Venkataramann Sivsankar[1], Thiagarajan Ramachandramoorthy[2], M. Senthil Kumar[3]

DETERIORATION OF COASTAL GROUNDWATER QUALITY IN RAMESWARAM ISLAND OF RAMANATHAPURAM DISTRICT, SOUTHERN INDIA

[1]Department of Chemistry, Thiagarajar College of Engineering, Tamil Nadu;
[2]PG & Research Department of Chemistry, Bishop Heber College, Tamil Nadu;
[3]Department of Civil Engineering Sethu Institute of Technology, Tamil Nadu, India

A study was carried out in the South-West, North-East and North-West segments dividing the local area of Rameswaram Island to characterize the physico-chemical characteristics of 87 groundwater samples which include pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, total alkalinity (TA), calcium hardness (CH), magnesium hardness, total hardness (TH), chloride and fluoride. heavy inorganic load in majority of the groundwater samples has been estimated due to the salinity, TDS, TH and chloride beyond the threshold level which substantiates the percolation of sea water into the freshwater confined zones. The Water Quality Index and Langeleir Saturation Index have also been calculated to know the potable and corrosive/incrusting nature of the water samples. The results are interpreted based on statistical tools. Greater than 80 % of the samples were found to have exceeded the limit of WHO drinking standard especially in TDS, CH, TA and chloride. The signature of salt-water intrusion is observed from the ratio of $Cl/CO_3^{2-} + HCO_3^-$ and TA/TH. A proper management plan to cater potable water to the immediate needs of the people is to be envisaged.

Key words: water quality, coastal area, seawater intrusion, Langeleir saturation index.

Introduction

According to the reports of UNICEF and World Health Organization (WHO), every year about 2 million people die from diarrhoeal diseases and much of the disease burden is caused by contaminated drinking water and inadequate sanitation (Kaufmann, 2007). Groundwater is highly valued because of certain properties not possessed by surface water (Goel, 2000). The unscientific and inefficient use of this vital resource (water) is contributing to its increasing scarcity and sharp deterioration in its quality (Romani, 2007). Presently several millions of people are affected by fluorosis caused by its excess amount greater than 1.5 mg/L in many States of India and many countries (Datta, 2007). Endemic fluorosis is related to the high concentration of fluoride in drinking water (Li et al., 1994). In continuation to our previous work (Sivasankar and Ramachandramoorthy, 2008; Ramachandramoorthy et al., 2008), the present study is aimed at characterizing the physico-chemical profile of groundwater samples collected from the local sources of Rameswaram Island, where salinity of water in the confined aquifers causing permanent loss to the fresh water storage capacity in terms of quality (Eilers et al., 1997; Masoud and Koike, 2006; Ward et al., 2003; Pozdnyakova and Zhang, 1999) and quantity as well.

Details of the study area

As far as the Hindus are concerned, pilgrimage is an essential part of their life for worship of God by undertaking "sthala yathra". Rameswaram is one of the pilgrimages, serving the purpose of promoting National Integration by attracting a vast confluence of people from Kashmir to Kanyakumari and from Bengal to Mumbai and also from various foreign countries.

Location and climate

The Ramanathapuram District is divided into two municipalities which is further subdivided into 7 Taluks with 429 Panchayats which includes 400 revenue villages and 236 hamlet villages (Statistical Handbook, 2006). In the Ramanathapuram District, Rameswarm is located at 9°28’ North Latitudes and 79°3’ East Longitudes with an average elevation of 10 m above the MSL, covering an area of 61.8 sq, km and a population of about 38,000. This religious Island in a shape of conch is a Taluk with 1 firka, 2 Revenue villages and 31 Hamlet villages. The climate prevails with a minimum temperature of 25°C in winter and a maximum of 36°C in summer. The average rainfall is 813 mm.

In Rameswaram Island, the fluvino-marine deposits include indurated sand and dune sands. The Aeolian deposits comprise red sands which are in the nature of ancient dunes and occur over a stretch of 8 km length and 3.2 km width, and lie concordant to the sea coast. These are separated by marshy deposits of black clays. The sands are underlain by calcareous sandstones.

The marine formation comprises coastal plain deposits of sand and clay in varied proportion. Marine calcareous hardpan occurs as low terraces and platforms, with admixture of quartz, limonite and garnet concentrations. There are vast stretches of saline and alkaline soils found in the coastal blocks. Rameswaram Island contains mainly sandy soil and large quantities of lime stone deposit. The potash content of soil is high in all the blocks. Gypsum, lime stone and magnesium are few chemical compounds that are noteworthy. There are vast stretches of saline and alkaline soils found in the coastal blocks.

Methods of Investigation

A total of 87 groundwater samples (50 in the South-West (SW) segment; 21 in the North-East (NE) segment 16 in the North West (NW)s segment) from different sites of local Rameswaram Island were collected in a pre cleaned one liter polythene bottles with necessary precautions (Brown et al., 1974) and characterized for various physico-chemical parameters namely pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, calcium hardness (CH), magnesium hardness (MH), total hardness (TH), total alkalinity (TA), chloride and fluoride. Standard procedures (APHA, 2005) were adopted for the determination of the various water quality parameters in the study.

Langeleir Saturation Iindex (LSI). Langeleir Saturation Index (Langeleir, 1946) is a system for estimating or predicting the amount or degree of problems with lime scale, a particular water supply will cause. The LSI value usually lies between – 3 and +3. If the LSI is positive, then the water will deposit $CaCO_3$; on the other hand, the negative LSI value makes the $CaCO_3$ to dissolve in water. According to Langelier, the corrosive action of water is principally due to an excess of free CO_2 and its interaction with calcium and magnesium carbonates. In the presence of carbon-dioxide, these salts are held in solution as bicarbonates and for any given concentration of calcium and magnesium there is a corresponding concentration of carbon dioxide to prevent the decomposition of these bicarbonates back into carbonates. Corrosion is accelerated by low pH values, so that in water of low alkalinity and high free carbon dioxide, the attack is much more rapid as compared to water which is high in alkalinity and is low in carbon dioxide content.

$$LSI = pH - pH\ (s)$$

$$pH\ (s) = (9.3 + a + b) - (c + d),$$

where $pH = -\log [H^+]$, $a = \log10(TDS) - 1/10$, $b = -13.12 \cdot \log 10\ (T^oC + 273) + 34.55$, $c = \log10\ (Ca^{2+}\ \text{as}\ CaCO_3,\ mg/L) - 0.4$, $d = \log10\ (\text{alkalinity as}\ CaCO_3,\ mg/L)$

Water Quality Index (WQI). Water Quality Index (Tiwari, 1985) is a very useful and efficient tool for communicating the overall quality of water. To determine the suitability of the groundwater for drinking purposes, WQI is computed by adopting the method which is formulated as, WQI = Antilog[SW^nn = 1 log10qn]. Where Wn, Weightage = K/Sn and K, Constant = 1/(S^nn=11/Si) Sn and Si correspond to the WHO/ICMR standard value of the parameters. Quality rating (q) is calculated as Qni = $[(V_{actual} – V_{ideal})/ V_{standard} – V_{ideal})] \cdot 100$. Where Qni = quality rating of ith parameter for a total of 'n' water samples V_{actual} = Value of the water quality parameter obtained from the laboratory analysis. $V_{standard}$ = Value of the water quality parameter obtained from the standard tables. V_{ideal} for pH = 7 and for the other parameters it is equivalent to zero.

Statistical analysis. The data was processed by applying principal component analysis (PCA) in order to gain the knowledge on the distribution of pollutants by detecting similarities and differences between the data. The data arranged in a matrix with chemical parameters as columns and samples as rows. The PCA was carried out with factors having eigen vectors higher than one (Kaiser criterion). The principal components (PCs) are extracted in decreasing order of importance, so that the first PC accounts for as much of the variation as possible and each successive component accounts are little less. As the first PC accounts for the co-variation shared by all attributes, this may be a better estimate than simple or weighted averages of the original variables. The variables in descending order by absolute value of their loading co-efficient are obtained by sorted size option. Thus the loadings were grouped on the basis of highest load highest. During the PCA the loadings were suppressed to less than 0.1 in absolute value, and thus small values are replaced with blanks. The quality of data for factor analysis is confirmed with Kaiser-Meyer-Olkin (KMO) test. Afterwards, the rotation of PCs was made by varimax-normalised algorithm, which allows simplifying interpretation by maximizing the variance (Kaiser, 1958) of the variable loadings on each factor. High loadings on single factors are obtained by varimax rotation. The PC loading of different segments of the study area were analysed and box plots are drawn for each physico-chemical parameter.

Results and discussion

During the study period the groundwater samples were analyzed for different water quality parameters. The data interpretation is made by correlation matrix and PCA. The descriptive statistics of the studied groundwater samples in the SW, NE and NW segments of local Rameswaram area is also shown in Table 1. The pH of the groundwater samples in the study area observed from neutral to alkaline nature, recorded with the mean pH values of 7.39, 7.38 and 7.57 in the SW, NW and NE segments respectively.

Table 1. Descriptive statistics of the divided segments in the residential area of Rameswaram Island, India

Parameters	Minimum			Maximum			Mean			Standard Deviation		
	SW	NW	NE	SW	NW	NE	SW	NW	NE	SW	NW	NE
pH	6.64	6.8	6.92	8.59	7.85	8.38	7.39	7.38	7.57	0.29	0.28	0.41
TA (mg/L)	126.7	103.7	115.2	492.5	403.4	218.9	204.3	230.8	168.7	72.6	82.4	28.4
Salinity (mg/L)	750	510	1010	3000	2980	2760	1499.6	1989.5	1415.6	418.7	694.0	526.5
EC (μS)	1350	910	1800	5400	5360	4970	2680	3560	2540	750	1240	950
TDS (mg/L)	714	483	951	2870	2840	2630	1421.0	1887.5	1341.9	400.0	661.3	503.4
CH (mg/L)	248.1	231.3	265	870.2	992.4	711	505.43	633.1	413.1	138.1	239.8	114.2
MH (mg/L)	0	0.2	1.2	549.2	181.3	448.1	28.11	20.1	52.78	79.8	38.0	116.7
TH (mg/L)	257.6	255.3	284.3	896.1	1012.2	910.6	533.5	653.2	465.9	144.6	229.9	158.8
Chloride (mg/L)	212.3	155.7	268.9	1301.9	1174.6	1095	425.0	638.1	425.2	168.0	260.6	223.1
Fluoride (mg/L)	WDL	0.16	WDL	1.84	1.84	1.64	0.56	0.88	0.64	0.4	0.46	0.54

The amount of TDS ranged from 714 to 2870 mg/L (mean: 1421.0 mg/L), 483 to 2840 mg/L (mean: 1887.5 mg/L) and 951 to 2630 mg/L (mean: 1341.8 mg/L) in the SW, NE and NW segments respectively. The higher TDS content may be deduced due to sea water percolation into the groundwater through small pockets of waterlogged areas is possible as reported earlier (Palanivelu, 2006)

In the present coastal area, the amount of salinity ranged between 750 and 3000 mg/L (SW), 510 and 2890 mg/L (NE) and, 1010 and 2700 mg/L (NW). The TH of the groundwater samples was registered between 257.6 and 896.1 mg/L; 255.3 and 1012 mg/L; 284 and 910.6 mg/L in the SW, NE and NW segments with the mean values of 533.5 mg/L, 653.1 mg/L and 465.9 mg/L respectively. From these values, the 'non carbonate type' nature was observed in all the samples where TH is greater than TA (Chow 1964) in the three segments which is due to the increase in chloride and other ions as witnessed in an earlier study (Subbarao 2006). The groundwater samples were estimated with more CH with respect to the recomendation of WHO (75 – 200 mg/L), which accounts for the existence of calcium rich minerals such as gypsum, limestone, etc. (Murugesan 2004). The chloride content ranged from 212.3 to 1301.9 mg/L, 155.7 to 1174.6 mg/L and 268.9 to 1096.0 mg/L in the SW, NE and NW segments respectively. The fluoride content varied from the minimum non-detectable level to 1.84 mg/L and 1.64 mg/L, in the SW and NW segments respectively whereas the NE segment was recorded between 0.16 mg/L and 1.84 mg/L.

The ratio of certain chemical parameters such as $Cl/CO_3^{2-} + HCO_3^-$ and TA/TH can be used to assess salt-water intrusion into the coastal aquifers (Rengaraj et al., 1996 and Shanmugam et al., 2006). According to Simpson (1946), the following scale is used to assess the groundwater contaminated by salt-water intrusion (Table 2).

In the study area, the SW and NW segments suffer from salt water intrusion with moderately contaminated aquifers for about 74 % and 75 % respectively. In the NE segment, about 55 % of the groundwater samples were found to be injuriously contaminated and 36 % were moderately contaminated. The NE segment suffers from severe salt water intrusion as compared to the SW and NW segments. According to the groundwater classification (Davis and Dewiest, 1966 & Freeze and Cherry, 1976) about 87 % of the groundwater samples were found suitable for irrigation and the remaining (~ 13 %) were fit for drinking. A similar study related to the pollution of groundwater due to saline water intrusion from the sea in the Manali area was reported by Swaminathan and Narayanan (1994).

The correlation matrix among the water quality parameters is shown in Table 3. The correlation values of EC, TDS, salinity, CH and TH with chloride is found significant at 1% level in the SW, NE and NW segments.

Table 2. Groundwater quality criteria using certain chemical ratios

Range of $Cl/CO_3^{2-} + HCO_3^-$		Description	Segments		
			SW n = 50	NE n = 22	NW n = 16
< 0.05		Normally fresh groundwater	0	0	0
0.05 – 1.30		Slightly contaminated groundwater	3	2	0
1.30 – 2.80		Moderately contaminated groundwater	37	8	12
2.80 – 6.60		Injuriously contaminated groundwater	9	12	4
6.60 – 15.50		Highly contaminated groundwater	1	0	0l
> 200		Sea water	0	0	0
TA/TH ratio	Minimum	***	0.18	0.21	0.24
	Maximum	***	0.85	0.81	0.57
	Mean	***	0.41	0.39	0.39

Table 3. Karl Pearson correlation matrix for the parameters in SW, NW and NE segments of Rameswaram area, Tamil Nadu, India

	pH	TA	Salinity	EC	TDS	CH	MH	Chloride	Fluoride
pH	**1**	0.215 *0.337* **- 0.624**	0.149 *0.184* **- 0.311**	0.147 *0.184* **- 0.309**	0.149 *0.184* **- 0.309**	0.162 *- 0.007* **- 0.515**	0.039 *0.167* **- 0.159**	0.050 *0.093* **- 0.324**	- 0.084 *- 0.127* **0.174**
TA		**1**	0.282 *0.405* **0.644**	0.281 *0.403* **0.644**	0.279 *0.400* **0.643**	0.241 *0.338* **0.528**	- 0.112 *- 0.089* **0.342**	0.708 *0.296* **0.561**	0.020 *0.026* **0.008**
Salinity			**1**	0.999 *0.999* **0.999**	0.999 *0.999* **0.999**	0.866 *0.859* **0.694**	- 0.112 *0.152* **0.584**	0.863 *0.943* **0.954**	- 0.037 *0.201* **0.145**
EC				**1**	0.999 *0.999* **0.999**	0.865 *0.858* **0.895**	- 0.111 *0.154* **0.583**	0.862 *0.943* **0.955**	- 0.038 *0.201* **0.141**
TDS					**1**	0.863 *0.858* **0.693**	- 0.111 *0.154* **0.584**	0.862 *0.943* **0.955**	- 0.038 *0.203* **0.144**
CH						**1**	0.207 - 0.267 **- 0.054**	0.743 *0.905* **0.745**	- 0.052 *0.001* **- 0.436**
MH							**1**	0.001 *0.091* **0.395**	- 0.042 *0.345* **0.504**
Chloride								**1**	- 0.060 *0.040* **0.015**
Fluoride									**1**

Fonts: Normal – SW; *Italic* – NW; **bold** – NE

This approves the abundance of calcium rich minerals such as gypsum, limestone ect in thestudy area. The NW segment is remarkably observed with a significant correlation at 5 % level for MH-Salinity and EC-TDS, which evidences the influence of magnesium ions in the quality of groundwater samples. The influence of TA with respect to salinity, EC, TDS, CH and chloride can be accounted from the correlation values 0.644 (TA with EC, salinity and TDS), 0.631 (TA with TH) and 0.561 (TA with chloride) in the NWsegment of Rameswaram local area.

The correlation between EC and chloride has been observed with 0.943(SW), 0.862(NE) and 0.955(NW) may be attributed to the fact that high conductance reflects the presence of high chloride content in the groundwater samples (Jeyavel Raja et al., 2007). The correlation values of fluoride with calcium in the three segments have been found with no significant influence with respect to each other as reported in the earlier studies (Gupta, 1986; Handa, 1975; Chi man leung, 2005; Paramesha Naik, 2007). But in the NW segment, a significant correlation between fluoride and MH (0.504) throws some light in the existence of minerals rich in magnesium and fluoride in the study area.

Table 4. Distribution of groundwater samples (%) within the recomendations of WHO (2006) for drinking water

Parameters	SW	NE	NW	WHO
pH	98	100	100	6.5 – 8.5
TDS	nil	14	12	500 mg/L
TA	70	41	81	200 mg/L
CH	nil	nil	nil	75 mg/L
MH	82	91	75	30 mg/L
TH	nil	nil	nil	100 mg/L
Chloride	nil	5	nil	200 mg/L
Fluoride	96	86	94	1.5 mg/L

Potable status of groundwater samples

The distribution of groundwater samples within the recomendations of WHO (2006) is shown in Table 4. The value of pH in most of the samples was found within the recomended limit of WHO. The TDS content in 14 % and

12 % of groundwater samples in the NE and NW segments respectively was found below the WHO limit. The NE segment was registered with less percentage (41 %) of water samples within the recomended limit of TA as compared to the other two segments. In the CH and TH contents, no sample was found within the WHO recomended limit in all the three segments. Most of the samples were found within the permissible limit of fluoride in all the segments.

Water Quality Iindex and Langelier Saturation Index

Water quality index is a suitable tool for deciding the suitability of groundwater for drinking purposes. In the present study area, the NW segment was dominated with about 44 % under Excellent category (WQI < 25) whereas the NE and SW segments dominated with 54 % and 46 % under Good category (WQI = 26 – 50). The groundwater samples under Poor category (WQI = 51 – 75) were accounted for about 14 %, 18 % and 25 % in the SW, NE and NW segments respectively. Less than 15 % and 5 % of the samples were observed under Very Poor (WQI = 76 – 100) and Unfit (WQI > 100) categories respectively in the three segments.

The LSI values of the groundwater samples infer the nature to deposit more $CaCO_3$ which enhances the scale forming tendency of the groundwater samples. Majority of the samples found to have positive LSI values in all the three segments.

Principal Component Analysis

PCA was conducted to characterize the linear correlations. The loadings of the variables for each of the PC are obtained. The first principal component is influenced by each original variable. Five principal components were obtained and the PCA suggests that the first dimension of the ordination is by far the most important as it has high eigen values of 2.642, 3.179 and 3.462 and accounts for a large proportion of 37.74 %, 45.41 % and 49.46 % in the SW, NE and NW segments respectively. The first three PCs in the SW and NE segments account for about 71 % and 81 % of the experimental variance. NW segment registers about 76 % of the experimental variance for the first two PCs. The factor analysis is done for the groundwater samples of the study area and represented in the Table 5. Each variable has high communality that shows variation in common with others and thus clarified for its inclusion in the analysis. In order to make the interpretation easier, varimax rotation is carried out to distinguish the PCs which come under same range of loadings.

Table 5. Factor analysis for the water quality parameters of groundwater in SW, NW and NE segments

Principal components	Principal Component loadings								
	PC-1			PC-2			PC-3		
	SW	NW	NE	SW	NW	NE	SW	NW	NE
CH	0.929	0.985	0.814	-0.190	-0.126	-0.454	-0.184	0.012	–
TH	0.927	0.974	0.913	0.296	-0.078	0.287	0.000	0.128	–
Chloride	0.854	0.958	0.885	0.047	-0.032	0.082	- 0.271	0.072	–
MH	0.070	- 0.328	0.446	0.863	0.322	0.834	0.317	0.694	–
TA	0.317	0.472	0.814	- 0.545	0.540	- 0.021	0.420	- 0.017	–
Fluoride	- 0.114	0.029	-0.063	- 0.195	- 0.279	0.815	- 0.371	0.807	–
pH	0.266	0.093	-0.564	- 0.181	0.906	0.477	0.771	0.027	–
Eigen value	2.642	3.179	3.462	1.239	1.316	1.882	1.117	1.115	–
Per. Var	37.740	45.410	45.459	17.690	18.810	26.900	15.960	16.500	–
Cum. Per. Var	37.740	45.410	49.460	55.430	64.220	76.350	71.390	80.710	–
CH	0.930	0.988	0.854	0.203	0.036	- 0.372	- 0.166	- 0.098	–
TH	0.906	0.982	0.880	0.093	0.083	0.375	0.341	0.018	–
Chloride	0.897	0.953	0.872	0.012	0.125	0.169	- 0.018	- 0.032	–
MH	0.032	- 0.297	0.362	- 0.182	0.274	0.874	0.904	0.727	–
TA	0.151	0.373	0.812	0.712	0.609	0.059	- 0.210	- 0.067	–
Fluoride	-0.017	0.163	- 0.143	- 0.226	- 0.259	0.804	- 0.371	0.797	–
pH	0.027	- 0.047	- 0.609	0.788	0.910	0.419	0.277	0.020	–

Note. Per.Var – Percentage Variance; Cum.Per.Var – Cumulative Percentage Variance.

Most significant variables in the components represented by loadings higher than 0.6, are taken into consideration for the interpretation (Mahloch,1974). An interpretation of the rotated three principal components was made by examining the component loadings noting the relationship to the original variables for the samples in the SW and NE segments. The first principal component accounts for about 38 % and 42 % of total experimental variance in the SW and NE segments respectively. The first principal component in the SW and NE segments registers high loadings for CH (0.929 and 0.985), TH (0.927 and 0.974) and chloride (0.854 and 0.958).

In the NW segment, the first principal component was observed with a total experimental variance of 49 % and high loadings for CH (0.814), TH (0.913), chloride (0.885) and TA (0.814). In the second PC, high loadings of MH (0.863) in the SW segment, TA (0.540) in the NE segment and MH (0.706) and F (0.815) in the NW segment reflected the existence of minerals associated with carbonates, bicarbonates and magnesium. The concentration of TDS, TA, CH, Cl and F has been found higher in the NE segment as compared to the other remaining two segments whereas heavy load of magnesium has been observed in the NW segment of local Rameswaram area.

Management plan

A proper management plan needs to be focused for the betterment of peoples' healthy and hygienic life.

1. Potable water is becoming scarce among the populace of the study area which needs immediate attention by way of treatment techniques such as desalination and water softening.
2. As the study area is a symbol of National Integration being visited by people from all parts of the world, a proper land developmental technique such as improved sub-surface drainage should also be adopted to improve the water quality.
3. Erection of a sewage water recycling plant is inevitable in order to recharge the underground water by constructing a battery of injection wells.
4. People of the area need to be educated with the problems and endemic diseases caused by polluted water and advised to make conjunctive and consumptive use of groundwater.

Conclusion

The groundwater samples of the present coastal area have been found with more salinity, TDS, CH, TA and chloride in majority of the samples beyond the drinking level standards of WHO. Non-carbonate hardness in all the samples has witnessed the existence of greater input of chloride especially after monsoon. Salt-water intrusion in the SW and NW segments causing moderate contamination of the groundwater samples was observed. The domination of scale forming tendency has been elucidated through histograms of LSI values in all the three segments. The principal component analysis for the SW, NE and NW segments substantiates the dissolution of heavy inorganic load especially associated with calcium.

As the aquifers are enriched mainly with hardness imparting calcium species, treatment techniques such as water softening, desalination may solve the existing water quality parametric complications. As the scarcity of potable water gets increasing, the Government and Public should work hand in hand for an integrated management by targeting towards furnishing water to all on a sustainable basis.

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