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Salt Water Intrusion Studies in GVMC Area, Visakhapatnam, Andhra Pradesh, India

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Abstract: In most towns and cities in India ground water forms to a smaller and larger extent, a part of water distribution system. The quality of water supplied to municipalities, which is a major source of drinking water for most people living in these areas. The groundwater quality depends on many factors such as local geology of the area ground water movement, which is also affected by industrial activity, in the proper sanitary system and in coastal areas by salt-water intrusion. To develop a sustainable water quality management, it is a necessary tool to assess the impact of the above parameters on the ground water quality. Chemical and physical characteristics of ground water determine its usefulness for municipal, commercial, industrial, and agricultural water supplies. Greater Visakhapatnam Municipal area forms an ideal study area to address the effect of various factors affecting the ground water quality. In this work, the study conducted on the effect of salt water intrusion on the ground water in the areas susceptible to salt water intrusion is presented. Greater Visakhapatnam Municipal Corporation is located on the east coast of India. To assess the quality of ground water ten sampling were selected. Seawater intrusion has been assessed using ground water chemistry and ionic ratios. The ionic ratios obtained in pre and post were compared to the standard values of seawater to determine whether sea water influences the aquifers. The values that are considered to be indicative of seawater intrusion are calculated for the study area. The major chemical compositions demonstrated that ionic ratios would be useful to delineate seawater intrusion and these ratios include Na^+/Cl^-, Ca/Mg , $Cl^-/(HCO_3 + SO_4)$ and Cl / TA. All boreholes generally less than 2, indicating the dissolution of silicate minerals, which contributes Calcium and Magnesium to the groundwater. Detailed analyses of ground water parameters have indicated a possible threat of salt-water intrusion to the ground water in the areas closure to coastal line. 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.

Keywords: *Coastal aquifers, Ionic ratios, Sea Water Intrusion, Water Balancing*

1. Introduction

Water is nature's most wonderful, abundant and useful compound and it is the basis of all lives–the ecological resources for the flora and fauna of our earth, and is a fundamental necessity for all lives. The quality of water is of utmost importance compared to the quantity in any water supply planning, and especially for drinking purposes, purity is equally important. Coastal zones usually accommodate high-density populations. For ages, mankind is attracted to these areas because of the availability of enough food (Ex: Fisheries, Agriculture), and increasing concentration of Human settlements, agricultural development and industrial purposes have become most striking in this coastal zone. Effect of marine environment on the inland aquifers is an important issue. Due to the rapid growth of population and uncertainty of rainfall, excessive withdrawal of groundwater resources is taking place. To protect the coastal aquifers, it is essential to know the sources and mechanization of salinity in the ground water for sustainable development of an area. This aspect of the study focuses on

1) Assessing whether salt water intrusion has occurred along the coastal tracks of Visakhapatnam and if possible to delineates the areas where saltwater is present;
2) Describing the possible sources and mechanisms of saltwater intrusion into the aquifer; and
3) Provide a description of the hydrogeologic framework of the aquifer system,

Saltwater intrusion is often associated with over pumping of ground water in coastal regional, resulting in overdraft conditions and creating an inland gradient of seawater. The intrusion into the coastal aquifer is a widespread phenomenon in many places in coastal regions (EI Moujubber 2006). The coastal zones usually accommodate high-density populations. For ages, mankind has been attracted to these areas because of the availability of enough food (Eg. Fisheries, Agriculture) and increasing concentration of Human settlements, agricultural development and industrial purposes become most striking in this coastal zone. Effect of marine environment on the inland aquifers is an important burning issue. Due to the rapid growth of population and uncertainty of rainfall, excessive withdrawal of groundwater resources is taking place. To protect the coastal aquifers, it is essential to know the sources and mechanization of salinity in the ground water for sustainable development of an area. The rapid growth of population and uncertainty of rainfall is leading to excessive of ground water resources.

1.1 Visakhapatnam Coastal Area

Visakhapatnam is situated in North Eastern Coast of Andhra Pradesh, with topography like a spoon-shaped basin, surrounded by hill ranges on three sides and sea on the other and is often called as bowl area for assessment of environmental related issues.The Population of Visakhapatnam district is 42, 88,113. Visakhapatnam is 5th most populous district out of total 23 districts in Andhra Pradesh and it is 44th most populous district in India. The population density of Visakhapatnam is about 384 Persons per Sq-Km; area of Visakhapatnam is 11,161 Sq. Km, and is 14th largest district in Andhra Pradesh and 41th largest in India in terms of total area. It lies between 17^{o} - 15' and 18^{o}-32' Northern latitude and 18^{o} - 54' and 83^{o} - 30' in Eastern longitude. Bay of Bengal lies on the east coast of Visakhapatnam (Visakhapatnam Census 2011). The investigated area is underlain by the khondlites suite of rocks (garentiferous-sillimanite-gneiss) belonging to the Precambrian Eastern Ghats. The charnockites (hypersthenes pyroxene granulites), quartzite and pegmatite include the rocks. The strike of the rocks varies from NE-SW through E-W to NW-SE with a dip of 75^{o}C SE to 75^{o}C SE. The rocks consist of quartz (55-60%), potash feldspar (15-20 %), Garnet (12 %), Sillimanite (15 %) and ores (3 %).

Materials & Methods

Water samples were collected from the study area along the seacoast. Ground water samples extended to a depth of 3.34 to 9.18 meters. Analysis of ground water samples was carried out immediately after their collection for estimating pH, Electrical conductivity and Temperature. Other parameters like Turbidity, Chlorides, Total Hardness, Calcium Hardness, Magnesium Hardness, Total Solids, TDS, Iron, Sulphates, Phosphates, Nitrates, Chromium and Fluorides have been analyzed by using the following standard analytical procedures (APHA 2005). For analytical study, water samples were collected from 10 sampling stations, namely INS Kalinga, Chepaluppada, Gollalapalem,Kapuluppada,Boyepalem, Jodugulapalem, Sagar Nagar, Endada, China Rushikonda and Pedda Rushikonda. Electrical resistivity sounding techniques and hydrochemical studies are widely used to determine the interaction between groundwater and saline water/seawater in coastal aquifers. This study is undertaken for 10 sampling stations of GVMC area given in Table-1 and location map given in Fig.1. .The suitability of groundwater at locations over the study area for drinking purpose has been seasonally (both Pre & Post Monsoon) evaluated in the coastal tract of Visakhapatnam GVMC area and the results are presented in Table- 2. Samples were drawn with a pre-cleaned plastic polyethylene bottles. Prior to sampling, all the sampling containers washed and rinsed thoroughly with the ground water. The accuracy of the results has been confirmed through the ion balance. Total anions must be in balance with total cations. Therefore, the sum of the concentrations of anions should equal the total concentration of cations and the ratio of total anions to total cations should be “1”. After balancing the parameters, the ratio of cations and anions varies from 0.99 to 1.09. The concentrations, in this case, must be in terms of ion equivalents. Based on the assessment of saltwater intrusion probability effective measures can be suggested. The characteristics of the above samples are compared with drinking water standards and those found exceeding the limits are marked in Table 3.

Hydro chemical indices for the study area

Groundwater chemistry is largely a function of the mineral composition of the aquifer through which it flows. The hydrochemical processes and hydro geochemistry of the groundwater vary spatially and temporally, depending on the geology and chemical characteristics of the aquifer. Hydro geochemical processes such as dissolution, precipitation, ion exchange processes and the residence time along the flow path control the chemical composition of groundwater.

In limestone terrains, calcium and bicarbonate ions are added to the ground water by dissolution (Jackson and Sherman, 1953; Lasaga, 1981a; Nahon, 1991).Seawater in general, has a uniform chemistry with the prevalence of Cl and Na possessing a molar ratio of 0.86 (mass ratio = 0.55). Sea water solutes are specifically characterized by the excess of Chloride over alkali ions (Na and K) and Mg greatly in excess of Ca. The chemical composition of groundwater in many coastal aquifers subjected to seawater intrusion deviates from simple conservative seawater – fresh water mixing (Moujabber *et al.* 2006). Several criteria are suggested to be used as indicators for seawater intrusion into the coastal aquifer. Revelle (1941) pointed out that the increase in total dissolved salts (electrical conductivity) is not sufficient proof of occurrence of seawater intrusion. The most obvious indication of sea water intrusion is an increase in Cl in sea water is the ratio of chloride to carbonate and bicarbonate ions which is known as Simpson ratio (Moujabber *et al.* 2006). According to Simpson (1946), the following scale is used for assessing the contaminated groundwater by salt-water intrusion given in Table 4. The ionic ratios obtained in Pre and post were compared to the standard values of sea water to determine whether sea water influences the aquifers. The values that are considered to be indicative of seawater intrusion are calculated for the study area and are given in the Table both in pre monsoon and post monsoon period. The Cl/(HCO_3 +SO_4)ratio, Ca/Mg ratio, the ratio of Cl/TA ratio at different locations indicates that transformation of fresh groundwater to saline water in these areas.

Results & Discussion

TDS, Chromium, Sodium & Total Alkalinity % of concentrations in pre-monsoon to post-monsoon period. This probably reconfirms that the effect of saltwater intrusion is more during post-monsoon period. This is logical as the groundwater table generally lowered during post-monsoon period.Ionic ratios of groundwater have been often used to evaluate seawater intrusion in coastal areas shows some selected ionic ratios and hydrochemical processes of the groundwater in the area. Results revealed that the values of the ratios gradually increase and approach the seawater value as TDS increases, which indicated an increase in the influence of seawater intrusion. Distribution of Ionic Ratios correlated with TDS is Given in fig.2. The ratios of Na/Cl showed insignificant correlation with TDS level (r^2 = 0.0009) but they are very similar (not distinctive to each other) to the seawater value. Thus, this ratio may not be a good indicator revealing the salinization process. Ratios of Ca/Cl exhibited generally, a moderate negative correlation with TDS (r^2 = 0.0138) in Pre monsoon and TDS (r^2=0.0493). They decreased as TDS increased, which was derived from Cl enrichment in groundwater due to saline water intrusion. Ratios of Mg/Cl are moderately varying (r^2 = 0.0172 in pre monsoon & r^2= 0.0217 in post monsoon) and showed a moderate negative correlation with TDS. The Ca/SO4 ratio showed some mixed behaviour but it mostly increased with the increase of TDS while ratios of Ca/HCO3 are not mostly correlated with TDS and are not generally varying in spite of increase of TDS. Ion ratio indicators of salt-water intrusion in the table. The Na/Cl ratios of the saline groundwater probably result from ion exchange of Na for Ca and Mg in clays, which is common in saline groundwater. In addition, the simultaneous enrichment in both ions indicates the dissolution of chloride salts or concentration by evaporation. This is responsible for the relatively high Na+ and Cl- in the saline groundwater and in coastal aquifers. The dissolution of halite in groundwater releases equal concentration of Na and Cl in the solution due to the dissolution of salt horizons and coastal groundwater affected by seawater intrusion. The molar ratio of Na/Cl ranges from 0.53 to 0.97. All the samples have Na/Cl molar ratio less than 1 except SWI-6 (1.29 in post monsoon >1), which indicates that ion exchange is the major process. The Mg/Ca ratio ranges from 0.33 to 1.03 in pre-monsoon and 0.30 to 1.38 in post- monsoon. All boreholes generally less than 2, indicating the dissolution of silicate minerals, which contributes Calcium and Magnesium to the groundwater.

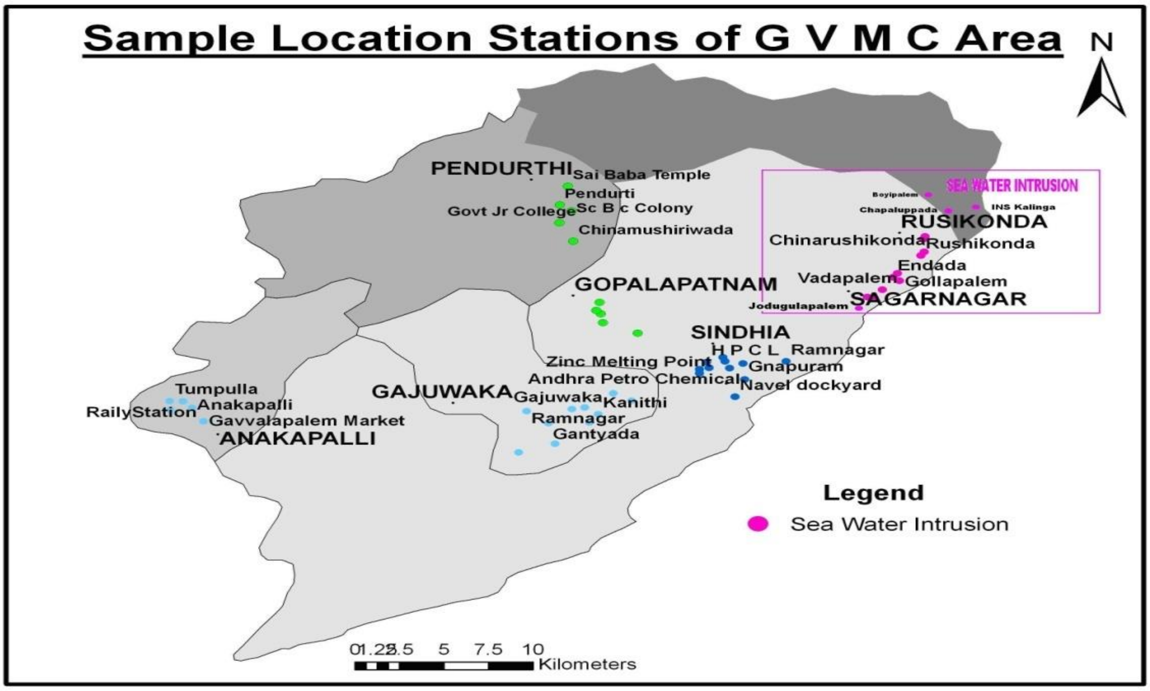

Fig. 1 *Study area with sampling locations*

***Table -1:** Sampling Stations*

Sl. No	Sampling Station	Sample No	Latitude	Longitude
1	INS Kalinga	SWI-1	17.5110N	83.2451E
2	Chepaluppada	SWI-2	17.5116N	83.2429E
3	Gollalapalem	SWI-3	17.5033N	83.23.50E
4	Kapuluppada	SWI-4	17.5115N	83.2310E
5	Boyepalem	SWI-5	17.5210N	83.2158E
6	Jodugula Palem	SWI-6	17.459N	83.2058E
7	Sagarnagar	SWI-7	17.4559N	83.2132E
8	Endada	SWI-8	17.4642N	83.2153E
9	China Rushikonda	SWI-9	17.4717N	83.2153E
10	Pedda Rushikonda	SWI-10	17.4729N	83.2302E

***Table 2:** Physico-Chemical Characteristics from the Study Area*

Type of well		SWI-1	SWI-2	SWI-3	SWI-4	SWI-5	SWI-6	SWI-7	SWI-8	SWI-9	SWI-10
pH	Pre	7.89	7.23	7.12	7.6	7.98	7.33	7.3	8.1	7.6	7.23
	Post	7.21	7	6.95	7.2	7.5	7.11	7.1	7.2	7.5	7.1
Temp	Pre	23.5	26	25.3	26	23	24	25.5	25.5	23.5	24.5
	Post	22.5	23	24	24	22	22	24	23	22	22.4
Turbidity	Pre	0.03	0.07	0.06	0.04	0.06	0.07	0.07	0.05	0.05	0.07
	Post	0.02	0.05	0.04	0.02	0.04	0.05	0.05	0.03	0.03	0.04
EC	Pre	1520	2320	1180	1470	2610	2070	1100	1740	1230	1640
	Post	1120	1840	1920	1040	2130	1840	860	1360	940	1240
Cl	Pre	198	243	195	249	169	250	265	189	256	236
	Post	147	174	165	150	97	155	140	97	174	184
TA	Pre	180	210	130	198	210	180	286	249	280	198
	Post	90	180	170	120	170	240	250	100	200	200
TH	Pre	258	153	195	241	210	180	232	285	120	204
	Post	152	94	155	121	120	99	106	128	81	79
Ca	Pre	91	124	76	94	58	102	112	79	96	86
	Post	87	80	95	85	76	82	95	85	72	58
Br^-	Pre	0.122	0.1	0.097	0.15	0.16	0.09	0.08	0.117	0.11	0.121
	Post	0.102	0.16	0.079	0.07	0.02	0.14	0.07	0.117	0.082	0.11
TDS	Pre	1018	1554	790	685	1748	1387	650	1166	824	1098
	Post	1000	1760	850	600	950	850	540	940	800	930
Mg	Pre	30	29	35	40	50	48	20	61	24	55
	Post	22	14	30	25	23	17	11	23	9	46
Na	Pre	114	110	128	198	99	128	126	101	326	134
	Post	45	106	125	106	85	177	130	88	169	182
K	Pre	41	46	46	50	35	42	70	110	35	64
	Post	10	11	9	11	17	4	9	55	19	6
SO_4	Pre	130	170	190	50	110	150	140	180	120	190
	Post	119	190	118	60	121	126	119	127	116	120
Fe	Pre	0.21	0.2	0.19	0.17	0.17	0.16	0.23	0.19	0.19	0.19
	Post	0.2	0.18	0.1	0.1	0.13	0.12	0.17	0.12	0.11	0.12
Cr	Pre	0.03	0.23	0.19	0.17	0.19	0.11	0.14	0.09	0.14	0.05
	Post	0.01	0.08	0.1	0.1	0.1	0.1	0.02	0.1	0.04	0.06
F	Pre	0.6	0.6	0.4	0.6	0.9	0.8	0.7	0.6	0.8	0.5
	Post	0.5	0.5	0.2	0.4	0.6	0.7	0.4	0.4	0.6	0.4
HCO_3	Pre	225	249	190	247	239	250	345	341	347	256.3
	Post	50	160	140	160	130	80	150	60	180	140
PO_4	Pre	0.71	0.85	1.04	0.6	0.98	1.01	0.96	0.87	0.97	0.74
	Post	0.5	0.56	0.9	0.4	0.8	0.47	0.8	0.6	0.84	0.55
NO_3	Pre	9.2	11.4	0.4	0.7	16.3	8.3	0.5	10	10.2	1.2
	Post	0.3	9.41	0.2	0.4	11.5	1.58	0.5	8.82	8.02	1.02

All the above units are in mg/l except for Turbidity in NTU, EC in µs/cm, & Temperature in (0C)

Table-3: *Effect of Salt water intrusion on different parameters*

Type of well		SWI-1	SWI-2	SWI-3	SWI-4	SWI-5	SWI-6	SWI-7	SWI-8	SWI-9	SWI-10
EC(μs/cm)	Pre					✓					
	Post										
Cl(mg/l)	Pre								✓	✓	
	Post										
TA (mg/l)	Pre		✓			✓		✓	✓	✓	
	Post							✓			
TH(mg/l)	Pre	✓			✓	✓		✓	✓		
	Post										
Ca(mg/l)	Pre	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Post		✓	✓	✓		✓	✓	✓	✓	
TDS	Pre	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Post	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mg(mg/l)	Pre			✓	✓	✓	✓		✓		✓
	Post										✓
Na(mg/l)	Pre									✓	
	Post										
K(mg/l)	Pre	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Post										
Cr(mg/l)	Pre		✓	✓	✓	✓	✓	✓	✓	✓	
	Post		✓	✓	✓	✓	✓		✓		✓
HCO_3(mg/l)	Pre							✓	✓	✓	
	Post										

The characteristics of the above samples are compared with drinking water standards and those found exceeding the limits are marked ✓

Table-4: *Chemical constituents exceeding the limits*

Parameter	Season	Affected Area	Source
EC(μs/cm)	Pre	SW – 5	A sudden increase or decrease in conductivity in a body of water can indicate pollution. Sewage leak will increase conductivity. higher concentration of dissolved solids that can influence conductivity
	Post		
Cl(mg/l)	Pre	SW-8, SW-9	Present in sewage and found in large amounts in ancient brines, seawater, and large quantities increase the corrosiveness of water, Drainage from salt springs and sewage.
	Post		
TA (mg/l)	Pre	SW-2, 5, 7-10	foam and carryover of solids with steam; embrittlement of boiler steel; bicarbonate and carbonate produce CO_2 in steam, a source of corrosion in condensate lines
	Post	SW- 7	
Mg(mg/l)	Pre	SW 3-6, 8, 10	Magnesium is present in large quantities in sea water. It causes most of the hardness and scale-forming properties of water. Calcium and magnesium are the principal cause of the **formation of scale** in boilers, water heaters, and pipes, and to the objectionable curd in the presence of soap.
	Post	SW-10	
TH(mg/l)	Pre	SW-1, 4,5, 7,8	
	Post		
Ca(mg/l)	Pre	SW 1-3, 5-7	The Result of metallic ions dissolved in the water; reported as the concentration of calcium carbonate. Calcium carbonate is derived from dissolved limestone or discharges from operating or abandoned mines.
	Post	SW 2, 3, 6-9	

TDS	Pre	SW 1-10	Occur naturally but also enters the environment from man-made sources such as landfill leachate, feedlots, or sewage. A measure of the dissolved salts or minerals in the water. May also include some dissolved organic compounds.
	Post	SW 1-10	
Na(mg/l)	Pre	SW-9	Dissolved from practically all rocks and soils, sodium (Na) and potassium (K) are also found in ancient brines, sea water, from leaching of the surface, underground deposits of salt and sewage, Human activities contribute through de-icing and washing products.
	Post		
K(mg/l)	Pre	SW 1-10	
	Post		
Cr(mg/l)	Pre	SW-2-10,	Enters environment from old mining operations runoff and leaching into groundwater, fossil-fuel combustion, cement-plant emissions, mineral leaching, and waste incineration. Used in metal plating and as a cooling-tower water additive.
	Post	SW-2,3, 4-6, 8, 10	
HCO_3(mg/l)	Pre	SW-7-9	foam and carryover of solids with steam; embrittlement of boiler steel; bicarbonate and carbonate produce CO_2 in steam, a source of corrosion in condensate lines
	Post		

Table-5: *Seasonal wise ionic ratios of ground water (2012)*

Sampling station	Na/Cl		Ca/Mg		Ca / (HCO_3+SO_4)		Cl/TA	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
SW-1	0.78	0.25	3.03	3.95	0.26	0.51	1.1	1.6
SW-2	0.63	0.50	4.28	5.71	0.30	0.23	1.2	1.0
SW-3	0.78	0.96	2.17	3.17	0.20	0.37	1.5	1.0
SW-4	1.32	0.54	2.35	3.40	0.32	0.39	1.3	1.3
SW-5	1.02	0.40	1.16	3.30	0.17	0.30	0.8	0.6
SW-6	0.83	0.98	2.13	4.82	0.26	0.40	1.4	0.6
SW-7	0.90	0.45	5.60	8.64	0.23	0.35	0.9	0.6
SW-8	1.04	0.35	1.30	3.70	0.15	0.45	0.8	1.0
SW-9	1.87	0.60	4.00	8.00	0.21	0.24	0.9	0.9
SW-10	0.73	0.92	1.56	1.26	0.19	0.22	1.2	0.9

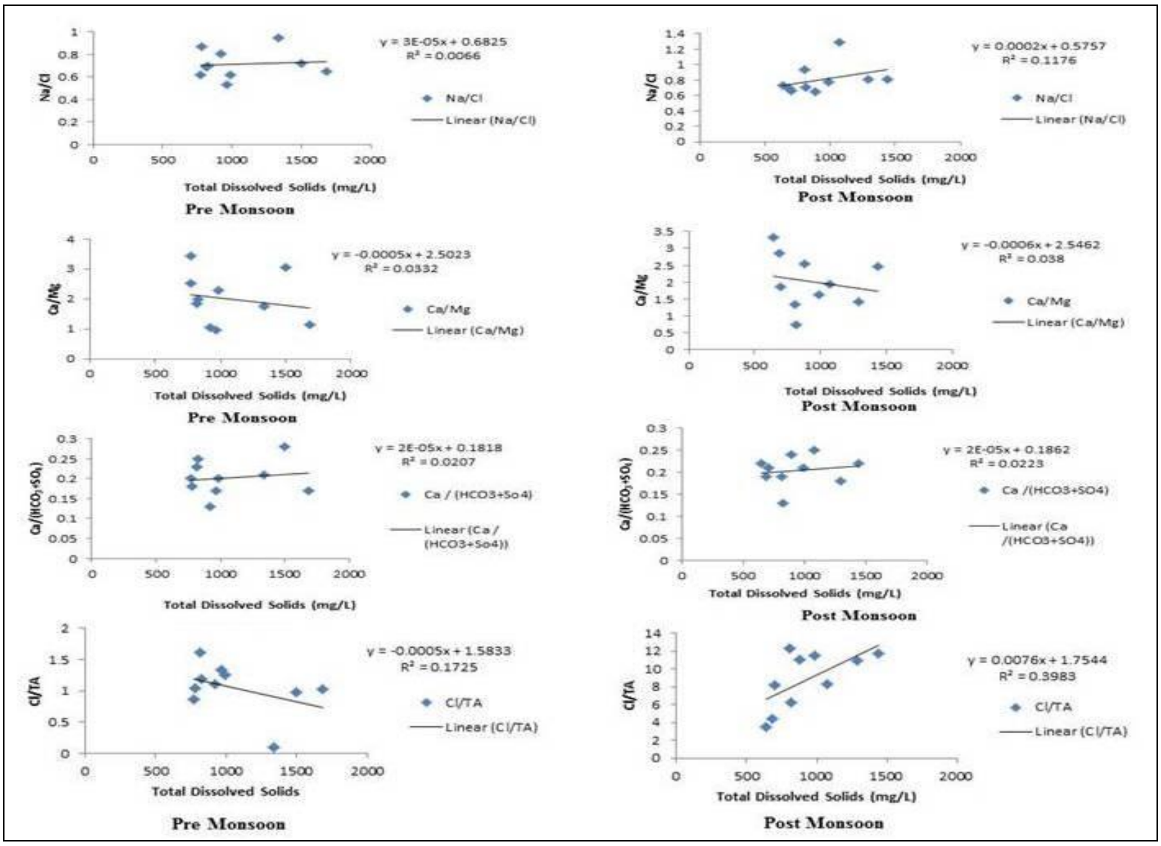

Figure 2: *Distribution of Ionic Ratios correlated with TDS*

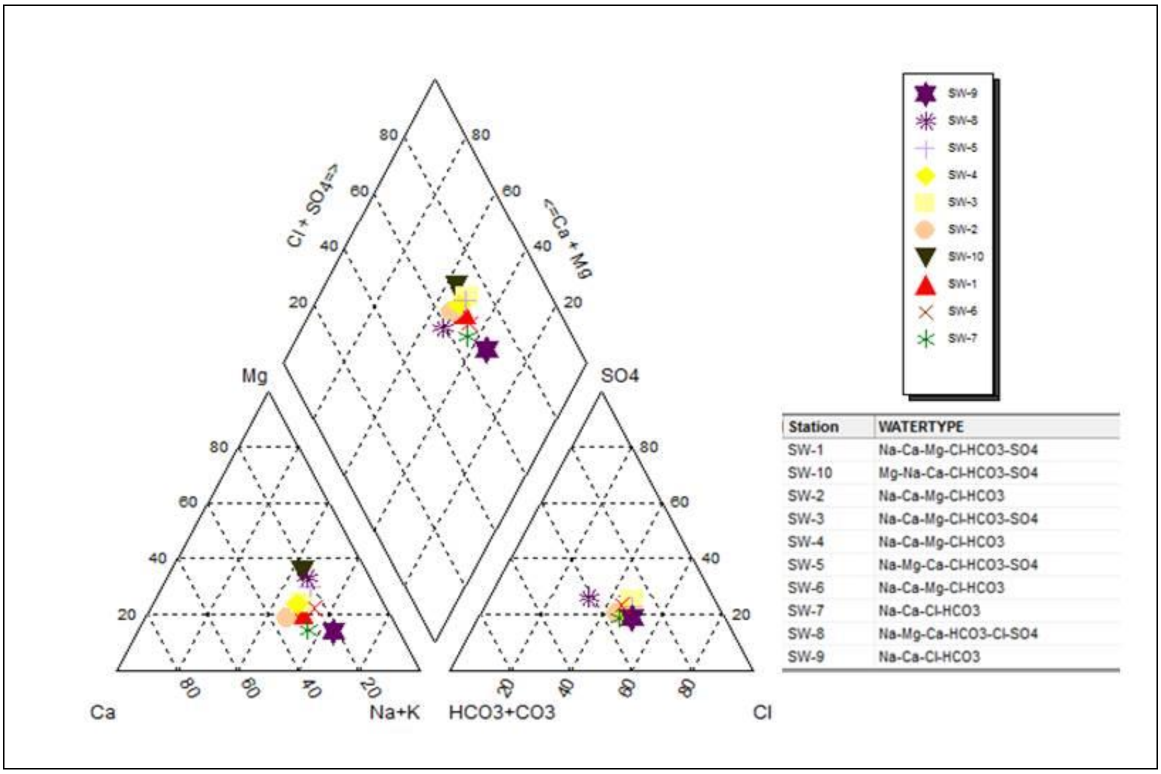

Figure 3: *Piper plot of ground water composition (Pre Monsoon)*

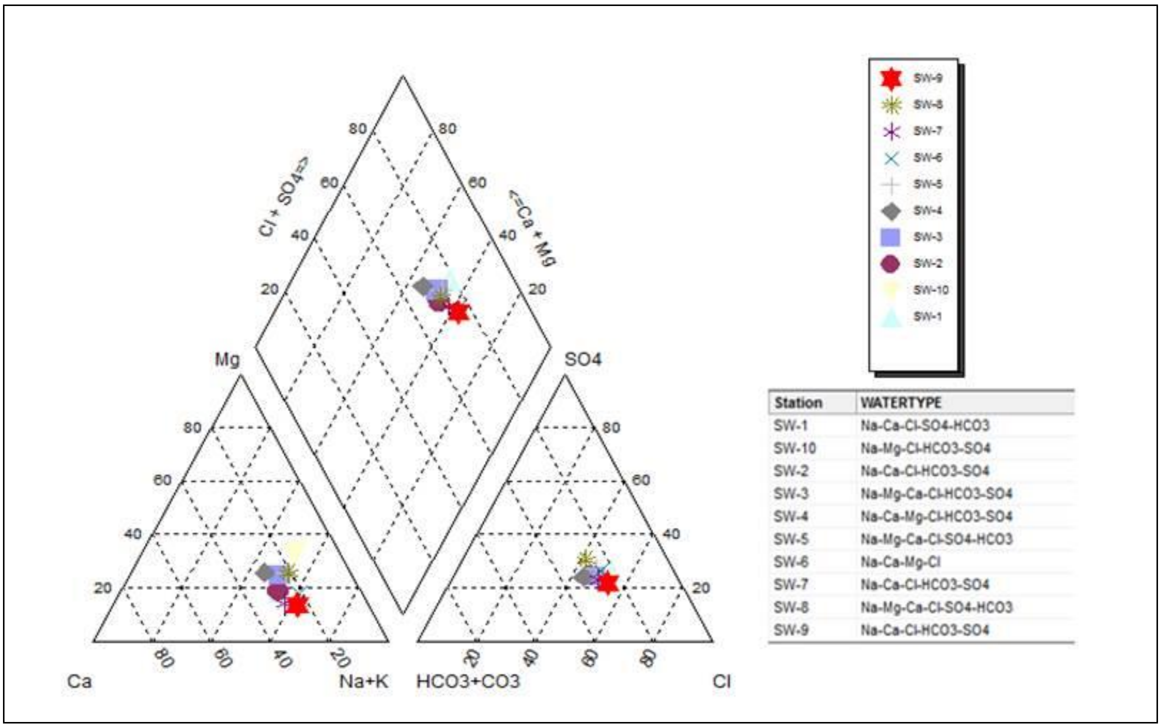

Figure 4: *Piper plot of ground water composition (Pre Monsoon)*

Variations in the concentrations of chemical parameters due to seasonal variation

In the present study, analysis of various chemical parameters in groundwater 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 Table-3. 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 affected area.

Piper Diagram for Physic-Chemical Parameters

The Piper-Hill diagram is used to infer hydro-geochemical facies. These plots include two triangles, one for plotting cations and the other for plotting anions. The cations and anion fields are combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of hydro-geochemical facies concept. These trilinear diagrams are useful in bringing out chemical relationships among groundwater samples in more definite terms rather than with other possible plotting methods. Analytical data attained from the hydro chemical investigation shown in Fig .4.20 & 4.21. A Piper diagram was created for the GVMC, Visakhapatnam area using the tri linear diagram. In general, we can categorize the sample points in the piper diagram into 6 fields. They are 1. Ca-HCO_3 type 2. Na-Cl type 3.Ca-Mg-Cl type 4.Ca-Na-HCO_3 type 5. Ca-Cl type 6. $NaHCO_3$ type. In the current study water types were restricted to the three types in pre-monsoon. The 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 fall in the Na-Ca-Cl-HCO_3 types. Assessment of the water types using piper plot proposes that there is a clear suggestion of the influence from the weathering 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 10 % of the samples Na-Ca-Mg-Cl type. The appreciable change in the hydro-chemical facies was noticed during 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.

Conclusions

Based on the analysis, it is inferred that the water intrusion is possibly generated by the presence of a large number of wells (excessive extraction of groundwater) in the Coastal tract areas. Due to heavy growth of human habitations, reclamation of land, lack of proper sewage systems, and lack of the efficient system of percolation of rain water in the area may be getting salinated. 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.

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