Assessment of impact of climatic change on groundwater quality around Igbokoda Coastal area, southwestern Nigeria.

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Abstract:

Hydrochemical assessment of 39 groundwater samples within Igbokoda coastal zone are presented and discussed in terms of impact of coastal saltwater on the quality and subsequent hydrochemical evolution.

The pH range from 6.8 to 9.8, temperature from 28.3 to 33.5°C, EC from 67 to 2440μS/cm and TH from 66.36 to 369.22mg/L. Hydrochemical results showed higher concentrations of Na^+ (3.56 – 624.14mg/L) compared to Ca^{2+} (19.21 – 104.32mg/L), K^+ (1.49 – 62.94mg/L) compared to Mg^{2+} (3.36 – 75.01mg/L) and Cl^- (72.0 – 2592.00mg/L) compared to HCO_3^- (15.25 – 152.50mg/L). This hydrochemical profile reflects a Na-Cl dominated water type suggesting impact of salt water on the groundwater system. Nonetheless, with the exception of higher Cl^- values, the major ions concentrations are within recommended WHO standard for drinking water while the concentrations of Fe (0.01-13.4mg/L) and Mn (0.00-1.00mg/L) above the WHO guideline values in about 88% and 35% of the samples respectively call for concern. Estimated major ionic ratios such as Mg/Ca (0.13 – 3.09), Cl/HCO_3 (1.18 – 25.50) signify brackish water in most of the locations due to impact of saltwater mixing. This is clearly reflected in the water characterization that revealed largely Na-(K)-Cl-SO_4 water type as brackish water and minor occurrence of Ca-(Mg)-HCO_3 water type as freshwater sources.

1. Introduction

Groundwater is essential for continuity of life on earth. It is the primary source of water for agriculture, domestic and[industrial purposes in many countries of the world (UNESCO, 2006). In many coastal towns or cities, groundwater which constitutes the major source of freshwater is under constant threat of saline water intrusion (Adepelumi et al., 2009). Groundwater occurrence is a function of different factors including geology, topographic relief, type and amount of vegetative ground cover and most importantly in recent time, climate change. However, Climate change has been part of the earth since its inception. History of the earth indicates that the cretaceous period (120 to 65 million years ago) was 5° to 7°C warm than today with higher carbon dioxide concentration in the atmosphere while the tertiary to quaternary periods (2.5 million years ago) were colder (Bruce, 2011)). Thus in the past million years, climate change has been characterized by series of changes from major ice ages (glacial periods) to interglacial periods about every 100,000 years with other shorter periods of variations. However, modern climate change, driven largely by a range of human activities is rapid (quick) than in the geological past leading to increase of green house gases such as carbon dioxide, methane and nitrous oxide in the atmosphere in excess of the heat requirement to keep the planet warm and sustain life. Other effects of modern climate change are that the global mean sea levels are thought to have risen by approximately 10-20cm during the last hundred years (Bruce, 2011). The sea level rise in conjunction with existing shoreline erosion in low-lying coastal area, have potential for more severe and frequent storm damage and flooding, inundation, erosion, increased salinity of rivers, bays, and aquifers and changes in the biophysical and biochemical properties of the coastal zone. Such human and climate-induced environmental conditions are not uncommon in the coastal areas of Nigeria which are characterized by commercial and industrial activities including oil and gas development. Consequently, this study focuses on hydrochemical evaluation of impact of coastal saltwater on the quality of groundwater system, in Igbokoda for sustainable groundwater management.

2. Location and Geology

The study area lies within latitude 6° 10' to 6° 25'N and longitude 4° 39' to 4° 53'E covering the coastal sand bars that stretch in a NW – SE direction from Okitipupa to the Atlantic ocean (Fig. 1). The area is low-lying (varying in altitude from less than 1m to about 12m above sea level), of wet equatorial climate with annual temperature of between 24°C to 27°C and an average annual rainfall above 2500mm (Iloeje, 1981 The two prominent rivers draining the area, Oluwa and Ufara; show considerable degree of meandering in view of their

proximity to the shoreline. Geologically the study area is underlain by sedimentary rock sequences of Dahomey Basin. Dahomey Basin evolved in the early to Late Cretaceous Pre-Santonian Transgressive and Regressive Complexes as a result of the separation of the South American and African Continents and the opening of the Atlantic Ocean. Deposition of a very thick sequence of continental grits and pebbly sand was initiated in the fault controlled depression on the Crystalline Basement Complex with the first sedimentation cycle characterized by marine transgression in the southwestern part of Nigeria during the Maastrichtian (Kogbe, 1975). However, Quaternary alluvium deposits underlain virtually in all places by the Quaternary coastal plain sands cover the study area. The coastal plain sands constitute the major shallow hydrogeological units and adequate annual recharge is guaranteed considering the high annual rainfall and other favourable climatic conditions.

3. Methodology

Field operations were carried out at the pick of the dry season to avoid dilution effects that may arise from run-off and infiltration of precipitation.   A total of 39 water samples comprising of 4 borehole water and 35 shallow hands dug well water were collected in polyethylene bottles. The samples for cations determination were acidified with concentrated nitric acid to prevent contamination. The water samples were refrigerated at 4°C before they were taken to the laboratory for analyses.

Temperature, electrical conductivity (EC) and pH were measured in-situ using multiparameter portable meter (model Testr-35). Major cations and selected trace metals were determined using Atomic Absorption Spectrometer (AAS) while the major anions were analysed using Ion chromatography method. As part of data evaluation, the results were compared with WHO (2004) standards for drinking water quality while the overall data was subjected to statistical evaluation using SPSS16.

4. Results and Discussion

Results of field physico-chemical and laboratory hydrochemical data sets are presented in Tables 1 and 2 respectively while the overall summary of the results of chemical analyses is presented in Table 1 alongside with maximum acceptable WHO (2004) standard for drinking water quality. Generally, in-situ measurements revealed pH of 6.8–9.8, temperature of 28.3–33.5^{o}C, EC of 67-2440μS/cm and TH of 66.36–369.22mg/L. The physico-chemical data show that the groundwater with the exception of a location (L34) with pH of 6.8 (mildly acidic) is mildly alkaline with marked difference in EC values of shallow well water and borehole water. For the shallow well water, EC varies from 67-773μS/cm with corresponding TDS values of 43.55-502.5mg/L indicating low to medium salinity while borehole water is characterized by EC values of 1311-2440 μS/cm with corresponding TDS of 852.20-1586mg/L indicating slightly high salinity. The total hardness (TH) follows a similar trend with values ranging from 66.36-502.50mg/L as $CaCO_3$ for shallow well water compared to borehole water with values ranging from of 852.2-1586mg/L $CaCO_3$. The order of concentration of cations in the shallow well water is Na>Ca>K>Mg while that of the borehole water is Na>K>Mg>Ca. However, both shallow well water and borehole water have similar order of anions concentration of Cl>HCO$_3$>SO$_4$>NO$_3$. In general, hydrochemical results showed higher concentrations of Na^+ (3.56 – 624.14mg/L) compared to Ca^{2+} (19.21 – 104.32mg/L), K^+ (1.49 – 62.94mg/L) compared to Mg^{2+} (3.36 – 75.01mg/L) and Cl^- (72.0 – 2592.00mg/L) compared to HCO_3^- (15.25 – 152.50mg/L). However, SO_4^{2-} and NO_3^- concentrations are generally low with average of 1.2mg/L and 0.52mg/L respectively. This hydrochemical profile reflects a Na-Cl dominated water type suggesting impact of salt water on the groundwater system. Nonetheless, with the exception of higher Cl^- values, the major ions concentrations are within recommended WHO standard for drinking water. However, the concentrations of Fe (0.01-13.4mg/L) and Mn (0.00-1.00mg/L) above the WHO guideline values in about 88% and 35% of the samples respectively call for concern. Estimated major ionic ratios such as Mg/Ca (0.13 – 3.09), Cl/HCO$_3$ (1.18 – 25.50) and cation exchange value (CEV) of 1.28 – 73.68 signify brackish water in most of the locations due to impact of saltwater mixing

. 5. Hydrochemical character

It is hypothesized that groundwater major ions chemistry can be employed to determine the interaction between groundwater and saline water/seawater in costal aquifers and that there exists a relationship between total dissolved solids with chloride, sodium, magnesium and sulphate concentrations of groundwater (Mondal et al (2010). To understand the relationship between different ionic species, inter-elemental correlation was made. TDS was related to HCO$_3^-$, Na$^+$+K$^+$, Ca^{2+}+Mg^{2+} etc as shown in Fig. 2. Correlation coefficient of 0.66 for (TDS vs. HCO$_3$), 0.87 for (TDS vs. Na$^+$ + K$^+$), 0.89 for (Ec vs. Na$^+$ + K$^+$) and 0.63(EC vs.Ca^{2+} + Mg^{2+}) implies that groundwater chemistry in the study area was mainly controlled by these ions. Furthermore, Na$^+$ + K$^+$ was strongly correlated with Cl$^-$ (r = 0.91) while Ca^{2+}+Mg^{2+} vs. Cl$^-$ has weak positive correlation of 0.44 indicating

that ionic input of Na^+, K^+ and Cl^- into the groundwater system of the study area are likely to be from the same source probably due to the influence of seawater intrusion in the coastal area. Apart from the cross plots evaluation, a crude model presumed that during sea transgression/regression processes, sea water were trapped in the geologic formations of the study area and the presently relatively high Cl^- values in the area were consequent of modification of the trapped salt water by HCO_3^- rich groundwater, ion exchange, precipitation of minerals or by solution of surrounding rock or even by combination of these processes. Therefore, it is possible to compare the ratio of groundwater chemical constituents of the study area with that of the seawater so as to trace the degree of variation from the sea water and possible process responsible for it. Table 4 shows ratios of major chemical parameters of Igbokoda coastal area compared with average values for seawater and Early Cretaceous brines in Israel. On the average, the chemical ratios of Igbokoda coastal groundwater deviate from the ocean/seawater. However, there are pockets of locations with similar ionic ratio with seawater. The salinity variation observed in different samples may be attributed to depth variation as well as subsequent modification of the initial seawater. Most of the boreholes tapping deep aquifer have ionic ratio close to the seawater. In general, freshwater was dominated by calcium and seawater by magnesium. The Mg^{2+}/Ca^{2+} ratio provided an indicator for delineating the sea-freshwater interface. Mondal et al. (2008) observed that extremely low HCO_3^-/Cl^- and variable high Mg^{2+}/Ca^{2+} (molar ratios) indicated the transformation of fresh groundwater to saline water in coastal aquifers. In this study the Mg^{2+}/Ca^{2+} ratio varies from 0.13 – 3.09 while HCO_3^-/Cl^- varies from 0.04 – 0.85 (Table 4) indicating the transformation of fresh groundwater to saline water in some portion of Igbokoda coastal aquifer. The highest Mg^{2+}/Ca^{2+} (3.09) was recorded at a borehole location with corresponding low HCO_3^-/Cl^- (0.04) ratio confirming transformation of fresh water to saline water due to impact of saltwater mixing. The critical r (Na+K)/Cl vary within 0.032-0.793 compared to a value of 0.88 for seawater while $rHCO_3^-/Cl^-$ vary between 0.039 and 0.847 compared to a value of 0.004 for seawater. This trend clearly reflects the dominance of freshwater in Igbokoda coastal aquifer mixing in places with salt water. Furthermore, the groundwater was characterized using Schoeller (1962) diagram (Fig.3) and Piper (1944) Trilinear diagram (Fig. 4). The Schoeller diagram as earlier observed revealed the overall chemical character of groundwater as alkali earth water predominantly Na-Cl water. The Schoeller diagram equally revealed low SO_4^{2-} and NO_3^- concentrations. Piper diagrams are traditional way of examining the structure of major solutes in water suites for hydrochemical facies classification and for exploring trends that might reveal insights into hydrochemical processes (Hem, 1985).

Water characterization using Piper diagram revealed dominant Na-(K)-Cl-SO_4 brackish water type with minor occurrence of Ca-(Mg)-HCO_3 water type as freshwater. Sodium and chloride are among dominant ions of seawater, while calcium and bicarbonate are generally the major ions of freshwater (Hem, 1985). Thus, high levels of Na^+ and Cl^- ions in coastal groundwater like the study area may indicate a significant effect of seawater mixing, while considerable amounts of HCO_3^- and Ca^{2+} mainly reflect the contribution from water–rock interaction (Park et al., 2005). The plot of HCO_3^-/Cl^- versus TDS (Fig 5a) showed that the regression slope was negative in the high (>1000 mg/l) TDS concentration range while the slope was positive in the low (<1000 mg/l) TDS concentration range indicating that groundwater with high TDS concentration was enriched with chloride and groundwater with low TDS concentration was not. The variations of Ca^{2+}/Na^+ ratios with TDS (Fig 5b) showed a similar trend and are subsequently subject to a similar interpretation. The shallow well of Igbokoda coastal area is characterized by relatively low salinity and weak concentrations of chloride compared to the deep borehole water. These relatively low (Cl^-) values are due to the infiltration of meteoric water into the alluvial /sandy aquifer formation characterizing the area. Gibbs diagrams (Fig. 6), representing a plot of log_{10} (TDS) versus $Na^+/$ (Na^+ + Ca^{2+}) being widely used in assessing the functional sources of dissolved chemical constituents in groundwater (Gibbs 1970) was employed (Fig. 6) to further explain the mechanisms controlling hydrochemical evolution of groundwater in the study area. Twenty-six percent (26%) of the samples suggest that the chemical weathering of rock-forming minerals were influencing the groundwater quality, whereas 74% of the remaining samples represent dilution dominance with mixing of seawater with the fresh coastal water.

6. Quality and Usability
In nature, even the cleanest water contains some impurities that come from the erosion of natural rock formations. Water dissolves and absorbs substances that it touches, including major cations (Ca, Mg, Na, and K) and major anions (HCO_3, SO_4, Cl and NO_3) from dozens of naturally occurring minerals. Thus, the chemistry of water is influenced as it flows downward through soil and the unsaturated zone. Because groundwater is in contact with soil as it moves down to the aquifer, dissolved minerals are picked up by the water, leading to a higher mineral content than the initial infiltrated water. At low levels, most of these dissolved minerals do not cause health problems and can even give water an appealing taste. Some of these minerals determine how "soft'

or "hard" our water is, and some may produce an unpleasant odor or taste. At higher levels, minerals can be considered contaminants, and like man-made chemicals, can make water unpalatable or unsafe to drink. According to Davis and DeWiest, (1966), drinking water standard are generally based on two main criteria; presence of objectionable tastes, odours and colour and presence of substances with adverse physiological (health) effects. As observed in the hydrochemical profile of groundwater in the study area, two major water types were noted; the shallow well water and the borehole water types. The shallow well water is tapped from the unconfined aquifer characterized by alluvial and sandy sedimentary deposits while the deeper borehole water is tapped from confined aquifer. The shallow well water in the unconfined aquifer is vulnerable to pollution in view of geology, the high population density and the increased agricultural activities. The chemical analyses results show that 59%, 88% and 35% of the groundwater system of the study area has chemical concentrations of Cl, Fe and Mn respectively above WHO recommended standard values for drinking water and as such need to be treated before consumption.

As for the irrigation quality assessment, the suitability of groundwater for agricultural purpose is based on the effects of the total salt content, sodium and specific ion toxicities of the water on both the plant and the soil. In fact, salts can be highly harmful, and can limit growth of plants physically, by restricting the taking up of water through modification of osmotic processes. Also salts may damage plant growth chemically by the effects of toxic substances upon metabolic processes. The irrigation quality in this study is judged using estimated sodium adsorption ratio (SAR) after Richards (1954) i.e.

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+}) + (Mg^{2+})}{2}}}$$

Estimated results indicate that except for locations L3 and L12 with SAR>10, all other values (0.27 -7.91) for the shallow well water are less than 10, implying that the shallow groundwater in the area is suitable for irrigation in line with the work of Mandel and Shiftan (1981); water containing SAR of between (0 – 10), can be applied on all irrigation soils. However, with the exception of location L17 with relatively high Mg (70.95mg/L) and low SAR of 3.22, generally the boreholes waters with SAR range of 19.87-24.33 are unsuitable for irrigation uses. Further evaluation comparing modified Wilcox classification model (Table 5) with the total soluble salts (electrical conductivity) and relative proportion of sodium ions to other cations expressed as Na % = $(Na^+ + K^+)$ * 100 / $(Ca^{2+} + Mg^{2+} + Na^+ + K^+)$ where the concentrations of ions are expressed in meq/L, indicate that 20.51% of the groundwater in the study area with low-medium salinity fall in the excellent–good water class and is suitable for irrigation purposes while the remaining 79.49% water sample with high-very high salinity fall in the permissible–doubtful class and is unsuitable for irrigation. Thus the Na-Cl rich water in the study area is unsuitable for irrigation while majority of the relatively fresh shallow well water is considered suitable for irrigation.

Summary and conclusion

Groundwater in the coastal area of Igbokoda is moderately hard to very hard alkaline water. Apart from high Cl, Fe and Mn concentrations in some locations, majority of chemical constituents are well within the official WHO safe limits. Irrigation quality assessment using sodium adsorption ratio and modified Wilcox irrigation classification model indicate that some of the shallow well water are suitable for irrigation purposes while the borehole water are unsuitable. The Piper trilinear diagram suggests dominant Na-(K)-Cl-SO$_4$ water type as brackish water and minor occurrence of Ca-(Mg)-HCO$_3$ water type as freshwater sources. Finally, this study has revealed evidence of impact of saltwater on the groundwater quality of the study.

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Table 1. Physico-chemical components of the analyzed groundwater samples

Locality	Code	Temp.(°C)	pH	EC (µS/cm)	TDS (mg/L)	TH (mg/L)
Palace road	L1	30.7	9.8	546	354.9	159.25
Palace road	L2	29.9	8.6	329	213.85	121.51
Palace road	L3	29.9	7.9	729	473.85	173.40
Palace road	L4	29.1	7.6	452	293.8	119.53
Palace road	L5	30.5	7.7	211	137.15	110.22
Iyamore	L6	30.5	8.2	116	75.4	104.15
Okogan	L7	30.6	7.4	67	43.55	76.26
Okogan	L8	29.9	7.3	462	300.3	175.71
Okogan	L9	30.3	7.4	90	58.5	96.65
Okogan	L10	30.1	7.8	129	83.85	94.99
Okogan	L11	30.1	7.8	330	214.5	152.55
Okogan	L12	30.1	8	600	390	146.32
Ebiseni Avenue	*L13	33.5	9	2440	1586	369.22
Ebiseni Avenue	*L14	31.5	9.3	1870	1215.5	195.99
Ebiseni Avenue	L16	30	8.4	516	335.40	232.43
Kelemo Zion	*L17	31.1	9.2	1739	1130.00	358.00
Kelemo Zion	L18	29.2	8.5	390	253.50	179.08
Iwaeni	L19	29.3	7.9	370	240.50	157.50
Iwaeni	L20	29.2	8.4	392	254.80	148.71
Araromi	L21	28.3	9.3	641	416.65	235.53
Oguntumiyi	L22	28.7	8.4	531	345.15	168.27
Larada	L23	28.7	8.4	773	502.50	319.78
Larada	L24	28.4	8.8	516	335.40	191.23
Ilara	L25	29.6	8.3	194	126.10	134.24
Ilara	L26	29.6	8.4	316	205.40	179.57
Ilara	L27	29.8	8.4	473	307.45	188.62
Kurugbere	L28	28.5	7.3	253	164.45	78.58
Kurugbere	*L29	28.5	7.2	1311	852.20	99.76
Weke	L30	29.5	8	593	385.45	178.74
Weke	L31	30.2	9.1	237	154.05	118.15
Weke	L32	29.1	8	717	466.05	241.91
Kofani	L33	29.5	7.9	122	79.30	104.17
Kofani	L34	30.6	6.8	106	68.90	80.70
Jedo	L35	29.5	7.6	98	63.70	66.36
GRA	L36	30.5	7.8	297	193.05	111.17
GRA	L37	29.5	7.6	209	135.85	113.95
GRA	L38	30.1	8.1	186	120.90	139.95
GRA	L39	30.4	7.4	227	147.55	116.94
GRA	L40	32	7.9	289	187.85	175.39

*Borehole

Table 2. Major chemical components of the analyzed groundwater samples

Code	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Mn^{4+} (mg/L)	Fe^{2+} (mg/L)	HCO_3^- (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)
L1	45.55	11.06	97.54	33.25	0.36	7.29	45.75	1.56	468	0.71
L2	24.52	14.65	50.11	9.81	1	13.74	45.75	ND	198	0.09
L3	49.62	12.03	238.04	44.41	0.11	3.84	61	1.46	504	0.19
L4	32.33	9.43	82.41	28.84	0.05	1.3	61	1.7	450	0.36
L5	30.81	8.09	89.57	9.23	0.18	3.49	45.75	0.37	810	0.06
L6	25.94	9.57	45.68	7.24	0.28	5.36	30.5	0.65	239	0.17
L7	20.11	6.33	27.51	1.49	0.04	0.69	30.5	ND	108	0.09
L8	55.62	8.95	95.68	8.63	0.07	0.41	30.5	2.46	234	0.36
L9	27.98	6.51	31.22	2.82	0.03	0.99	61	ND	72	0.06
L10	27.66	6.3	33.44	3.67	0	0.88	30.5	0.01	90	0.17
L11	44.81	9.88	52.24	16.72	0	0.35	30.5	2.65	180	0.09
L12	40.14	11.2	200.52	37.58	0.75	12.35	30.5	0.4	486	0.26
*L13	24.25	75.01	624.14	44.33	0	1.55	122	ND	2592	0.14
*L14	63.94	8.83	525.47	62.94	0.03	4.07	76.25	1.67	1944	0.13
L16	69.45	14.34	58.47	13.45	0.34	5.09	30.5	1.91	234	0.27
*L17	26.45	70.95	99.84	46.31	0	1.98	152.5	0.34	1332	0.07
L18	51.12	12.5	172.51	12.97	0.32	7.68	61	0.78	234	1.69
L19	45.82	10.47	73.54	16.88	0.22	2.77	45.75	0.94	288	ND
L20	42.35	10.44	77.84	33.61	0.13	1.72	15.25	1.39	288	0.99
L21	75.01	11.72	83.34	29.71	0.02	0.29	45.75	5.32	396	0.02
L22	52.31	9.15	82.74	21.54	0.01	0.41	30.5	4.92	288	0.2
L23	104.32	14.41	87.58	37.71	0.34	2.75	30.5	5.01	360	0.22
L24	58.11	11.21	78.59	42.11	0.04	0.86	45.75	0.6	324	0.3
L25	40.41	8.1	32.34	7.53	0.06	1.85	30.5	ND	72	0.13
L26	59.24	7.69	48.58	8.01	0.1	2.3	30.5	1.02	288	0.1
L27	59.01	10.03	78.69	22.11	0.13	1.37	30.5	0.69	324	0.04
L28	19.21	7.44	64.57	13.65	0.05	1.51	30.5	ND	288	0.01
*L29	28.35	7.04	396.04	22.95	0.35	1.73	91.5	0.32	1152	0.04
L30	51.92	11.93	81.12	20.71	0.11	0.65	91.5	1.08	324	0.06
L31	35.04	7.45	44.69	9.03	0	0.01	45.75	0.09	252	0.46
L32	78.57	11.11	88.13	29.54	0.07	0.31	76.25	0.27	432	4.39
L33	31.14	6.42	29.07	4.38	0	0.65	61	0.3	180	0.39
L34	23.24	5.51	8.94	4.04	0	0.3	76.25	0.07	162	ND
L35	21.04	3.36	3.56	1.64	0	0.87	61	0.48	162	0.94
L36	33.58	6.64	46.57	3.72	0	0.23	45.75	0.14	162	0.92
L37	33.95	7.09	34.48	6.54	0	0.17	45.75	0.54	144	0.65
L38	43.87	7.39	34.55	7.35	0	0.36	45.75	0.12	189	1.77
L39	36.22	6.44	47.25	6.1	0	0.17	30.5	0.11	216	2.13
L40	57.04	8.01	27.59	5.75	0.03	0.39	76.25	0.16	162	1.07

*Borehole, ND = Not detected

Table 3. Summary of the hydrochemical analyses results

Parameters	Min	Max	Mean	Median	Sdev	WHO(2004)
Temp.(oC)	28.3	33.5	29.91	29.9	1.02	-
pH	6.8	9.8	8.13	8	0.67	6.5-8.5
EC (µS/cm)	67	2440	509.41	370	511.31	1000
TDS (mg/L)	43.55	1586	331.11	240.5	332.33	500
TH (mg/L)	66.36	369.22	159.35	148.71	71.27	500
Ca^{2+}(mg/L)	19.21	104.32	43.33	40.41	18.62	250
Mg^{2+} (mg/L)	3.36	75.01	12.43	9.15	14.5	150
Na^{+} (mg/L)	3.56	624.14	104.47	73.54	131.62	200
K^{+} (mg/L)	1.49	62.94	18.93	13.45	15.61	200
Mn^{4+}(mg/L)	0	1	0.13	0.05	0.21	0.5
Cu^{2+} (mg/L)	0	0.07	0.01	0	0.02	1
Zn^{2+} (mg/L)	0.05	0.85	0.28	0.2	0.19	0.3
Fe^{2+} (mg/L)	0.01	13.74	2.38	1.3	3.16	0.3
HCO_3^{-} (mg/L)	15.25	152.5	52.01	45.75	27.71	-
SO_4^{2-} (mg/L)	0.01	5.32	1.2	0.65	1.43	250
Cl^{-} (mg/L)	72	2592	426.36	288	510.6	250
NO_3^{-}(mg/L)	0.01	4.39	0.53	0.2	0.84	50

Table 4. Ionic Ratio compared to Seawater value

Parameters	Min	Max	Mean	Stdev	*Seawater	**E.Cret.
rMg/Ca	0.130	3.093	0.363	0.602	3.3	0.501
rNa/K	1.866	18.463	6.257	4.264	46.974	105.06
rCa/Na	0.039	5.910	0.882	0.969	0.044	0.105
r(Na+K)/Cl	0.032	0.793	0.310	0.141	0.871	0.882
rHCO3/Cl	0.039	0.847	0.204	0.159	0.004	0.007
rSO4/Cl	0.000	0.017	0.003	0.005	0.105	0.009
CA-I	1.280	73.680	11.742	14.613	-	-

*Based on average values of data for seawater and early Cretaceous brines, from Collins, 1975.

**Based on data for Early Cretaceous brines in Israel, from Bentor, 1969.

Chloro-alkaline value (CA-1), from schoeller, 1967. {CA-1 = Cl-(Na+K)/Cl

Table 5 Modified Wilcox quality classification of irrigation waters

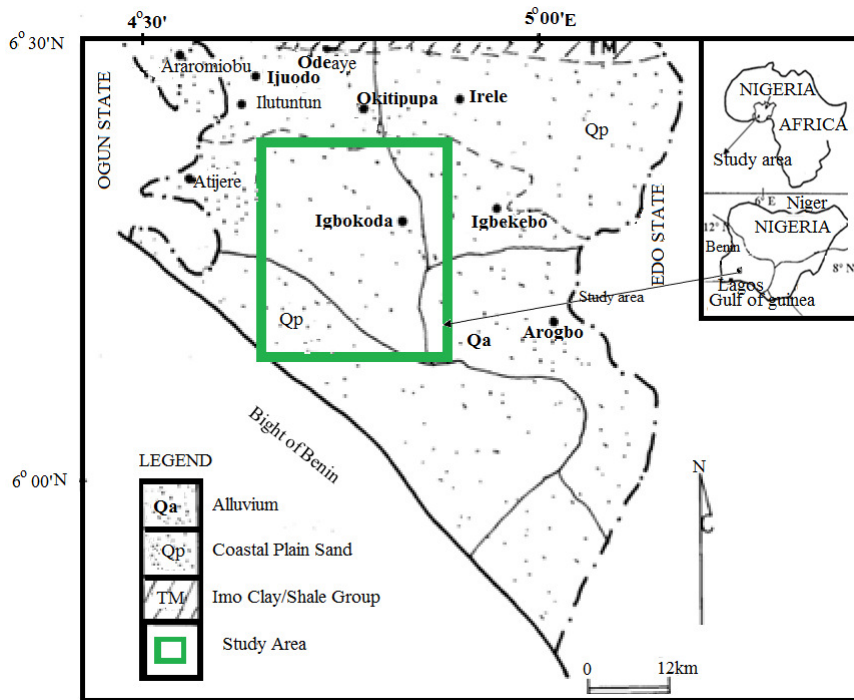| Water classification	Na%	EC(µS/cm)	Salinity Hazard	% Compliance
Excellent	20	250	Low	2.56
Good	30-40	250-750	Medium	17.95
Permissible	40-60	750-2000	High	51.28
Doubtful	60-80	2000-3000	Very high	28.21

Data source; Todd (1980)

Figure 1: Geology and Location Map of the Study Area (Modified after PTF, 1997)
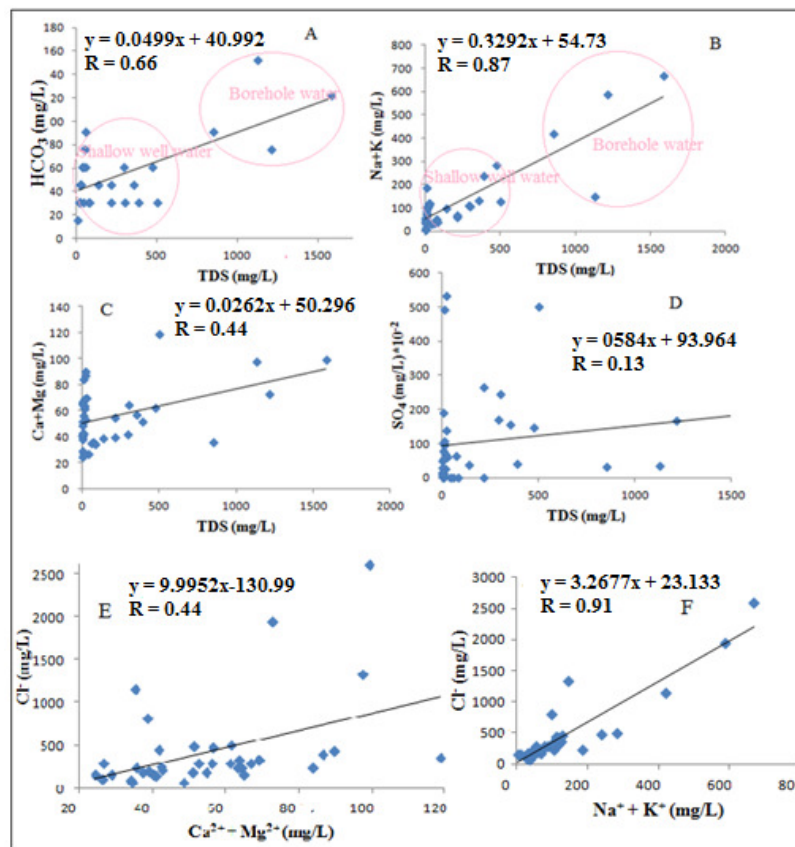

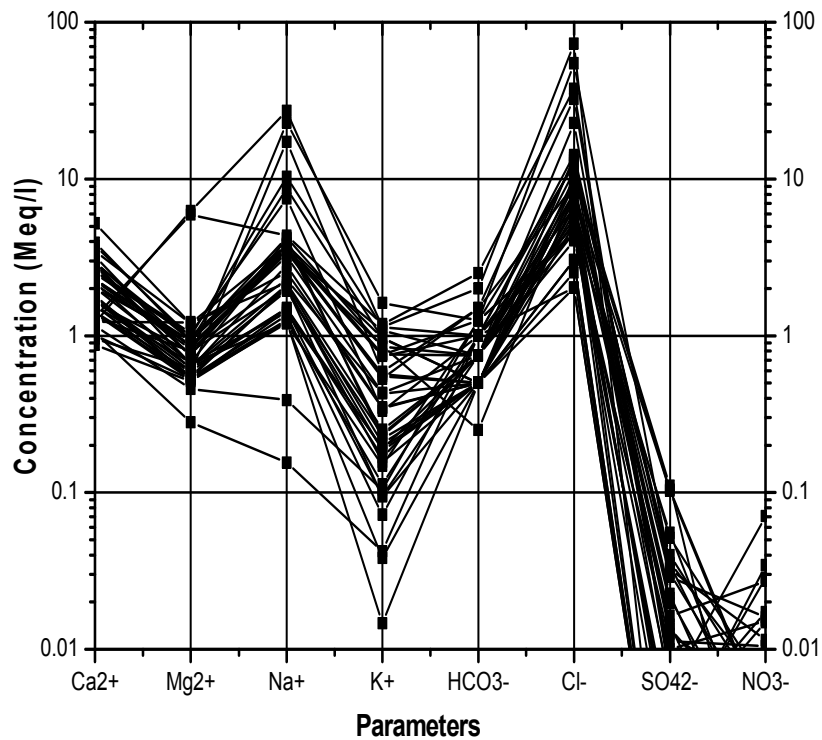Fig. 2: Cross- plots of ionic parameters (A-E)

Fig. 3. Groundwater characterization of the study area using Schoeller diagram
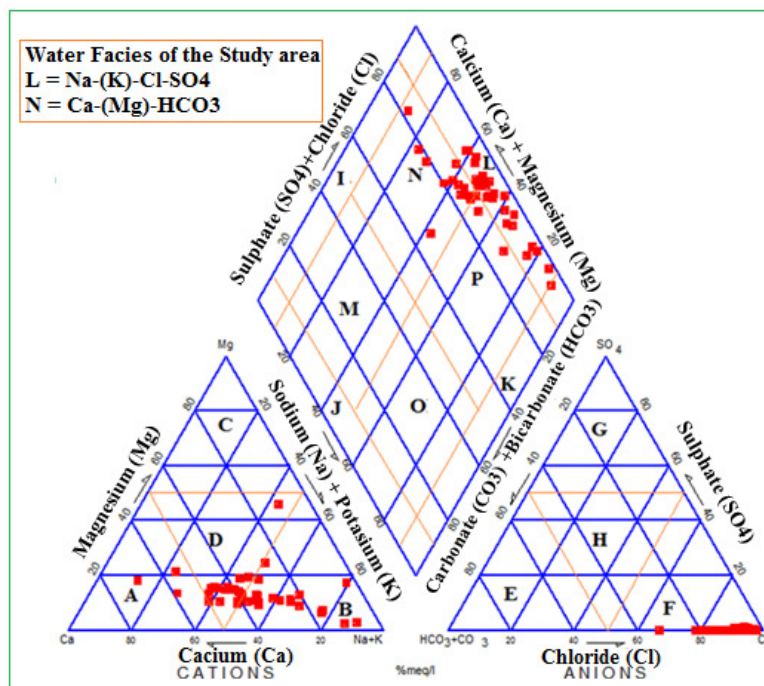

Fig. 4. Water type classification using the Piper Trilinear diagram (Back and Hanshaw, !965)

A = Calcium type, B = Sodium or potassium type, C = Magnesium type, D = No dominant type.

E = Bicarbonate type, F = Chloride type, G = Sulfate type, H = No dominant

I = Ca + Mg type, J = HCO_3 + CO_3 type, K = Na + K type, L = Cl + SO_4 type, M = Ca(Mg) HCO_3 type, N = Ca(Mg) Cl SO_4 type, O = Na(K) HCO_3 type, P = Na(K) Cl(SO_4) type
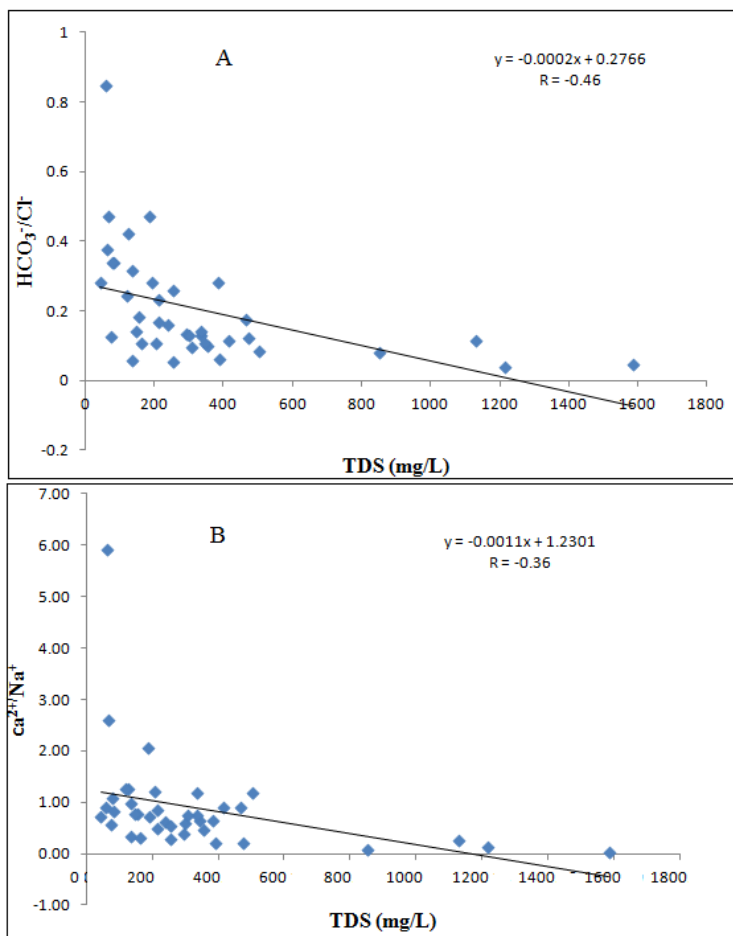
Fig 5 Cross plots of TDS versus HCO_3^-/Cl^- and Ca^{2+}/Na^+

Fig. 6. Gibb's plot
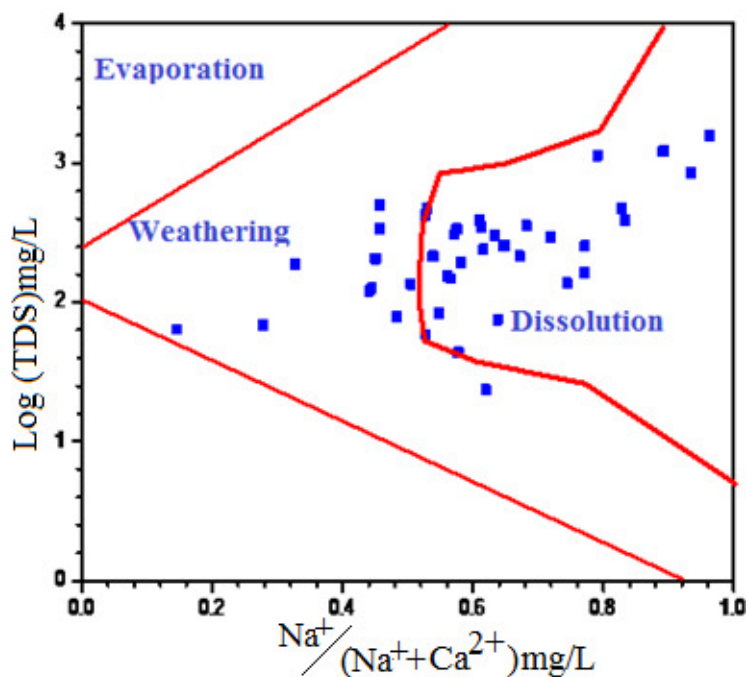
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