Hydrochemistry of Groundwater in and around Chennai, India - A Case Study

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Abstract

Groundwater quality in and around Chennai is to be known prior to its utility for the survival. With this objective, 240 samples from 60 places were collected in and around Chennai. The analysis and classification is stipulated by international standards. Hydro-chemical and statistical analysis were carried out to assess the groundwater quality. The physico-chemical parameters, sodium / chloride ratio, chloride / bicarbonate ratio, calcium / magnesium ratio are used to identify the intrusion of salt water in the coastal aquifers. Calcium / Sodium ratio is used to identify the hard rock interaction or sedimentary rock interaction. From the study, it is concluded that, groundwater in Chennai is a threat under the saltwater intrusion. The anthropogenic activity is a key factor for seawater intrusion and contamination.

Keywords: Physico-chemical analysis, water quality, groundwater classification and seawater intrusion

Introduction

In India apart from thousands of villages many urban centers are located on the coastal tracks. In these centers apart from dwelling apartments industrial establishments have also come up. Due to this overexploitation of groundwater resources has happened. This paves the way for the intrusion of sea water into the groundwater in these areas. For industry, drinking and agriculture purposes the ground water plays a very important role. It has been reported[1-2] that the wells become either dry or intrusion of salt water is due to low rainfall and high evapotranspiration and there is no replenishments with fresh rain water. The water becomes more saline during post monsoon because of increase in water table which leads to dissolve of the salts. In the wells near to the coastal areas sea water intrusion takes place due to over exploitation of groundwater. Potability of groundwater has been well documented[3-7]. Physicochemical characteristics due the seasonal variation and influence of heavy metal in the groundwater has been studies[8-12]. One of the most common methods for assessing sea water intrusion into the wells or water sources near coastal areas is a periodic analysis of groundwater chemistry[13-18]. The aim of the present communication is to assess and report the quality of water in Chennai.

Study area: The study area Chennai city covers half of the Kanchipuram and Thiruvallur District. The entire region is covered by sand up to a depth of about 18m. The latitude and longitude of the study area is 12.992 to 13.134 and 80.240 to 80.298. It is shown in table-1 and figure-1. The entire region is covered by sand up to a depth of about-10m with respect to sea level. In some locations the inner horizon of sand is mixed with clay and made up of clayey sand. The sand and clayey sand region is followed by the weathered rock up to depth of about – 20 m with respect to sea level.

Material and Methods

To access the quality of water in Chennai, study has been undertaken on 2011. 240 water samples from 60 places in and around Chennai were collected from bore wells. The samples were collected in polythene bottles for the analysis of the ions. The EC, pH and TDS were measured immediately at sampling site using portable meters. All the analysis is carried out using AR chemicals and distilled water. Collected samples were brought to the laboratory on the same day and analyzed for determining the various chemical parameters such as sodium, potassium, magnesium, calcium, sulphate, chloride, fluoride, dissolved oxygen, biological oxygen demand, total hardness, carbonate, bicarbonate and hydroxide using standard procedures prescribed in APHA. TDS, Na^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-} levels were also measured. Groundwater quality assessment has been made based on the above physico-chemical parameters and metal concentration in the water samples collected from Chennai city. The Langelier saturation index has been calculated and it is between -3 and +3 and this suggests that the water was corrosive in the areas under study. Calculations of ionic deviations have been done to understand the hydro chemical processes. Sea water mixing index has been made to evaluate the relative degree of sea water mixing. Mg^{2+}/Ca^{2+} ratio with TDS and Na^+/Cl^- ratio with TDS had been made and based on this relation saline intrusion has been assessed and discussed. Results are presented and discussed in this paper.

Table-1
Location Site with Latitude and Longitude

| S.No	Sample Code	Latitude	Longitude	Sample Places
1	C1	12.989	80.195	Adampakkam
2	C2	13.001	80.256	Adayar
3	C3	13.087	80.215	AnnaNagar
4	C4	12.682	79.985	Chengalpattu
5	C5	13.292	80.171	Chennaivekkam
6	C6	13.231	80.179	Cholavaram
7	C7	12.951	80.135	Chrompet
8	C8	13.023	80.201	Ekkattuthangal
9	C9	13.204	80.321	Ennore
10	C10	13.078	80.274	George Town
11	C11	13.201	80.321	IndiraGandhi Kuppam
12	C12	12.916	80.254	Injambakkam
13	C13	13.035	80.137	Iyappanthangal
14	C14	13.318	80.337	Kattupalli
15	C15	13.35	80.283	Kattur
16	C16	12.793	80.212	Kelambakkam
17	C17	13.043	80.199	KK Nagar
18	C18	12.846	80.057	Kuduvancheri
19	C19	12.994	80.091	Kundrathur
20	C20	12.922	80.132	Kuppuswamy Nagar
21	C21	12.978	80.178	Madipakkam
22	C22	13.16	80.267	Manali
23	C23	13.032	80.111	Mangadu
24	C24	13.093	80.258	Mannady
25	C25	12.941	80.244	Mettukuppam
26	C26	13.29	80.224	Mettupalayam
27	C27	13.27	80.279	Minjur
28	C28	13.025	80.237	Nandanam
29	C29	12.846	80.226	Navallur
30	C30	12.948	80.254	Neelankarai
31	C31	12.753	80.105	Nellikuppam
32	C32	13.067	80.223	Nungambakam
33	C33	12.64	80.171	Paiyanoor
34	C34	12.966	80.123	Palavaram
35	C35	13.118	80.232	Parambur
36	C36	12.906	80.095	Perungalathur
37	C37	12.809	80.151	Pongari
38	C38	13.335	80.191	Pooneri
39	C39	12.617	80.174	Poonjeri
40	C40	13.049	80.075	Poonthamalee
41	C41	13.043	80.157	Porur
42	C42	13.337	80.145	Puduvoyal
43	C43	13.183	80.284	Sadayakuppam
44	C44	13.139	80.268	Salaivayul
45	C45	12.895	80.223	Sholinganallur
46	C46	12.755	80.001	Singa Perumal Kovil
47	C47	13.003	80.199	St.Thomas Mount
48	C48	13.024	80.237	T.Nagar
49	C49	12.993	80.248	Tharamani
50	C50	12.724	80.187	Thiruporur
51	C51	13.157	80.303	Thiruvattriyur
52	C52	12.87	80.243	Uthandi
53	C53	12.892	80.085	Vandaloor
54	C54	12.98	80.224	Velacherry
55	C55	13.058	80.137	Velppanchavadi
56	C56	13.085	80.260	Vepery
57	C57	13.219	80.249	Vichoor
58	C58	13.231	80.245	Villivoyol
59	C59	13.072	80.197	Virugambakkam
60	C60	13.139	80.285	Washermint
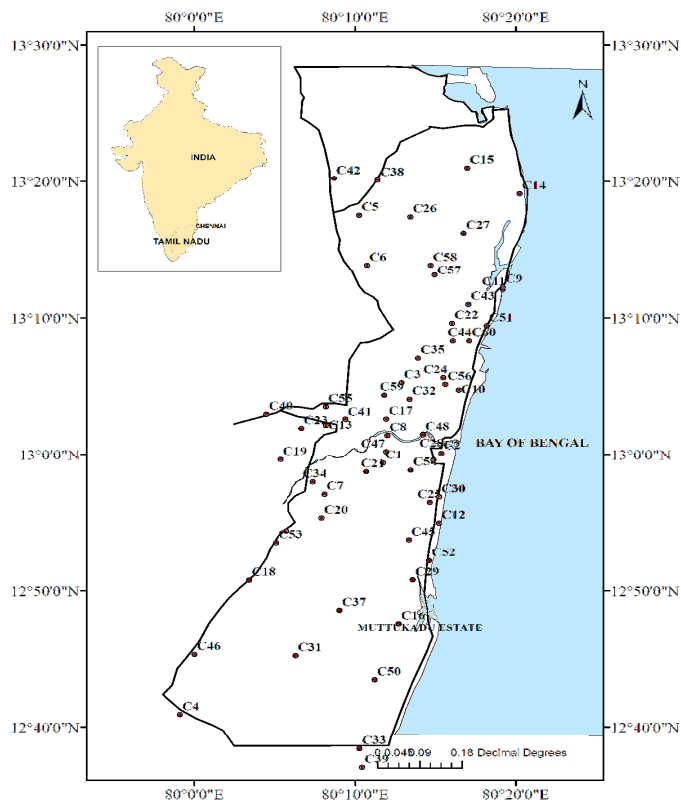
Figure-1
Study Area Map of Chennai City, Tamil Nadu, South India

Results and Discussion

Based on classification[15] the table-2 shows that the salinity character was dominant in 57% of water samples in the study area undertaken. Total dissolved solids also showed a wide variation from 500 to 13390 ppm. Higher values of EC and TDS are recorded in George Town and Taramani. This is closer to Covam River or Adyar River or Buckingham Canal or Bay of Bengal. Based on classification[19], 17% of groundwater samples are fresh water and this is based on the Total Dissolved Solids which is generally less than 1000 ppm.

Chemical analysis of samples indicates that most dominating ions are sodium, chloride, calcium, magnesium, bicarbonate,

sulfate, potassium, nitrate, phosphate and fluoride and they are in the order as indicated here. The sodium is the dominating cation varied from 46 to 4624. The potassium content of natural waters is usually less than that of sodium, calcium, magnesium. The cation such Ca, Mg, K are varied from 20 to 730, 36.8 to 1456 and 0.3 to 1893 ppm respectively.

The concentration of carbonate ions are in traces, and the bicarbonates concentrations are considerable in all water samples analyzed. Among the anions, chloride is the most dominating anion varied from 90 to 4500ppm. The high chloride content of the groundwater is mostly due to sea water intrusion. Another important major anion is sulphate. Sulphate is found in the water samples and this may be from the geological sources. The other anion such as bicarbonate, sulphate, nitrate, phosphate and fluoride varies from 75 to 625, 12.6 to 1948.57, 0 to 500, 0 to 2 and < 1ppm respectively. From the careful observation of these data it is clear that the sodium and chloride ions showed a wide range of distributions and higher standard deviation.

This suggests a possible intrusion of nearby saline water which has comparatively high concentration of sodium and chloride. Water Quality Index is less than 20% in 83% the water samples in Chennai city. Water Quality in the following places C4, C7, C8, C12, C14, C18, C20, C21, C30, C36, C46, C47, C53, C59 is analyzed, calcium content is more compared to the sodium content as well as Ca/Na ratio is greater than 1 indicating that nature of the place was hard rock interaction, but it has high TDS content which may be due to the anthropogenic activity. In overall Chennai 50% of the sampling station exists the permissible limit and they are converted into brackish in nature. 35% of the sampling station are started to convert from fresh to brackish and the remaining 15% of the samples are fresh in nature (C3, C4, C7, C8, C14, C31, C38, C42, and C47).

From this study it is seen that groundwater quality is worst in the C2, C5, C9, C10, C11, C15, C16, C17, C22, C24, C25, C26, C28, C29, C32, C33, C35, C39, C41, C43, C44, C45, C49, C51, C52, C56 and C60. Maximum values are found in all the parameters in these areas. The groundwater quality is excellent C3, C4, C7, C8, C14, C31, C38, C42 and C47 in these areas and water can be used for the house hold purposes. In the remaining areas water quality is not worst or best but it is in the

intermediate level and the water in these areas can be used for the house hold purposes. Kurtosis was applied on data matrix to measure peakedness of the probability distribution.

Distribution with positive kurtosis has a higher probability of variables than the normal distribution around the mean and also indicates a higher probability of distributed variables with extreme values. A distribution with negative kurtosis indicates a lower probability of normally distributed variables of values near the mean as well as extreme values[20]. From the statistical table, high positive values for TDS, sodium, potassium, chloride indicating distribution is peaked. Minimum coefficient of variation indicates that there is not much variation in pH in all the samples. Minimum Standard deviation and Standard error for pH and maximum for sodium and total dissolved solids.

High level of sodium and chloride in coastal groundwater indicates the significant effect of sea water mixing, but there is a considerable amount of bicarbonate and calcium which indicates the hard rock interaction. The plot of bicarbonate/chloride versus TDS shows regression slope is negative in the high TDS range, while the slope is positive in the low TDS concentration range. The ground water with high TDS concentration is enriched with chloride and the groundwater with low TDS concentration is not or less affected by saline water. Variation of Calcium/Sodium ratios with TDS showed a similar trend and subsequently similar interpretation in both the seasons.

The high TDS recorded in the following groundwater samples such as the C2, C5, C9, C10, C11, C15, C16, C17, C22, C24, C25, C26, C28, C29, C32, C33, C35, C39, C41, C43, C44, C45, C49, C51, C52, C56 and C60 indicating the intrusion of salt water, the low TDS recorded in 35% of the sampling station. It is shown in figure-2. Figure-3 indicates that there is a minimum value of Calcium and Magnesium with bicarbonate except 25% of the sampling station where there is a hard rock interaction as indicated above. From the figure-4 it is clear that 50% of the sampling station ratio of sodium and chloride are high and equal indicating that there is intrusion of salt water and 25% of the sampling station indicates the content of calcium is higher than sodium due to hard rock interaction.

Table-2
Statistical Data of Groundwater sample in Chennai

Parameters	Mg	Ca	HCO$_3^-$	Cl$^-$	TDS	Sodium
Maximum	1456.0	730.0	725.0	4500.0	13390.0	4624.0
Minimum	39.6	20.0	100.0	90.0	350.0	46.0
Average	223.9	157.8	396.7	595.4	1565.0	865.54
Median	160.5	125.0	375.0	312.0	1100.0	459.4
Kurt	12.87	9.49	-0.55	11.15	23.7	4.55
Mode	200.0	82.5	375.0	918.0	590.0	46.0
Std. Dev.	266.9	120.5	155.37	818.1	1988.0	1010.0
Std. Error	34.5	15.6	20.1	105.6	256.6	130.4
Coefficient of Variation	11.9	7.6	3.9	13.7	12.7	11.7

*All parameters are expressed in ppm and EC is in µs/cm
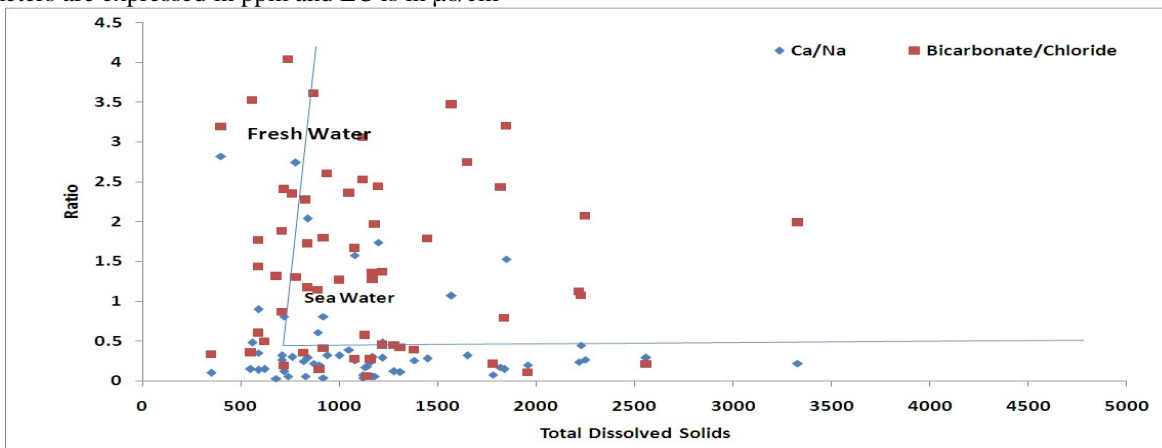

Figure-2
Ionic Ratio versus TDS
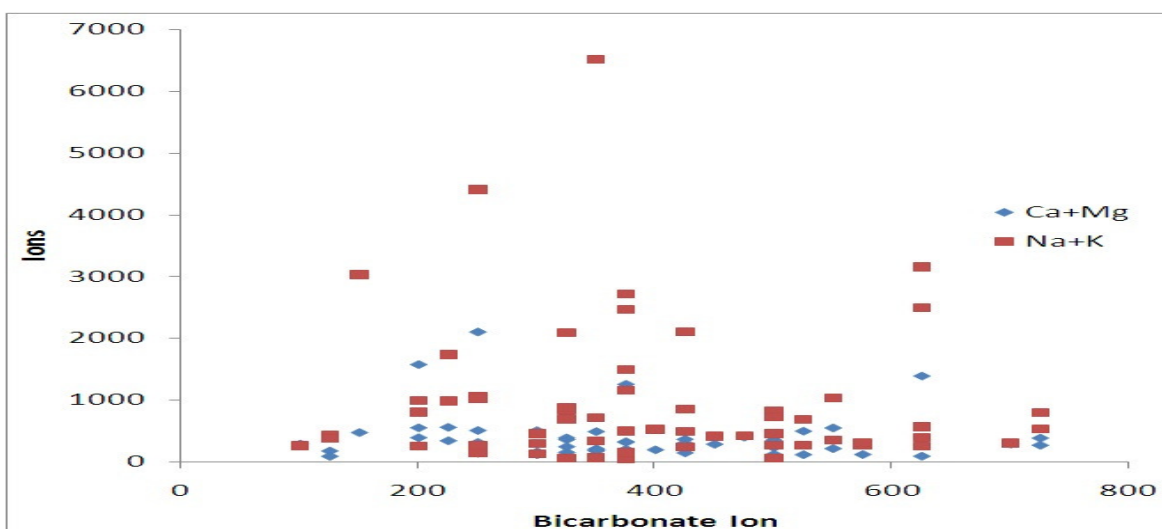
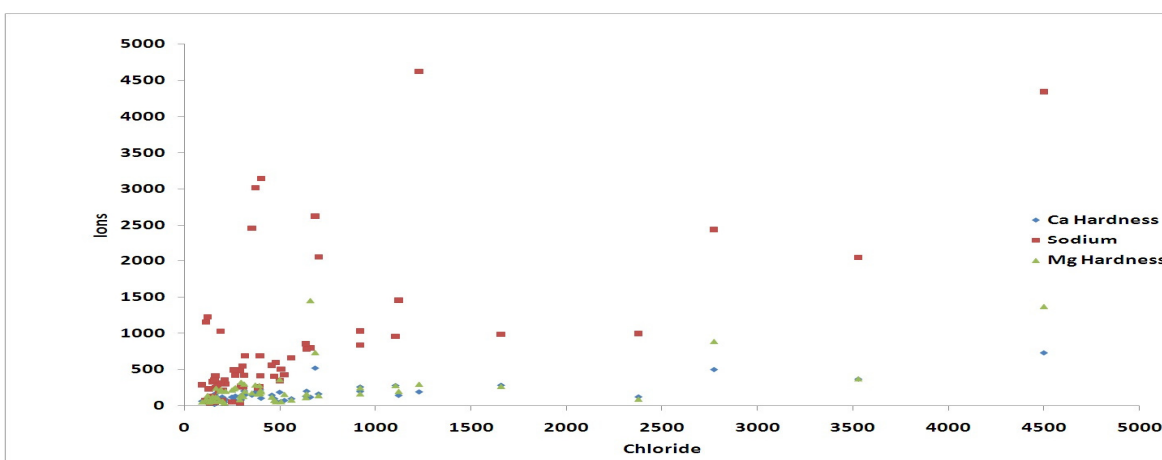

Figure-3
Ions Versus Bicarbonate Ion

Figure-4
Ions versus Chloride

Sodium/Chloride ratio indicates if the ratio is less than 0.86 it indicates that the water is freshwater (15%), if the ratio between the 0.86 to 1 it indicates that the water starts converting into brackish in nature, if the ratio is greater than 1 it indicates that there is intrusion of anthropogenic activity. The ratio of Calcium/Magnesium ratio is less than 1 in 50% of the places and it indicates that there is an intrusion of salt water and the remaining place the water is fresh or moderate in nature. If the ratio of calcium/sodium ratio is greater than 1 in 25% of the place it indicates that soil is rocky in nature. These are shown in figure-5. The Statistical data for this ratio is shown in table 3. Corrosivity Ratio is greater than 1 indicates that it will undergo corrosion, if it is less than 1, there will be no corrosion[21]. In our study area expect 15% of the samples others will undergo corrosion; it is due to intrusion of salt water or anthropogenic activity.

From the figure-6 it is clear that among the anions the chloride was dominating anion and it is so in more than 50% of the samples but sulfate was present only 20%. Calcium is dominating only 25% where there is a hard rock interaction, the magnesium is dominating only 10%, and other remaining places are dominated by sodium and potassium. pH is within the range of 6 to 7.2. In 50% of the places water is having TDS around 1500 to 4000ppm. Figure-7 Trilinear is a diagram which indicates that sodium and chloride are having equal percentage but dissolved solid is around 60 to 80%. From the statistical data shown in table 4, it is clear that iron was present in 85% of the groundwater samples in Chennai city; the metal zinc is present in the water sample with maximum value of 0.62 ppm and lead with 0.07 ppm. Copper and Nickel present with the maximum value of 1.24 and 10.56 ppm.

Table-3
Statistical Data for the Ionic Ratio

Parameters	Cl/HCO_3^-	Ca/Mg	Na/Cl	Ca/Na	CR
Maximum	17.60	2.30	10.50	2.80	29.70
Minimum	0.25	0.08	0.16	0.03	0.36
Average	1.94	0.94	2.03	0.46	3.48
Median	0.77	1.00	1.24	0.27	1.21
Kurt	13.73	0.66	5.87	6.67	11.09
Mode	0.31	1.23	0.88	0.32	0.55
Std. Dev.	3.02	0.42	2.31	0.61	5.36
Std. Error	0.39	0.05	0.30	0.08	0.69
Coefficient of Variation	15.54	4.51	11.34	13.15	15.40

Table-4
Statistical Data for the Heavy Metals

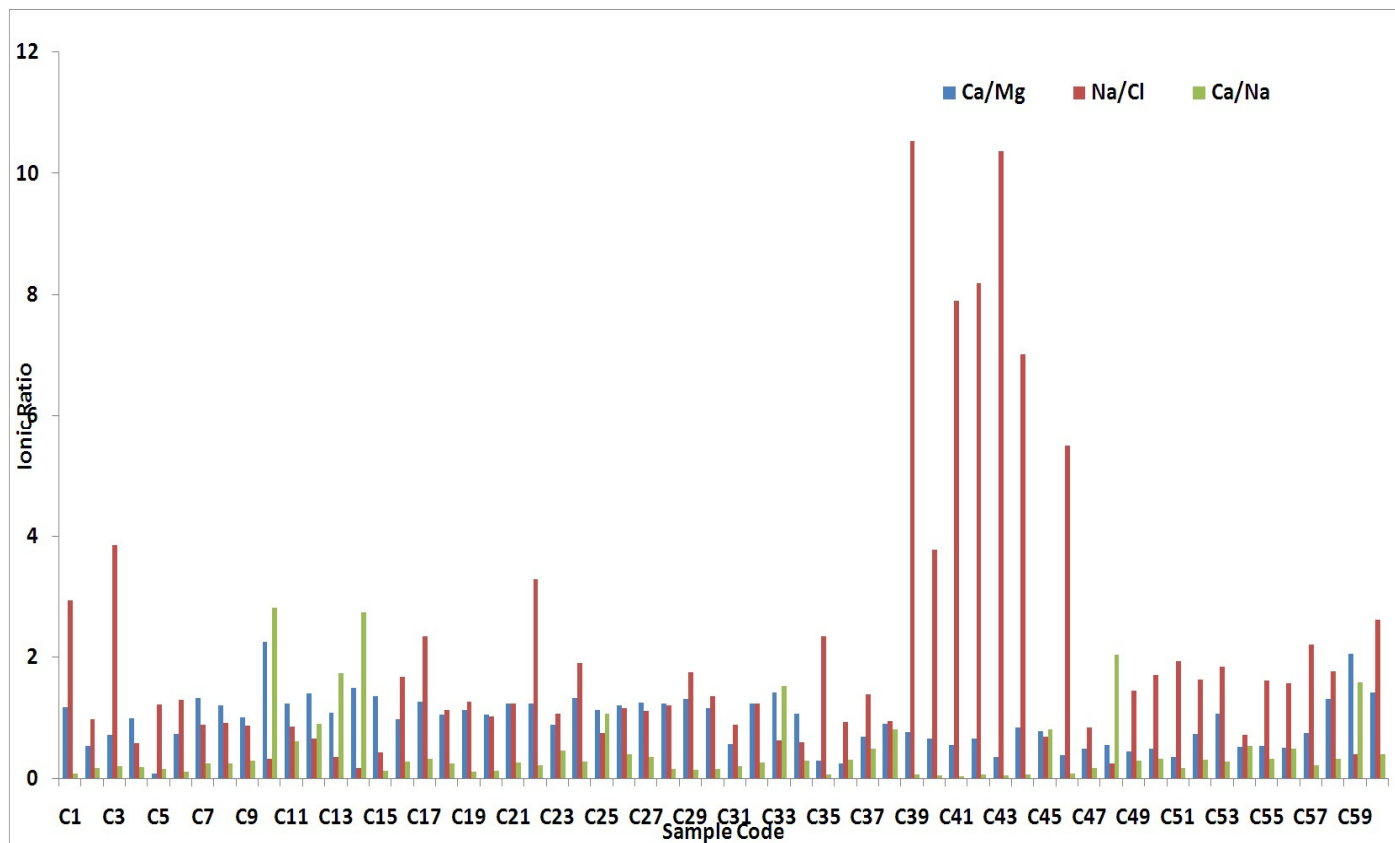| Parameters	Iron	Nickel	Cu	Zinc	Pb
Maximum	15.81	10.56	1.24	0.62	0.07
Average	7.03	0.52	0.17	0.19	0.01
Median	4.91	0.00	0.00	0.00	0.00
Kurt	-1.64	59.97	2.61	-1.48	0.62
Mode	14.73	0.00	0.00	0.00	0.00
Std.dev.	6.1	3.94	0.28	0.24	0.02
Std. Error	0.79	0.51	0.04	0.03	0.00
Coefficient of Variation	8.67	76.07	16.48	12.98	19.46

Figure-5
Ionic Ratio Versus Sample Code
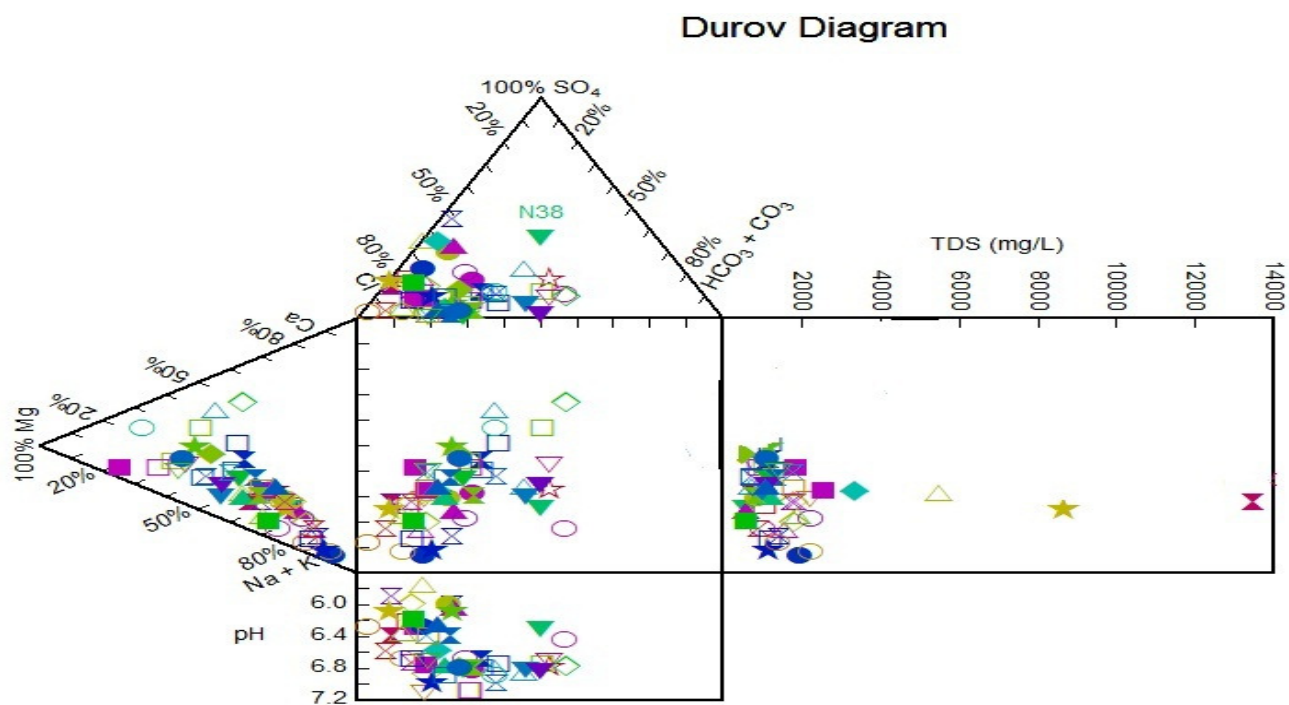

Figure-6
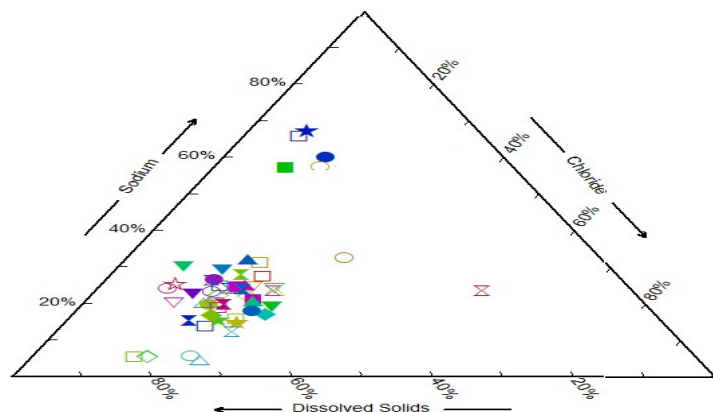**Durov Diagram of the sampling station**

Figure-7
Trilinear Diagram of the sampling station

Conclusion

Calcium / Sodium ratio is greater than 1 as well as the calcium and bicarbonate is the dominating ions in the following sampling places C4, C7, C8, C12, C14, C18, C20, C21, C30, C36, C46, C47, C53, C59 reveals that groundwater is formed by hard rock interaction and it has high TDS content which may be due to the anthropogenic activity. In overall Chennai 50% of the sampling station exists the permissible limit and becomes into brackish nature. 35% of the sampling stations are under fresh to brackish and the remaining 15% of the samples are fresh in nature (C3, C4, C7, C8, C14, C31, C38, C42, and C47). From this study it is seen that groundwater quality were very poor in C2, C5, C9, C10, C11, C15, C16, C17, C22, C24, C25, C26, C28, C29, C32, C33, C35, C39, C41, C43, C44, C45, C49, C51, C52, C56 and C60. The groundwater quality is tolerance in C3, C4, C7, C8, C14, C31, C38, C42 and C47 and it can be used for the domestic purposes. In the other areas water quality is not poor and it is in the threshold limits.

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