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The Effect of Ground Water due to Saltwater Intrusion in Coastal Tract of Visakhapatnam City, Andhra Pradesh, India

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Abstract: Seawater intrusion into groundwater aquifers occurs mostly in big cities and developing coastal cities. The rise of sea levels and excessive use of groundwater for clean water source trigger saltwater intrusion. Identification of saltwater intrusion into groundwater can be done by groundwater sampling and major ion analysis. The periodic wise ground water quality analysis done, this fact prompted me to take up the study on ground water quality analysis of the entire coastal area. The study area in the present work has the large coastal line. The present study area is between 17o42' North latitude and 82o02' East range of hills. Based on topographical conditions, the city and its environs can be divided into four categories viz. Hilly region, Upland tracks, Rolling plains and Plains. Thus, extension studies are carried out over a period of three years both pre-monsoon and post-monsoon period and all physic-chemical and chemical parameters are determined as per the procedures summarized. There are many reports of Ground water being contaminated by salt-water intrusion to different levels. Also, there are different chemical methods to evaluate the effects of saltwater intrusion. The major ions dissolved in water are Ca, Mg, Na, K, Cl, HCO3, and SO4; the major ion ratios are Cl/Br, Ca/Mg, Ca/ (HCO3 and SO4), and Na⁄Cl. The susceptible areas of seawater intrusion in the study area are delineated and presented in the Figure year wise. It can be seen from the figure that the areas such as SW-1 (INS Kalinga), SW-2(Chapaluppada), SW-5(Kapuluppada), SW-3 (Gollalapalem), SW-8 (Jodugula Palem), SW-9 (Chinna Rushikonda) have indicated salt water affected areas. It is also perceived that recharge from precipitation or other sources are not balanced and this has not compensated the replenishment of groundwater. The salt-water intrusion problem can be controlled by using recharge wells near the areas and scientific way of pumping should be implemented.
Key words: Ground water, Piper Diagram, Salt water Intrusion, Ionic Ratios , Visakhapatnam

I. INTRODUCTION

Water plays a substantial role in all systems of life. Water, the important components for all alive beings, is consistently polluted in all countries. India is no exclusion to this phenomenon. The global world is facing the challenge of decontamination of water. Inspite of various uses the organic compounds are toxic in nature and environmental pollution by these poisonous chemicals is emerging as a serous global problem. The significance of water for human is clear from the fact that 75% of its body requires of water. Industrial, municipal wastes and chemical composts, herbicides, and insecticides have move in the soil, penetrated into aquifers, and degraded the water quality. Cities located in coastal tract areas are generally built with rocks mainly composed of quaternary sedimentary deposits from the sea and loose fluvial deposits. Uncontrolled groundwater pumping will also reason a reduction in the groundwater level which can lead to land collapsing in quite large areas. In some coastal areas, intensive pumping of contemporary ground water has caused salt water to intrude in fresher aquifers. Rivers are the life line of the country. When they are affected, the consequences are detrimental to humanity at large. In this context to generate environmental awareness among the students and public, study of the pollution of the ground water of Visakhapatnam coastal city is the district head quarter and which in the north region of the Andhra Pradesh has been undertaken (Nirdosh patil et. al 2010). In recent times the environment activists of this area, especially ground water of Visakhapatnam coastal area have often demonstrated against the excessive pollution. Saline water intrusion whether into ground water is a complex condition precise by the geologic and hydrologic faces of the area. Natural water systems are dynamic. They respond in quality and quantity to natural phenomena and to man's activities changes in land use and consumptive drawing. Identification and assessment of the nature and extent of saline water intrusion instigates with an understanding of the common mechanisms by which interruption occurs. Under natural situations fresh ground water in coastal aquifers is discharged into the ocean at or seaward of the coastline. A balance or equilibrium tends to become ' established between the fresh ground water and the salt water pressing in from the sea. Where coastal aquifers are over pumped. Almost all coastal areas of India are rapidly growing at the pace of population growth. It is not possible by the administration to supply sufficient water supply, which is a bitter fact. As municipalities grow people in the outskirts of the cities, resort to their own water supplies and for which the only inevitable source is groundwater. That is how ground water is being highly exploited in the cities. Visakhapatnam also is not devoid of that. After examining in the literature, less study was carried out on coastal tract groundwater quality. There are many reports of Ground water being contaminated by salt-water intrusion to different levels. Also there are different chemical methods to evaluate the effects of salt water intrusion. The periodic wise ground water quality analysis done, this fact prompted me to take up the study on ground water quality analysis of the entire coastal area. The study area in the present work has large coastal line. Thus, extension studies are carried out over a period of three years both pre monsoon and post monsoon period and all physic chemical and chemical parameters are determined as per the procedures summarized Ground water quality of coastal tract of Visakhapatnam has a distinctive significance and needs greater consideration since it is the only major source for drinking, domestic, industrial purposes. The main purpose behind this study focused on the quality assessment and its appropriateness for drinking, domestic & Industrial purpose in coastal tract of Visakhapatnam City.

II. METHODOLOGY

In this study for the purpose of revealing the water quality of thirty four bore wells covering the study area have been established quantitatively by determining the physical and chemical characteristics per season due to effect of salt water intrusion in the study area. The present study area is between $17^{o}42'$ North latitude and $82^{o}02'$ East range of hills. Based on topographical conditions, the city and its environs can be divided into four categories viz. Hilly region, Upland tracks, Rolling plains and Plains. For present paper, Electrical resistivity sounding techniques and hydro chemical studies are extensively used to define the contact between groundwater and saline water in coastline aquifers. Ground water samples were collected at 10 (ten) different sampling points and given their latitudes and longitudes of the coastal tract of Visakhapatnam city in Table-1. The ground water samples were collected as per the standard method (APHA 21st Edition) for the physic chemical analysis of various constituents part for reached the objectives and taken the subsequent laboratory analysis, for Physico chemical parameters like pH, Temperature, Conductivity, Chlorides(Cl), Total Alkalinity, Total Hardness(TH), Calcium Hardness(CaH), |Total Dissolved Solids(TDS), Sodium(Na), Potassium(K), Nitrates(NO3), Sulphates(So4), Phosphates(Po3), Cobalt (CO), Nickel (Ni),Copper (Cu), Chromium(Cr) ,Iron(Fe), Zinc(Zn), Lead(Pb), Manganese(Mn) which has been carried out, in the Environmental Monitoring Laboratory, GITAM Institute of sciences, GITAM University by using Atomic Absorption Spectrophotometer. The repeated measurements were made to ensure precision and accuracy of results.

III. RESULTS AND DISCUSSIONS

Physicochemical characteristics of groundwater samples were analysed and given in the Table 2. The results are compared with the WHO (World Health Organisation) and BIS (Bureau of Indian standards). In the study area pH values ranges from 7.3 to 8 in pre monsoon and 7-7.5 in post monsoon. The electrical conductivity in the groundwater ranged from 1200 to 2630 µS/cm from pre monsoon and 810-2100 µS/cm from post monsoon. Higher Electrical conductivity values are observed in SW-1, SW-2, SW-3, SW-8, SW-9 indicating the flow path and can be considered as a forewarning of the salt water Intrusion. The large variances in EC are mainly accredited to anthropogenic activities and also to the geochemical processes that occur in this region. EC commonly increases along a groundwater flow path because of the joint effects of ion exchange, evaporation and topographic conditions (Toth 1999). TDS also shows similar variation like EC, and the values range from 768 to 1683 mg/l in pre monsoon and 518-1344 mg/l in post monsoon. The Total Dissolved solids concentration basically depends on the different ions present in water. It happen actually additionally enters environments from man-made sources, for example, landfill leachate, feedlots, or sewage. A measure of the disintegrated salts or minerals in the water. May likewise incorporate some broke down natural mixes. The calcium and magnesium ions in waters are generally used to classify the suitability of water. Indeed, the values of Na 110 to 240 in pre-monsoon, and 115 to 182 mg/l in post monsoon. High sodium and clhloride values displayed in SW-9. Sodium (Na) and potassium (K) are additionally found in old brackish waters, ocean water, from filtering of surface, underground stores of salt and sewage, Human exercises contribute through de-icing and washing items. Chloride values ranges from 95-290 mg/l in pre monsoon, 150-260 mg/l in post monsoon respectively present in sewage and found in huge sums in primordial brackish waters, seawater, and substantial amounts build the destructiveness of water, Drainage from salt springs and sewage. The chloride ion is the most predominant natural form of the element chlorine and is extremely stable in water. The chloride in groundwater may come from diverse sources such as weathering, leaching of sedimentary rocks and soil, domestic and municipal effluents. The concentration of Bi Carbonates varies from 160 to 330 mg/l in pre monsoon and 62-190 mg/l in post monsoon. (Sarath Prasanth et al. 2012).

A. Statistical Analysis

Values of all the ground water quality parameters were accomplished with 95% confidence level (CL). The statistical assessment from physicochemical data of the water samples in the pre and post monsoon were concise in Table 2 respectively. Correlation indicates the relationship between two variables such that a modification in one variable causes a conforming change in the further variable. It gives a rough but impartially useful sign of water quality and also simplifies a rapid observing of the status of water pollution. A pair of parameters having correlation coefficient r up to 0.5 do not have any significant correlation between them, $r \geq \pm 0.5$ bears significant linear correlation between them and $r \geq \pm 0.8$ indicates very strong linear correlation between them (Jeyaraj et al., 2002).

$$r = \frac{n\sum xy - \sum x \sum y}{\left[\left\{n\sum x^2 - \left(\sum x\right)^2\right\}\left\{n\sum y^2 - \left(\sum y\right)^2\right\}\right]^{1/2}}$$

The correlation coefficient for different environmentally important water quality parameters are calculated using equation. (Saxena et al.,2004). Where, x and y are any two variables and n is the number of samples. The numerical values of correlation coefficient (r) of the physico-chemical parameters of all the groundwater samples for the three seasons were listed in Tables 4 and Table 5.

B. The Ratio of Major anions and Cations

The Na/Cl proportions of the saline groundwater most likely result from particle trade of Na for Ca and Mg in muds, which is normal in saline groundwater. What's more, the concurrent enhancement in both particles shows disintegration of chloride salts or fixation by vanishing.

This is in charge of the moderately high Na+ and Cl-in the saline groundwater and in beach front aquifers. The disintegration of halite in groundwater discharges parallel convergence of Na and Cl in the arrangement because of disintegration of salt skylines and beach front groundwater influenced via seawater interruption (El Moujabber M et.al 2006). Some research clarified that when calculating the Na/Cl ratio, if the result is smaller than 0.86, it means that the groundwater has been polluted by seawater; temporarily, if the ratio is >1, it means the groundwater is dirtied by anthropogenic source (Klassen Jet.al 2014), The ratio of Ca/Mg and Ca/(HCO3 and SO4) can also be used as an indicator, where if it is >1, it means that sea water intrusion is taking place (The molar proportion of Na/Cl ranges from 0.53 to 0.97. Every one of the examples have Na/Cl molar proportion under 1 aside from SWI-6 (1.29 in post rainstorm >1), which shows that particle trade is the real procedure. The Mg/Ca proportion ranges from 0.33 to 1.03 in pre storm and 0.30 to 1.38 in post rainstorm. All boreholes by and large under 2, showing the disintegration of silicate minerals, which contributes Calcium and Magnesium to the groundwater.

The Piper-Hill chart is utilized to gather hydro-geochemical facies.

These plots incorporate two triangles, one for plotting cations and the other for plotting anions. The cations and anion fields are consolidated to demonstrate a solitary point in a jewel molded field, from which surmising is drawn on the premise of hydro-geochemical facies idea. These tri-direct graphs are valuable in bringing out concoction connections among groundwater tests in more positive terms as opposed to with other conceivable plotting strategies (Piper, 1953). Systematic information accomplished from the hydro synthetic examination appeared in Fig .4.4.1 and 4.4.2. A Piper graph was made for the GVMC, Visakhapatnam territory utilizing the tri straight chart. All in all, we can order the example focuses in the flautist graph into 6 fields. They are 1. Ca-HCO3 class 2. Na-Cl class 3.Ca-Mg-Cl class 4.Ca-Na-HCO3 class 5. Ca-Cl class 6. NaHCO3 class.

In this study water types were controlled to the three types in pre-monsoon. Majority of the samples (50%) are plotted in the Na-Ca-Mg-Cl-HCO_3-SO_4 field. 30 % of the samples showed Na-Ca-MgCl-HCO_3 type. Rest of them was fall in the Na-Ca-Cl-HCO_3 types. Estimation of the water types using piper plot suggests that there is a clear idea of the impact from the enduring of hard rocks. In Post monsoon period, 40% of the samples Na-Ca-Mg-Cl-HCO_3-SO_4 type, 40 % of the samples Na-Ca-Cl-HCO3-SO4 type and 20 % of the samples Na-Ca-Mg-Cl type.

The considerable change in the hydro-chemical facies was observed through the study period (pre and post monsoon), which was might be due to the leaching of alkali salts through precipitation, dissolution of the minerals are the major processes occurring.

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IV. CONCLUSIONS

In the present study, Analysis of various chemical parameters in ground water in salt-water susceptible areas in GVMC has indicated the possibility of Salt Water Intrusion in several places along the coast of GVMC both in pre monsoon and post monsoon seasons. The susceptible areas of seawater intrusion in the study area are delineated and presented in the Figure year wise. It can be seen from the figure that the areas such as SWI-1 (INS Kalinga), SWI-2(Chapaluppada), SWI-5(Kapuluppada), SWI-3 (Gollalapalem), SWI-8 (Jodugula Palem), SWI-9 (Chinna Rushikonda) have indicated salt water intruded area in all the years. However some more areas have shown their susceptibility only during some years. Kapuluppada, Jodiugulapalem, Chinna Rushikonda, as susceptible for salt water intrusion. This might be due to heavy ground water withdrawal in those seasons. Based on the analysis, it is concluded that the water intrusion is possibly generated by the presence of large number of wells (excessive extraction of groundwater) in the Coastal tract areas. It is also perceived that recharge from precipitation or other sources are not balanced and this has not compensated the replenishment of groundwater. The salt-water intrusion problem can be controlled by using recharge wells near the areas and scientific way of pumping should be implemented.

Table-1: Sampling stations and geo- coordinates of the study area

Sampling Code	Station Name	Latitude	Longitude
SW-1	INS Kalinga	17.855408°	83.416328°
SW-2	Chepaluppada	17.844817°	83.402974°
SW-3	Gollalapalem	17.891927°	83.428525°
SW-4	Kapuluppada	17.834261°	83.382529°
SW-5	Boyepalem	17.729156°	83.285908°
SW-6	Jodugula Palem	17.750901°	83.348846°
SW-7	Sagarnagar	17.765157°	83.356231°
SW-8	Endada	17.772833°	83.365576°
SW-9	China Rushikonda	17.796937°	83.381602°
SW-10	Pedda Rushikonda	17.797129°	83.386933°

Image-1: Geographical Map of the study area with sampling stations

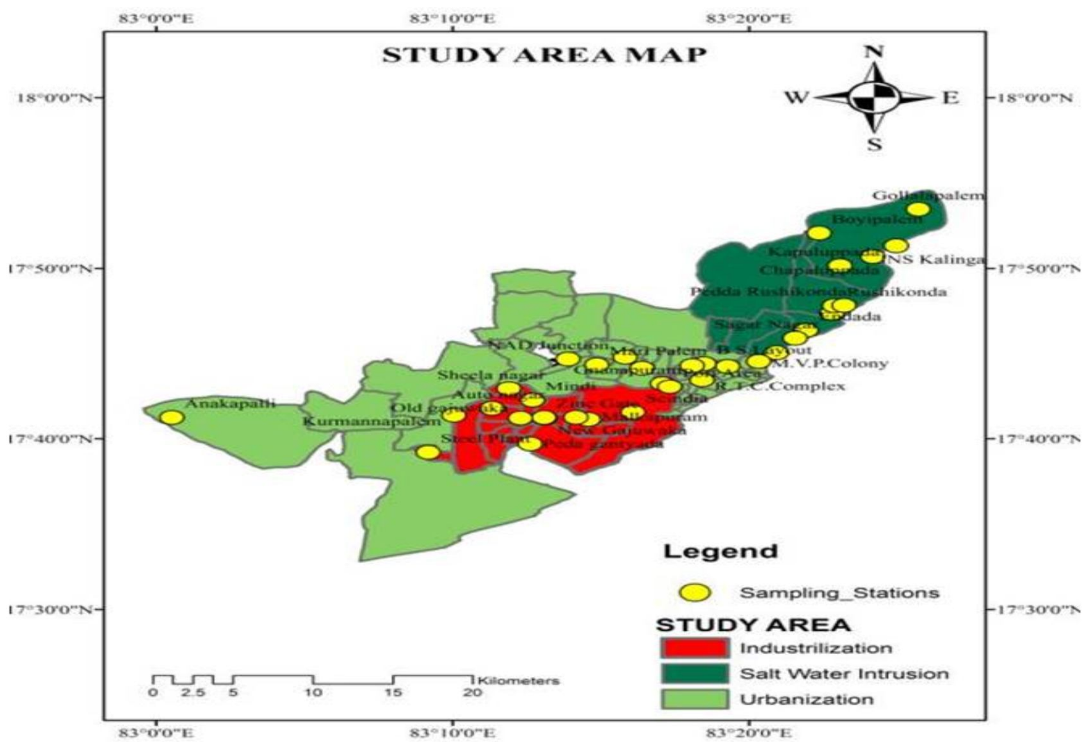

Table.2. Seasonal wise physic chemical characteristics of ground water

Code of the Sample		SWI-1	SWI-2	SWI-3	SWI-4	SWI-5	SWI-6	SWI-7	SWI-8	SWI-9	SWI-10
pH	Pre	8	7.4	7.35	7.8	7.9	7.6	7.4	7.5	7.6	7.3
	Post	7.3	7.2	7	7.5	7.4	7.25	7.2	7.25	7.3	7.2
Temp	Pre	24	25	25.5	25	24	24	25	25	23	24
	Post	24.5	26	23	23	23	23	23	22	22	23
Turbidity	Pre	0.4	0.8	0.7	0.5	0.7	0.66	0.6	0.4	0.5	0.6
	Post	0.3	0.6	0.5	0.3	0.5	0.42	0.4	0.5	0.4	0.5
EC	Pre	1600	2350	1200	1500	2630	2100	1260	1350	1280	1610
	Post	1150	1900	1950	1100	2100	1800	810	1180	890	1300
Cl	Pre	250	180	230	270	255	230	240	95	280	290
	Post	220	170	200	240	210	190	225	150	260	260
TA	Pre	182	220	140	200	220	195	280	96	270	185
	Post	100	195	180	130	160	210	260	120	190	195
TH	Pre	260	275	320	288	230	192	250	240	140	220
	Post	155	105	170	129	110	108	160	220	90	82
Ca	Pre	92	99	112	106	66	56	76	82	48	78
	Post	56	38	40	42	37	30	39	52	31	22
PO_4	Pre	0.93	0.84	1.02	0.7	0.56	0.98	1.2	0.79	0.89	0.65
	Post	0.3	0.46	0.8	0.6	0.4	0.29	0.6	0.5	0.65	0.45
NO_3	Pre	8.6	10.5	0.6	1.2	16.5	6.54	0.6	9.5	9.1	0.9
	Post	2.5	8.22	0.5	0.5	16	3.54	0.6	6.5	8.6	0.8
TDS	Pre	1024	1504	768	960	1683	1344	806	864	819	1030
	Post	736	1216	1248	704	1344	1152	518	755	569	832
Mg	Pre	39	32	42	51	52	46	25	72	35	96
	Post	25	29	31	38	36	39	19	50	27	55
Na	Pre	110	124	130	155	190	158	180	145	240	135
	Post	158	115	120	125	192	152	150	174	182	166
K	Pre	28	31	39	49	27	30	64	33	50	65
	Post	17	20	19	25	21	12	16	51	22	11
SO_4	Pre	120	75	130	160	175	155	125	150	120	118
	Post	110	62	120	135	155	95	115	125	110	98
Fe	Pre	0.2	0.18	0.2	0.15	0.15	0.19	0.2	0.16	0.21	0.25
	Post	0.19	0.16	0.09	0.12	0.14	0.16	0.16	0.11	0.17	0.15
Cr	Pre	0.04	0.09	0.08	0.15	0.18	0.13	0.15	0.08	0.15	0.09
	Post	0.02	0.07	0.09	0.09	0.12	0.18	0.05	0.09	0.06	0.06
F	Pre	0.5	0.62	0.4	0.5	0.7	0.7	0.4	0.5	0.7	0.6
	Post	0.4	0.5	0.3	0.3	0.6	0.6	0.3	0.5	0.6	0.5
HCO_3	Pre	211	230	160	230	225	235	320	330	310	230
	Post	62	122	125	184	150	90	120	80	190	125
Br^-	Pre	0.901	0.983	0.112	0.17	0.083	0.10	0.096	0.105	0.121	0.1367
	Post	0.874	0.8923	0.098	0.08	0.065	0.08	0.085	0.057	0.012	0.0872

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Table.3: Effect of Salt water intrusion on different parameters

Code of the Sample		SWI-1	SWI-2	SWI-3	SWI-4	SWI-5	SWI-6	SWI-7	SWI-8	SWI-9	SWI-10
EC	Pre					✓					
	Post										
Cl	Pre				✓	✓				✓	✓
	Post									✓	✓
TA	Pre		✓			✓		✓		✓	
	Post						✓	✓			
TH	Pre	✓	✓	✓	✓	✓		✓	✓		
	Post								✓		
Ca	Pre	✓	✓	✓	✓			✓	✓		✓
	Post										
TDS	Pre	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Post	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mg	Pre	✓	✓	✓	✓	✓	✓		✓	✓	✓
	Post			✓	✓	✓	✓		✓		✓
Na	Pre									✓	
	Post										
K	Pre	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Post				✓	✓			✓	✓	
Cr	Pre		✓	✓	✓	✓	✓	✓	✓	✓	✓
	Post		✓	✓	✓	✓	✓		✓	✓	✓
HCO_3	Pre								✓	✓	✓
	Post										

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Table-4: Correlation study of physic chemical characteristics of ground water(Pre Monsoon)

	pH	*Temp*	*Turbidity*	*EC*	*Cl*	*TA*	*TH*	*Ca*	*PO4*	*NO3*	*TDS*	*Mg*	*Na*	*K*	*SO4*	*Fe*	*Cr*	*F*	*HCO3*	*Br-*
pH	1.00																			
Temp	-0.36	1.00																		
Turbidity	-0.40	0.23	1.00																	
EC	0.31	-0.18	0.58	1.00																
Cl	0.22	-0.49	0.10	0.01	1.00															
TA	0.07	-0.42	0.26	0.14	0.59	1.00														
TH	-0.07	0.88	0.20	0.08	-0.22	-0.41	1.00													
Ca	-0.10	0.80	0.09	0.19	-0.19	-0.45	0.95	1.00												
PO4	-0.31	0.24	0.01	0.49	-0.10	0.23	0.09	0.02	1.00											
NO3	0.51	-0.41	0.07	0.68	-0.28	0.03	0.34	-0.40	-0.43	1.00										
TDS	0.31	-0.18	0.58	1.00	-0.01	0.14	0.08	-0.19	-0.49	0.68	1.00									
Mg	-0.20	-0.09	-0.21	0.01	-0.04	-0.55	0.10	-0.02	-0.64	-0.11	-0.01	1.00								
Na	0.09	-0.56	-0.05	0.06	0.31	0.62	0.71	-0.73	-0.01	0.23	-0.06	-0.24	1.00							
K	-0.51	-0.02	-0.10	0.56	0.45	0.40	0.13	-0.07	0.17	-0.72	-0.56	0.21	0.27	1.00						
SO4	0.48	-0.06	-0.25	0.09	0.06	-0.22	0.09	-0.23	-0.32	0.13	0.09	0.24	0.29	0.18	1.00					
Fe	-0.50	-0.33	0.02	0.36	0.43	0.17	0.28	-0.18	0.27	-0.47	-0.36	0.24	-0.07	0.57	-0.52	1.00				
Cr	0.15	-0.24	0.26	0.27	0.36	0.62	0.37	-0.49	-0.17	0.15	0.26	-0.20	0.80	0.23	0.50	0.35	1.00			
F	0.23	-0.75	0.24	0.66	0.21	0.29	0.73	-0.70	-0.50	0.64	0.66	0.13	0.44	0.29	0.10	0.02	0.39	1.00		
HCO3	-0.14	-0.21	-0.44	0.29	-0.34	0.26	0.55	-0.53	0.18	0.12	-0.29	-0.03	0.55	0.32	0.02	0.07	0.29	0.05	1.00	
Br-	0.22	0.06	0.07	0.30	-0.15	0.03	0.29	0.38	0.05	0.27	0.30	-0.32	-0.55	0.41	-0.68	0.01	-0.58	0.01	-0.27	1.00

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Table-5: Correlation study of physico chemical characteristics of ground water (Post Monsoon)

	pH	*Temp*	*Turb*	*EC*	*Cl*	*TA*	*TH*	*Ca*	*PO4*	*NO3*	*TDS*	*Mg*	*Na*	*K*	*SO4*	*Fe*	*Cr*	*F*	*HCO3*	*Br-*
pH	1.00																			
Temp	-0.11	1.00																		
Turb	-0.52	0.24	1.00																	
EC	-0.24	0.36	0.61	1.00																
Cl	0.26	-0.26	-0.49	-0.46	1.00															
TA	-0.42	-0.02	0.31	0.00	0.17	1.00														
TH	-0.24	-0.21	-0.08	-0.18	-0.58	-0.36	1.00													
Ca	0.13	0.17	-0.32	-0.17	-0.47	-0.67	0.78	1.00												
PO4	-0.36	-0.34	0.08	-0.18	0.19	0.22	0.22	-0.07	1.00											
NO3	0.33	0.03	0.41	0.42	-0.24	-0.13	-0.22	-0.02	-0.26	1.00										
TDS	-0.24	0.36	0.61	1.00	-0.46	0.00	-0.18	-0.17	-0.18	0.42	1.00									
Mg	0.08	-0.33	0.29	0.15	-0.10	-0.27	-0.03	-0.28	-0.21	-0.01	0.15	1.00								
Na	0.32	-0.56	-0.07	-0.20	0.22	-0.12	-0.09	-0.10	-0.33	0.55	-0.20	0.24	1.00							
K	0.16	-0.34	0.13	-0.18	-0.55	-0.51	0.69	0.57	0.16	0.24	-0.18	0.31	0.19	1.00						
SO4	0.44	-0.62	-0.36	-0.06	0.17	-0.36	0.31	0.26	0.20	0.23	-0.06	0.09	0.45	0.32	1.00					
Fe	0.23	0.38	-0.29	-0.30	0.32	0.16	-0.48	-0.09	-0.60	0.12	-0.30	-0.40	0.27	0.48	-0.42	1.00				
Cr	0.09	-0.25	0.21	0.58	-0.36	0.16	-0.13	-0.33	-0.22	0.24	0.58	0.34	0.04	0.00	0.13	0.31	1.00			
F	0.19	-0.11	0.36	0.30	-0.10	0.03	-0.48	-0.40	-0.52	0.72	0.30	0.32	0.63	0.03	-0.14	0.35	0.43	1.00		
HCO3	0.38	-0.28	-0.08	-0.11	0.58	0.19	-0.50	-0.46	0.55	0.21	-0.11	-0.10	0.01	0.11	0.28	0.17	0.02	0.02	1.00	
Br-	-0.07	0.91	0.06	0.15	-0.27	-0.28	-0.03	0.43	-0.41	0.03	0.15	-0.36	-0.38	0.16	-0.57	0.49	0.44	0.08	-0.43	1.00

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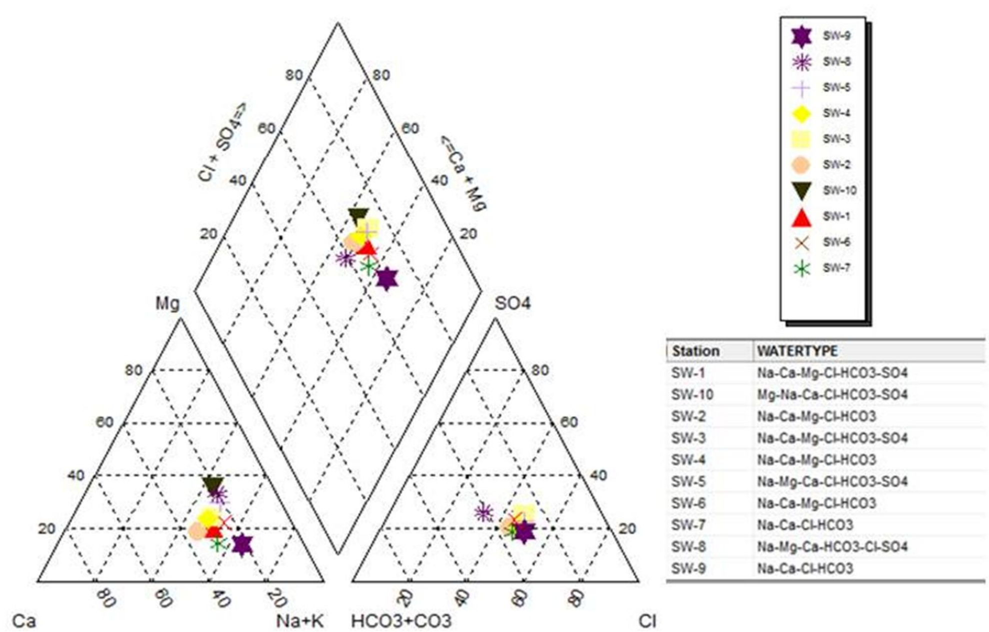
Table.6. Seasonal wise ionic ratios of ground water

Sampling station	Na/Cl		Ca/Mg		Ca / (HCO_3+So_4)		Cl/TA	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
SW-1	0.44	0.72	2.36	2.24	0.28	0.33	1.37	2.20
SW-2	0.69	0.68	3.09	1.31	0.32	0.21	0.82	0.87
SW-3	0.57	0.60	2.67	1.29	0.39	0.16	1.64	1.11
SW-4	0.57	0.52	2.08	1.11	0.27	0.13	1.35	1.85
SW-5	0.75	0.91	1.27	1.03	0.17	0.12	1.16	1.31
SW-6	0.69	0.80	1.22	0.77	0.14	0.16	1.18	0.90
SW-7	0.75	0.67	3.04	2.05	0.17	0.17	0.86	0.87
SW-8	1.53	1.16	1.14	1.04	0.17	0.25	0.99	1.25
SW-9	0.86	0.70	1.37	1.15	0.11	0.10	1.04	1.37
SW-10	0.47	0.64	0.81	0.40	0.22	0.10	1.57	1.33

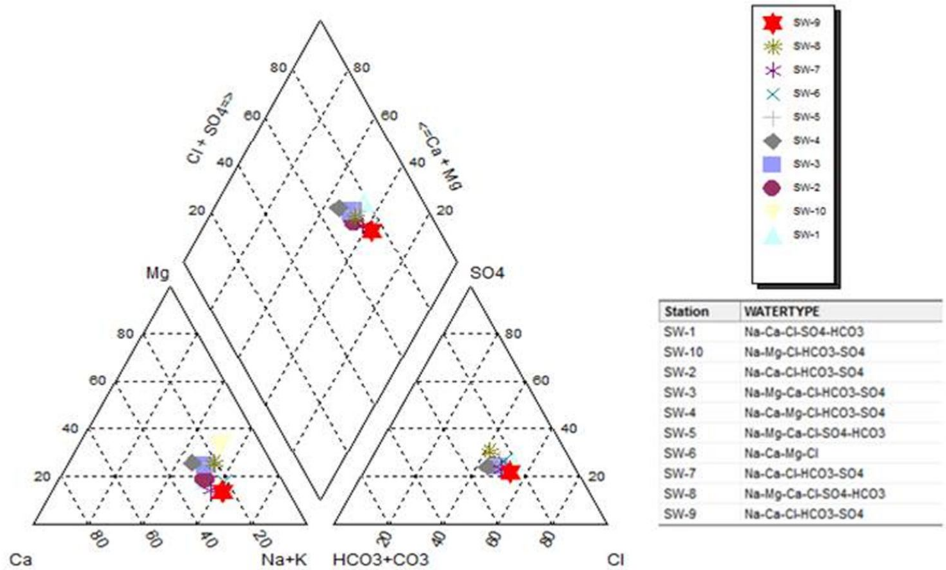
Table 7: Ionic ratio indicators for salt-water intrusion

Ionic Ratio	Sea water intrusion indication	Samples with sea water patterns (2013)		Remarks with reference to the SWI	
		Pre	Post	Pre	Post
Ca/Mg	< 1	1-9	1- 9	SWI	SWI
Na/Cl	>1	1	1-6,8- 10	SWI	SWI
Ca/(HCO_3+SO_4)	<0.86	1-7, 10	1-4, 6, 7, 9, 10	SWI	SWI
TA/TH	<1	1-5, 8, 10	1	SWI	SWI

2.1 Piper plot of ground water composition (Pre Monsoon)



2.2 Piper plot of ground water composition (Pre Monsoon)



Station	WATERTYPE
SW-1	Na-Ca-Cl-SO4-HCO3
SW-10	Na-Mg-Cl-HCO3-SO4
SW-2	Na-Ca-Cl-HCO3-SO4
SW-3	Na-Mg-Ca-Cl-HCO3-SO4
SW-4	Na-Ca-Mg-Cl-HCO3-SO4
SW-5	Na-Mg-Ca-Cl-SO4-HCO3
SW-6	Na-Ca-Mg-Cl
SW-7	Na-Ca-Cl-HCO3-SO4
SW-8	Na-Mg-Ca-Cl-SO4-HCO3
SW-9	Na-Ca-Cl-HCO3-SO4

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