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Research Paper

Assessment of Groundwater Quality of East Coastal Region in Tamilnadu, India

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Abstract: *Assessment of groundwater quality studies was carried out in the east coastal region (ECR) from Bamban to Thiruvanmiyur in Tamil Nadu, south India., to find the suitability of groundwater for drinking and irrigation purposes. Totally, 36 groundwater samples were collected randomly from bore well, dug well and hand pumps during summer, post monsoon, pre monsoon and monsoon periods of 2011. It has been made by estimating pH, electrical conductivity, total dissolved solids, total hardness, alkalinity, major cations of Na^+, K^+, Ca^{2+}, and Mg^{2+} and major anions of CO_3^{2-}, HCO_3^- Cl^-, SO_4^{2-} and NO_3^-. Comparison with WHO standards Water Quality Index (WQI) in relation to drinking water quality proved that most of the water samples were found not suitable for drinking purposes. Domestic water quality parameters like, hardness and corrosives ratio revealed that most of the sampling locations were found unfit for domestic purposes. Chemical indices such as sodium percent, sodium adsorption ratio, residual sodium carbonate, permeability index, Kelley's ratio and magnesium hazard / ratio used for evaluating the water quality for irrigation suggested that the majority of the groundwater samples were found not suitable for irrigation. Chemical indices indicated that groundwater quality in the study area was chemically unsuitable for drinking purposes, classified as unsuitable category for domestic purposes and 50% of sampling locations were unsuitable for irrigation purposes.*

Keywords: Chemical indices, drinking, irrigation, seasonal variations.

Introduction

Groundwater is the main resource for drinking, domestic, irrigation and industrial purposes instead of surface water. The quality of groundwater is equally important to its quantity, owing to the suitability of water for various purposes. Coastal areas often exhibit a complex distribution of fresh water and salt water or in general, of different water types. Therefore, there has been a tremendous increase in demand for fresh water due to seawater intrusion, population growth and intense agricultural activities. Degradation of groundwater quality in coastal region generally occurs due to natural processes such as saline water intrusion, wind driven sea spray and marine aerosols deposited on the top soil, evaporation and interaction of groundwater with brines and sedimentary formation.[1] Apart from the natural process, anthropogenic contaminations such as industrial effluents, agricultural fertilizers, municipal waste water, septic tank effluent and land fill are other major causes of water quality deterioration[2,3].

The basic problem that concerns is surface water and groundwater, which is directly affected due to saline intrusion and migration of sea water towards landward side. Hence, the fresh water aquifers are turned into saline water zones in the coastal - deltaic plains. These problems of over - abstraction occurred in both rural and urban settings, with aquifers being depleted in the hard rock terrain of India and Tamilnadu in the coastal regions. In many coastal towns or cities of Tamilnadu, the growth of human settlements together with the development of agricultural, industrial and touristic activities, has led to the over exploitation of the groundwater. Such over exploitation induces a rise in the freshwater–saltwater interface and thus the degradation of groundwater quality and also the groundwater is a critical issue in coastal area where quantity is abundant. Groundwater along the coastal area of Tamil Nadu has been exploited heavily for agricultural, domestic and drinking purposes. Further, structural and climatic circumstances were found amenable for seawater intrusion [4,5]. Therefore, in the assessment of fresh groundwater potential, hydrochemistry plays an important role in coastal regions. Hydrochemical parameters were used to evaluate the impact of seawater intrusion process, the knowledge of which can be helpful to control the water quality in the coastal area[6]. Number of studies on groundwater quality with respect to drinking and irrigation purposes have been carried out in the different parts of India[7-9]. Hence, the present work is to explore the groundwater quality by carrying out groundwater qualitative analysis of some physico-chemical parameters of groundwater in south east coastal region in Tamil Nadu, India.

Study area and Methodology

Tamil Nadu is situated on the south east coast of peninsular India and comprising about 1,30,000 sq.km. The length of its coastline is about 1050 km with its significant portion of the east coast bordering of Bay of Bengal. The coastline starts from Pulicat along the east coast and extends up to Erayamanthurai in Kanniyakumari districts. Total length of the present study area (Figure.1) distance is 771 kms from Pamban (Rameshwaram) to Thiruvanmiyur (Chennai) and it could be covered by ten districts namely Ramanathapuram, Thiruvarur, Thanjavur, Puthukottai, Nagapattinam, Perambalur, Cuddalore, Viluppuram, Kancheepuram and South Chennai. The location of the thirty six chosen sites along the southeast coastal region from Rameshwaram to Thiruvanmiyur in Tamil Nadu during post monsoon (January), summer (May), pre monsoon (August) and monsoon seasons (November) of 2011. Geographically, it is located 9^0 17' 3.51" N - 12^0 59' 0.45'' N latitude and 79^0 13' 32'' E - 80^0 15' 32.63'' E longitude.

The base map of the study area was prepared and digitized using Arc GIS 9.3 software. The sampling sites were chosen to reflect the different activities of groundwater quality of chemical parameters extracted and all the water sampling collected through bore well, hand pump and dug well within min 2 to max 12 meters depth. Though district receives the rain under the influence of both southwest and northeast monsoons. The northeast monsoon chiefly contributes to the rainfall in the district and summer rains are negligible. The annual mean temperature of the study area is 28^0C. The soil natures of the coastal area are entirely alluvial, but vary in quality. Annual rainfall ranges from 1000 to 1500 mm and annual mean temperature of the study area is 28^0C.

Before sampling for chemical analysis, sample bottles were cleaned by soaking them in dilute nitric acid for 48 hrs, followed by rinsing with tap water until free of detergent, then rinsed with 5% nitric acid and then thoroughly washed with distilled-deionized water. High purity (Anal R grade) chemicals from merck and double distilled water was used for preparing solutions for analysis. Water quality parameters such as pH, electrical conductivity and Total dissolved solids were measured at the time of collection of samples by using L1 613 Elico digital pH meter, L1 CM 180 Elico digital conductivity meter and Elico TDS meter.

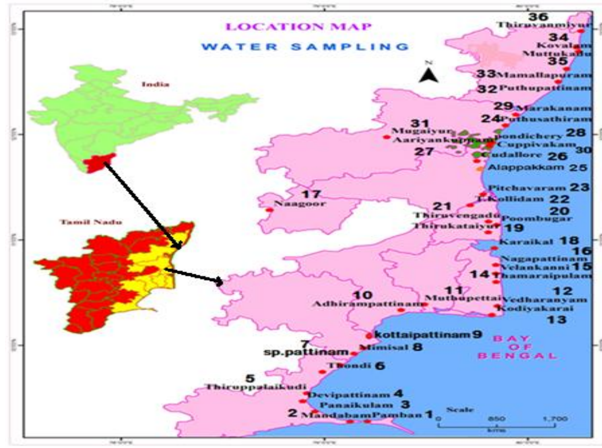

Figure 1: Location map of sampling stations

The other Water Quality Parameters (WQPs), DO measured within one hour, except BOD (BOD was determined after 5 days of incubation) were determined within 48 - 72 hours from the time of collection of sample and analyzed by (iodometric) Winkler method. Total hardness, calcium and magnesium ions were analyzed by complexometric titration methods using eriochrome black-T (EBT) and murexide indicator. Cl^-, CO_3^{2-}, HCO_3^-, Na^+, K^+, SO_4^{2-} and NO_3^- were analyzed using standard methods as suggested by the American Public Health Association manual methods (APHA, 1995)[1].

With respect to cations,. Sodium and potassium were estimated by Flame emission photometric method (Systronics Mediflame, Model 127,India). With respect to anions, Chloride were determined by Argentometric titration method with K_2CrO_4 indicator, Carbonate, Bicarbonate ions were determined by volumetric method using phenolphthalein and methyl-orange as indicator, nitrates were measured by UV spectrometric methods and Sulphates measured by $BaCl_2$ method using Turbidimetric method. The ionic balance error for studying ions was within ± 5 %. The total cations (TZ^+) and total anions (TZ) balance shows the charge balance error percentage.[10] Calculating the normalized inorganic charge balance which is defined as {Σcation - Σanion / Σcation + Σanion} and represents the fractional difference between the total cations and anions.[11]

Results and Discussion

The experimental results of physico - chemical characterization of groundwater undertaken for the study are discussed here under various sub-headings.

Groundwater chemistry: The experimental result of physico - chemical characterization of ground waters, during the various seasons and statistical parameters were presented in Tables 1. The analytical data indicated that the pH values of the water samples, varied from 6.5 - 8.6, 7.8 - 9, 7.7 - 8.9 and 7.3 - 8.5 with a mean value of 7.9, 8.3, 8.4 and 8.17 during post monsoon, pre monsoon, summer and monsoon respectively which indicate alkaline nature of the groundwater samples. Electrical conductivity values showed in the ranges minimum 90 and maximum 16700µS/cm. Higher values of EC and TDS are may be contributed by Na^+, K^+, Ca^{2+}, Mg^{2-}, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-. Based on the TDS classification[11], 55%, 61%, 61% and 47% of the groundwater samples were labeled as brackish type (TDS > 1000 mg/L) and the remaining fresh waters (TDS < 1000 mg/L) during post monsoon, pre monsoon, summer and monsoon seasons respectively. The order of abundance of the major cations and anions has been arrived at: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO_3^- > NO_3^- > SO_4^{2-} > CO_3^{2-}$.

The cations of Na^+, K^+, Ca^{2+}, Mg^{2+} were recorded minimum of 1, 1, 20 and 5ppm and maximum 1012, 250, 260 and 175 ppm respectively during post monsoon. Among the anions in ppm, the minimum concentration of CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^- by 0, 80, 32, 1, 3ppm and maximum 344, 1080, 1588, 480, 259ppm showed respectively during post monsoon. Similarly, the minimum, maximum and average concentration of anions during pre monsoon, summer and monsoon have also been recorded and used for assessment of water quality. In general, higher concentration of ions in the groundwater obtained which may be due to weathering of silicate rocks and anthropogenic activities. Evaporation leads to the concentration of ions, thereby increasing the chemical budget of ground water.[12] Dissolved oxygen and Biological oxygen demand as per WHO, BIS guidelines indicated that groundwater in the sampling locations were free from organic matter or pollution.

Table 1: Statistical values of WQPs in the study area

Parameters	Post monsoon			Summer			Pre monsoon			Monsoon		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
pH	6.5	8.6	7.9	7.7	8.9	8.4	7.8	9.0	8.3	7.3	8.5	8.17
EC	90	9500	2231	360	16700	2616	472	15790	2683	420	6300	1776
TDS	58	6080	1464	262	12877	1883	330	11646	1863	275	4221	1195
TA	80	1270	486	88	884	317	56	896	356	54	744	245
CO_3^{2-}	0	344	49	0	156	56	0	182	57	0	136	45
HCO_3^-	80	1080	436	36	868	263	38	876	298	72	728	200
TH	92	1144	376	20	2804	324	97	6725	573	0	676	189
Ca^{2+}	20	260	94	16	1056	114	24	1046	117	12	442	74
Mg^{2+}	5	175	40	4	1048	66	8	1030	69	14	316	31
Na^+	1	1012	262	6	1840	404	46	1762	407	26	644	252
K^+	1	250	41	2	152	44	5	154	45	2	70	24
SO_4^{2-}	1	480	48	1	640	93	7	636	97	4	292	48
NO_3^-	1	259	60	1	239	71	3	412	64	1	296	53
Cl^-	32	1588	386	37	6785	705	52	6779	728	36	1240	381
DO	6.3	8.5	7.3	5.5	8.1	7.2	6	7.3	6.9	6	8.4	7.3
BOD	1.9	4.3	3.13	1.5	3.9	2.6	1.5	4.0	2.6	1.8	4.4	3.3
All the parameters were given in unit mg/L (ppm) except temperature, pH and EC as given in ^oC, pH units and µS/cm respectively												

Table 2: Standards and Weights used in the study

Parameters	WHO-1984	Assigned Weight	Relative Weight
pH	7.5	4	0.16
TDS mg / L	1000	3	0.12
TH mg / L	75	2	0.08
Na^+ mg / L	200	1	0.04
K^+ mg / L	12	1	0.04
Ca^{2+} mg / L	100	2	0.08
Mg^{2+} mg / L	30	1	0.04
Cl^- mg / L	250	5	0.2
SO_4^{2-} mg / L	250	3	0.12
NO_3^- mg / L	50	4	0.16
HCO_3^- mg / L	-	2	0.08
Total		28	1.00

Table 3 : Classification of water quality based on WQI

WQI classes	Water quality	% of samples sites			
		Post monsoon	Pre monsoon	summer	monsoon
< 50	Excellent	(2.7%)	-	-	-
50-100	Good	(36%)	(19.4%)	(16.7%)	(38.8%)
100-200	Poor	(38.8%)	(50%)	(47.2%)	(44.4%)
200-300	Very poor	(11.1%)	(16.6%)	(25%)	(13.8%)
>300	Unsuitable	(11.1%)	(11.1%)	(11.1%)	(2.7%)

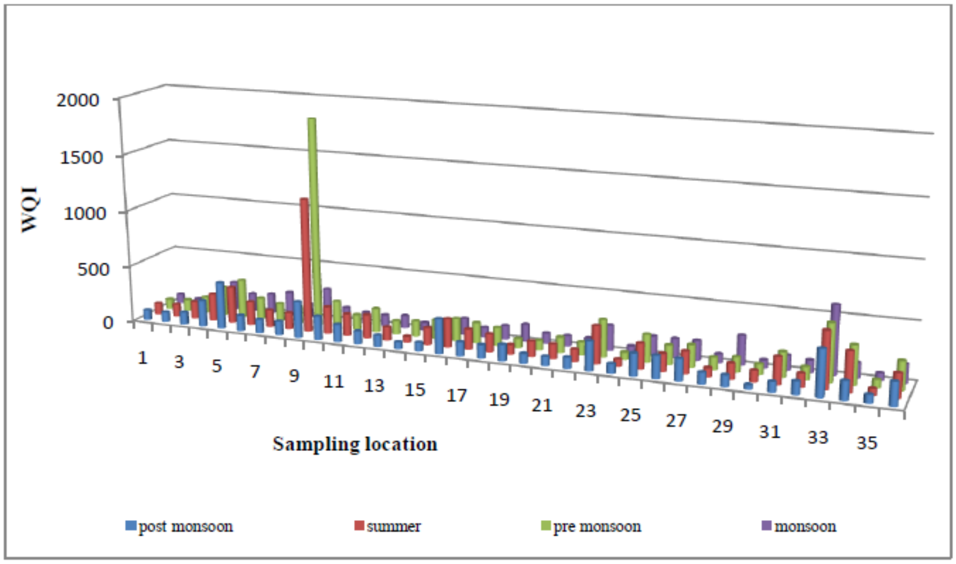

Figure 2: Trend diagram shows that variation of WQI values

Table 4: Classification of groundwater based on SAR values (Todd 1959 and Richard 1954)

SAR values	Sodium hazard class	Remarks on quality	% of samples sites			
			Post monsoon	Pre monsoon	Summer	Monsoon
<10	S1	Excellent	94.4%	80.5%	80.5%	91.6%
10-18	S2	Good	(5.5%)	(16.6%)	(16.6%)	(8.3%)
19-26	S3	Doubtful	-	-	-	-
>26	S4	Unsuitable	-	(2.7%)	(2.7%)	-

Drinking Water Quality: The suitability of water for drinking purposes was determined by using Water Quality Index (WQI)[13-15] scheme as developed by[16] Yidana and Yidana (Yidana and Yidana 2010) and World Health Organization standard values (WHO 1984) [17].

Water Quality Index: To assess the overall quality of the ground water samples a Water Quality Index scheme [18] was developed and applied. The Water Quality Index is defined as a rating that reflects the composite influence of different water quality parameters. Parameter consideration to develop a Water Quality Index (WQI) depends on the purpose for which water is used. Parameters were selected according to the availability of data as well as their relative importance in defining water quality for human consumption. The standards set for this purpose is according to the World Health Organization guidelines. In this approach, in the first step weights (W) were assigned to the variables of Total Dissolved Solids (TDS), pH, Hardness, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^- and HCO_3^- and it's used in assessing water quality based on their importance on water quality for drinking purpose. In second step, the relative weight (Wr) is calculated from the following equation.

$$Wr = w_i / \sum_{1}^{n} w_i$$

Where, Wr is the relative weight, wi is the weight of each parameter and n is the number of parameters. Calculated relative weight (Wr) values of each parameter are also given in Table 2. In the third step, a quality rating scale (qi) for each parameter is assigned[19-20] by dividing its concentration in each water sample by its relative standard according to its guideline laid down by WHO and result multiplied by 100.

$qi = (Ci / Si) \times 100$

Where qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/L, and Si is the WHO Standard of drinking water for each chemical parameter in mg/L, according to the guidelines of WHO for computing the WQI, the SIi is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$SIi = Wi \times qi$

$WQI = \sum SIi$

SIi index is the sub index of ith parameter, qi is the rating based on concentration of ith parameter and n is the number of parameters. The computed Water Quality Index (WQI) was classified as follows: Excellent, E (WQI<50), Good, G (WQI, 50-100), Poor, M (100–200), Very Poor, P (200–300) and >300 unsuitable for drinking water. There are different categories of water quality with respect to the various seasons were assessed and presented in Table 3 and Figure 2. According to Water Quality Index (WQI) classification, the groundwater samples undertaken for the study has been classified as excellent water quality, good water quality, poor water quality, very poor water quality and unfit for water quality during four seasons. Seasonal study results stated that there was no appreciable change recorded with respect to seasons. However, during post monsoon and monsoon season's drinking water quality has improved in many study sites which may be due to dilution factor. *i.e,* 36% and 38.8% of water samples were found suitable for drinking purposes in post monsoon and monsoon seasons respectively (Table 3). For all other seasons, most of the samples were poor to very poor quality of water due to leaching of ions, over-exploitation of groundwater, direct discharge of effluents, and agrochemicals are responsible for the poor quality of water [21-23]

Irrigation water quality: Water qualities play an important role in suitable irrigation practice. High levels of dissolved ions in water affect plants growth and soil fertility. Hence, the classification system was found useful to evaluate the suitability of water for irrigation purposes and selection of crops. Among many, the parameters such as sodium hazard, percent sodium, residual sodium carbonate, magnesium hazard / magnesium ratio, Kelley ratio and Permeability index were found useful for irrigation water quality assessments [24-27] and discussed as follows under subheadings:

Sodium Adsorption Ratio (SAR): The relative activity of sodium ion in the exchange reaction with soil is expressed in terms of a ratio known as sodium adsorption ratio (SAR). It is one of the major factors considered in determining the suitability of groundwater for irrigation purposes. The SAR measures the relative proportion of Na^+ ions to those of Ca^{2+} and Mg^{2+}ions in water samples. Hence, SAR of water is directly related to the adsorption of sodium by soil. A high Na^+ ion concentration changes in soil properties and reduces soil permeability, which leads to formation of an alkaline soil.[28] SAR can be estimated by the formula as the following.[29]

$$SAR = Na^+ / (Ca^{2+} + Mg^{2+} / 2)^{1/2}$$

Where all cationic concentrations are expressed in mille equivalents per liter. SAR values of the study samples were determined and presented in Table 4. During post monsoon, the SAR values were found under S1 category except the sample sites of Adhirampattinum and Mamallapuram (post monsoon) S2 category. During the pre monsoon and summer, 80.5% of the samples were found under on S1 category and remaining the samples was S2, S4 category. During monsoon, 91.6% of the samples were found under on S1 category and remaining S2 category. SAR values for the study samples were determined and classification presented in Table 4. With respect to SAR values, it is found that all the sampling locations were suitability for irrigation purposes except very few sampling location of Adhiram pattinum (premonsoon) and Adhiram pattinum (summer).

Salinity hazard: The total concentration of soluble salts or dissolved salts in irrigation water can also be expressed in terms of specific conductance. A detailed classification of groundwater samples is given in Table 5. The salinity hazard classes, C1 to C5 expressed the nature of the water samples as excellent / good / doubtful and unsuitable. The study results showed that, irrespective of the seasons, almost all water samples are not suitable for irrigation, except very few sampling stations (Tamaraipulam, Puthusathiram, Cuppivakkam, Muttukadu) during all the four seasons. For detailed analysis SAR and EC on USSL diagram / classification the excellent category C1S1 class and moderate category C2S1 and all other classes (C3S1, C3S2, C3S4, C3S3, C3S4, C4S1, C4S2, C4S3 and C4S4) are not suitable for irrigation purposes. In this study, no one samples found under C1S1, very few C2S1. Hence, it was very difficult to use these waters for irrigation purposes in soils without control of salinity and sodium contents (Figure 3).

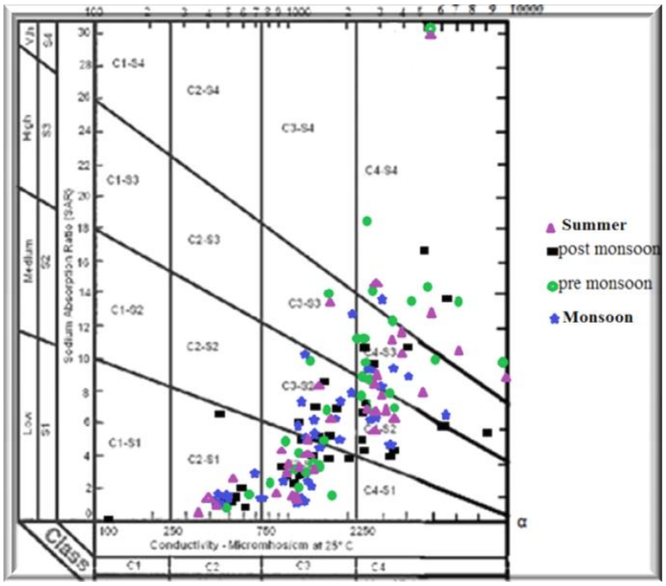

Figure 3: US salinity hazard diagram (after Richards 1954)

Table 5: Salinity hazard classes in the study area (Richard 1954)

EC µS/cm	Salinity hazard class	Remarks on quality	% of samples sites			
			Post monsoon	Pre monsoon	Summer	Monsoon
100-250	C1	Excellent	(2.7%)	-	-	-
250-750	C2	Good	(16.6%)	(11.1%)	(13.8%)	(19.4%)
750-2250	C3	Doubtful	(44.5%)	(38.9)	(36.2%)	(55.6%)
>2250	C4and C5	unsuitable	(36.1%)	(50%)	(50%)	(25%)

Table 6: Sodium percent Water classes (Wilcox, 1955)[35]

% Na	Classification	% of sampling sites			
		Post monsoon	Pre monsoon	Summer	Monsoon
>20	Excellent	(2.7%)	-	-	-
20-40	Good	(13.9%)	(5.6%)	(16.7%)	(16.7%)
40-60	Permissible	(30.6%)	(25%)	(22.2%)	(25%)
60-80	Doubtful	(44.5%)	(61.1%)	(52.8%)	(50%)
>80	Unsuitable	(8.3%)	(8.3%)	(8.3%)	(8.3%)

Percent sodium (% Na): The high sodium percentage can reduce the soil permeability and soil structure (fertility)[30-31] through the exchange process of Na^+ ions in water for Ca^{2+} and Mg^{2+} ions.[32] it can be expressed as the following equation

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

Where the quantities of Ca^{2+}, Mg^{2+}, Na^+ and K^+ are expressed in mille equivalents per liter or equivalents per million. By using the sodium percent, waters can be classified as excellent, good, permissible, doubtful and unsuitable category. The description of unsuitable classes are sampling afford the soil properties. The experimental results showed that there was no major change with respect to seasons, however 50% and above, the sampling sites are not suitable for irrigation purposes. Further, Wilcox diagram [33] was drawn by using % Na versus electrical conductivity in order to assess the suitability. The diagram also supports the Na% classification (Table 6 and Figure 4).

Soluble Residual sodium carbonate (RSC): The excess of carbonate and bicarbonate values in groundwater samples over those of calcium and magnesium affects the suitability of groundwater for irrigation. This is expressed as RSC [34-35]

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

Where all the concentrations are expressed in meq/L. According to Richards (1954), there are three categories which are good, medium and bad. During the monsoon and post monsoon seasons, water samples showed moderate RSC, which may due to climate change and rise of temperature during summer and high pH. Most of the samples 61 to 67% showed negative values which indicated that dissolved Calcium and Magnesium contents were higher than carbonate and bicarbonate contents (Table 7 and Figure 5).

Magnesium hazard (MH): A high level of magnesium is usually due to the presence of exchangeable Na^+ ion in irrigated soils. At equilibrium more Mg^{2+} present in the water will adversely affect the soil quality, rendering it alkaline, resulting in decreased and adversely affected crop yields. The Magnesium hazard is expressed as follows:

$$MH = (Mg^{2+}) / (Ca^{2+} + Mg^{2+}) \times 100$$

Where all the ionic concentrations are expressed in meq / L. According to Szaboles and Darab (1964)[36] the Magnesium hazard values above 50 is said to be unsuitable for irrigation.

In post monsoon seasons, 6 (16.7%) of the samples were unsuitable and 9 (25%) of the samples were unsafe for irrigation in pre monsoon, summer and monsoon seasons respectively (Table 8 and Figure 6).

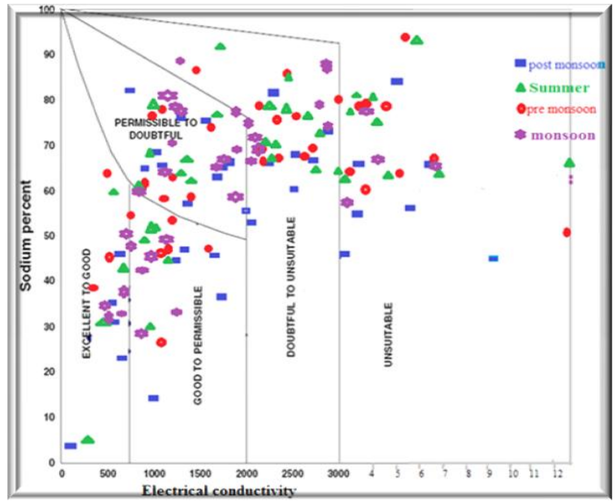

Figure 4: Percent sodium vs EC plot (after Wilcox 1955)

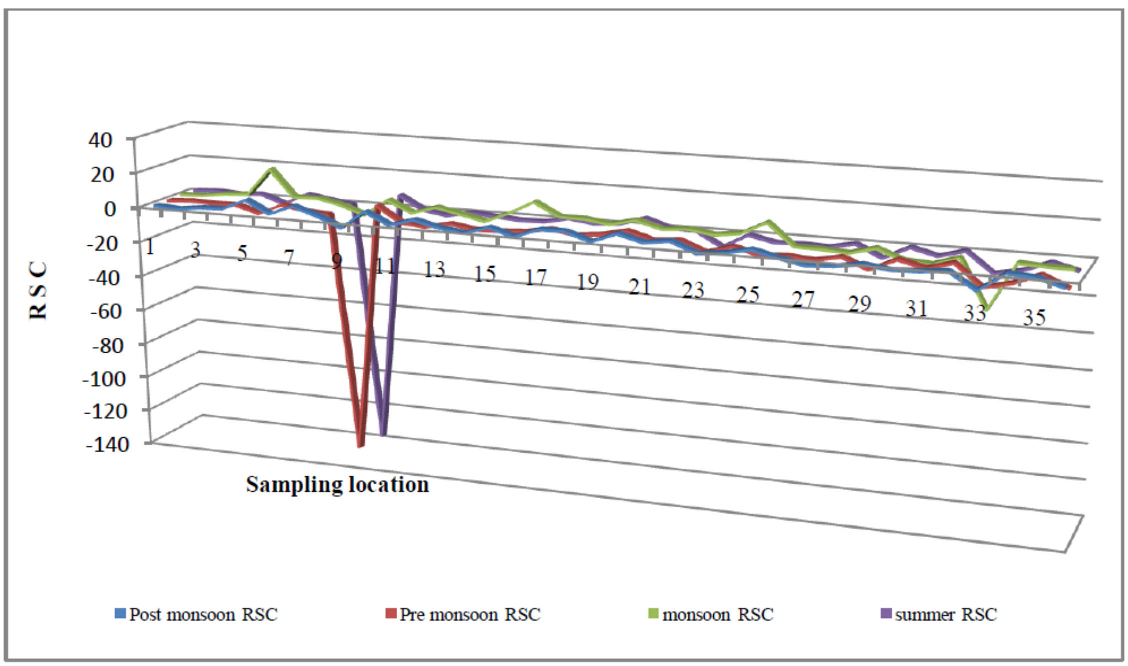

Figure 5: Trend diagram shows that variation of RSC value in the study area

Table 7: Residual Sodium Carbonate classes in the study area (Richards (1954)[19]

RSC	Water category	% of sampling sites			
		Post monsoon	Pre monsoon	Summer	Monsoon
<1.25	Good	(38.9%)	(33.3%)	(11.1%)	(44.4%)
1.25-2.5	Doubtful	(16.7%)	(19.4%)	(25%)	(22.2%)
>2.5	Unsuitable	(44.4%)	(47.2%)	(63.8%)	(33.3%)

Table 8: Classification of MH in groundwater quality

MH	Water category	% of sampling sites			
		Post monsoon	Pre monsoon	Summer	Monsoon
<50	Safe	(83.3%)	(75%)	(75%)	(75%)
>50	Unsafe	(16.7%)	(25%)	(25%)	(25%)

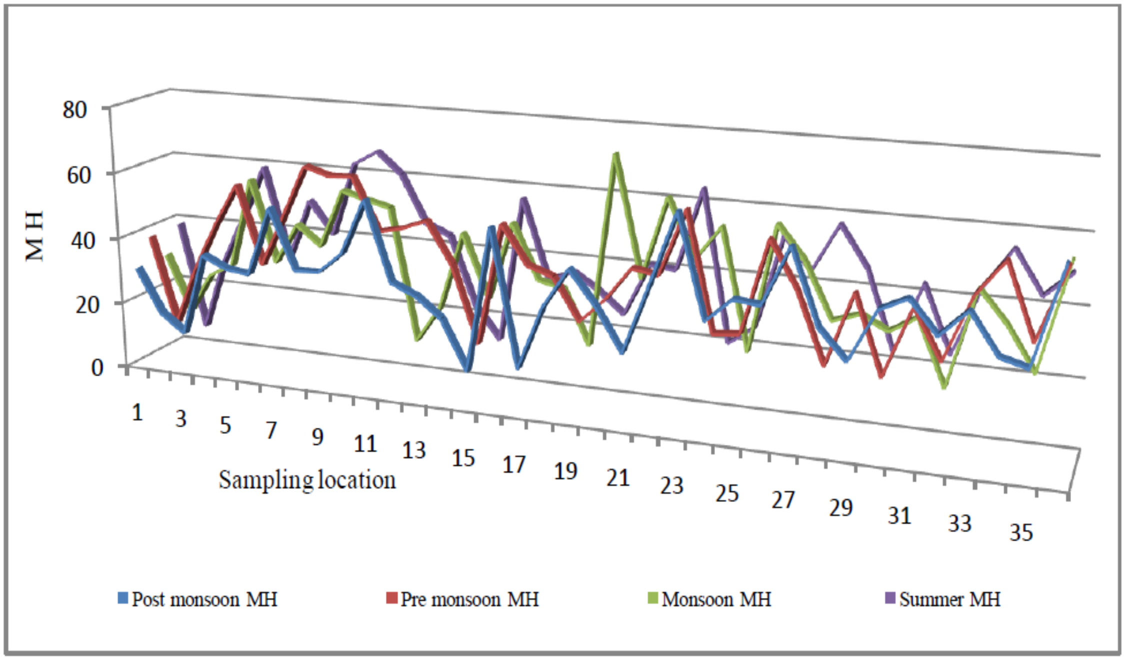

Figure 6: Trend diagram shows that variation of MH in the study area

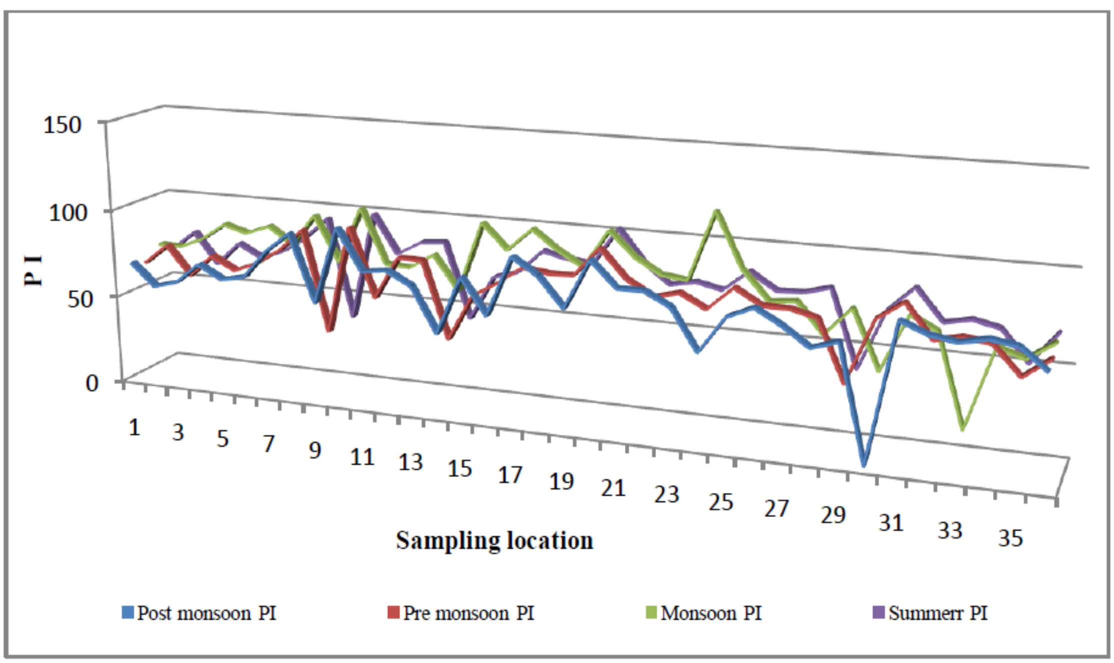

Figure 7: Trend diagram shows that variation of PI value in the study area

Table 9: Classification of premeability index value (Doneen (1964))

PI	Water classes	% of sampling sites			
		Post monsoon	**Pre monsoon**	**Summer**	**Monsoon**
>75	class I	(36.1%)	(30.5%)	(50%)	(55.6%)
25-75	class II	(63.8%)	(69.5%)	(50%)	(44.4%)
<25	class III	-	-	-	-

Permeability index (PI): Permeability index is an essential index to determine the quality of irrigation water in relation to soil for improved in agriculture. This PI has been determined as the folloing equation[37]

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

Where all the ionic concentrations are expressed in terms of meq/L. Doneen[38] (1964) classified PI into three classes, class I (PI > 75%), class II (25% ≤ PI ≤ 75%) and class III (PI < 25%). Waters of class I and class II are categorized as good for irrigation with 75% or more of maximum permeability and class III unsuitable with 25% of maximum permeability. In the present study, it has been found that water samples are classified under I and II class category as good for irrigation purposes. Doneen's chart implies that the water with PI value above 75 and 25 - 75 are for safe irrigation purposes (Table 9 and Figure 7).

Kelley's ratio (KR): Kelley's ratio is another parameter useful to classify the irrigation water quality which expresses the concentration of Na^+ ion against calcium and magnesium ions.[38] It has been calculated for all the study samples by using the following equation as the data shown in Table 10 and Figure 8. The groundwater with KR >1 are generally considered as unfit for irrigation purposes

$$KR = Na^{+} / Ca^{2+} + Mg^{2+}$$

Table 10: Classification of Kelley's ratio value

KR	Water classes	% of Sampling sites			
		Post monsoon	**Pre monsoon**	**Summer**	**Monsoon**
>1	Unsafe	(47.2%)	(66.6%)	(69.4%)	(61.1%)
<1	Safe	(52.8%)	(33.3%)	(30.5%)	(38.9%)

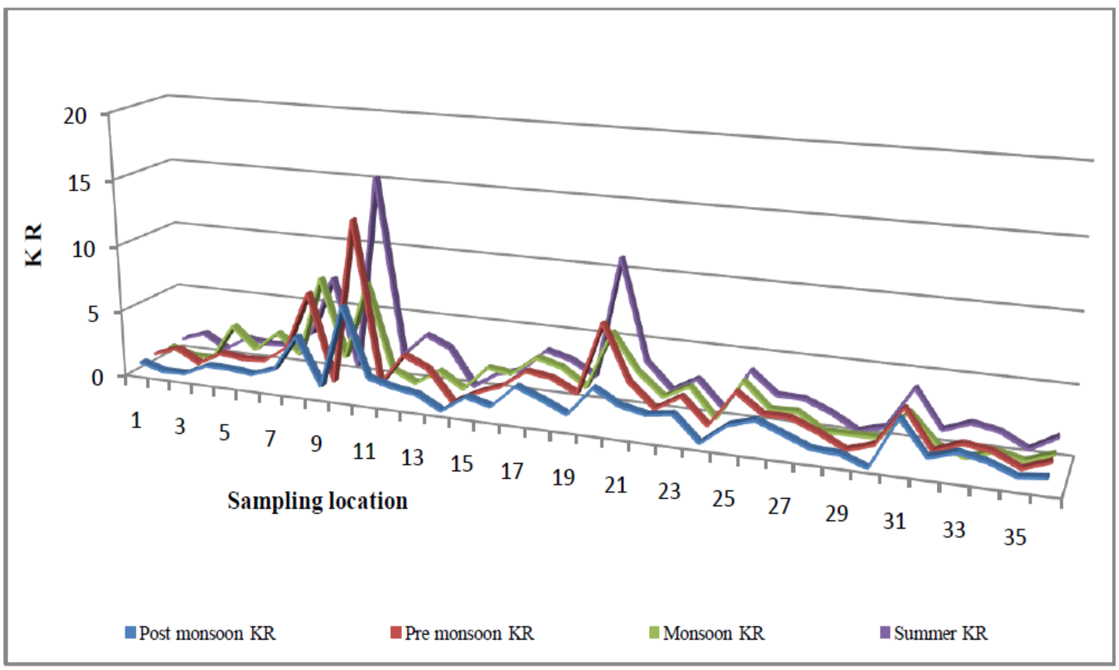

Figure 8: Trend diagram shows that variation of KR in the study area

Where all the ionic concentrations are expressed in meq/L.

In comparison, the KR of the water samples with respect to various seasons, 47.2%, 66.6%, 69.4% and 61.1% of water samples during post monsoon, pre monsoon, summer and monsoon respectively showed KR > 1 and found unsafe for irrigation purposes. Further, the climate change on KR indicate that groundwater during summer Na^+ ion level was found to be increased which may be due to the exchange prevalence among Na^+ as Ca^{2+} / Mg^{2+} ions. The safe limits of KR (< 1) and the trend among the seasons *viz* post monsoon > monsoon > pre monsoon > summer clearly stated that seepage versus exchange Na of Na% ions is in inverse trend i.e. winter, rainy seasons the groundwater became diluted and safe for irrigation purposes. Among all the study sites (Panaikulam, Thondi, S.P Pattinam Mimesal Muthupettai Tamaraipulam Nagapattinam Nagoor Karaikal Thirukadaiyur Poombukar Kollidam Pitchavaram Puthusathiram Aalapakkam Aariyankkuppam Marakkanam Cuppivakkam Muhaiyur and Mamallapuram) with more agricultural plantation fully paddy field *i.e.*, seasonal cultivation using lake and river waters.

Conclusion

Groundwater quality study, in the east coastal region Tamilnadu, India., based on water chemistry and suitability for drinking, domestic and irrigation water quality has been carried out.

Based on water quality in the study area, the following conclusions were drawn

- Water quality index (WQI) data stated that 40%, 17%, 17% and 40% of groundwater sampling stations were found potable during post monsoon, pre monsoon, summer and monsoon respectively in the study area.
- Assessment made by using TH and CR, number of locations were found unsuitable for domestic purposes.
- PI, RSC, MH, SAR and %Na classification confirm 50% of locations were unsafe for irrigation processes.
- The sequence of the abundance of major ions in the study samples was found in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $Cl^- > HCO3^- > NO_3^- > SO_4^{2-}$.

This study also represents a base for future hydrochemical work for planning, protection and decision making, regarding groundwater management in the study area.

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