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Research Paper

Deciphering Fresh and Saline Groundwater Interface in South Chennai Coastal Aquifer, Tamil Nadu, India

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Abstract: *The interface between fresh and saline groundwater was studied in south Chennai coastal aquifer, through ArcGIS software using hydrochemical parameters (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, B^{3+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, NO_3^{-} and SO_4^{2-}) of 22 groundwater samples which was collected twice during pre-monsoon (August 2011) and post-monsoon seasons (January 2012). It was found that groundwater was slightly acidic to alkaline, and more than 81.8% of groundwater samples had EC > 1,000 µS/cm in both the seasons. The dominant cations and anions of the study area are in the order of $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}>B^{3+}$ and $Cl^{-}>HCO_3^{-}>SO_4^{2-}>NO_3^{-}>CO_3^{2-}$, respectively. The Piper trilinear diagram shows that the groundwater exhibits Na^{+} –Cl^{-}, Mixed Ca^{2+}- Na^{+} -HCO_3^{-}, Mixed Ca^{2+} -Mg^{2+} -Cl^{-} and Ca^{2+} -HCO_3^{-} hydrochemical facies. Gibbs diagram shows that the groundwater samples falls from freshwater to saline water. Chloro-Alkaline indices 1, 2 calculations shows that 100% of groundwater samples are negative, thus indicates exchange of Mg^{2+} and Ca^{2+} from water with Na^{+} and K^{+} of the rocks. The fresh and saline groundwater interface has been deciphered varies from 950 m in highly populated region to 250 m in partially populated region from the shoreline in pre-monsoon season and from 550 m in highly populated region to100 m in partially populated region from the shoreline in post-monsoon season. The interface is moving towards the inland due to the over exploitation of groundwater for various purposes, which disturbed the hydrodynamic balance of the region. It is inferred that the region which is highly populated is more intruded compared to partially populated area due to the over exploitation of groundwater. It's an important issue to protect and preserve the groundwater resources from further depletion/contamination.*

Keywords: ArcGIS, Coastal aquifer, Exploitation, Hydrochemical, Interface, Seawater.

Introduction

Groundwater is a precious, finite, renewable resource with certain advantages such as its accessibility to a large number of users. A coastal aquifer, characterized by having at least one side of its perimeter in direct contact with sea, the growth of human settlements, together with the development of agricultural, industrial and touristic activities, has led to the overexploitation of the aquifers. Such overexploitation induces a rise in the freshwater–saltwater interface (seawater intrusion) and thus, a degradation of the chemical quality of the groundwater [1]. This problem is very common in many parts of the world. It is often associated with over pumping in coastal regions, resulting in overdraft conditions and creating an inland gradient of seawater. Both the quantity and quality of the groundwater resources are decreasing day by day along the coasts. Excessive withdrawal of groundwater coupled by significant decrease in recharge contributes to seawater intrusion in coastal region. The extent of seawater intrusion is influenced by nature of geological settings, hydraulic gradient, rate of groundwater withdrawal and its recharge [7].

Seawater intrusion is a major source of groundwater contamination. The freshwater and seawater interface in coastal region is moving towards the inland due to the over exploitation of groundwater for various purposes, which disturbed the hydrodynamic balance of the region. It is important to decipher the freshwater and seawater interface for better groundwater management to minimize the further depletion/contamination. Due to urbanisation, the interface has been moved towards the inland through over extraction of groundwater by the locality and also by the government agencies for water marketing. The relationship between the aquifer and sea is even more complicated in several coastal aquifers, where the interface is not in equilibrium with the present ocean level [13]. The vertical interface can be found out using Ghyben – Herzberg Relation but the horizontal interface can be found out using some indicators such as EC, Na, Cl, Cl/HCO_3, Na/Cl, Ca/Mg, Cl/ (HCO_3+SO_4), Cl/B and B [10] through ArcGIS software. The horizontal interface has been deciphered in south Chennai coastal aquifer using such indicators.

The present study was carried out with the main objective of deciphering fresh and saline groundwater interface using ArcGIS software in south Chennai coastal aquifer which was carried out in the months of August 2011 and January 2012. Groundwater chemistry has been employed to study the possible intrusion of seawater in the study area.

Study Area: Chennai (Madras), the capital of Tamil Nadu state, is the fourth largest metropolis of the Indian subcontinent. The population of the Chennai city is about 4.6 million (2011 census). The south Chennai coastal aquifer system covers the area between latitudes 12°48’15’’ N and 12°59’15’’ N and between longitudes 80°10’13’’ E and 80°16’30’’ E, which lies from Thiruvanmiyur to Muttukadu. The area is surrounded by salt water on three sides. It is bounded by the Bay of Bengal in the east, Muttukadu estuary in the south and Adyar River in the north (Figure 1). Muttukadu estuary in the south has saline back water. The Buckingham Canal forms the western boundary of the area. This canal originally established for navigation, but now it is used to collect storm water to moderate flood during monsoon.

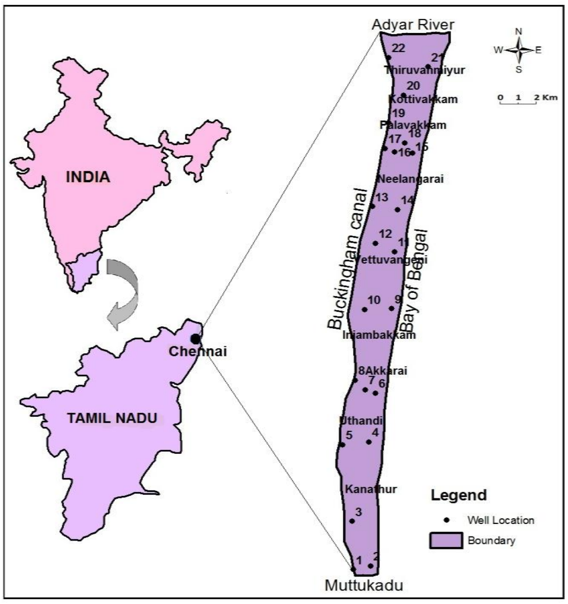

Fig. 1: Location of sampling wells in the Study area

This canal also carries domestic sewerage and hence it is highly contaminated [11]. The total linear distance of the area is about 20 km in the north-south direction and about 1.5 km in the east-west direction. The study area covers an areal extent of about 35 km^2 and it has a terrain elevation ranging between 3 and 12 m above mean sea level (MSL). The land use and land cover map derived from IRS-LISS III (24-02-2004), represent the settlement is comparatively high towards north than in the south.

The study area has a humid and subtropical climate. Summer (April-May) temperature varies from 35°C to 42°C and winter (December –January) temperature varies from 25°C to 34 °C. The average relative humidity varies from a maximum of 84% in December to a minimum of 58% during the month of May. The annual average rainfall is about 1200 mm with the aquifer receiving around 60 per cent of its rainfall from northeast monsoon during the months of October, November and December [11]. The southwest monsoon which prevails from July to September, the northeast monsoon and the transition period contribute 40%, 51% and 9% of the annual rainfall respectively.

The study area is generally comprises of unconsolidated sediments of sand and clay. The Precambrian gneiss of charnockitic composition is at the basement of this area, which is overlaid by unconsolidated quaternary sediments. These quaternary sediments comprise of sand, clay, sandy clay and clayey sand. The sandy formation covers most part of the area and the clay is dominant in the western boundary which is along Buckingham canal. The clay, sandy clay and clayey sand are also present as patches in the quaternary formation. The upper unconsolidated formation and lower weathered/fractured rocky formations function as an unconfined aquifer [11].

Material and Methods

A preliminary well inventory survey was carried out to identify the monitoring wells for groundwater sampling. A total of 22 groundwater samples (Figure 1) were collected from both dug wells and tube wells during the pre-monsoon (August 2011) and post-monsoon (January 2012) seasons in order to decipher the freshwater and seawater interface through various hydrochemical parameters (Ca^{2+}, Mg^{2+}, Na^+, K^+, B^{3+}, CO_3^{2-}, HCO_3^-, Cl^-, NO_3^- and SO_4^{2-}) using ArcGIS software. Electrical Conductivity (EC) and Hydrogen ion concentration (pH) were measured on the spot by EC and pH portable meter. The procedures stipulated by APHA [2] were followed for sampling and preservation of samples. From each site about 1 litre of water sample was collected in bottles and carried to the laboratory for analysis of chemical quality. Total hardness (TH) and calcium (Ca^{2+}) hardness are determined by complexometric EDTA titration methods using eriochrome black-T (EBT) and murexide indicator respectively. Magnesium (Mg^{2+}) concentration is calculated from total hardness and calcium hardness. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations are estimated by titration methods using phenolphthalein and methyl-orange as indicator. Argentometric method with K_2CrO_4 indicator is used to determine chloride (Cl^-) concentration. Sulphate (SO_4^{2-}) measured by $BaCl_2$ method using spectrophotometer, nitrate (NO_3^-) was analyzed using cadmium column reduction method. Estimation of sodium (Na^+) and potassium (K^+) are carried out by Flame-Photometric method. Boron (B^{3+}) was analyzed by spectrophotometric technique. The accuracy of the result was checked by calculating the ionic balance errors and it was generally within ±5%. Hydrochemical parameters were analyzed to find the fresh and saline groundwater interface through some indicators like EC, Na, Cl, Cl/HCO_3, Na/Cl, Ca/Mg, Cl/ (HCO_3+SO_4), Cl/B and B using ArcGIS software for both pre-monsoon and post-monsoon seasons.

Results and Discussion

The water quality parameters were analyzed and compared with standards desirable limit recommended by the Bureau of Indian Standards (BIS) [3]. The distribution pattern of cations and anions in groundwater of south Chennai coastal aquifer, based on the average values of these ions(mg/L) are as $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > B^{3+}$ and $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > CO_3^{2-}$ respectively. Overall, distribution pattern of all the hydrochemical parameters tested may be ranged as $Cl^- > Na^+ > HCO_3^- > Ca^{2+} > SO_4^{2-} > Mg^{2+} > K^+ > NO_3^- > B^{3+} > CO_3^{2-}$.

Hydrochemical Parameters of Groundwater: Range limits of physico-chemical analytical results of 22 groundwater samples for pre- and post-monsoon seasons are presented in Tables 1. In general, pH of groundwater samples was slightly acidic to alkaline in nature. The EC values vary from 400 to 5600 µS/cm with an average value of 1750 µS/cm in pre monsoon season whereas in post monsoon season, it varies from 340 to 5270 µS/cm with a mean value of 1354 µS/cm. Based on total dissolved solids, groundwaters are classified [9] into desirable for drinking (up to 500 mg/l), permissible for drinking (500–1,000 mg/l), useful for agricultural purposes (up to 3,000 mg/l), and unfit for drinking and irrigation (above 3,000 mg/l). Out of the 22 groundwater samples, five samples are within the desirable and four are within the permissible limits of drinking, ten samples are useful for irrigation purposes and three samples are unfit for drinking and irrigation purposes.

Sodium and chloride are the dominant ions of the study area. 40.9% of groundwater samples are above desirable limit of sodium in pre-monsoon season whereas in post-monsoon season, 31.8% of groundwater samples are above desirable limit (Figure 2). The possible source of sodium concentration in groundwater is due to the dissolution of rock salts, weathering of sodium bearing minerals and influence of seawater from the coast. 45.45% of groundwater samples are above desirable limit of chloride in pre-monsoon season whereas in post-monsoon season, 27.3% of groundwater samples are above desirable limit (Figure 3).

Table 1
Comparisons of Water Quality Parameters with Standards

Chemical Parameter	Premonsoon		Postmonsoon		BIS standard		Samples exceeding desirable limit	
	Range	Mean	Range	Mean	Desirable	Permissible	Premonsoon	Postmonsoon
pH	6.3 - 8.1	7.2	6.7 - 7.9	7.3	6.5	8.5	15	Nil
Total Dissolved Solids	256 – 3584	1120	218 - 3373	867	500	2000	1, 2, 4, 5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21	1, 5, 6, 10, 11, 12, 13, 14, 15, 16, 19, 21
Total Hardness	58.9 - 645.1	270	42.3 - 500.3	167.6	300	600	1, 2, 10, 13, 15, 16, 19	5, 13,19
Calcium	17 – 158	67.5	13 - 84	37.6	75	200	1, 2, 6, 10, 15, 16	13, 19
Magnesium	4 – 61	24.7	2.4 - 70.8	17.9	30	100	1, 2, 10, 13, 15, 16, 19	5, 13
Sodium	36 – 2305	316	9.6 - 2045.2	273.3	200	300	1, 2, 5, 6, 10, 13, 15, 19, 21	5, 6, 13, 14, 15, 19, 21
Potassium	1 – 39	10.9	0 - 36	6.8	-	-	-	-
Boron	0.1 - 1.3	0.38	0.05 - 1.2	0.26	1	5	19, 21	19, 21
Chloride	36.3 - 1098.3	315	8.86 - 1248.4	208.4	250	1000	1, 2, 5, 6, 10, 14, 15, 18, 19, 21	5, 6, 14, 15, 19, 21
Bicarbonate	27.6 – 788	276	12.2 - 982.1	241.1	300	600	1, 5, 8, 10, 13, 14, 15, 19	5, 10, 12, 19
Nitrate	0.6 - 34.7	13.6	0.38 - 32.6	11.6	45	100	Nil	Nil
Sulphate	35 - 341.7	111	29.1 - 379.5	122.5	200	400	12, 13, 19, 21	5, 13

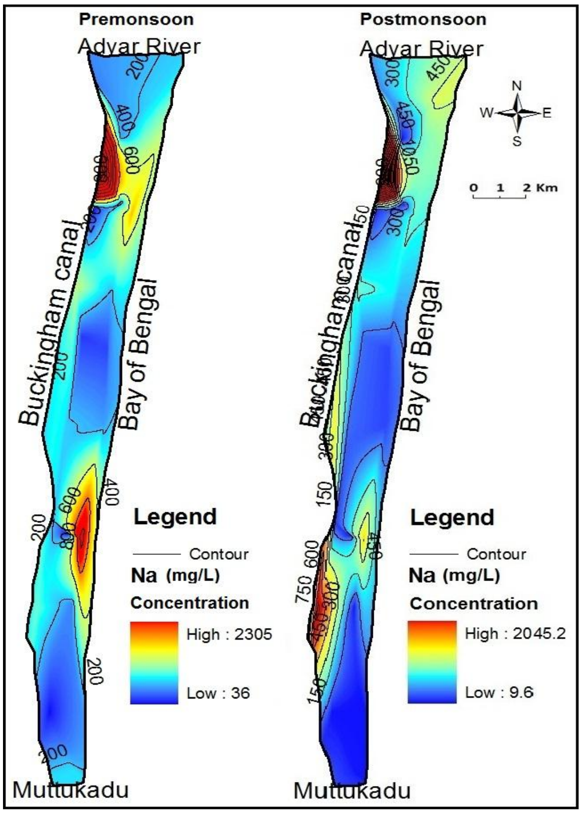

Figure 2: Spatial and Seasonal variation of Sodium in Groundwater

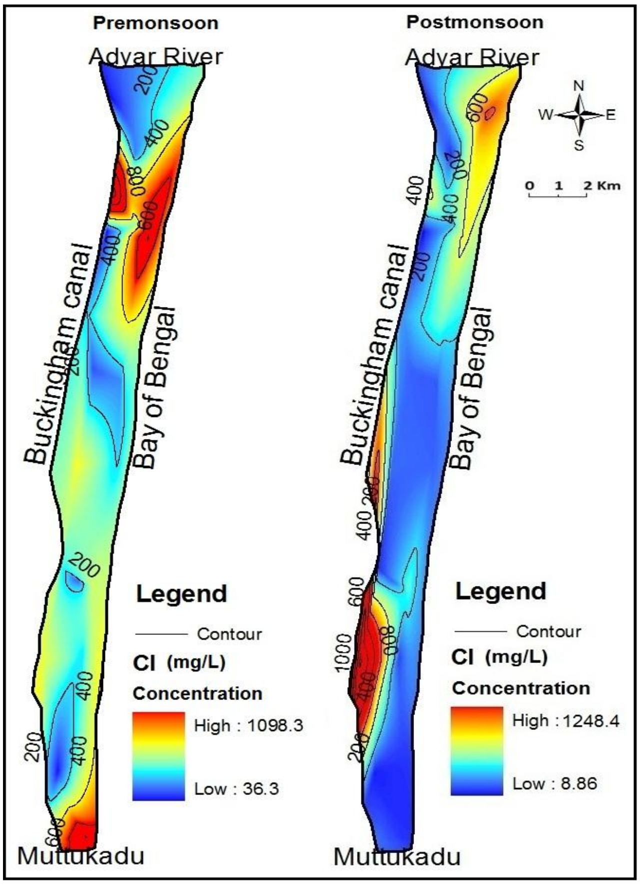

Figure 3: Spatial and Seasonal variation of Chloride in Groundwater

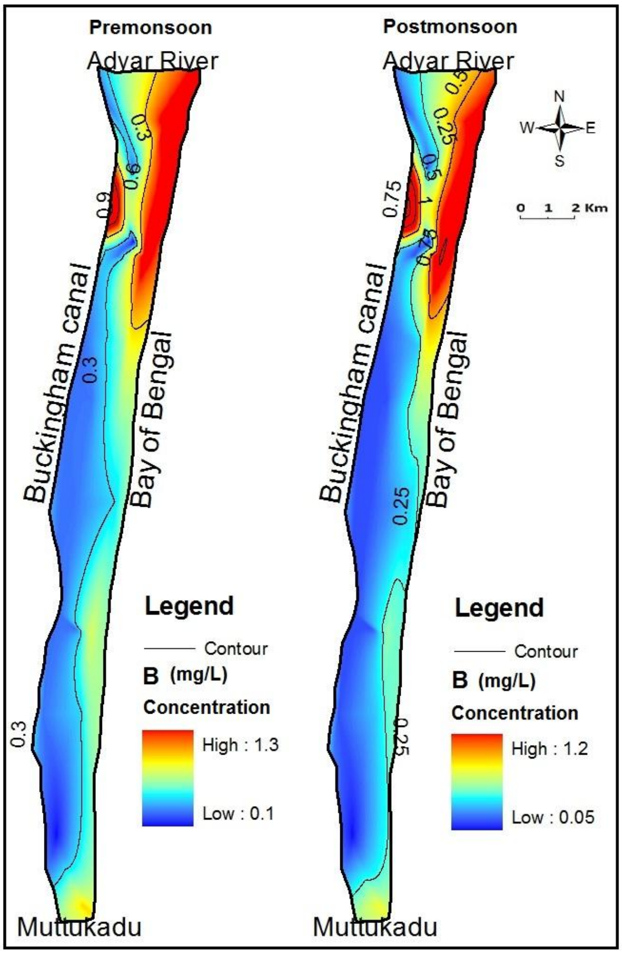

Figure 4: Spatial and Seasonal variation of Boron in Groundwater

The natural process such as weathering, dissolution of salt deposits and influence of seawater from the coast are responsible for chloride content in the groundwater. Since boron is the main indicator of seawater intrusion, it has been analyzed for this study. Its value ranges from 0.1 to 1.3 mg/L in pre-monsoon season whereas in post-monsoon season, it varies from 0.05 to 1.2 mg/L (Figure 4).

It is inferred that the overall concentrations of groundwater samples in post-monsoon season is lower compared to that of pre-monsoon season due to the dilution effect of groundwater through rainfall which occurs during monsoon period. The water samples collected near the highly populated coastal area and Buckingham canal have high TDS values due to the over extraction of groundwater which leads to intrusion of seawater and presence of clay patches near the canal, respectively. The middle part of the study area has low TDS values since it has highly terrain elevation.

Correlation Matrix: A correlation analysis is a bivariate method that describes the degree of relationship between two variables. For this purposes, Spearman's rank correlation coefficient has been calculated using quality parameters of ground water samples of south Chennai coastal aquifers collected in both pre-monsoon and post-monsoon seasons shown in Table 2 and 3. Spearman's rank correlation coefficient is denoted by ρ (rho) and its value will always be between -1.0 and +1.0. A positive ρ corresponds to an increasing while a negative ρ corresponds to a decreasing monotonic trend between two water quality parameters. A high correlation coefficient (near 1 or -1) means a good relationship between two variables and its value around zero means no relationship between them [12].

In the study area, pH shows negative correlation with all the variables in pre-monsoon season and most of the variables in post-monsoon season. The value of EC indicates the good positive correlation with most of the variables such as Cl^-, Mg^{2+}, B^{3+}, Na^+, HCO_3^- and K^+ in pre-monsoon season and Cl^-, HCO_3^-, Na^+ and SO_4^{2-} in post-monsoon season. The good positive correlation was observed between Mg^{2+} and Ca^{2+}, K^+ and Mg^{2+}, B^{3+} and Mg^{2+}, B^{3+} and Na^+, B^{3+} and K^+, Cl^- and Mg^{2+}, Cl^- and Na^+, Cl^- and K^+, Cl^- and B^{3+}, HCO_3^- and Na^+, HCO_3^- and Cl^- whereas in post-monsoon season, it was observed between Cl^- and Mg^{2+}, HCO_3^- and Mg^{2+}, HCO_3^- and Na^+, HCO_3^- and Cl^-, SO_4^{2-} and Ca^{2+}, SO_4^{2-} and Mg^{2+}, SO_4^{2-} and Na^+, SO_4^{2-} and HCO_3^-. The good negative correlation was observed between pH and Ca^{2+} in pre-monsoon season.

Table 2
Correlation Matrix for Premonsoon season

Well	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	B^{3+}	Cl^{-}	HCO_3^{-}	NO_3^{-}	SO_4^{2-}
pH	1	-0.37	-0.70	-0.53	-0.19	-0.45	-0.24	-0.34	-0.27	-0.30	-0.48
EC		1	0.54	0.83	0.79	0.71	0.82	0.98	0.73	0.19	0.49
Ca^{2+}			1	0.76	0.14	0.49	0.26	0.55	0.38	0.13	0.23
Mg^{2+}				1	0.42	0.85	0.64	0.84	0.45	0.15	0.45
Na^{+}					1	0.38	0.75	0.73	0.71	0.17	0.60
K^{+}						1	0.69	0.72	0.24	0.44	0.52
B^{3+}							1	0.79	0.55	0.43	0.51
Cl^{-}								1	0.66	0.15	0.42
HCO_3^{-}									1	0.07	0.53
NO_3^{-}										1	0.28
SO_4^{2-}											1

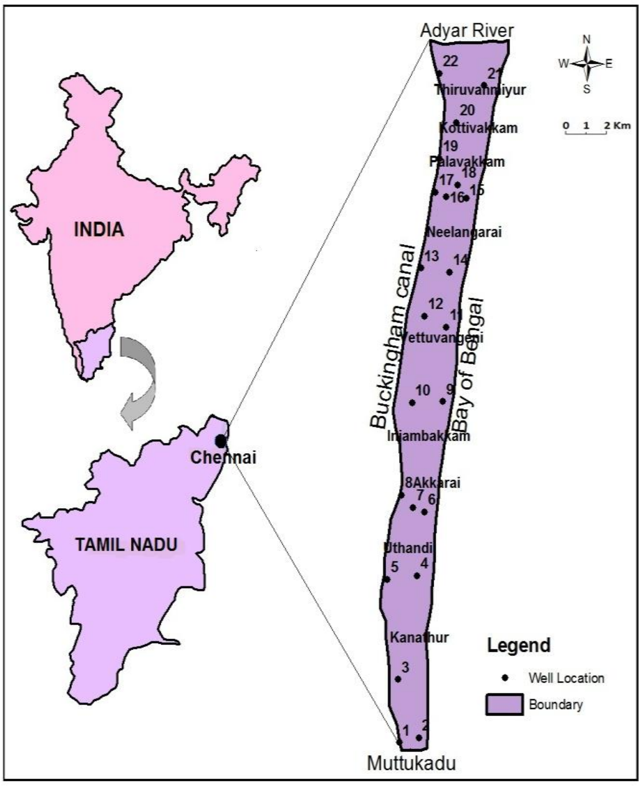

Fig. 1: Location of sampling wells in the Study

Mechanism controlling Groundwater chemistry: The quality of groundwater is significantly changed by the influence of weathering and anthropogenic inputs. Gibbs's diagram representing the ratios of [Na^{+}: (Na^{+} + Ca^{2+})] and [Cl^{-} :(Cl^{-} +HCO_3^{-})] as a function of TDS, are widely employed to assess the functional source of dissolved chemical constituents. It is widely used to establish the relationship of water composition and aquifer lithological characteristics [5]. Three distinct fields such as precipitation dominance, evaporation dominance and rock–water interaction dominance areas are shown in the Gibbs diagram (Figure 5). The predominant samples fall in the rock–water interaction dominance and evaporation dominance field of Gibbs diagram in both the pre-monsoon and post-monsoon seasons. The rock–water interaction dominance field indicates the interaction between rock chemistry and the chemistry of the percolation waters under the subsurface. The groundwater samples fall from freshwater to saline water.

Table 3
Correlation Matrix for Postmonsoon Season

Well	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	B^{3+}	Cl^{-}	HCO_3^{-}	NO_3^{-}	SO_4^{2-}
pH	1	-0.33	-0.33	0.03	-0.34	-0.17	-0.37	-0.30	-0.13	-0.50	-0.20
EC		1	0.48	0.64	0.82	0.26	0.49	0.90	0.88	0.16	0.74
Ca^{2+}			1	0.57	0.59	0.32	0.45	0.29	0.41	0.35	0.79
Mg^{2+}				1	0.47	0.11	0.04	0.64	0.70	-0.20	0.85
Na^{+}					1	0.17	0.73	0.61	0.70	0.17	0.74
K^{+}						1	0.18	0.29	-0.07	0.13	0.21
B^{3+}							1	0.32	0.30	0.54	0.43
Cl^{-}								1	0.79	0.10	0.60
HCO_3^{-}									1	0.01	0.65
NO_3^{-}										1	0.11
SO_4^{2-}											1

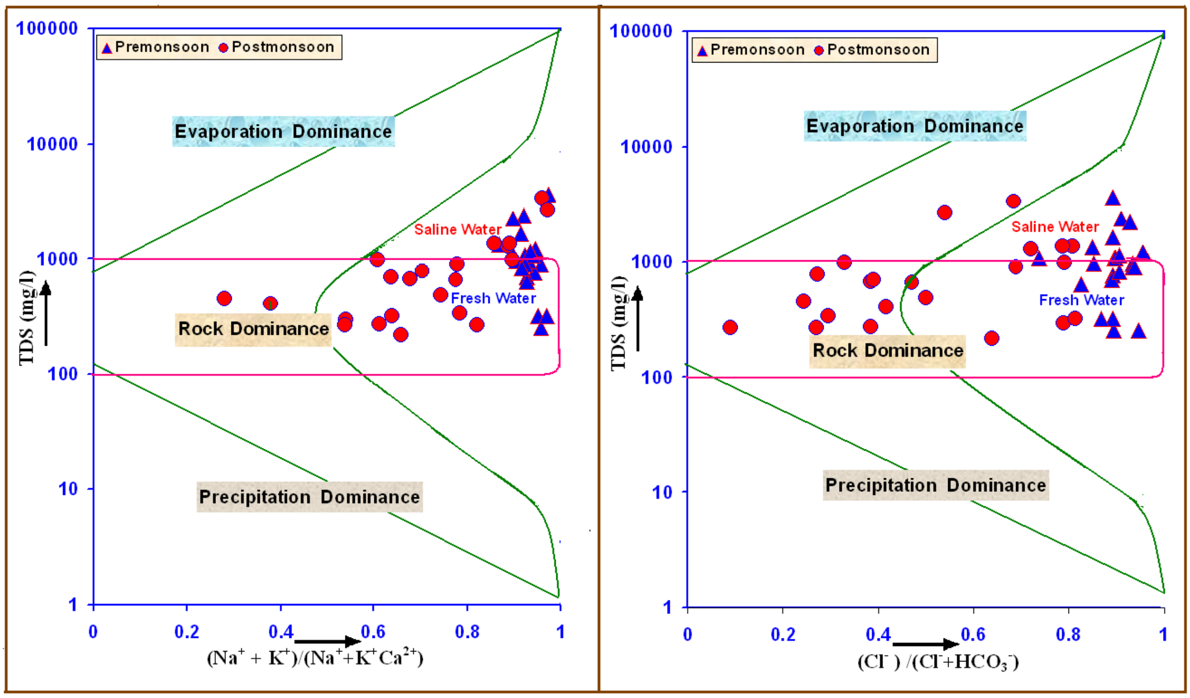

Figure 5: Gibbs diagram for controlling factor of Groundwater quality

Hydro-geochemical facies: Hydro-geochemical facies are generally distinct zones that cation and anion concentrations are described within defined composition categories. Piper [8] graphical representation method was used to assess the nature of hydro-geochemistry of the aquifer. Piper trilinear diagram is the most appropriate diagram for interpretations of composite parameters in groundwater. It is a combination of anions and cations triangles that lie on a common baseline. Major cations and anions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, NO_3^{-} and SO_4^{2-} were plotted in hydrochemical trilinear diagram. Piper trilinear diagram (Figure 6) of this study shows that the groundwater of the coastal aquifer exhibits Na^{+} –Cl^{-}, Mixed Ca^{2+}- Na^{+} -HCO_3^{-}, Mixed Ca^{2+} -Mg^{2+} -Cl^{-} and Ca^{2+} -HCO_3^{-} hydrochemical facies in pre-monsoon season and Na^{+} –Cl^{-}, Mixed Ca^{2+}- Na^{+} -HCO_3^{-}, Mixed Ca^{2+} -Mg^{2+} -Cl^{-}, Ca^{2+} -HCO_3^{-} and Ca^{2+} -Cl^{-} hydrochemical facies in post-monsoon season. This indicates that samples are enriched with sodium and chloride followed by bicarbonate, calcium and magnesium and from this it is evident that sea water and tidal channel/canals plays a major role in controlling the groundwater chemical composition in the coastal shallow aquifer. Further, the trilinear diagram revealed that most of the wells falling in facies Na^{+}-Cl^{-} showed the saline water intrusion of coastal aquifers with high percentage of sodium and chloride.

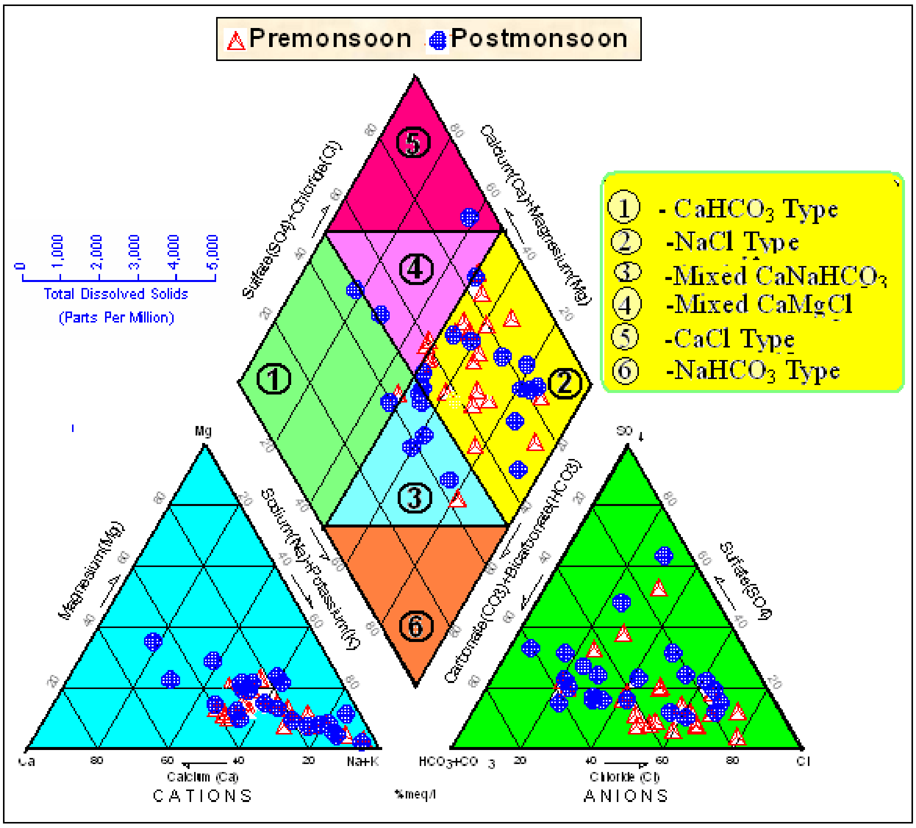

Figure 6: Piper Trilinear diagram for hydrogeochemical facies of Groundwater

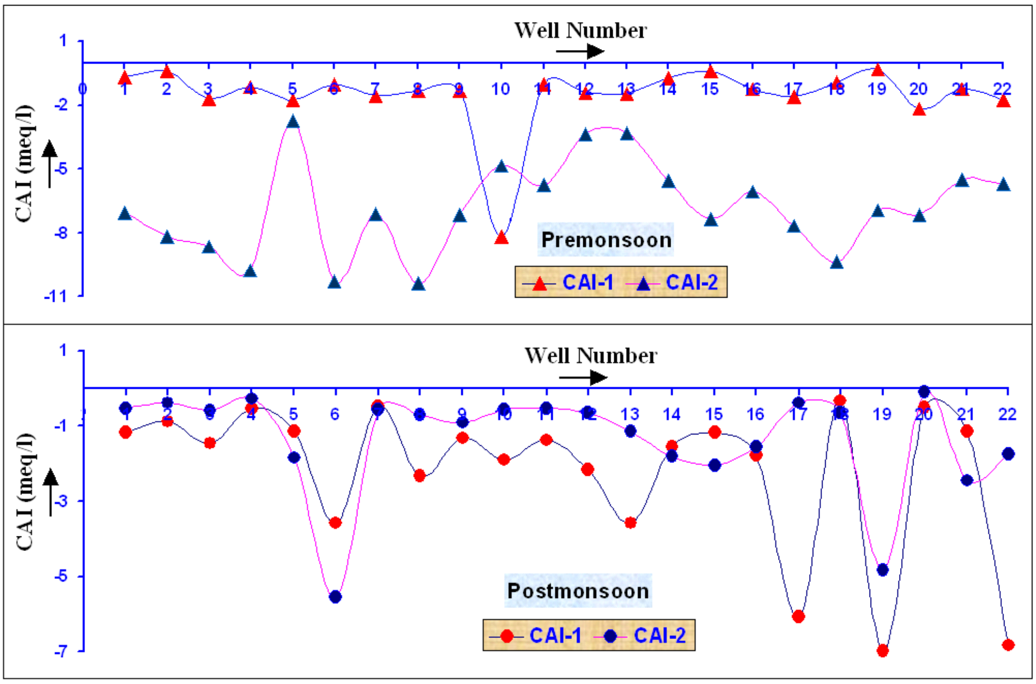

Figure 7: Chloro-Alkaline Indices of Groundwater for Ion-exchange process

Ion-exchange process in the aquifer: Changes in chemical composition of groundwater along its flow path can be understood by studying the Chloro-Alkaline Indices (CAI). Two Chloro-Alkaline Indices such as CAI 1: $[Cl^- - (Na^+ + K^+)]/Cl^-$ and CAI 2: $[Cl^- - (Na^+ + K^+)]/SO_4^{2-}+HCO_3^- +CO_3^-+NO_3^-$ are considered for the interpretation of ion exchange between groundwater and host environment [6]. 100% of water samples collected from this south Chennai coastal aquifer in both post-monsoon and pre-monsoon seasons had negative CAI 1 and CAI 2 values (Figure 7). Positive Chloro-Alkaline Indices indicate exchange of Na^+ and K^+ from the water with Mg^{2+} and Ca^{2+} of the rocks and is negative when there is an exchange of Mg^{2+} and Ca^{2+} of the water with Na^+ and K^+ of the rocks [12]. In this present study, CAI 1 values range from -8.154 to -0.452 with mean value of -1.532 in pre-monsoon season and it varies from -6.970 to -0.323 with mean value of -2.197 in post-monsoon season while CAI 2 values range from -2.178 to -0.575 with mean value of -1.283 in pre-monsoon season and it varies from -5.552 to -0.095 with mean value of -1.358 in post-monsoon season. All the computed values of CAI are negative, thus indicating exchange of Mg^{2+} and Ca^{2+} from water with Na^+ and K^+ of the rocks (reverse ion-exchange process).

Fresh and Saline groundwater Interface: The hydrochemical parameters of this study area were analyzed to study the present status of seawater intrusion. The interface between fresh and saline groundwater for both pre-monsoon and post-monsoon season has been deciphered using ArcGIS software through some indicators such as EC, Na, Cl, Cl/HCO_3, Na/Cl, Ca/Mg, $Cl/(HCO_3+SO_4)$, Cl/B and B. Electrical Conductivity, sodium, chloride, boron values are high near the coastal region which is due to the over extraction of groundwater results in seawater intrusion. The sources for sodium and chloride are not only from seawater intrusion, it may also be from weathering, dissolution of salt deposits and sewage influence. But boron contribution is only from seawater intrusion in this study area.

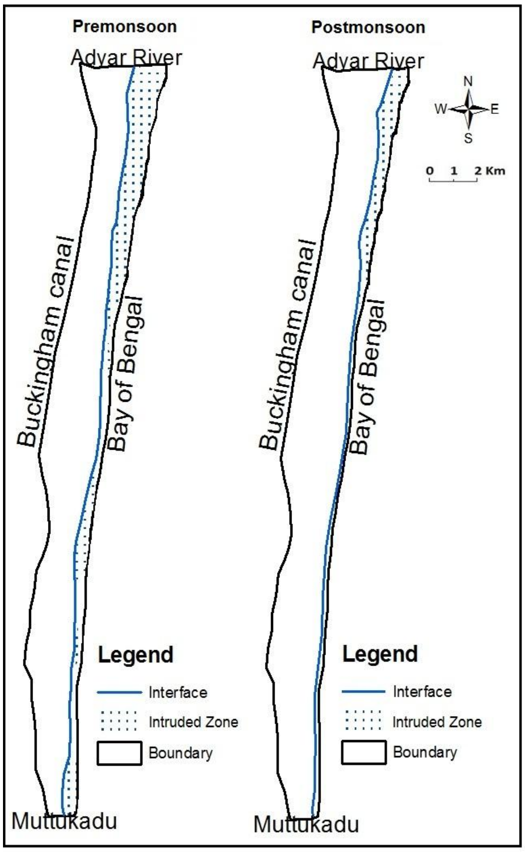

Figure 8: Intruded Area of South Chennai Aquifer

The final interface has been deciphered by considering boron as the main indicator is shown in Figure 8. The interface varies from 950 m in highly populated region (northern part) to 250 m in partially populated region (southern part) from the shoreline in pre-monsoon season and from 550 m in highly populated region (northern part) to100 m in partially populated region (southern part) from the shoreline in post-monsoon season. The interface has been moved towards the inland due to the over exploitation of groundwater for various purposes in pre-monsoon season whereas in post-monsoon season, it has been moved towards the coast due to the dilution of intruded groundwater through rainfall in the monsoon season. It is inferred that the region which is highly populated is more intruded compared to partially populated area due to the over exploitation of groundwater.

The intruded area covers the part of Thiruvanmiyur, Kottivakkam, Palavakkam, Neelangarai and Vettuvangeni in which highly intruded area was Thiruvanmiyur, Kottivakkam and Palavakkam. The northern part of the area was more intruded than the southern part of the area.

Conclusion

The present study was carried out to decipher the freshwater and seawater interface through hydrochemical parameters using ArcGIS software. Groundwater samples are slightly acidic to alkaline. Four major hydrochemical facies (Na^+ -Cl^-, Mixed Ca^{2+}-Na^+ -HCO_3^-, Mixed Ca^{2+} -Mg^{2+} -Cl^- and Ca^{2+} -HCO_3^-) were identified using Piper trilinear diagram. The groundwater samples collected near the seacoast and Buckingham canal has high concentration of sodium and chloride due to the seawater influence and presence of clay patches, respectively. Gibbs diagram shows that the groundwater samples falls from freshwater to saline water. Urbanized part of the region has poor quality of groundwater due to the combined effect of over pumping of freshwater which leads to seawater intrusion and also rock-water interaction and evaporation process. Chloro-Alkaline indices 1, 2 calculations shows that 100% of groundwater samples are negative, thus indicating exchange of Mg^{2+} and Ca^{2+} from water with Na^+ and K^+ of the rocks. According to the overall assessment of the study area, water quality was found to be useful for domestic and drinking purposes, except in locations like 1, 2, 5, 6, 10, 13, 14, 15, 16, 19 and 21 in pre-monsoon season whereas in post-monsoon season it 5, 13, 15, 19 and 21 which show traces of groundwater contamination. The fresh and saline groundwater interface has been deciphered varies from 950 m in highly populated region to 250 m in partially populated region from the shoreline in pre-monsoon season and from 550 m in highly populated region to100 m in partially populated region from the shoreline in post-monsoon season. The interface is moving towards the inland due to the over exploitation of groundwater for various purposes, which disturbed the hydrodynamic balance of the region. The northern part of the area which is fully urbanized was more intruded than the southern part of the area. Therefore, steps should be taken to improve the groundwater quality in this area by optimizing the extraction of groundwater and by adopting the rainwater harvesting systems mainly in the urbanised part of the region.

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