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GROUNDWATER QUALITY AND ITS SUITABILITY FOR DRINKING AFTER TSUNAMI IN COASTAL BELT OF KANYAKUMARI TO COLACHEL, TAMIL NADU, INDIA

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ABSTRACT

Hydrochemistry of groundwater in coastal area of Kanyakumari to Colachel after Tsunami was used to assess the quality of groundwater for determining its suitability for drinking purposes. Physical and chemical parameters of groundwater such as electrical conductivity, pH, total dissolved solids (TDS), Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}, NO_3^-, F^-, B^- and SiO_2 were determined. Concentrations of the chemical constituents in groundwater vary spatially and temporally. Interpretation of analytical data shows that mixed Ca-Mg-Cl, Ca-Cl and Na-Cl are the dominant hydrochemical facies in the study area. Alkali earths (Ca^{2+}, Mg^{2+}) and strong acids (Cl^-, SO_4^{2-}) are slightly dominating over alkalis (Na^+, K^+) and weak acids (HCO_3^-, CO_3^{2-}). The abundance of the major ions is as follows: $Na^+ > Ca^{2+} > Mg^{2+} > K^+ = Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > CO_3^{2-}$. Groundwater in the area is generally very good, pleasant, fresh to brackish, average to very low saline and low alkaline in nature and fit for drinking purposes. Permissible average total hardness and TDS in all places of the study area identify the suitability of groundwater for drinking. Based on the TDS value, the groundwater in these areas is of bicarbonate/ calcium chloride/sodium chloride type. Fluoride and boron are within the permissible limits for human consumption and crops as per the international standards. Nitrate concentration is slightly high in some areas. In the study area less groundwater extraction keeps the water table high. The elevated topography, more rainfall and limited groundwater extraction, keeps the Kanyakumari coastal belt free from seawater intrusion. The surface water resources have been fully utilized. The surface flow is more during monsoon periods. Quality of water is generally good throughout the district except some places in the study areas like Keelamanagudi, Thengampudur and Colachel and some pockets along the coastal belt. Comparing the results of water parameters before and after Tsunami there is not much change in the quality of water for drinking.

INTRODUCTION

Quality of groundwater is equally important to its quantity owing to the suitability of water for various purposes. Water quality analysis is an important issue in groundwater studies. Variation of groundwater quality in an area is a function of physical and chemical parameters which are greatly influenced by geological formations and anthropogenic activities. Sujatha & Rajeswara Reddy (2003) have studied groundwater and its suitability for irrigation in the southeastern part of the Ranga Reddy district, Andra Pradesh, India. Ahmed et al. (2002) have compared the analytical results of groundwater in Rajshahi city of Bangladesh with the recommended limits suggested by World Health Organisation (WHO 1971). They have classified groundwater into various types. Anbazhagan & Nair (2004) have used the geographical information system (GIS) to represent and understand the spatial variation of various geochemical elements in Panvel Basin, Maharashtra, India. Saleh et al. (1999) have prepared correlation matrixes for the relationship between physical and chemical parameters of groundwaters. They focused on boron concentration in groundwater to classify the irrigation water for various types of crops in the Damman and Kuwait group of aquifers, Kuwait. Knowledge on hydrochemistry is more important to assess the quality of groundwater for understanding its suitability for various needs.

Previous investigations in the coastal area of Kanyakumari district, Tamil Nadu include groundwater estimation by Ground and Surface Water Resources, Water Resources Organization, Public Works Department, Government of Tamilnadu, Chennai (1973 to 2004) India, and chemistry of groundwater by the Indian Public Works Department (2004). However, spatial variation of concentrations of common trace elements in groundwaters such as boride and boron and the suitability of groundwater for drinking and irrigational needs were not included. As groundwater in the coastal belt of Kanyakumari to Colachel area is affected by Tsunami on 26th December, 2004 , it is essential to assess the suitability of groundwater for drinking after Tsunami. There are no major industries in this area except Indian Rare Earths Ltd. at Manavalakurichi. Hence, the present work had the objective of understanding the spatial distribution of hydrogeochemical constituents of groundwater related to its suitability for domestic use after Tsunami. Hard rock terrain with network of irrigation system and less groundwater extraction keeps the water table high in the coastal belt. The salt water-freshwater interface line runs parallel to the coast within 0.2 to 0.56 km from the shore. Around salt pan areas the quality is poor due to the presence of salt pan as well as from the backwater of river Palayar. However, there is not much change in the water quality parameters due to salt pan. The elevated topography, more rainfall and limited ground water extraction, keeps the Kanyakumari coastal belt free from seawater intrusion.

MATERIALS AND METHODS

Description of the study area: Kanyakumari district coastal belt is approximately between latitudes 8°05’30” to 8° 34’30” N and longitudes 77°06’30” to 77° 35’00” E. Kanyakumari district covers an area of 1671.84 km^2 (Fig. 1) in which along the coastal belt 70 km length and 5 km width Kanyakumari to colachel coastal belt was taken as study area after Tsunami in December 2004 (total study area is 350 sq km).

The average maximum temperature recorded during April to May was about 35.93°C. The average minimum temperature was about 23.85°C recorded usually during the months of November and December. The average annual rainfall of the basin is about 1448.6 mm. The northeast monsoon from October to December contributes about 538.6mm, and the southwest monsoon from June to September about 538.3mm. During hot whether period from March to May rainfall is 326.3mm and during January and February the rainfall is 45.4mm in the study area.

The whole area is generally undulated with ups and downs slopping towards different directions. All major rivers originate from the Western Ghats and flow towards southeast. Wind velocity generally reach maximum in July-August indicating the setting of monsoon over the district. The maximum wind speed of 17.74 km/hr is recorded during August, and the minimum of 5.53km/hr during December. Humidity in the area is generally high at 95% during May, whereas the minimum (45%) during February. Water samples were tested every month from July 2005 to July 2006 in order to analyze the parameters of water quality in the study area.

Field and laboratory methods: Groundwater samples were collected from 175 representative open wells and 3 PWD wells during July 2005 and July 2006 at regular intervals for tests. Electrical conductivity (EC) and pH were measured using digital meters immediately after sampling in the field. For chemical constituents, such as sodium, potassium, calcium, magnesium, chloride, bicarbonate, carbonate, sulphate, nitrate, fluoride, boron, silica and TDS, waters were analysed in the laboratory using the standard methods as suggested by APHA (1989, 1995). Flame photometer was used to measure Na^+ and K^+ ions. Boron concentration was determined with the help of Atomic Absorption Spectrophotometer. The accuracy of the chemical analysis was verified by calculating ion-balance errors where the errors were generally around 10%.

RESULTS AND DISCUSSION

Understanding the quality of groundwater is as important as its quality because it is the main factor determining its suitability for drinking. The pH values of groundwater ranged from 7.5 to 8.4 with an average value of 7.9 during July 2005. However, during July 2006, it ranged from 7.4 to 8.3 with an average value of 7.8. This shows that the groundwater of the study area is mainly alkaline in nature. The average EC values ranged from 410 to 1330 micromhos/cm during July 2005 and 400 to1850 micromhos/cm during July 2006. The average TDS values ranged from 260 mg/L to 403 mg/L during July 2005 and 280 mg/L to 675 mg/L during July 2006. Physical and chemical parameters including statistical measures, such as minimum, maximum, average, median, mode and standard deviation are reported in Table 1 during July 2005 and July 2006. The abundance of the major ions in groundwater is in the following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+ = Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > CO_3^{2}$. Silica in groundwater varied from 23.8 mg/L to 63 mg/L during July 2005, and 29.2 mg/L to 69.9 mg/L during July 2006. The average values were 35 mg/L and 45 mg/L respectively during July 2005 and July 2006. The average value of boron concentration in groundwater is 0.13 mg/L during July 2005 and 0.23 mg/L during July 2006. Fluoride contents are very low, less than 1mg/L.

Table 1: Minimum and maximum values of physical and chemical parameters of groundwater with statistical parameters.

Parameters		Minimum		Maximum		Average		Median		Mode		Standard deviation	
		Jul-05	Jul-06	Jul-05	Jul-06	Jul-05	Jul-06	Jul-05	Jul-06	Jul-05	Jul-06	Jul-05	Jul-06
pH	~	7	7.1	8.2	8.6	7.5	7.8	8.1	7.6	8.2	7.5	0.53	0.32
EC		85	182	1170	1540	652	734	410	492	403	502	262	403
TDS		48	125	845	1051	322	608	288	413	272	415	289	318
Na^+		6	23	104	162	76	92	69	66	62	106	76	96
K^+		1	6	8	18	6.5	14.8	5.2	8.6	5	12.5	2	18
Ca_2^+		9	12	83	180	43	167	39	68	48	66	20	14
Mg_2^+		2	5	24	48	33	58	31	42	80	65	41	76
Cl^-		4	43	763	882	259	367	126	193	156	128	96	518
HCO_3^-		18	49	75	131	103	235	97	166	175	217	79	85
CO_3^{2-}		0	10	6	2	2	8	0	0	0	8	12	7.4
SO_4^{2-}		0	9	73	82	29	55	23	72	41	48	21	29
NO_3^-		0	0	8	16	6	7.4	12	2.5	4	0	8	12.7
SiO_2		0	9.2	43	49	31	18	62	66	59	63	9	63
B		0	0	0.5	0.3	0.29	0.23	0.18	0.21	0.19	0.11	0.12	0.29
F^-		0	0	0.17	0.19	0.25	0.38	0.21	0.54	0.3	0.65	0.21	0.32
TH		32.8	60.8	730	1216	417	892	314	418	0	2	9	318
SAR	~	0.1	0.14	0.34	5.69	1.1	1.9	1.7	2.1	~	~	1.6	2.8
RSC		-12.6	-57	0.8	0.19	-3.3	-7	-4	-5	~	~	6.2	12.9
%Na		11.1	3.7	37	23	15	17.7	12	19.4	~	~	76	92
PI %		15.8	8.6	66.3	66.9	40.7	40.5	43.7	48.7	~	~	16.6	22.7

All units are in mg/L except EC (micromhos/cm) and pH, SAR

Correlation of physico-chemical parameters of groundwater: Correlation coefficient is a commonly used measure to establish the relationship between two variables. It is simply a measure to exhibit how well one variable predicts the other (Kurumbein & Graybill 1965). The correlation matrices for 16 variables are prepared for July 2005 and July 2006 (Table 2) and illustrate that EC and TDS show good positive correlation with Mg^{2+} and Cl^{-}. TDS and Mg^{2+} also exhibit high positive correlation with SO_4^{2-} and Cl^{-} ions. EC-SO_4, TDS-Ca, TDS-B, Ca-Mg, Ca-Cl, Mg-B, Cl-SO_4 and Cl-B are also the more significant correlation pairs during July 2005. However, Na-SO_4 and Mg-B are the good positive correlation pairs during July 2006. Furthermore, Na and SO_4 ions also show more significant correlation pairing with NO_3 during July 2006. pH and F exhibit negative correlation with most of the variables, and SiO_2 exhibit no significant correlation with any one of the variables in the matrixes.

Hydrochemical facies: The geochemical evolution of groundwater can be understood by plotting the concentrations of major cations and anions in the Piper (1944) trilinear diagram (Fig. 3). The plot shows that most of the groundwater samples analysed at regular intervals during 2005, 2006 fall in

Table 2: Correlation of physio-chemical parameters of groundwater of July 2005-2006.

Parameters	EC	pH	TDS	Na	K	Ca	Mg	Cl	HCO_3	CO_3	SO_4	NO_3	B	F	SiO_2
July 2005															
EC	1														
pH	0.009	1													
TDS	0.858	-0.002	1												
Na	0.579	0.289	0.624	1											
K	0.232	0.391	0.336	0.038	1										
Ca	0.509	-0.165	0.609	0.276	0.253	1									
Mg	0.767	0.02	0.865	0.408	0.323	0.728	1								
Cl	0.873	-0.003	0.889	0.564	0.357	0.752	0.635	1							
HCO_3	0.271	-0.103	0.19	0.257	0.013	0.08	0.093	0.0282	1						
CO_3	-0.17	0.289	-0.146	0.182	0.142	-0.279	-0.19	-0.17	0.181	1					
SO_4	0.509	-0.156	0.794	0.506	0.154	0.58	0.452	0.6073	0.263	-0.194	1				
NO_3	0.395	0.145	0.104	0.177	0.011	0.175	0.19	0.1903	-0.075	-0.095	0.181	1			
B	0.509	0.035	0.581	0.107	0.254	0.691	0.692	0.6076	0.245	-0.509	0.654	0.081	1		
F	0.013	0.085	0.023	0.035	0.007	0.016	0.011	0.0127	0.11	0.089	0.046	0.018	0.013	1	
SiO_2	-0.04	-0.018	0.019	-0.083	0.53	0.11	0.058	0.0609	-0.362	-0.257	0.098	0.19	-0.09	-0.14	1
July 2006															
EC	1														
pH	0.01	1													
TDS	0.876	-0.001	1												
Na	0.546	0.241	0.647	1											
K	0.207	0.365	0.337	0.031	1										
Ca	0.538	-0.138	0.671	0.215	0.284	1									
Mg	0.72	0.028	0.835	0.44	0.388	0.789	1								
Cl	0.843	-0.001	0.873	0.524	0.344	0.8	0.668	1							
HCO_3	0.236	-0.101	0.17	0.286	0.002	0.098	0.092	0.0216	1						
CO_3	-0.11	0.241	-0.12	0.176	0.125	-0.266	-0.191	-0.141	0.125	1					
SO_4	0.576	-0.14	0.712	0.513	0.153	0.587	0.415	0.6641	0.203	-0.131	1				
NO_3	0.303	0.101	0.138	0.148	0.006	0.106	0.182	0.1578	-0.008	-0.014	0.186	1			
B	0.524	0.027	0.557	0.15	0.229	0.647	0.696	0.6926	0.292	-0.523	0.6	0.076	1		
F	0.003	0.076	0.02	0.034	0.005	0.003	0.018	0.0087	0.102	0.007	0.036	0.007	0.009	1	
SiO_2	-0.02	-0.003	0.006	-0.074	0.11	0.124	0.072	0.0644	-0.368	-0.219	0.031	0.148	-0.036	-0.11	1

the field of mixed Ca-Mg-Cl type of water. Some samples are also representing Ca-Cl and Na-Cl types. From the plot, alkaline earths (Ca^{2+} and Mg^{2+}) significantly exceed the alkalis (Na^{+} and K^{+}) and strong acids (Cl^{-} and SO_4^{2-}) exceed the weak acids (HCO_3^{-} and CO_3^{2-}) Aquachem software was used for plotting the Piper diagram.

Drinking water quality: The analytical results of physical and chemical parameters of groundwater were compared with the standard guideline values as recommended by the World Health Organisation (WHO 1971, 1983) for drinking purposes (Table 3). The table shows the most desirable limits and maximum allowable limits of various parameters. The concentrations of cations, such as Na^{+}, Ca^{2+}, and Mg^{2+} are within the maximum allowable limits for drinking except few samples.

Total dissolved solids: To ascertain the suitability of groundwater for any purpose, it is essential to classify the groundwaters depending upon their hydrochemical properties based on their TDS values (Catroll 1962, Freeze & Cherry 1979), which are presented in (Table 4). The groundwater of the area is freshwater except for a few samples representing brackish water at Manakudi. Most of the groundwater samples are within the maximum permissible limit for drinking as per the WHO standards. At the junction point where Palayar and sea joins, the Echori effect was also studied and there was no such effect affected the surface and groundwater properties.

The TDS zonation map for July 2006 (Fig. 5) was prepared by setting most desirable (500 mg/L) and maximum allowable (1,500 mg/L) limits. The map shows that 2/3 of the basin is below 500 mg/L of TDS, indicating low content of soluble salts in groundwater, which can be used for drinking without any risk.

Total hardness: The classification of groundwater (Table 5), based on total hardness (TH), shows that majority of the groundwater samples fall in the permissible limit of 500mg/L (Sawyer & McCarty 1967).

The hardness values ranged from 34.3 mg/L to 170 mg/L with an average value of 97 mg/L during July 2005, and 39.8 mg/L to 203 mg/L with an average value of 98 mg/L during July 2006. The maximum most desirable limit is 100 mg/L as per the WHO standard. The study area is delineated into three zones based on the desirable and maximum permissible limits of TH for July 2006 (Fig. 6).

Table 3: Groundwater samples of the study area exceeding the permissible limits by WHO for drinking purposes.

Parameters	WHO international standard (1971,1983)		Wells representing permissible limits in the study area		Desirable/ Undesirable effect
	Most desirable limits	Maximum allowable limits	Jul-05	Jul-06	
pH	7 - 8.5	9.2	7.2 - 8	7.5 -8.4	Taste
TDS (mg/L)	500	1500	288	308	Taste
TH (mg/L)	100	500	85	165	Taste
Na (mg/L)	~	200	53	92	Taste
Ca (mg/L)	75	200	14	20	Taste
Mg (mg/L)	50	150	1	16	Taste
Cl (mg/L)	200	600	100	135	Taste
SO_4 (mg/L)	200	400	10	28	Taste
NO_3 (mg/L)	45	~	1	6	Taste
F (mg/L)	~	1.5	Nil	Nil	Fluorosis

Table 4: Nature of groundwater based on TDS values for drinking purposes.

TDS (mg/L)	Nature of water	Jul-05		Jul-06	
		Representing wells	No.of wells	Representing wells	No.of wells
< 1000	Freshwater	1-7, 11-35, 38-51	46	1-7, 12-34, 37-51	45
1000-10000	Brackish water	8, 9, 10, 36, 37	5	8, 9, 10, 11, 35, 36	6
10000-100000	Saline water	Nil	Nil	Nil	Nil
> 100000	Brine water	Nil	Nil	Nil	Nil

Table 5: Classification of groundwater based on toatl hardness (TH) for drinking purposes.

TH (mg/L)	Water class	Jul-05		Jul-06	
		Representing wells	No.of wells	Representing wells	No.of wells
<75	Soft	1-8, 13-34, 39-51	43	1-8, 13-34, 39-51	43
75-150	Moderately hard	9, 10, 11, 12, 35, 36, 37, 38	8	9, 10, 11, 12, 35,36,37,38	8
150-300	Hard	Nil	Nil	Nil	Nil
>300	Very hard	Nil	Nil	Nil	Nil

Chloride: The chloride ion concentration varied between 17 mg/L and 168 mg/L in July 2005, and 23 mg/L to 182 mg/L in July 2006. However, the average values calculated for July 2005 and 2006 are within the prescribed limits of 100mg/L to 135 mg/L.

Nitrate: The nitrate concentration in July 2005 groundwaters ranged from 1 mg/L to 9 mg/L with an average of 6 mg/L. In July 2006 samples, it ranged from 1 mg/L to 6 mg/L with the average of 3.4 mg/L. The concentration of nitrogen in groundwater is derived from the biosphere (Saleh et al. 1999). Nitrogen is originally fixed from the atmosphere and then mineralized by soil bacteria into ammonium. Under aerobic conditions nitrogen is finally converted into nitrate by nitrifying bacteria (Tindall et al. 1995). All samples tested from July 2005 to July 2006 are within the permissible limit of nitrate (45 mg/L). The high concentration of nitrate in drinking water causes blue baby disease/ methaemoglobinaemia in children and gastric carcinomas (Gilly et al. 1984). In most of the study area nitrate is within the limit except some places in Colachal.

Sulphate, Magnesium: Sulphate is unstable if it exceeds the maximum allowable limit of 400 mg/ L and causes a laxative effect in humans with the excess magnesium in groundwater. It varied from 10mg/L to 28 mg/L for all the tested samples during July 2005 and July 2006. The maximum allowable limit of magnesium (150 mg/L) has been suggested for drinking. Magnesium varied from 1mg/ L to 16mg/L in all the tested samples.

Fluoride: Fluoride is one of the main trace elements in groundwater, which generally occurs as a natural constituent. Bedrock containing fluoride minerals is generally responsible for high concentration of this ion in groundwater (Handa 1975, Wenzel & Blum 1992, Bardsen et al. 1996). The concentration of flouoride in groundwater of the basin varied between 0.07 mg/L and 0.24 mg/L during July 2005 with an average value of 0.05 mg/L and median of 0.41. However, fluoride content in the area is very low; all samples examined exhibit suitability for drinking

CONCLUSION

Interpretation of hydrochemical analysis reveals that the groundwater in coastal area of Kanyakumari to Colachal belt is freshwater to brackish with alkaline nature, which is good for drinking. The

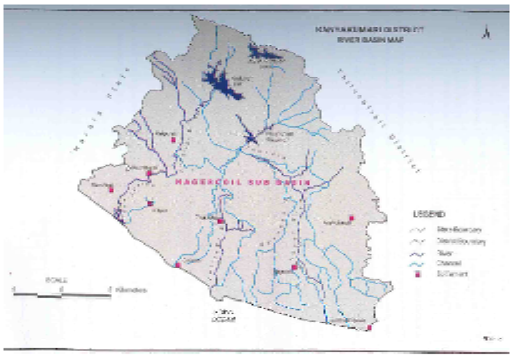

Fig. 1: Coastal belt of Kanyakumari-Colachal coastal area.

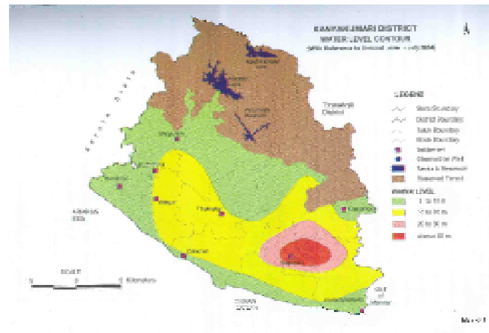

Fig.2: Water level contours of Jan. 2006 in Kanyakumari-Colachal coastal area.

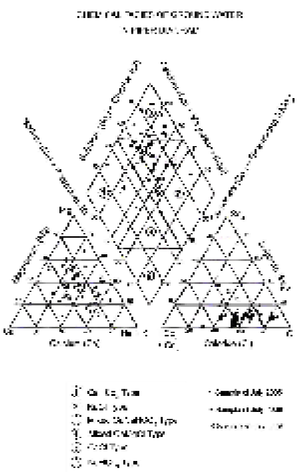

Fig. 3: Chemical facies of groundwater in Piper diagram- Kanyakumari-Colachal coastal area.

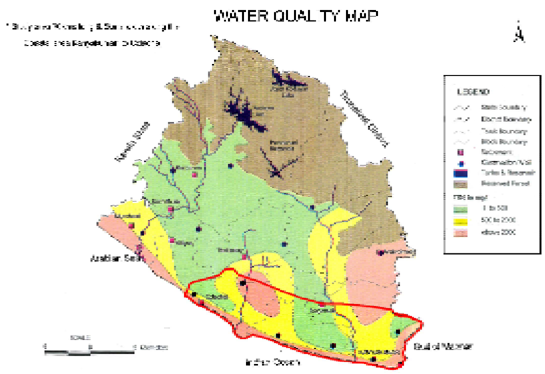

Fig.4: Water Quality map of Kanyakumari-Colachal coastal area.

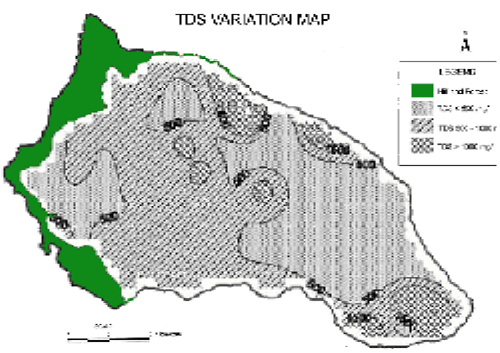

Fig. 5: Drinking water quality based on TDS values of Jul. 2006 in Kanyakumari-Colachal coastal area.

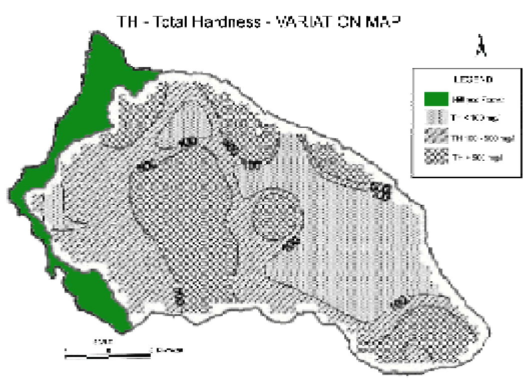

Fig. 6: Drinking water quality based on hardness values of July 2006 in Kanyakumari-Colachal coastal area.

sequence of the abundance of the major ions is in the order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+ = Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > CO_3^{2-}$. Alkali earths ($Ca^{2+}$ and Mg^{2+}) slightly exceed alkalis (Na^+ and K^+) and strong acids (Cl^- and SO_4^{2-}) exceed weak acids (HCO_3^- and CO_3^{2-}). This leads to a mixed Ca-Mg-Cl type of groundwater. However, some groundwater samples of the study area represent Ca-Cl and Na-Cl types. Magnesium, chloride and sulphate ions show positive correlation with EC and TDS. TH is generally within the limit in the groundwaters thereby, causing the groundwaters of the study area to be suitable for drinking as per July 2005 and July 2006 tests results. The concentrations of major ions in groundwater are within the permissible limits for drinking. Concentration of fluoride is within the permissible limit for drinking.

After Tsunami, during 2005 and 2006 at Manakudi, the EC values varied from 1300 to 1700 micromhos/cm due to the presence of brackish water, while in all other places EC value were within the permissible limit. While moving towards west, the quality of water improves, EC values varies from 900 to 1800 micromhos/cm. In the inland area, the EC value is normal around 250 to 500 micromhos/cm. Analysing the results after Tsunami, there was not much change in the water quality. Therefore, the surface and sub-surface waters in the coastal area are good for drinking purposes.

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