Group I.

Water quality index

Water quality index provides the overall influence of individual water quality for drinking purpose. It is classified into five, such as excellent (<50), good (51–100), poor (101–200), very poor (201–300) and unsuitable for drinking (>300). Based on the importance of water quality parameters, maximum and minimum weight was assigned.

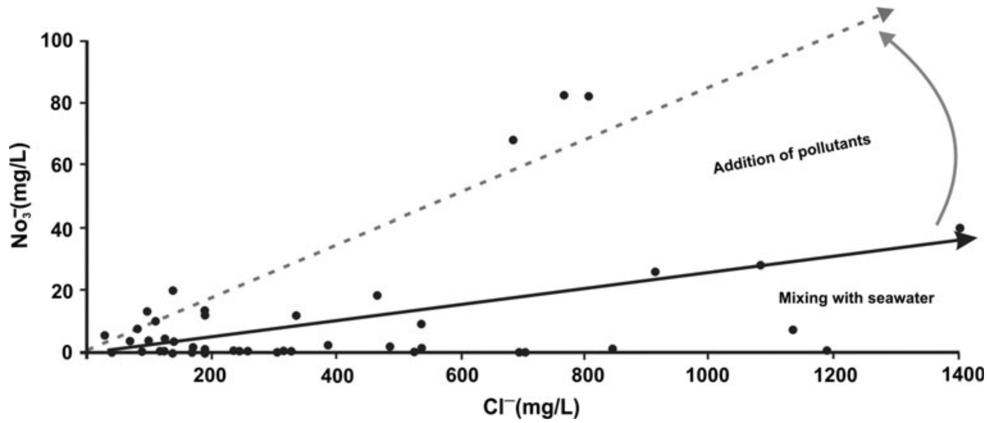


Fig. 6 Relationship between Cl^- and NO_3^- concentration (Re et al. 2011)

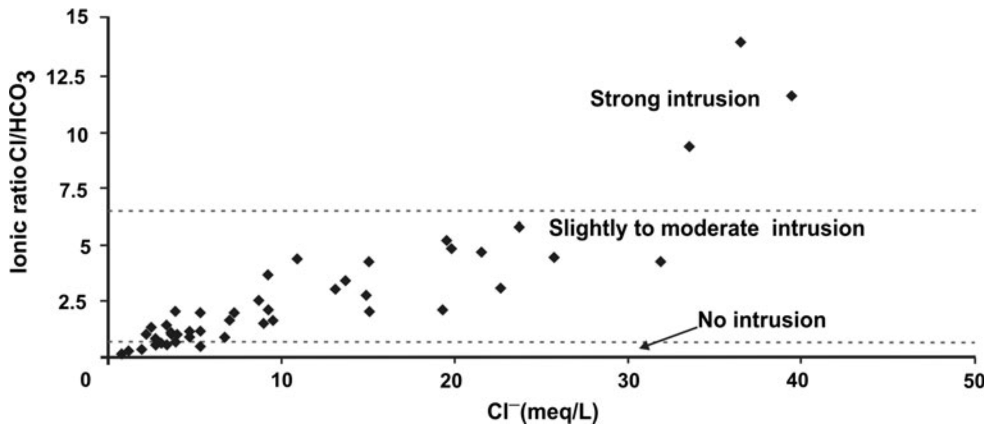


Fig. 7 Relationship between Cl^- and Cl/HCO_3 ratio

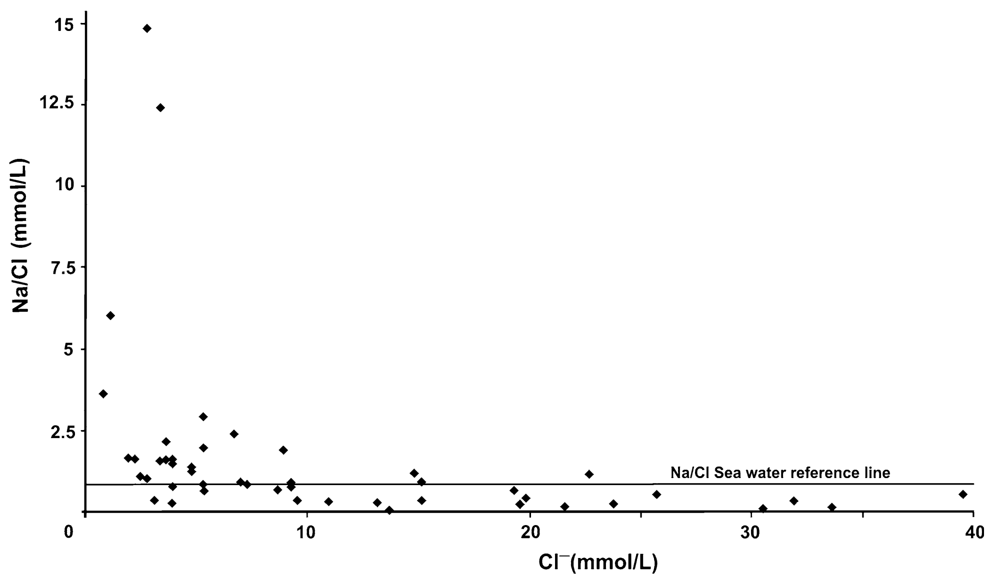


Fig. 8 Relationship between Cl^- and Na/Cl ratio

Maximum weight of 5 was assigned for the parameters: TDS, chloride, nitrate and fluoride, because they play a vital role in groundwater quality (Vasanthavigar et al. 2010; Srinivasamoorthy et al. 2008). Other parameters such as bicarbonate, sodium, potassium, calcium and magnesium were assigned weight 1–4 depending on their importance in water quality evaluation. After assigning the weight for each parameter, the relative weight was calculated (Table 6). Further, quality rating (q_i) is assigned in each parameter based on concentration of the sample (C_i) divided by drinking water quality standard (S_i) using the following equation:

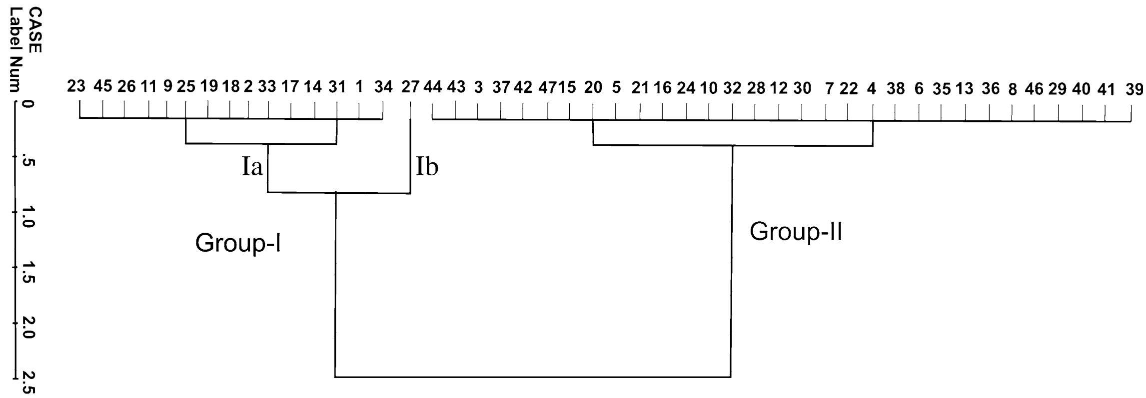


Fig. 9 Dendrogram refers to the map showing the location of the samples (Fig. 1)

Table 5 Different water groups in Vedaraniyam region using cluster analysis

Cluster	Sample no.
Group Ia	1, 2, 9, 11, 14, 17, 18, 19, 23, 25, 26, 31, 33, 34, 45
Group Ib	27
Group II	3, 4, 5, 6, 7, 8, 10, 12, 13, 15, 16, 20, 21, 22, 24, 28, 29, 30, 32, 36, 37, 38, 39, 40, 41, 42, 43, 44, 46

Table 6 Water quality index and relative weight

Chemical parameters	BIS:10500 1,991	Weight (W_i)	Relative weight $W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$
TDS (mg/L)	500	5	0.152
Bicarbonate (mg/L)	120[a]	1	0.030
Chloride (mg/L)	250	5	0.152
Nitrate (mg/L)	45	5	0.152
Fluoride (mg/L)	1	5	0.152
Calcium (mg/L)	75	3	0.091
Magnesium (mg/L)	30	3	0.091
Sodium (mg/L)	200[b]	4	0.121
Potassium (mg/L)	10[b]	2	0.061
		$\sum w_i$ 33	$\sum w_i$ 1.000

[a] US Public Health Service value

[b] BIS 1998

$q_i = (C_i/S_i) \times 100$

Finally, WQI is computed based on the following equation:

$\mathrm{SI}_i = W_i/q_i$

$\mathrm{WQI} = \sum \mathrm{SI}_i$

where SI_i is the sub index of ith parameter.

Therefore, the water quality rating of the studied samples obtained ranges from 52 to 397. About 36 % of the samples were found to be good for drinking purpose, 43 % were poor, 19 % were very poor and the remaining 2 % unfit for human consumption.

Irrigation water quality

Periodical monitoring of groundwater quality is necessary for planning, design and operation of irrigation systems to ensure a minimum of deleterious salts or compounds in the irrigation water (Sangodoyin and Ogedenbe 1991). The irrigation suitability was based on the salinity, Na %, SAR, RSC, PI, Kelly ratio and Wilcox diagram. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Saleh et al. 1999; Thorne and Peterson 1954). Salinity, sodicity and toxicity generally need to be considered for evaluation of the suitable quality of groundwater for irrigation (Shainberg and Oster 1978).

EC is a good measure of salinity hazard to crops. According to Raghunath (1987), EC were classified into five major types (Fig. 10). Table 7 shows that 25 samples (53.2 %) are within the permissible limits and can be used for irrigation on almost all types of soil, 7 samples are in a doubtful class and 13 samples (27.7 %) are of unfit category.

Sodium percentage

Sodium percentage is widely used to assess the groundwater quality, because a higher level of sodium in irrigation water may increase the exchange of sodium content of irrigated soil and affect soil permeability, structure and create toxic condition for plants (Bangar et al. 2008; Durfer and Backer 1964; Todd 1980). Hence, Na % is assessed based on Raghunath (1987), using the following equation

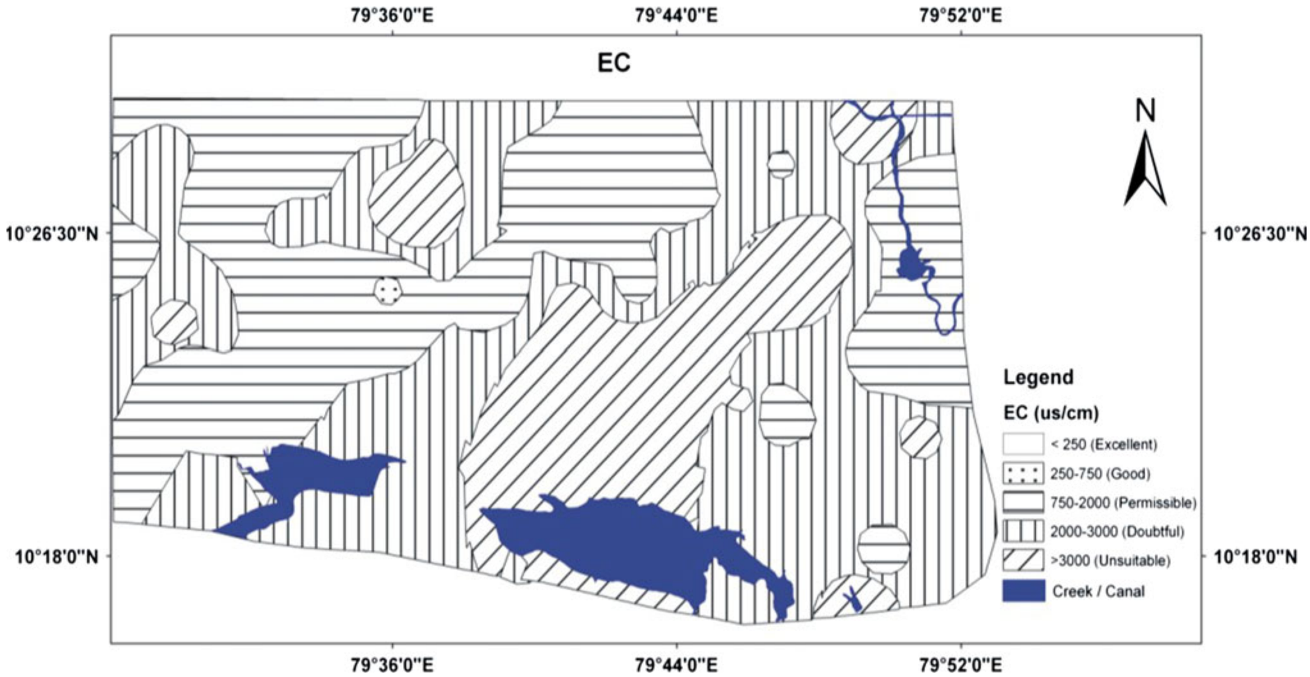


Fig. 10 Spatial distribution of suitability of groundwater for irrigation based on EC

$$\text{Na}\ \% = \frac{(\text{Na}^+ + \text{K}^+) \times 100}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)}(\text{meq/l})$$

Based on the relative proportions of cation concentration, 40.4 % of samples were within the permissible limits, 10.6. % were excellent, 29.8 % were good, 14.9 % were doubtful and 4.3 % were unsuitable for irrigation (Fig. 11; Table 7). Excess sodium in waters produces the undesirable effects of changing soil properties and reducing soil permeability. Hence, the assessment of sodium concentration is necessary while considering the suitability for irrigation (Nishanthiny et al. 2010). The sample locations fall along the coastal regions and Na might have been acquired from the seawater by saline intrusions (Chidambaram et al. 2007).

Sodium absorption ratio

Sodium absorption ratio (SAR) has been extensively used as an indicator of sodium hazard in irrigation water (Gholami and Srikantaswamy 2009). Richard (1954) has classified water quality based on the following equation

$$\text{SAR} = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})^{1/2}/2}(\text{meq/l})$$

According to Richard's classification, the computed SAR value shows that 91.4 % of samples are excellent, 4.3 % are good and 4.3 % are doubtful for irrigation (Fig. 12). Wilcox's (1955) diagram relating to sodium percentage and electrical conductivity of the particular sample shows that 10.5 % samples fall under the excellent to good class, 36 % under good to permissible, 12.8 % under permissible to doubtful and doubtful to unsuitable class, respectively, and the remaining samples (27.7 %) are unsuitable for irrigation (Fig. 13). High concentrations of sodium ion in irrigation water have a tendency to be easily absorbed by clay particles due to exchange of calcium and magnesium ion. These exchange processes decrease the soil permeability and reduce internal drainage.

Residual sodium carbonate

RSC is another parameter to identify the irrigation water quality, assessed based on the presence of carbonate and bicarbonate, along with the sum of calcium and magnesium ions, which is calculated using the following equation (Lloyd and Heathcote 1985):

$$\text{RSC} = (\text{CO}_3^- + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})(\text{meq/l})$$

The unfit water samples (containing excess of carbonate and bicarbonate) for irrigation will precipitate calcite in soil from solution and increase sodium in solution, resulting in soil dispersion (Emerson and Bakker 1973) as well as impaired nutrient uptake by plants (Kanwar and Chaudhry 1968). According to the RSC classification, 91 % of the samples (<1.25) are suitable for irrigation, 4.5 % of samples are marginal (1.25–2.5) and the remaining samples are not suitable for irrigation (>2.5). The samples show

Table 7 Irrigation quality of groundwater based on EC, SAR and Na % value

Parameter	Range	Classification	Sample numbers	No. of samples	% of samples
Raghunath (1987)					
EC (μS/cm)	<250	Excellent	Nil	–	–
	250–750	Good	7, 35	2	4.3
	750–2,000	Permissible	3, 4, 5, 6, 8, 10, 12, 13, 16, 20, 21, 22, 24, 28, 29, 30, 32, 36, 38, 39, 40, 41, 44, 46, 47	25	53.2
	2,000–3,000	Doubtful	1, 15, 17, 31, 37, 42, 43	7	14.9
	>3,000	Unsuitable	2, 9,11,14,18,19, 23, 25, 26, 27, 33, 34, 45	13	27.7
Richards (1954)					
SAR	<10	Excellent	1–22, 24–27, 29, 30, 33–42, 44–47	42	91.4
	10–18	Good	23, 31	2	4.3
	18–26	Doubtful	28, 32	2	4.3
	>26	Unsuitable	Nil	–	–
Raghunath (1987)					
Na %	<20	Excellent	14, 18, 29, 45, 46	5	10.6
	20–40	Good	6, 7, 9, 15, 17, 22, 25, 33, 34, 37, 38, 42, 44, 47	14	29.8
	40–60	Permissible	1, 2, 4, 5, 8, 11–13, 16, 19, 21, 24, 26, 27, 30, 35, 36, 40, 41	19	40.4
	60–80	Doubtful	3, 10, 20, 23, 31, 39, 43	7	14.9
	>80	Unsuitable	28, 32	2	4.3

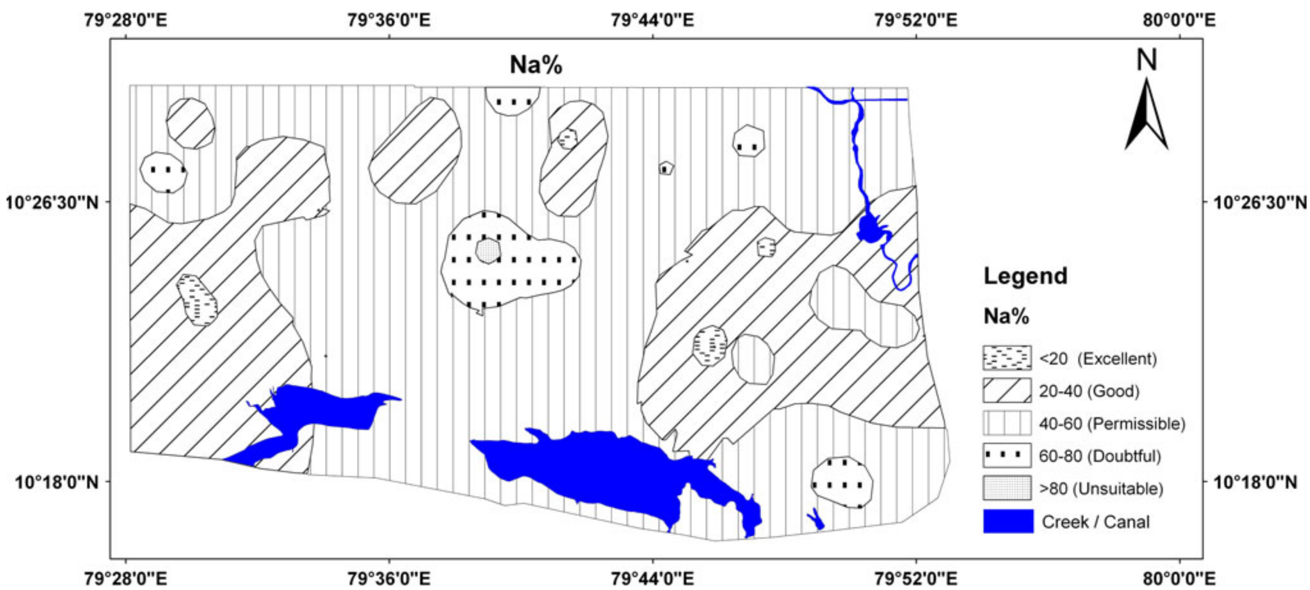


Fig. 11 Spatial distribution of suitability of groundwater for irrigation based on Na %

comparatively lesser concentration of CO_3^{2-} and HCO_3^- reflecting lesser impact of weathering and the realease of Ca and Mg by the ion exchange process (Thivya et al. 2013).

Permeability index

Doneen (1964) has classified the irrigation water quality into three class based on permeability: class I and II having maximum permeability >75 % are suitable for irrigation; class III having 25 % of maximum permeability is not suitable for irrigation. In the current study, the index ranged from 13.7 to 95.4 %. Based on the PI value, 83 % of the samples are under class I and II and are most suitable for irrigation and the remaining 13 % are unfit for irrigation.

$$PI = \frac{(Na^+ + \sqrt{HCO_3^-}) \times 100}{(Ca^{2+} + Mg^{2+} + Na^+)} (meq/l)$$

When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles,

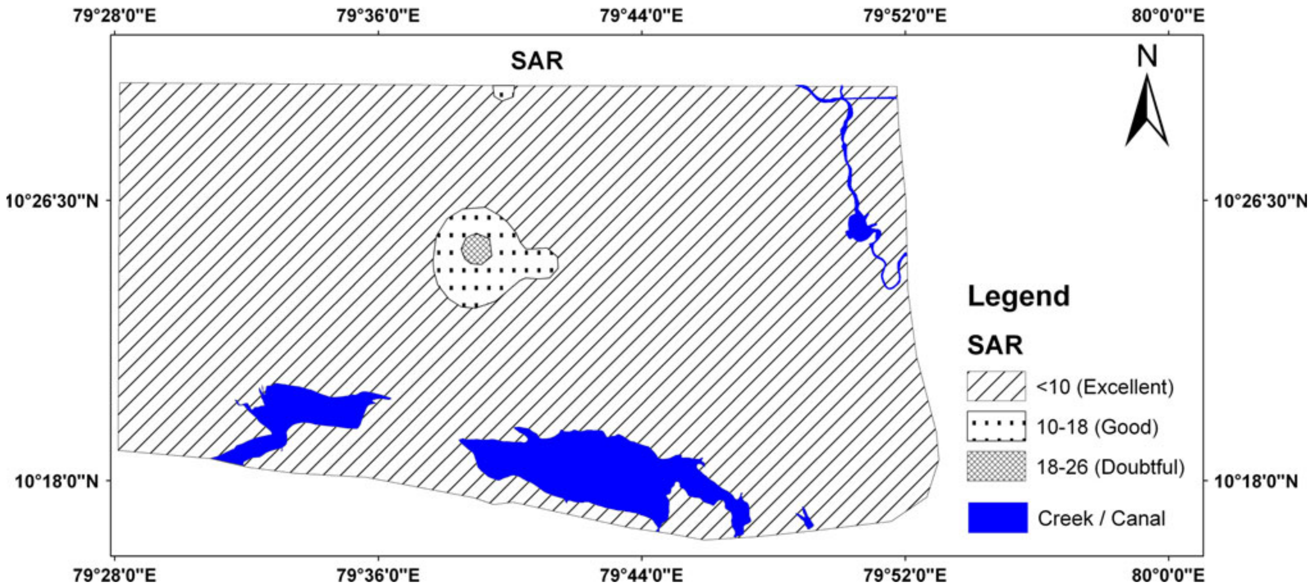
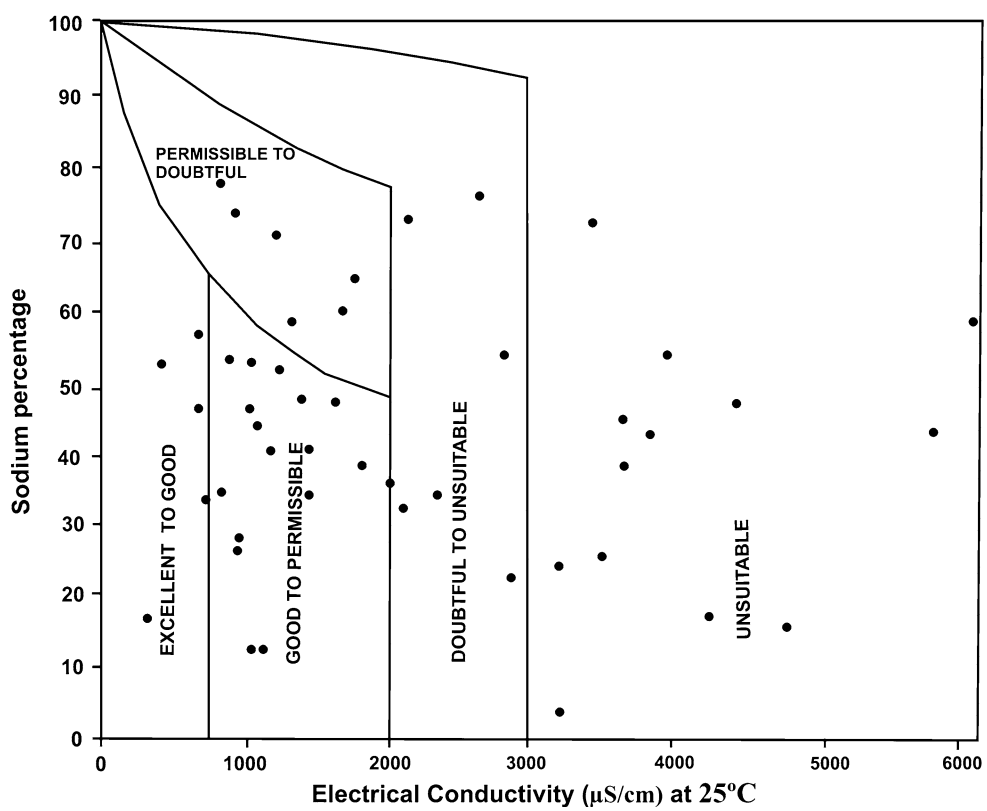


Fig. 12 Spatial distribution of suitability of groundwater for irrigation based on SAR

Fig. 13 Sodium percent and electrical conductivity plot



displacing Mg^{2+} and Ca^{2+} ions. This exchange process of Na^{+} in water for Ca^{2+} and Mg^{2+} in soil reduces the permeability and eventually results in soil with poor internal drainage. As represented in the factor analysis, the ion exchange process also plays a significant role in determination of PI. When air and water circulation is restricted during wet conditions, such soils become hard when dry (Collins and Jenkins 1996; Saleh et al. 1999).

Kelley's ratio

Kelley (1940) and Paliwal (1967) proposed the suitability of irrigation water quality based on the sodium concentration against calcium and magnesium. According to Kelley's ratio, 66 % samples (<1) are of good quality groundwater suitable for irrigation and the remaining samples are not suitable for irrigation (>1). Kelley's ratio is calculated as follows:

$$\text{Kelley's ratio} = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \text{(meq/l)}$$

Both cation exchange and reverse ion exchange are encouraged by aquifer materials and land use practices, in waterlogged area, marshy/swampy land, creek, mud/tidal flat represented by montmorillonite clays, which lead to the release of Na or Ca into groundwater and adsorption of Ca or Na, respectively (Alison et al. 1992; Blake 1989; Cerling et al. 1989; Foster 1950).

Conclusion

The present study of groundwater samples in Vedaraniyam coast shows that the water quality of the studied samples exceeded the BIS limits in some areas, which has the potential to affect human health adversely. The chemical composition of groundwater shows that sodium concentration was dominant in the cations and chloride in anions. Na/Cl and Mg/Cl ratios indicate that nearly 50 % of the samples are mixed with saline water intrusion. Anthropogenic input from salt pan and aquaculture practice increased salt-affected areas around 33.2 sq. km, which contributed to the increase in sodium and potassium concentration in groundwater. Elevated level of phosphate and nitrate concentrations is attributed mainly to the leaching of salts from agricultural runoff and domestic sewage such as ill-maintained septic tank and sewer lines. Further the calculated SAR, Na %, RSC and PI values show that around 80–90 % of water is useful for irrigation without any adverse impacts on the soil. It is obvious that Vedaraniyam aquifer has been moderately polluted and needs a long-term planning and implementation program for improving the groundwater quality. The study on the water quality parameters for drinking and irrigation shows that most of the groundwater samples are not suitable for drinking purpose and only few samples are unfit for irrigation purpose. The land use practices and the ion exchange process play a significant role in determining major geochemical processes of the study area. To ensure a sustainable management of this resource in this fragile ecosystem, proper management of the water extraction structures and maintenance of the surface water sources are needed.

References

Akoteyon IS, Soladoye O (2011) Groundwater quality assessment in Eti-Osa, Lagos-Nigeria using multivariate analysis. J Appl Sci Environ Manag 15(1):121–125

Alison EC, Janet SH, Blair FJ (1992) The chemical influence of clay minerals on groundwater composition in a lithologically heterogeneous carbonate aquifer. In: Kharaka YK, Maest AS (eds) Proceedings of the 7th international symposium on water–rock interaction (WRI7, Vol 2), Utah, Balkema, pp 779–782

Bangar KS, Tiwari SC, Vermaandu SK, Khandkar UR (2008) Quality of groundwater used for irrigation in Ujjain district of Madhya Pradesh, India. J Environ Sci Eng 50(3):179–186

Belkhiri L, Boudoukha A, Mouni L, Baouz T (2010) Multivariate statistical characterization of groundwater quality in Ain Azel plain, Algeria. African J Environ Sci Technol 4(8):526–534

Blake R (1989) The origin of high sodium bicarbonate waters in the Otway Basin, Victoria, Australia. In: Miles DL (ed) Proceedings of the 6th international symposium on water–rock interaction (WRI-6). Malvern, England, pp 83–85

Nishanthiny SC, Thushyanthy M, Barathithasan T, Saravanan S (2010) Irrigation water quality based on hydro chemical analysis, Jaffna, Sri Lanka. Am Eurasian J Agric Environ Sci 7(1):100–102

Cerling TE, Pederson BL, Damm KLV (1989) Sodium calcium ion exchange in the weathering of shales: implications for global weathering budgets. Geology 17:552–554

Chapagain SK, Pandey VP, Shrestha S, Nakamura T, Kazama F (2010) Assessment of deep groundwater quality in Kathmandu Valley using multivariate statistical techniques. Water Air Soil Pollut 210(1–4):277–288. doi:10.1007/s11270-009-0249-8

Chidambaram S, Vijayakumar V, Srinivasamoorthy K, Anandhan P, Prasanna MV, Vasudevan S (2007) A study on variation in ionic composition of aqueous system in different lithounits around Perambalur region, Tamil Nadu. J Geol Soc India 70(6):1061–1069

Chidambaram S, Karmegam U, Prasanna MV, Sasidharm P, Vasanthavigar M (2011) A study on hydrochemical elucidation of coastal groundwater in and around Kalpakkam region, southern India. Environ Earth Sci 64:1419–1431

Collins R, Jenkins A (1996) The impact of agricultural land use on stream chemistry in the middle Hills of the Himalayas, Nepal. J Hydrol 185:71–86

Das M, Kumar A, Mohapatra M, Muduli SD (2010) Evaluation of drinking quality of groundwater through multivariate techniques in urban area. Environ Moni Asses 166:149–157. doi:10.1007/s10661-009-0991-9

Davis SN, DeWiest RJM (1966) Hydrogeology. Wiley, New York

Doneen LD (1964) Notes on water quality in agriculture, Published as a water sciences and engineering. Department of Water Sciences and Engineering, University of California, paper 4001

Durfer CM, Backer E (1964) Public water supplies of the three largest cities in the U.S. US Geological Survey water supply paper no. 1812, 364

Dutta J, Nath M, Chetia M, AK Misra (2010) Monitoring of fluoride concentration in ground water of small tea gardens in Sonitpur district, Assam, India: Correlation with physico-chemical parameters. Int J Chem Tech Res 1199–1208

Emerson WW, Bakker AC (1973) The comparative effect of exchangeable Ca, Mg and Na on some soil physical properties of red brown earth soils. 2. The spontaneous dispersion of aggregates in water. Aust J Soil Res 11:151–152

Fianko JR, Osae S, Adomako D, Achel DG (2009) Relationship between land use and groundwater quality in six districts in the eastern region of Ghana. Environ Moni Asses 153:139–146. doi:10.1007/s10661-008-0344-0

Foster MD (1950) The origin of high sodium bicarbonate waters in the Atlantic and Gulf Coast plains. Geochim Cosmochim Acta 1:33–48

Freeze RA, Cherry JA (1979) Groundwater. Prentice-Hall, New Jersy, p 604

Ghandour EIM, Khalil JB, Atta SA (1985) Distribution of carbonates, bicarbonates and pH values in groundwater of the Nile delta region, Egypt. Groundwater 23:35–41

Gholami S, Srikantaswamy S (2009) Analysis of agricultural impact on the Cauvery river water around KRS dam. World Appl Sci J 6(8):1157–1169

Gilliom RJ, Alley WM, Gurtz ME (1995) Design of the national water quality assessment program: occurrence and distribution of water quality condition. US Geological Survey Circular 1112. US Geological Survey Sacramento, p 28

Giménez-Forcada E, Bencini A, Pranzini G (2010) Hydrogeochemical considerations about the origin of groundwater salinization in some coastal plains of Elba Island (Tuscany, Italy). Environ Moni Asses 32:243–257. doi:10.1007/s10653-009-9281-2

Jiang Y, Yan J (2010) Effects of land use on hydrochemistry and contamination of Karst groundwater from Nandong underground river system, China. Water Air Soil Pollut 210:123–141. doi:10.1007/s11270-009-0229-z

Joshi DM, Kumar A, Agrawal N (2009) Assessment of the irrigation water quality of River Ganga in Haridwar District. J Rasayan Chem 2:285–292

Kanwar JS, Chaudhry ML (1968) Effect of Mg on the uptake of nutrients from the soil. J Res Pb Agric Univ 3:309–319

Kelley WP (1940) Permissible composition and concentration of irrigation water. In: Proceedings of the American Society of Civil Engineering, vol 66. pp 607–613

Khan TA (2011) Multivariate analysis of hydrochemical data of the groundwater in parts of Karwan–Sengar sub-basin, Central Ganga basin, India. Global NEST J 13(3):229–236

Kim G (2010) Integrated consideration of quality and quantity to determine regional groundwater monitoring site in South Korea. Water Res Manag 24:4009–4032. doi:10.1007/s11269-010-9644-6

Kumar S, Bhattacharjee JW, Sharma RK (1992) Relationship between fluoride, total hardness and total alkalinity in the ground water of Barmer district. Pollut Res 11:111–116

Kumar M, Kumar P, Ramanathan AL, Bhattacharya P, Thunvik R, Singh UK, Tsujimura M, Sracek O (2010) Arsenic enrichment in groundwater in the middle Gangetic plain of Ghazipur district in Uttar Pradesh. India. J Geochem Explor 105(3):83–94

Lee CSL, Li XD, Shi WZ, Cheung SCN, Thornton I (2006) Metal contamination in urban, suburban, and country park soils of Hong Kong: a study based on GIS and multivariate statistics. Sci Total Environ 356:45–61

Lloyd JW, Heathcote JA (1985) Natural inorganic hydrochemistry in relation to groundwater. An introduction. Clarendon Press, Oxford

Mary IA, Ramkumar T, Venkatramanan S (2012) Application of statistical analysis for the hydrogeochemisty of saline groundwater in Kodiakarai, Tamilnadu, India. J Coastal Res 28(1A):89–98. doi:10.2112/JCOASTRES-D-09-00156.1

Nagarajan R, Rajmohan N, Mahendran U, Senthamilkumar S (2010) Evaluation of groundwater quality and its suitability for drinking and agricultural use in Thanjavur City, Tamil Nadu, India. Environ Moni Asses 17:1289–1308. doi:10.1007/s10661-009-1279-9

Naidu MS, Srinivas N, Rao VP (1998) Urban water quality in North coastal Andhra Pradesh. Indian J Environ Protect 18(4):273–277

Nickson RT, Arthur JM, Shrestha B, Kyaw-Nyint TO, Lowry D (2005) Arsenic and other drinking water quality issues, Muzaffargarh district, Pakistan. Appl Geochem 20(1):55–68

Olaniya MS, Nawlakhe WG, Sharma HC, Saxena KL (1978) Pollution studies of well waters in sewage farm at Jaipur. Indian J Environ Health 20(4):398–412

Paliwal KV (1967) Effect of gypsum application on the quality of irrigation waters. Madras Agric J 59:646–647

Pathak JK, Alam M, Sharma S (2008) Interpretation of groundwater quality using multivariate statistical technique in Moradabad city, Western Uttar Pradesh State, India. E-J Chem 5(3):607–619

Prasanna MV, Chidambaram S, Shahul Hameed A, Srinivasamoorthy K (2009) Study of evaluation of groundwater in Gadilam basin using hydrogeochemical and isotope data. Environ Moni Asses. doi:10.1007/s10661-009-1092-5

Prasanna MV, Chidambaram S, Srinivasamoorthy K (2010) Statistical analysis of the hydrogeochemical evolution of groundwater in hard and sedimentary aquifers system of Gadilam river basin, South India. J King Saud Univ (Science). doi:10.1016/j.jksus.2010.04.001

Raghunath HM (1987) Groundwater, 2nd edn. New Age International Publications, New Delhi

Ramakrishnaiah CR, Sadashivaiah C, Ranganna G (2009) Assessment of water quality index for the groundwater in Tumkur taluk, Karnataka state, India. E-J Chem 6(2):523–530

Ramkumar T, Venkatramanan S, Mary IA, Tamilselvi M, Ramesh G (2010) Hydrogeochemical quality of groundwater in Vedaraniyam town, Tamil Nadu, India. Res J Environ Earth Sci 2(1):44–48

Ravichandran P (2005) Coastal aquaculture and its impact on fisheries development in India. In: Proceedings of the seventh Indian fisheries forum, Bangalore, India, November 8–12, pp 30–34

Re V, Faye SC, Faye A, Faye S, Gaye CB, Sacchi E, Zuppi GM (2011) Water quality decline in coastal aquifers under anthropic pressure: the case of a suburban area of Dakar (Senegal). Environ Moni Asses 172:605–622. doi:10.1007/s10661-010-1359-x

Richards LA (1954) Diagnosis and improvement of saline and alkali soils. US Laboratory Staff, US Department of Agriculture, Agricultural Handbook, pp 60

Rizk ZS, Garamoon HK, EL-Etr AA (1998) Contribution to hydrogeochemistry of the quatenary aquifer in the Al-Ain area, United Arab Emirates. In: Alsharhan S, Glennie K, Whittle GL, Kenddall CG St C (eds) Quaternary deserts and climatic change. AA Balkema, Rotterdam pp 439–453

Saleh A, Al-Ruwaih F, Sheata M (1999) Hydrogeochemical processes operating within the main aquifers of Kuwait. J Arid Environ 42:195–209

Sangodoyin AY, Ogedenbe K (1991) Surface water quality and quantity from the standpoint of irrigation and livestock. Int J Environ Stud 38:251–262

Shainberg I, Oster JD (1978) Quality of irrigation water. International Irrigation Information Centre. IIIC Publication No.2. ISBN 0-08-023822-X. Bet Dagan, Israel. pp 65

Srinivasamoorthy K, Chidambaram M, Prasanna MV, Vasanthavigar M, John Peter A, Anandhan P (2008) Identification of major sources controlling groundwater chemistry from a hard rock terrain—a case study from Mettur taluk, Salem district, Tamil Nadu, India. J Earth Syst Sci 117(1):49–58

Subramani T, Elango L, Damodarasamy SR (2005) Groundwater quality and suitability for drinking and agricultural use in Chithar river basin, Tamilnadu, India. Environ Geol 24:194–202

Thivya C, Chidambaram S, Singaraja C, Thilagavathi R, Prasanna MV, Anandhan P, Jainab I (2013) A study on the significance of lithology in groundwater quality of Madurai district, Tamil Nadu (India). Environ Dev Sustain. doi:10.1007/s10668-013-9439-z

Thorne DW, Peterson HB (1954) Irrigated soils: their fertility and management, 2nd edn. The Blakiston Co., New York

Todd DK (1980) Groundwater hydrology, 2nd edn. John Wiley and Sons, New York, p 535

Vasanthavigar M, Srinivasamoorthy K, Vijayaragavan K, Rajiv Ganthi R, Chidambaram S, Anandhan P, Manivannan R, Vasudevan S (2010) Application of water quality index for groundwaterquality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. Environ Moni Asses 171:595–609. doi:10.1007/s10661-009-1302-1

Vengosh V, Keren Rami (1996) Chemical modifications of groundwater contaminated by recharge of treated sewage effluent. J Contam Hydrol 23:347–360

Wilcox LV (1955) Classification and use of Irrigation water, US Geological Department Agri Arc, 969, pp 19