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The Study of Sea Water Intrusion in Coastal Aquifer of Niger Delta Region, Nigeria

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Abstract: The study area is located in Port Harcourt River State, south-south Nigeria. It lies within the sedimentary terrain of Nigeria, influenced by intense and extensive industrial pollution which in turn has trigged deterioration of groundwater quality. With an effort to quantitatively describe the present situation of groundwater and analyze its potability, 20 bore-hole well samples were collected and analyzed for understanding the hydrochemical characteristics. Results obtained showed that pH was found within acidic to the basic range. The values obtained from Ec suggested that groundwater was classified to be between good to an excellent category based on Langenegger classification. Detay and Carpenter classification suggested that groundwater within the study area fell within very weakly mineralized and weak mineralized water types. Comparing the parameters with NIS and WHO desirable limits. Parameters such pH, Cl^-, NO_3^-, Ca^{2+}, Na^+, K^+ and Mg^{2+} were below the desirable limits. TDS and Ec values were slightly above desirable as certain sampling locations; TH value revealed sample locations QA-01 to 20 were above the desirable limit. Bivariate plots suggested that groundwater were of various origin Plot of TDS against TH revealed that groundwater sample fell into; into three categories; moderately hard fresh, hard fresh and very hard fresh category. Findings from the seawater mixing index suggested that groundwater was slightly affected by the mixing of seawater components.

Key words: Seawater Intrusion · Coastal · Groundwater · Geochemical and Nigeria

INTRODUCTION

Groundwater is an essential resource for economic development and needed for human survival. As one of the most important natural resources, groundwater is considered more advantageous when compared to surface water [1]. Gates *et al*. [2] stated that groundwater is not easily contaminated, good water quality, natural regulation having a wide distribution. However, groundwater is considered more difficult to explore when compared to surface water, for better exploration of groundwater a better understanding of geology is required since its exist below the earth surface [1]. Although groundwater is not easily polluted when compared to surface water, but it could be difficult to remediate contaminants once pollution occurs [3-5]. There have been a series of reports on groundwater pollution within the coastal area of Niger Delta, Nigeria. Onwuka and Omonona [6], Davies *et al.* [7], Duru *et al.* [8] and Akakuru and Akudinobi [9] with emphasis on seawater intrusion and effect on anthropogenic activities on groundwater quality. *et al.* [10] were of the view that in coastal regions, the magnitude of the sea water intrusion is influenced by the thickness or saturated thickness of the unconfined aquifer. To highlight seawater intrusion, a multidisciplinary approach has been used by scholars these include; analytical methods, geophysical and modeling, have studied the phenomenon to locate the position of the interface between freshwater and marine water Demirel [11], El Achheb *et al.* [12], Gemail *et al.* [13], Grassi and Cortecci [14], Pulido-Le Boeuf [15], Spechler [16], Trabelsi *et al.* [17], Wilson *et al.* [18],

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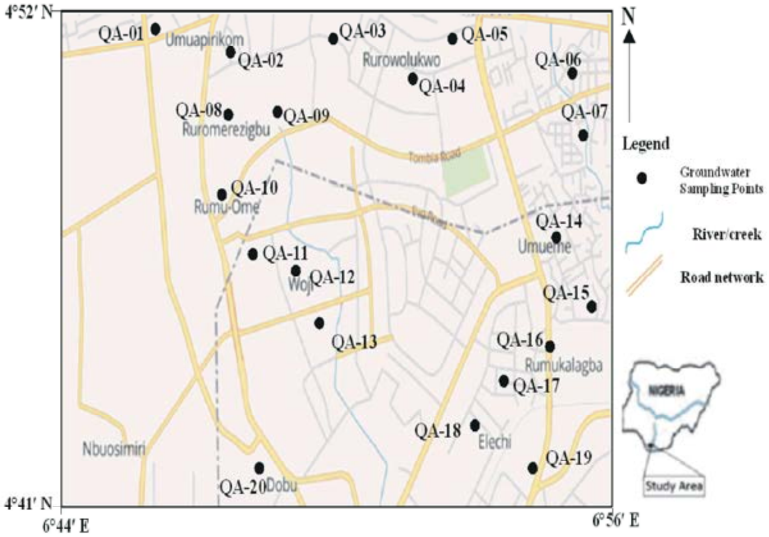

Fig. 1: Map of the Study Area showing groundwater sampling Points

Kouzana *et al.* [19]. In most coastal area across the globe, groundwater being the primary source of freshwater is exploited indiscriminately to meet the increasing demands for water usage [20]. Sivaranjani *et al.* [21] were of the view that coastal aquifers constitute an important source of fresh water supply but are often confronted with the problem of seawater intrusion. In coastal plains, due to inadequate storage facilities, most of the rainwater flows towards sea as runoff. Aside that excessive withdrawal of groundwater disturbs hydrodynamic equilibrium that exists between the freshwater-seawater in the aquifer and causes upward movement of the seawater [22]. Barlow [23] further pointed out that coastal aquifers are highly sensitive to both regional and global phenomena such as; storm surges, sea-level, rise change in climatic condition, shoreline erosion, coastal flooding, etc. Additionally, human activities can also trigged salinization process in coastal regions [24]. Aside coastal aquifers, surface water sources can also be influenced by interaction with the seawater. The rivers and estuaries allow the natural inflow of seawater due to the backwater from the sea and thereby increase the salinity of surface water. On a general note, ground and surface water are considered prone to seawater interaction, but for the purposed of this study emphasis is placed on groundwater as it remains the major of water for domestic and other use.

Location/Drainage: The study area is located in Port Harcourt River state, geographically it lies between latitude 4°41′N - 4°52′N and longitude 6°44′N - 6°56′E as shown in Fig. 1. The relief of the study area is low-lying and the rivers are influenced by tidal fluctuation [25, 26]. The study area lies at an average altitude of about 13m above mean sea level. The area falls within the coastal belt dominated by Low-Lying coastal plains which structurally belong to the sedimentary formation of the recent Niger Delta. It consists mainly of muddy deposit pushed out of the River Niger into a relatively tide-less salt sea. The area is drained by many rivers [26].

Geology/Hydrogeology: The study area is a coastal terrain of Niger Delta Basin. Oteri and Atolagbe [27] were of the view that the sub-aerial Niger Delta showed features of saline/brackish mangrove swamp belt separated from the sea by sand beach ridges for most of the coastline [28]. Oteri and Atolagbe [27] subdivided the Niger Delta Formation into three formations which are Akata, Agbada and Benin Formations. The Benin Formation consisting predominantly of massive highly porous sands and gravels with locally thin shale/clay interbeds forms a multi-aquifer system in the delta. Oteri and Atolagbe [27] further stated though several boreholes have been drilled into the aquifers of the Benin Formation yielding good quality water, but many have also been abandoned due to high salinity. The basin consist of massive highly porous sands and gravels forms a multi-aquifer system. The unconfined aquifer in the coastal beach ridges has a fresh water lens overlying salt water. The confined aquifers in most parts of the delta contain fresh water underlain by salt water. In certain zones of the delta however, salt water intrusion into the confined aquifers has occurred with salt water - bearing sands overlying fresh water - bearing sands. These are in turn underlain by saltwater bearing sands [27]. Saltwater intrusion into unconfined and confined aquifers also occur in the Niger Delta. In coastal beach ridges or sandy islands within the saline mangrove belt, fresh water lens floating above salt water bearing sands are found to occur in the unconfined aquifers [29]. Based on the depth of occurrence of the first saline water sands in the confined aquifers of the Benin Formation, the delta can be divided into two major areas: areas where fresh water sands are encountered at shallow depth underlain by saline water sands and the areas where saline water sands are encountered at shallow depths underlain successively by fresh water sands and saline water sands [27]. Water supply problems relating to salinity are confined to the saline mangrove swamp with associated sandy islands and barrier ridges at the coast.

MATERIALS AND METHODS

Sampling and Laboratory Analysis: A total of 20 groundwater samples were collected see Fig. 1.

Statistical software was used to subject the laboratory results to interpretative platforms, like graphs and tables.

Seawater Mixing Index: As an effective tool for quantitative estimation of the relative degree of seawater mixing in coastal water a parameter called Seawater Mixing Index (SMI) is proposed [21].

$$SMI = a \times \frac{C_{Na}}{T_{Na}} + \mathrm{b} \times \frac{C_{Mg}}{T_{Mg}} + C \times \frac{C_{Cl}}{T_{Cl}} + \mathrm{d} \times \frac{C_{SO4}}{T_{SO4}} \quad \text{Eqn (1) as propsed by [12]}$$

where the constants a, b, c and d denote the relative proportion of Na, Mg, Cl and SO4 in seawater, respectively (a=0.31, b=0.04, c=0.57, d=0.08); C is the measured concentration in mg/L and T represents the regional threshold values of the considered ions, which can be estimated from the interpretation of cumulative probability curves. If the calculated SMI value is greater than 1, the water may be considered to have the effect of seawater mixing.

Electrical Conductivity (Ec): Tutmeza *et al*. [30] stated that Ec is an important parameter use in evaluating the suitability of water for various usage. The value of Ec for the study area ranges from 11.3 to 1357µS/cm with an

Table 1: Method used to analyze physicochemical parameters.

S/No	Parameters	Analytical Method
1	pH	pH meter HachsensION + PH1 portable pH meter and HachsensION + 5050 T Portable Combination pH Electrode
2	Electrical Conductivity (EC)	HACH Conductivity
3	Total dissolved solids (TDS)	TDS meters (model HQ14D53000000, USA).
4	Magnesium (Mg^{2+})	EDTA titrimetric method
5	Calcium (Ca^{2+})	Titrimetric method
6	Chloride (Cl^-)	Titrimetric method
7	Nitrate (NO_3^-)	Ion-selective electrode (Orion 4 star)
8	Sulphate (SO_4^{2-})	Turbidimetric method using a UV-Vis spectrometer
9	Potassium (K^+)	Jenway clinical flame photometer (PFP7 model)
10	Sodium (Na^+)	Jenway clinical flame photometer (PFP7 model)
11	Bicarbonate (HCO_3^-)	Titrimetric method

Table 2: Result of Physicochemical Parameters

Sample Code	Physicochemical parameters	Minimum	Maximum	Average
QA-01 - 20	Electrical Conductivity (µS/cm)	14.8	1625	249.1
QA-01 - 20	pH	4	7.1	5.8
QA-01 - 20	TDS (mg/L)	29.3	620.8	140.2
QA-01 - 20	CalciumCa^{2+} (mg/l)	1.16	18.7	8.16
QA-01 - 20	Magnesium Mg^{2+} (mg/l)	0.7	47	11.3
QA-01 - 20	Sodium Na^+ (mg/l)	0.2	31	4.5
QA-01 - 20	Nitrate NO_3^- (mg/l)	0.36	8.2	3.24
QA-01 - 20	Bicarbonate HCO_3^- (mg/l)	6.97	71.8	22.6
QA-01 - 20	Potassium K (mg/l)	0.45	19.1	7.14
QA-01 - 20	Sulphate SO_4^{2-} (mg/l)	4.4	99.2	37.5
QA-01 - 20	Chloride Cl (mg/l)	7.4	101.7	43.26
QA-01 - 20	SMI	0.15	3.29	0.24

Table 3: Water Quality Classification of based on Ec [32]

Range	Quality	Sample Numbers
0-333	Excellent	n = QA-01, 03, 04, 05, 06, 08, 09, 10, 11, 12, 13, 14, 15, 17, 18, 19 and 20
333-500	Good	
500-1,100	Permissible	n = QA-02, 07 and 16
1,100-1,500	Brackish	
1,500-10,000	Saline	

Table 4: Water Classification on based on Electrical Conductivity [33]

Electrical conductivity (µS/cm)	Mineralization	Samples
<1000	Very weakly mineralized water	n =QA-01, 03-15, 17-20
1000-2000	Weakly mineralized water	n = QA-02 and 16.
2000-4000	Slightly mineralized water	
4000-6000	Moderately mineralized water	
6000-10,000	Highly mineralized water	
<10,000	Excessively mineralized water	

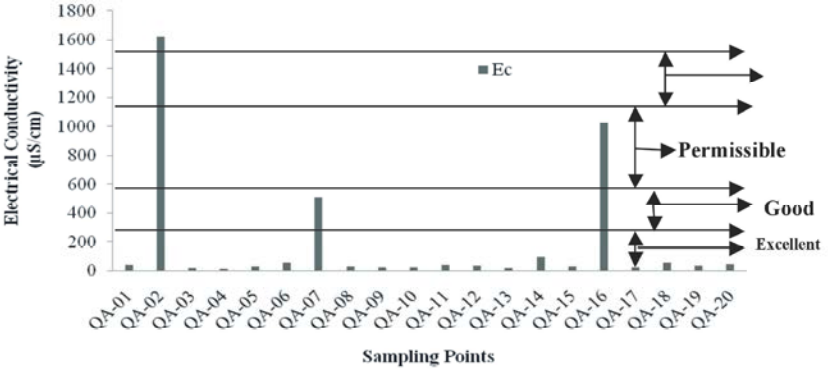

Fig. 2a: Plot of Electrical conductivity (Ec) against sampling Points according to [32]

average value of 249.1 µS/cm. Table 6 showed that value were below [31] desirable limit expect at sample location QA-02 and 16 that were slightly above the permissible limit.

One of the important parameter used in indirectly measurement salinity of water is Ec. According to Langenegger [32] stated that Ec can be used in indirect measure of salinity in many areas, which generally affects the taste and thus has significance on the user acceptance of the water as potable. Result from the study revealed that sample locations QA-01, 03, 04, 05, 06, 08, 09, 10, 11, 12, 13, 14, 15, 17, 18, 19 and 20 were classified to be excellent, hence considered fit for use. While sample locations QA-02, 07 and 16 were classified to be permissible based on Langenegger [32] classification as shown in Table 3.

Water classification based on EC (Table 4) showed that 98 % of groundwater samples were classified to be very weak mineralized water, 2% were classified to be weak mineralized water according to Detay and Carpenter [33] classification.

Water Quality Assessment

Hydrogen Ion Concentration (pH): The pH value indicates the acidic or alkaline material present in the water. When a substance dissolves in the water they produced charged molecules known as ions. Hydrogen (H^+) ions are found more in acidic water whereas Hydroxyl (OH^-) ions are in basic water. The pH scale of the study area ranges from 4 to 7.1 with mean value of 5.7 see Table 2. Result obtained revealed that value was below [34, 35] permissible limit see Table 6.

Chloride (Cl^-): Chloride in groundwater are originated from various sources including the dissolution of halite and related minerals, marine water entrapped in sediments and anthropogenic sources. According to WHO [34] the desirable limit of chloride in water is 250.0 mg/l. The value Cl^- for the study range from 7.4 to 101.7 mg/l with an average value of 43.26 mg/l as shown in Table 2. Result obtained revealed that value was below [34, 35] desirable limit and thereby considered fit for drinking as shown in Table 6.

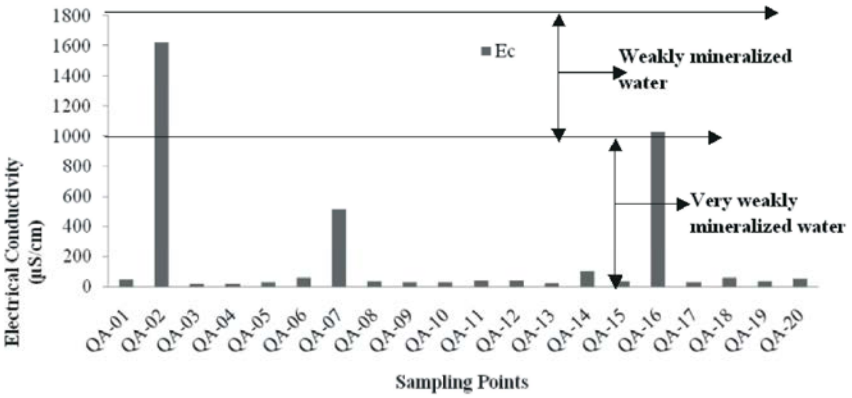

Fig. 2b: Plot of Ec versus sampling points based on [32] classification

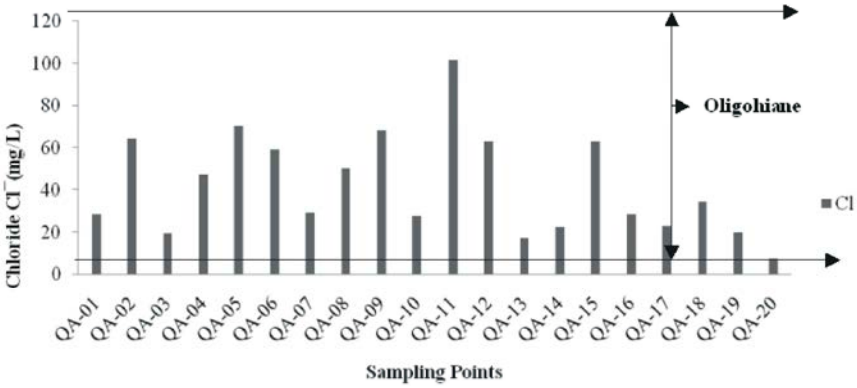

Fig. 3: Plot of Chloride (Cl^{-}) against Sampling Points according to Stuyfzand [36].

Table 5: Classification of chloride in the study area (Source: modified after, [36]).

Chloride Type	Chloride (mg/L)	Sample Numbers
Very Oligohaine	<5	
Oligohaine	30-150	n = 24
Fresh	150-300	
Fresh-brackish	150-300	
Brackish	300-1,000	
Brackish-salt	1,000-10,000	
Salt	10,000-20,000	
Hypersaline	>20,000	

According to Stuyfzand [36] chloride classification groundwater sample was classified to oligohaine, in other words it can be referred to water with very low salt content or brackish water as shown in Table 5.

Sodium (Na^{+}): Sodium is the most abundant member of the alkali metal group of studied groundwater. The concentration sodium of for the study ranges from 0.2 to 31 mg/l with an average value of 4.54 mg/l as shown in Table 2. Result obtained revealed that values were below [34, 35] desirable limit and considered fit for drinking based on the standard see Table 6.

Calcium (Ca^{2+}): Calcium is commonly present in natural waters, often resulting from the dissolution of calcium- rich rocks [37]. The concentration of Calcium in groundwater varies from 1.16 to 18.7 mg/l with an average value of 8.16 mg/l see Table 2. Table 6 showed that values were below [34, 35] desirable limit and considered fit for drinking based on the standard.

Total Hardness (TH): Total hardness is caused primarily by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulphate in water. In the area, TH value

Table 6: Water quality parameters-all values in mg/l except EC its µS/cm

					Value standard		Drinking Water Standard	
Sample Code	Physicochemical parameters	Minimum	Maximum	Average	Below	Above	[35]	[34]
QA-01 - 20	Electrical Conductivity (µS/cm)	14.8	1625	249.1	QA-01, 03-15, 17-20	QA-02 & 16	1000	1000
QA-01 - 20	pH	4	7.1	5.8	Nil	Nil	6.5-8.5	6.5-8.5
QA-01 - 20	TDS (mg/l)	29.3	620.8	140.2	QA-02-20	QA-01	500	500
QA-01 - 20	CalciumCa^{2+} (mg/l)	1.16	18.7	8.16	Nil	Nil	100	75
QA-01 - 20	Magnesium Mg^{2+}(mg/l)	0.7	47	11.3	All samples	Nil	0.2	250
QA-01 - 20	Sodium Na^+ (mg/l)	0.2	31	4.5	Nil	Nil	200	200
QA-01 - 20	Nitrate NO_3^- (mg/l)	0.36	8.2	3.24	Nil	Nil	50	3
QA-01 - 20	Bicarbonate HCO_3^- (mg/l)	6.97	71.8	22.6	N/A	N/A	N/A	N/A
QA-01 - 20	Potassium K (mg/l)	0.45	19.1	7.14	N/A	Nil	N/A	200
QA-01 - 20	Sulphate SO_4^{2-} (mg/l)	4.4	99.2	37.5	Nil	Nil	100	250
QA-01 - 20	Chloride Cl (mg/l)	7.4	101.7	43.26	Nil	Nil	250	200
QA-01-20	Total hardness (mg/l)	410	4680	1695.2	All samples were above	All samples were above	150	250

Note: Values are in mg/L.

varies between 410 and 4680 mg/l with an average value of 1695.27 mg/l. Result obtained showed that values were above [34, 35] desirable limit. Water hardness has no known adverse effects; however, some evidences indicate its role in heart diseases [38] and hardness of 150-300 mg/l and above may cause kidney problems and kidney stone formation [38] as it causes unpleasant taste and reduce ability of soap to produce lather. Total hardness is an important parameter of water for domestic use.

Magnesium (Mg^{2+}): Magnesium is an essential ion for functioning of cells in enzyme activation, but at higher concentrations, it is considered as laxative agent [39], while deficiency may cause structural and functional changes in human beings. The value of Mg^{2+} ranges from 1.2 to 36.2 mg/l with an average value of 8.76 mg/l as shown in Table 2. Findings showed that all sampled locations were below [34, 35] desirable limit and considered fit for domestic use based on the standard see Table 6.

Potassium (K^+): On a general note the behavior of potassium (K^+) is similar to that of sodium content in the water [40; 41]. It maintains fluids in balance stage in the human body. In present investigation, potassium concentration ranged from 0.45 to 19.1 mg/l with an average value of 7.14 mg/l see Table 2 All sample locations were considered to be above [34, 35] desirable limit, hence considered fit for domestic use see Table 6.

Sulphate (SO_4^{2-}): In the present investigation, the sulphate concentration ranges from 4.4 to 99.2 mg/l with an average of 37.58 mg/l as shown in Table 2. The sulphate (SO_4^{2-}) ion one of the important anions present in natural water that produce catharsis, dehydration and gastrointestinal irritation effect upon human beings when it is present in excess. It is mainly derived from gypsum on oxidation of pyrites [40, 42]. The sulphide minerals add the soluble sulphate into the groundwater through oxidation process [43]. Findings showed that all sampled locations were below [34, 35] desirable limit and considered fit for domestic used based on the set standard see Table 6.

Nitrate (NO_3^-): Nitrates are important natural constituents of water; high concentrations may indicate sources of past or present pollution. Result obtained from the study revealed that the concentration of nitrate ranges from 0.36 to 8.3 mg/l with an average value of 3.24 mg/l, values were observed to be below [34,35] desirable limit.

Bicarbonate (HCO_3^-): The concentration of bicarbonate controls the alkalinity of groundwater. Bicarbonate concentration in the samples varies from 6.97 to 71.8 mg/l with an average value of 22.6 mg/l. Higher bicarbonate in samples might be due to minute mineral dissolution.

Geochemical Assessment: The plot of concentrations of Na against TDS was used to deduce influence of major components and groundwater salinity. The groundwater concentrations of Na^+ and Cl^- were plotted against TDS. The plot showed that most Na^+ and Cl^- ions showed ($r^2 = 0.001$ and 0.028, respectively) with TDS (Fig. 4a and b). All others component i.e., Na^+, Ca^{2+}, Mg^{2+} and K^+ also well correlated with Cl^- with r^2 values 0.298, 0.008, 0.010 and 0.288 respectively (Fig. 4 c to f) denotes groundwater originated from various sources.

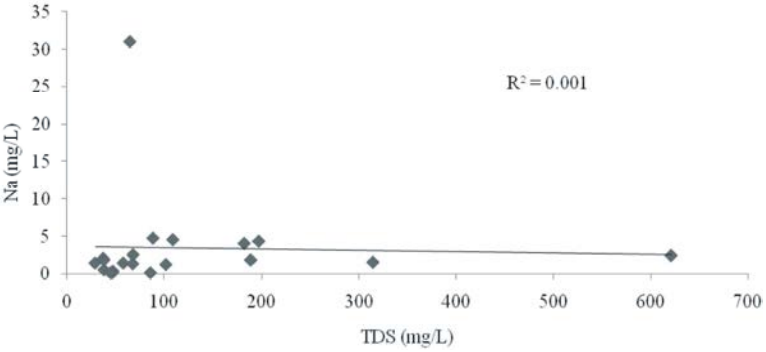

Fig. 4a: Bivariate plots of Na versus TDS.

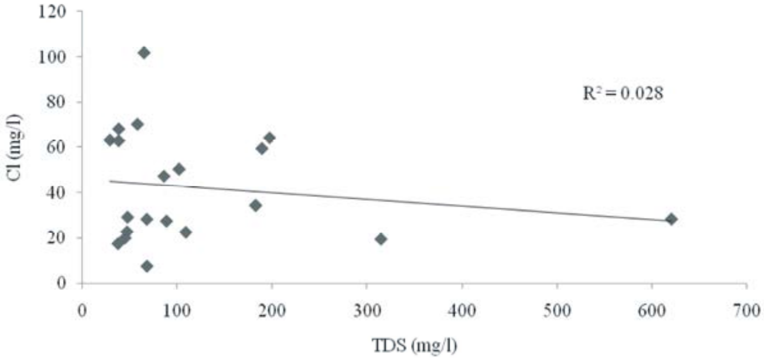

Fig. 4b: Bivariate plots of Cl¯ versus TDS

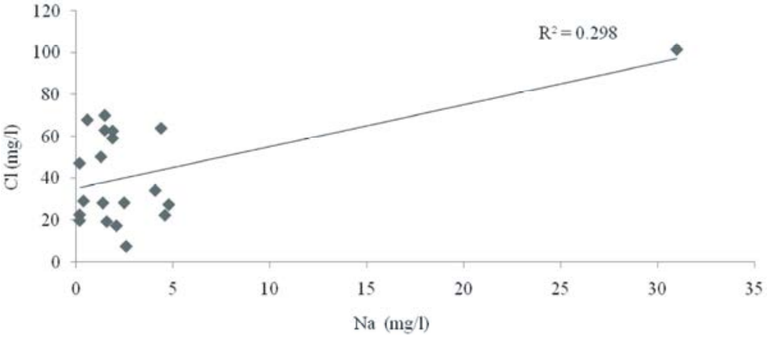

Fig. 4c: Bivariate plots of Cl versus Na.

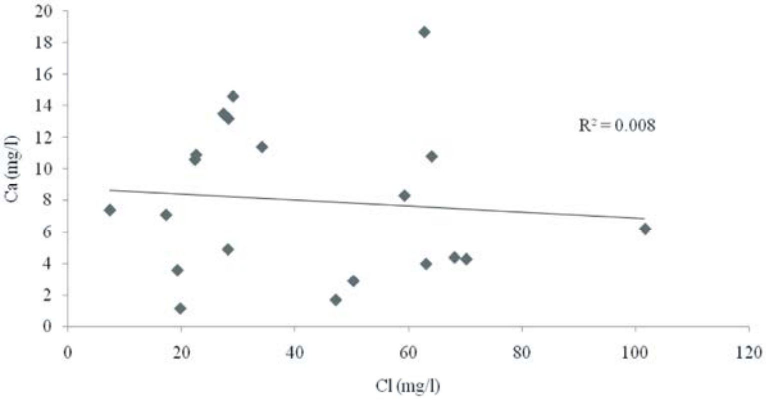

Fig. 4d: Bivariate plots of Ca versus Cl.

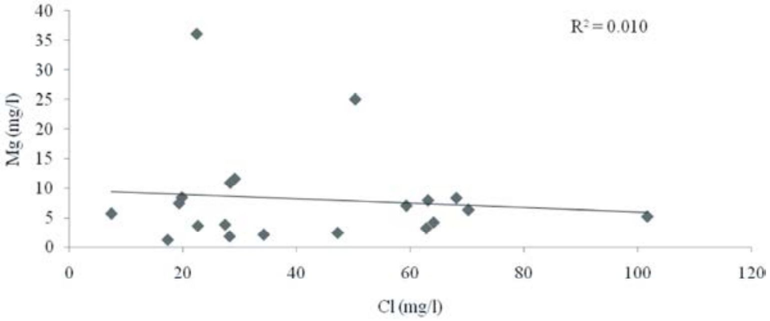

Fig. 4e: Bivariate plots of Mg versus Cl.

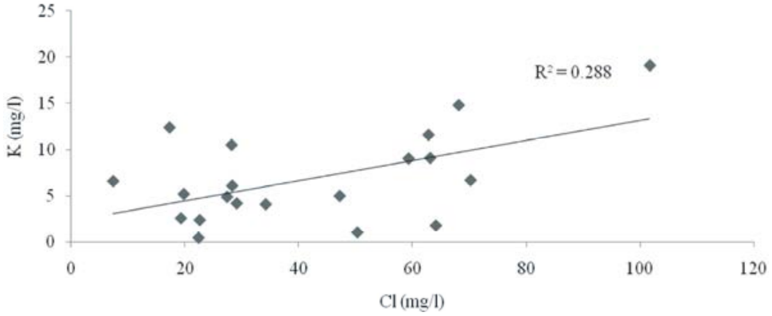

Fig. 4f: Bivariate plots of K versus Cl.

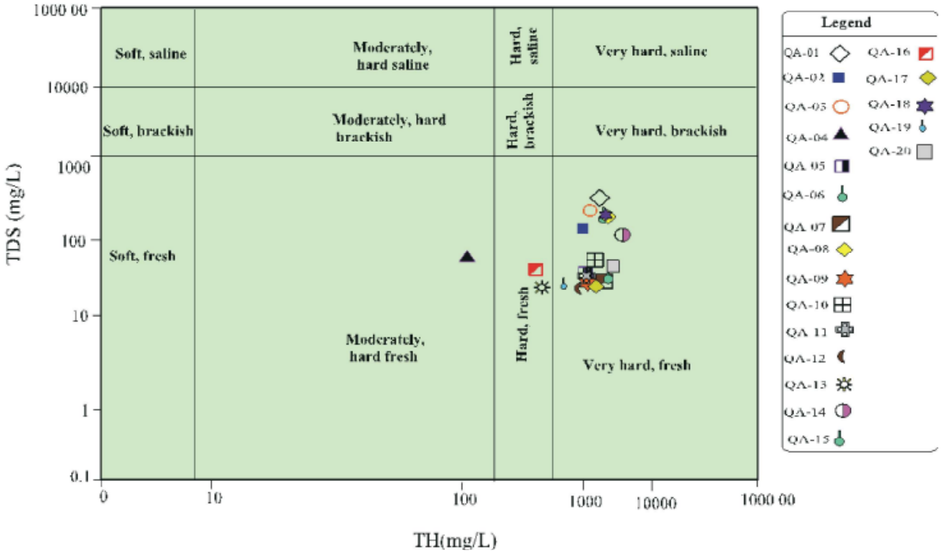

Fig. 5: Relationship between TDS vs TH concentration in the study area

The plot of TDS versus TH is generally used to classify groundwater into the following categories; fresh, hard, brackish and saline. From Fig. 5 it was observed that sample locations QA-01 to 03, 05 to 12, 14, 15, 17 to 20 were classified to be very hard/fresh water, while sample locations QA-12 and 16 were classified to be hard fresh and sample location QA-04 was classified to be moderately/hard fresh water type as shown in Fig. 5.

Seawater Mixing Index (SMI): Seawater mixing index (SMI) was used to determine the extent of fresh groundwater mixed with saline water and it is evaluated using the SMI see equations 1. The value of SMI for the study varies from 0.15 to 3.29 with an average 0.24 as shown in Table 2. Result obtained revealed that 68 % of groundwater was affected by seawater intrusion while 32 % was unaffected by seawater intrusion.

CONCLUSION

The analytical results of sampled groundwater were interpreted by comparing groundwater with local and international standard, bivariate plots, TDS vs TH plots and SMI. Results obtained from the study showed Ec and TDS values revealed that values were slightly below and above NIS and WHO at some sampling locations. Analyzed parameters such as; pH, Ca^{2+}, Mg^{2+}, Na^+, NO_3^-, K^+, HCO_3^-, SO_4^{2-} were below NIS, 2007 and WHO, 2011 desirable limit. The values pH obtained from showed that groundwater fell within acidic to basic category, with the value range of 4 to 7.1 was below desirable limit According to the classification of Langenegger, Detay and Carpenter Ec classification groundwater was classified to be excellent, very weak mineral mineralized respectively. Bivariate plots suggested that groundwater was of different origin and also showed no, negative and positive correlation. Plots of TDS versus TH revealed that groundwater fell within three categories moderately, hard fresh, hard fresh and very hard, freshwater type. Deduction from SMI showed that groundwater was slightly affected by SMI. In conclusion, it is also advised that regular monitoring of groundwater quality is required so as to avoid further seawater intrusion as the area is bordering the coast.

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