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Groundwater Quality and Role of the Monsoon in Chennai City, South India

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The groundwater quality of Chennai, a metropolitan city in South India was investigated during pre and post monsoon season in 2005 to study the role of hydro geochemistry, influence of monsoon rainfall and suitability of water for domestic consumption. Seventy four water samples were collected from the urban limits of the city and analyzed for pH, electrical conductivity, alkalinity, major ions and nitrate concentration using standard methods. Sodium and chloride are the dominant cation and anion respectively. Strong alkalies dominate alkaline earth metals among cations while dominance among anions is of the order of chlorides > bicarbonates > sulphates. Seven hydro chemical facies were identified with dominant types being NaCl, $NaHCO_3Cl$ types which also showed responses to monsoon recharge. The monsoon season significantly increased the groundwater levels as well as controls the hydro chemical reactions. Contamination by sea water, especially in the eastern part of the city, onsite leaching of salts with recharge are responsible for the increased mineralization of the groundwater. The drinking water compliance for domestic uses is average for maximum allowable limits, while below average when compared with desirable limits.

Key Words: Groundwater quality, Hydrochemistry, Monsoon, Chennai city.

INTRODUCTION

Groundwater is emerging as one of the important sources of water supply for domestic uses especially in the towns and cities in view of urbanization and increase in population pressure. Groundwater quality can become an important issue under these situations that can affect the beneficial uses of water. The quality of groundwater is therefore as much important as the quantity available. Geochemical processes that occur between the groundwater and aquifer materials control reactions of dissolved minerals[1,2] and hence quality of water. Variation of groundwater quality can be defined as a function of physical and chemical parameters which in addition to geological formations[3-5] are also greatly influenced by anthropogenic activities[6-8], especially in urban areas. Hence, it is important to study and to understand the relation between surface processes and the hydro chemical characteristics of the groundwater. The evaluation of the water chemistry can be done using various graphical methods and charts[9-11] effectively.

Seasonal variations can also affect the quality of groundwater[10,12]. In urban areas, the storm water run off is considered to be one important source of surface and ground water quality concern. Storm water run off, its quality and impacts on groundwater are dependent on the quantum of rainfall and its seasonal pattern[13,14], which might affect the recharge process.

In this study, the groundwater quality of Chennai city in Tamil Nadu, India and role of the monsoon, which is the main source of water supply to the city are reported. Chennai city is located in the peninsular part of the Coramandal coast in the Bay of Bengal. It is influenced by the Indian monsoon (south west and north east monsoons), which brings the major rainfall for the city and can influence the storage in the surface water sources of the city as well as groundwater recharge. In addition, the rapid increase in population, the land use changes and over extraction of water are probable threats for the quality of groundwater in Chennai city at present.

Study area: Chennai is the capital city of Tamil Nadu state in South India on the Bay of Bengal coast. It has an area of 172 km^2 and is called the Greater Chennai, while the Chennai metropolitan area has now been expanded to cover 1189 km^2 incorporating the north, west and southern suburban areas. The present study pertains to the greater Chennai city. Chennai has a low lying plain terrain with a gentle slope from the west towards eastern part of the city adjoining the coastline.

The average annual rainfall for the city area is 1200 mm. The rainfall occurs mostly during the monsoon season, which is from June to September (south west monsoon, 32 %) and October to December (north east monsoon, 61 %). The winter is brief (Jan-Feb) and a warm summer (Mar-May) follow with a total rainfall less than 10 %.

EXPERIMENTAL

Hydrogeology: The hydrogeology of the top layer of the aquifer in the Chennai city area has three major formations, alluvium, sedimentary and hard rocks. The charnokites form the major rock types and residual outcrops can be seen in the southern part of the city below the Adyar river. The eastern part of the city is extensively covered by the recent alluvium and runs parallel to the coastline. The river alluvium followed by gondwana, sandstone, clay and crystalline shale comprise most of the central part of the city between Adyar and Coovum rivers. The western part of the city has alluvium followed by tertiary sediments. The northern part of the city is covered by recent alluvium underlain by clay and shales[15,16]. The drinking water supply is dependant on the monsoon rainfall in the city. Hence, the dependence on the groundwater is significant in periods of distress, especially for domestic consumption. Based on hydrogeology, Chennai city was divided into five zones, namely east (along the coast), north, central, west and south (Fig. 1).

Water sampling and analysis: The information on the groundwater quality was collected through primary collection of ground water samples from the city and analysing them for selected chemical parameters. The city was divided in to 2 km^2 grid cells and one sample was collected from a shallow well (< 10 m) selected randomly inside the grid. A total of 40 wells from all the zones were sampled twice, one during June 2005 (pre monsoon) and another during January 2006 (post monsoon) for the water quality analysis. 1 L of the water sample was collected in a clean polythene container and transported under cold conditions to the laboratory. The pH and electrical conductivity of the samples were measured in the sampling site itself using YSI 600 multi parameter water quality probe. However, four samples could not be analyzed and a total of 76 samples were available for analysis.

The chemical analyses were done as per standard methods (APHA, 1998). The carbonates and bicarbonates were estimated by titration with standard acid and the total alkalinity was calculated. Calcium and magnesium were estimated using EDTA complexometric titration. The chlorides were analyzed by the argentometric titration. The sodium and potassium were analyzed with SYSTRONICS Flame photometer. The cadmium reduction column method was used for the estimation of the nitrates in the samples.

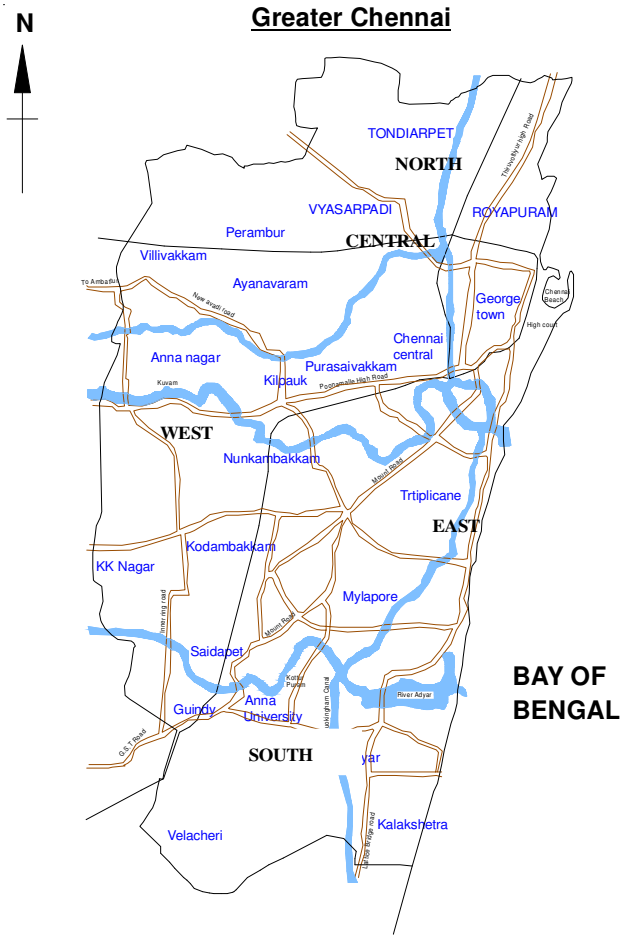


Fig. 1. Map of Greater Chennai (study area)

Groundwater levels from different parts of the city for July 2005 and January 2006 were collected from different agencies of the Government of Tamil Nadu and the Central Ground Water Board, Chennai from among the observation wells maintained by them. The average water levels (BGL) were computed for each zone of the city by considering all available wells for that region for pre (July 2005) and post (Jan 2006) monsoon seasons.

The data analyses were done in the MS Excel worksheets and the hydro chemical analyses of the water quality parameters were done using AQUACHEM software package (SWS[17]).

TABLE-1
AVERAGE STANDARD OF THE GROUNDWATER QUALITY OF DIFFERENT ZONES IN CHENNAI CITY

Zone	Unit	East		South		Central		West		North		BIS (1991)
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
pH		7.72	0.36	7.60	0.65	7.51	0.52	7.73	0.59	7.63	0.56	6.5-9.2
EC	µS/cm	4383	1687	1605	683	1438	910	1716	697	2032	1169	500-1500
Sodium	ppm	525.70	233.84	170.04	68.97	172.97	100.12	223.45	112.30	303.47	204.84	
Potassium	ppm	15.52	5.88	6.24	2.69	4.94	3.15	6.01	2.55	7.13	4.21	
Magnesium	ppm	90.01	71.59	29.00	19.32	40.18	35.94	34.03	22.70	31.17	20.83	30-100
Calcium	ppm	81.64	82.46	66.77	48.14	66.46	41.85	59.29	37.01	62.27	39.13	75-200
Chloride	ppm	1287.50	928.29	210.37	142.78	327.26	217.61	452.27	228.57	694.32	558.87	250-1000
Sulphate	ppm	353.82	252.12	194.27	117.34	194.03	113.91	191.18	108.57	356.65	277.96	200-400
Nitrate	ppm	31.15	26.19	29.81	24.38	27.60	22.01	6.48	2.69	5.36	-	45-100
Alkalinity	ppm	569.66	173.66	507.30	184.73	481.51	146.11	464.60	143.39	492.05	173.85	300-600

RESULTS AND DISCUSSION

Groundwater quality: The average values with standard deviation of the water quality parameters for each zone is given in Table-1. The pH values indicated mild alkaline conditions with a narrow range of fluctuations (0.6) in all the zones. The overall mean pH value was 7.63 with SD of 0.55. The electrical conductivity however showed wide variations between the zones. The overall average value was 1985 µS/cm, while in the eastern zone of the city adjoining the coastline, the average value was 4383 µS/cm. The next highest value was recorded in the north zone (2032 µS/cm), followed by west zone (1716 µS/cm), south zone (1605 µS/cm) and the lowest mean value is recorded in central zone (1438 µS/cm).

The sodium and chloride are the major dominant cation and anion respectively in all the zones (Table-1). Among cations, the sodium is the major ion followed by calcium, magnesium and potassium. Among the anions, the chloride is the major ion followed by bicarbonates and carbonates, sulphates more or less equally and carbonates share is very less (Table-1). This is the general trend seen in all the 5 zones.

Among the cations, the sodium was the dominant ion in all the zones, with high average values (525 ppm) in the eastern zone followed by northern (303 ppm), western (233 ppm), southern (170 ppm) and central zone (172 ppm). Similarly the potassium concentrations are also high in the eastern zone (15 ppm) while in other zones the concentration is nearly half of it. The alkaline earth metals are the lower in concentration varying from 81 ppm in the eastern zone to 66 and 59 ppm in the central and western zones. The magnesium concentrations were high in the eastern zone (90 ppm) and followed a similar trend of calcium in other zones.

The anions are dominated by chlorides in all the zones. The abundance is of the order; chlorides > alkalinity > sulphate. The alkalinity varied from 569 ppm in the eastern zone to 464 ppm in the western zone with similar concentration in south, central and north zones. The average nitrate concentrations showed lesser values in west (6 ppm) and north (5 ppm) while higher concentrations (up to 31 ppm) in other zones.

The suitability of the groundwater for domestic purposes in different zones of the city was compared with the standards for drinking water by BIS[18]. All the samples comply with the pH requirement, but the electrical conductivity was found to be generally high in all the zones, especially in the eastern zone. Similarly, the chlorides were also found to exceed the allowable limits in all the zones. The nitrates did not exceed the recommended concentration limits. Most of the groundwater samples analyzed in the Chennai city show high mineralization and may require treatment for drinking purposes.

Groundwater chemistry: The term hydro geochemical facies is used to describe the types of water based on the dominance of major ions that occur in groundwater in terrains especially different in chemical composition, that affect quality. The occurrence of particular type of facies is dependant on the lithology, solution kinetics and groundwater flow rate and residence time[1,19].

The hydro chemical diagrams are evolved to facilitate the interpretation of the probable water aquifer material interactions[20]. The Pipers tri linear diagram is a classical tool to study water types and infer hydro chemical changes.

The Fig. 2a and 2b shows the tri linear plot of groundwater samples collected before and after monsoon. The hydro chemical process appears complex and seven types of water can be seen with sodium chloride and sodium bicarbonate chloride types dominating the samples. The major hydro chemical types are NaCl, $NaHCO_3Cl$, $NaHCO_3$, $NaClHCO_3$, $NaClSO_4$, $CaNaHCO_3Cl$ and $CaNaHCO_3Cl$. The NaCl type dominates in general (44 %) with $NaHCO_3Cl$ closely following it (32 %). The sodium dominates the cations while chlorides and bicarbonates share the dominance among the anions.

The distribution of hydro chemical facies shows the dominance of strong alkalis over the alkaline and alkaline earth metals. The contamination by sea water in the eastern and northern zone may have contribution to the presence of alkalis where as in the central and western zone also, the same situation is present. The source of strong alkaline metals may also be due to anthropogenic sources[21], as domestic waste water disposal through the Buckingham canal, Coovum, Adyar rivers (Fig. 1) and solid waste dump sites are present in many parts of the Chennai city. The recharging rain water can carry considerable amount of soluble substances to the groundwater as sodium chloride is one important constituent of the leachate from the domestic waste sites[6].

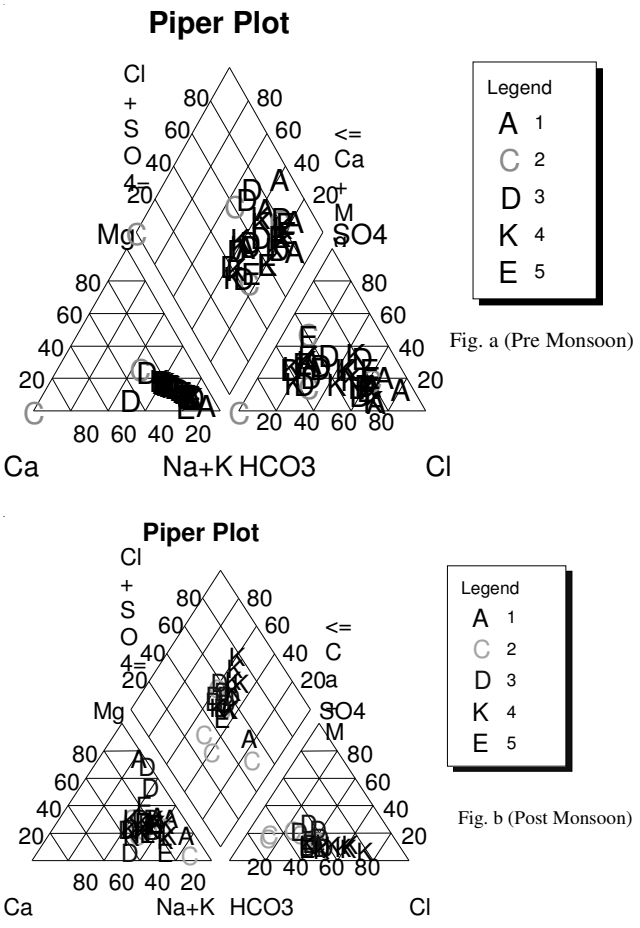


Fig. a (Pre Monsoon)

Fig. b (Post Monsoon)

Fig. 2. Piper's tri linear classification of groundwater samples from different zones of the Chennai city during pre (a) and post (b) monsoon seasons.

Gibbs diagram is another tool for understanding the mechanisms controlling groundwater chemistry such as rock weathering, evaporation and precipitation events. Several researchers have used these tools to infer the role of influencing mechanisms[9,10,22] especially, when water samples are collected and analyzed during different seasons.

Gibb's diagram permit understanding three major types of chemical interrelationships- the precipitation dominance, evaporation dominance and rock dominance. The Gibb's diagram is plotted by calculating the ratio's of $Cl/Cl + HCO_3$ for anions, Na + K/(Na + K + Ca) for cations and plotting against the respective value of total dissolved solids.

Fig. 3 shows the Gibb's diagram for the water samples collected during the pre and post monsoon season in Chennai city. The plot of samples clearly shows that the rock water interaction is the major mechanism in the groundwater chemistry while evaporation dominance or precipitation processes have less relevance. The situation being similar in the case of pre and post monsoon seasons also indicate less influence of the climatic regime on the groundwater chemical changes in Chennai city. The plot of samples in the tri linear plot in the post monsoon season (Fig. 1b) adds evidence to dominance of the rock water interactions. Most of the water samples from the zones move from the dominant NaCl type during pre monsoon to a mixed types of calcium sodium bicarbonate and calcium magnesium chloride types during post monsoon. Table-2 also shows the increases in the concentration of the magnesium and bicarbonates during post monsoon season compared to pre monsoon levels. The ion exchange[23] along with leaching of the salts by the post monsoon recharging water may be responsible for the changes noticed in the concentration of major ions[22].

Since the major part of this coastal city is covered by alluvium of estuarine origin[15] and groundwater samples showing enrichment of sodium, chloride, magnesium and bicarbonate ions, the role of sea water and the ion exchange process may play significant role in the groundwater chemical composition. The removal of sodium ions (post monsoon season) may be taking place with the fresh infiltrating water into the aquifer as vertical recharge has been shown to be a major source of groundwater[15, 24] in Chennai city. Sodium ions present in the groundwater may exchange calcium ions. The conversion of calcium bicarbonate water into sodium bicarbonate due to ion exchange in many aquifers has been reported[10,22,23,25]. The increasing dominance of magnesium concentration in post monsoon season (Table-2) has also been reported in a seasonal study of groundwater in Guntur district by Subba Rao[10] who has inferred ion exchange between sodium and calcium and/or precipitation of calcium carbonate[22] leading to higher concentration of magnesium than calcium in the groundwater.

Role of monsoon: The annual average rainfall for the Chennai city is 1200 mm. During 2005, the total rainfall received was 2566 mm, an excess of 102 % above the average. The impact of this copious monsoon rainfall was evident in the increase in groundwater levels recorded during January 2006. Table-3 shows the average groundwater levels (BGL in m) computed for the observation wells available for each zone of the city during July 2005 (pre monsoon) and January 2006 (post monsoon) and the increase in water levels. The Table-3 also shows the minimum, maximum and standard deviation of the water level data for each zone.

The maximum increase in water level was recorded in the central zone (4.93 m) and the lowest in the eastern zone (3.50 m). In the north and south zone, the SD is small suggesting uniform increases, while in the eastern zone, the SD is 2.03 m, suggesting wide fluctuations in the zone. There is continuous abstraction of groundwater for domestic use in all the zones, that could not be quantified, which may also have contributed to the water level fluctuations noticed in the observation wells.

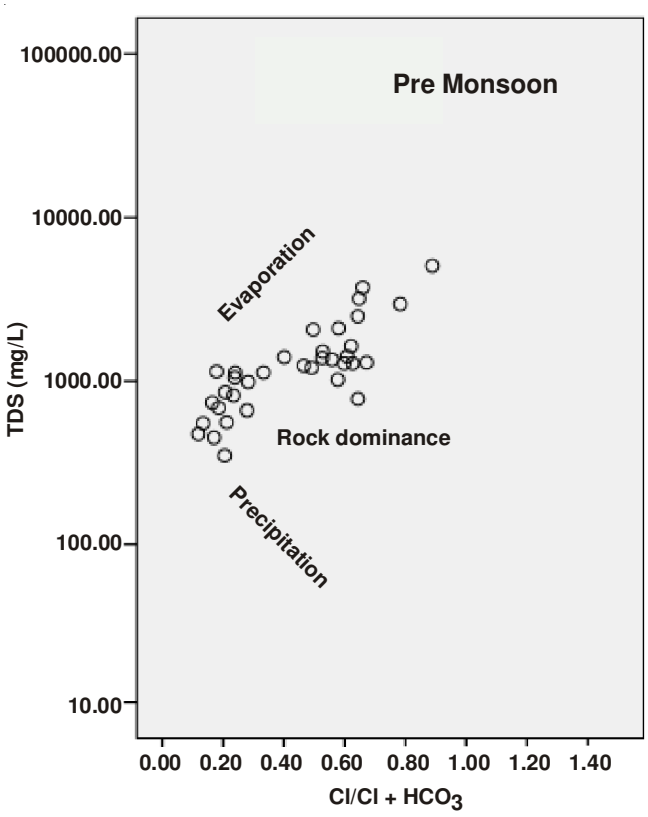
The groundwater quality showed good responses (Table-2) to the monsoon recharge in all the zones. Post monsoon increase in electrical conductivity is noticeable in the eastern zone while it is moderate in the central and western zone. But electrical conductivity showed a decrease in the northern zone. Similarly, in all the zones, a general decrease in the concentration of sodium and potassium can be seen, while there is an increase in magnesium concentration. The other major ions showed differential responses in different zones of the city, in response to recharge.

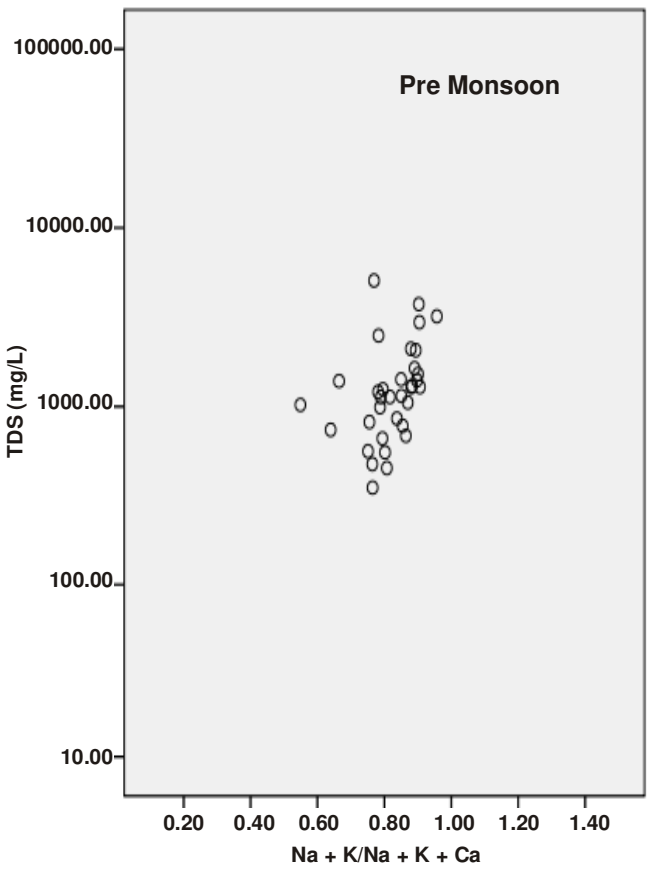
The hydro chemical diagrams explained this differential response, which may have been due to the combined effect of post monsoon groundwater recharge, hydro geological differences in the city, urbanization, waste disposal practices and

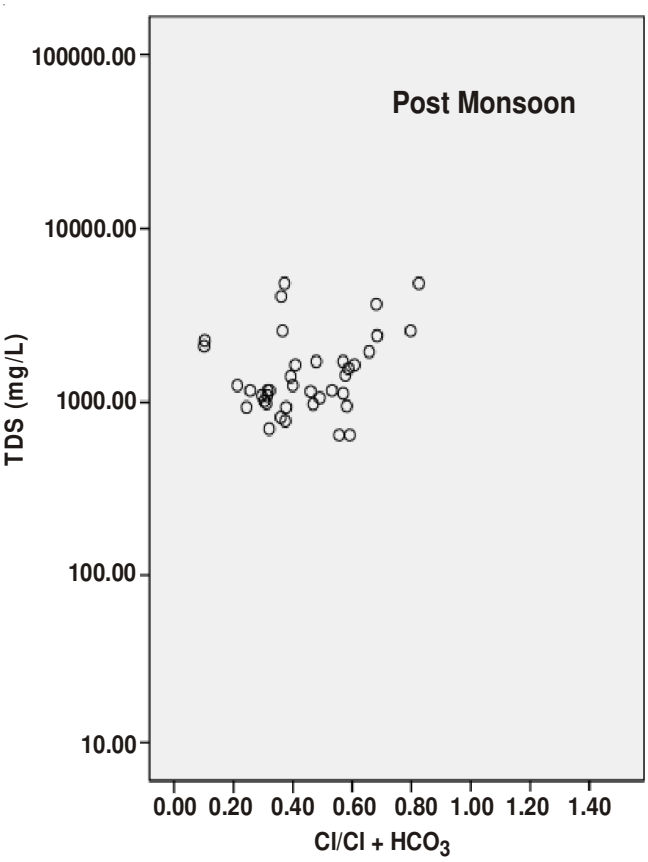
TABLE-2
PRE AND POST MONSOON CHANGES IN MAJOR ION CHEMISTRY OF GROUNDWATER IN DIFFERENT ZONES OF THE CHENNAI CITY

Zone	East		North		Central		West		South	
Parameter/ season	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon	Pre Monsoon	Post Monsoon
pH	7.88	7.53	8.08	7.18	7.75	7.32	7.99	7.48	7.98	7.34
Electrical conductivity	3810.00	5100.00	2094.00	1970.00	1319.00	1536.67	1500.91	1912.50	1260.00	1835.00
Alkalinity	551.22	592.70	485.34	498.76	518.28	450.88	432.44	494.08	452.40	543.90
Sodium	556.40	487.33	378.69	228.26	204.32	146.84	258.72	191.12	159.43	175.34
Potassium	13.95	17.48	7.51	6.75	4.55	5.27	5.42	6.55	6.13	6.29
Magnesium	54.74	134.10	21.53	40.80	27.91	52.44	23.60	43.60	18.14	37.68
Calcium	104.55	53.00	50.95	73.60	63.21	69.17	45.06	72.33	43.43	82.33
Chloride	1329.60	1234.90	572.82	815.81	377.81	285.13	373.09	524.85	304.28	147.77
Sulphate	451.42	109.84	408.65	96.65	252.85	128.67	231.24	128.24	286.75	132.62
Nitrate	–	31.15	–	5.36	–	27.60	–	6.48	–	29.81

the contamination by sea water, especially in the eastern zone of the city. It is likely that the extent of influence exerted by the quantum of monsoon recharge may be the driving force behind the hydro chemical reactions taking place in the aquifer and hence influence the groundwater quality.







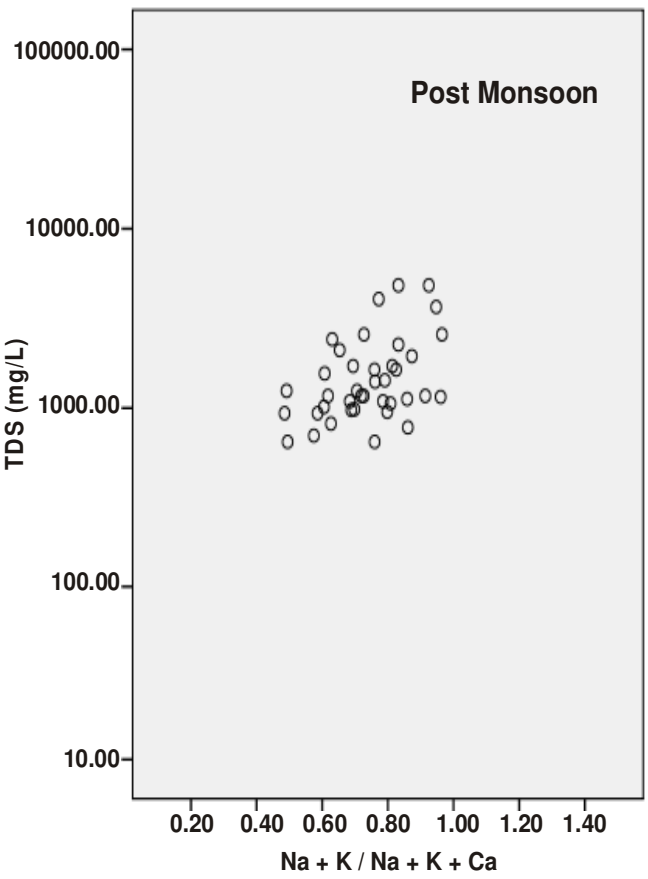


Fig. 3. Gibb's diagram of water samples collected during pre and post monsoon season in the Chennai city

TABLE-3
GROUNDWATER LEVELS (BGL IN M) OBSERVED DURING JULY 2005 AND JANUARY 2006 AND THE CHANGE IN WATER LEVEL (M) IN DIFFERENT ZONES OF CHENNAI CITY.

Zone		Jul 2005	Jan 2006	Change in Water level
East	Mean	5.90	2.40	3.50
	Std. Deviation	3.07	2.03	
	Minimum	1.50	0.53	
	Maximum	8.20	5.20	
South	Mean	8.20	3.38	4.82
	Std. Deviation	1.06	0.99	
	Minimum	6.70	2.50	
	Maximum	9.55	4.90	
Central	Mean	6.72	1.79	4.93
	Std. Deviation	2.89	1.02	
	Minimum	4.14	0.28	
	Maximum	10.85	2.53	
West	Mean	7.66	2.83	4.83
	Std. Deviation	3.25	2.44	
	Minimum	4.47	0.69	
	Maximum	12.17	6.17	
North	Mean	5.13	1.43	3.70
	Std. Deviation	3.36	0.04	
	Minimum	2.75	1.40	
	Maximum	7.50	1.45	

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