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PHYSICOCHEMICAL, BACTERIOLOGICAL AND HYDROGEOCHEMICAL ASSESSMENT OF GROUND WATER WITHIN UYO AND ITU AREAS OF AKWA IBOM STATE, SOUTHEASTERN NIGERIA

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ABSTRACT

Ten (10) groundwater samples collected from boreholes in Itu and Uyo localities of Akwa Ibom State were evaluated for physicochemical, bacteriological and hydrogeochemical assessment using standard analytical techniques. Results showed average pH of 4.49, temperature of 29.14 ^oC, EC of 45.30 μs/cm; TDS of 21.60 mg/l, Hardness of 4.30 mg/l, K of 2.49 mg/l. Mg was found to be 0.74 mg/l, Ca is 13.14 mg/l, SO4 has values of 3.9 mg/l, HCO3 concentration was also found to be 1.35 mg/l, Cl observed to be 4.07 mg/l. furthermore, NO_3 concentration was also observed to be 17.71 mg/l, Mn^{2+} had 0.049 mg/l concentration, BOD5 is 5.82 mg/l, P2O5 was found to be 12.00 mg/l, Cr is 0.025 mg/l, NH3 is 0.142 mg/l, Zn is 0.138 mg/l, Cy is 0.006 mg/l, Fe is 0.159 mg/l, Pb is 0.002 mg/l, Ni is 0.19 mg/l, Cu^{2+} is 0.034 mg/l, Turbidity is 0.40 mg/l, Salinity is 0.002 ppt, and Alkalinity is 2.40 mg/l.. Comparing these values with WHO (2011a) standards, it was discovered that some parameters, including Ni, Cr, Fe, Mn and NO_3-, had concentrations that were above the permissible limits in some locations while a few other locations showed concentrations which were within the permissible limits. Bacteriological investigations of faecal coliform count (FCC), total coliform count (TCC) and total heterotrophic count (THC) revealed an excessive presence of coliform. Hydrogeochemical assessment revealed no evidence of saline intrusion and the groundwater is of terrestrial origin. Based on different ionic concentrations, the Piper trilinear diagram revealed two fundamental types of water; the calcium sulphate and calcium bicarbonate waters. The groundwater was classified as acceptable for agricultural purposes based on the magnesium ratio and sodium adsorption ratio, which also indicate that the groundwater is excellent, soft and suitable.

KEYWORDS: Bacteriological, groundwater, hydrogeochemical, Itu, physicochemical, Uyo

INTRODUCTION

Water is essential and remains one of the commonly used natural resources. It is used by human beings for all purposes. Majority of our economic activities and life depend on the availability/non-availability of water (gboekwe and Akankpo, 2011). Globally, over the years, there have been rising unpredictable issues in the water sector relating to the deteriorating state of the hydrosphere, unavailable freshwater reservoirs, contamination-prone aquifers and unsustainable water management practices. Efforts made to control the risk in the water sector include checking water pollution, desertification, preventing threats and hazards and promoting policies that will ensure proper allocation, especially in developing countries (Chapman, 1992: Castro, 2007).

These concerns are critical especially in the third world countries. For water risks to be clearly understood in developing countries the issues of water scarcity and unsafe drinking water must be clearly looked into; these include over exploitation of the aquifers, deterioration of the water tables and aquatic ecosystems, water-related threats, as well as issues regarding water quality and quantity. Groundwater has been a major supply of water consumption for domestics, industrial and agricultural purposes (Akpan et al., 2016; Gupta *et al*., 2009). However, growth in population often leads to contamination of the groundwater (Pranavam *et al.,* 2011).
Groundwater has been under extreme conditions of contamination due to population growth, agricultural and industrial activities.

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The consequence of these influenced conditions on groundwater is alarming, with overwhelming effects on humans and the ecosystem. When groundwater is withdrawn with little or no recharge, it causes a large drawdown and deterioration in its quality (Uman, 2013). Groundwater is alleged to be contaminated once it is unhealthy for the intended purpose (Ehirim and Nwankwo, 2010: Udosen et al., 2014). The utilization of groundwater resource to meet the growing population in the study area has called for major concern in recent times. Previous work carried out in the area by Adedeji *et al.,* (2010), Edet *et al.,* (2011), Udousoro and Umoren (2014), Beka and Udom (2014) revealed that the groundwater is not potable. This research examines the quality of groundwater in the study area with respect to physicochemical, bacteriological and hydrogeochemical parameters. Results would be compared with the permissible limit of WHO (2011a)standard to ascertain it suitability for drinking.

GEOLOGY AND STUDY LOCATION

The area under study covers latitudes 4° 28' - 5° 32' N of the equator and longitudes 7° 27' - 8° 22' East of the Greenwich Meridian (Fig. 1) is a part of the Niger Delta Basin (Ofoma et al., 2005). The origin of this basin is attributed to the basement tectonic associated with crustal divergence and translation during the Late Jurassic to Early Cretaceous continental rifting, which led to the opening of the south Atlantic and the development of the Benue Trough. The major lithostratigraphic units in this basin as described by Short and Stauble (1967) comprises the Akata Formation, which is overlain by the paralic Agbada Formation and the top, largely continental lithofacies unit of the Benin Formation. The Akata lithostratigraphic unit consists predominantly of shale, the transitional Agbada lithostratigraphic unit is made up of alternation of sands and shale. The main constituents of the Benin Formation, which is the aquiferous unit, are poorly indurated sands and sandstones.

HYDROGEOLOGIC SETTING

Three hydrostratigraphic units, including the coastal plain sand, the lower sand aquifers and the alluvial deposit, exist in the area (Edet, 1993, Esu *et al.*, 1999). The coastal plain sand aquifer is widespread and estranged from the lower sand aquifer by the Imo Shale aquiclude. The coastal plain sand comprised of gravel, clay and sandstone intercalations. The extent of the aquifer varies from 35m in the north to 200m in the south. The major groundwater flow direction is from north to south into the Atlantic Ocean. There are also variations in the northeast-southwest and northwest-southeast directions into the Imo river and the Cross River (Edet, 1993). Itu and Uyo, which falls within the central part of the hydrogeological area in the state, have estimated water table values between 40m and 55m. The static water levels within the Itu area ranges from 34.8m to 55.2m while in Uyo area, it is in the range of 14.0m to 38.7m (AK-RUWATSSA, 2015).

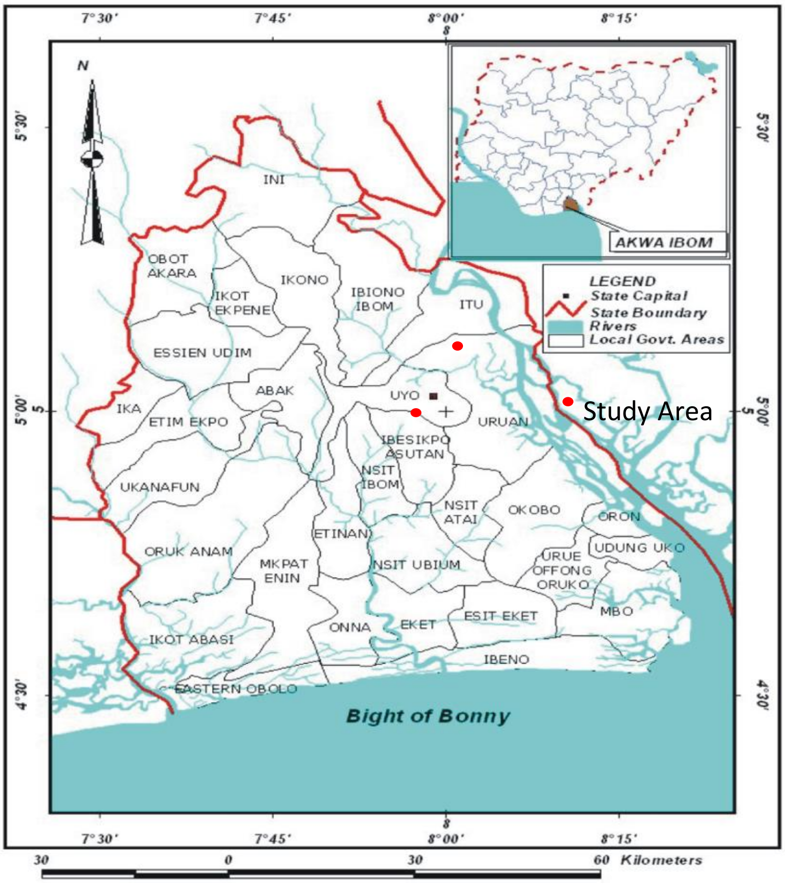

Figure 1. Map of Akwa Ibom State showing study area (Udousoro and Umoren 2014)

MATERIAL AND METHODS

Ten (10) borehole samples were collected within Uyo and Itu (Figure 2) in clean sterile plastic containers. The wells were pumped out for about 10 minutes to remove the torpid water. These were immediately moved to Cross River State Water Board for laboratory analyses of physicochemical and bacteriological parameters using standard techniques (APHA, 1992). Physicochemical parameters of temperature, total dissolved solids (TDS), pH and electrical conductivity (EC) of the water were examined in situ using a hand held Hanna Combo pH/EC/TDS/Temperature tester (Model HI98130 high range), while other parameters of turbidity, total suspended solids (TSS), hardness, alkalinity, chloride (Cl^-), nitrite (NO_2^-), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), ammonia (NH_3), nitrate (NO_3^-), manganese (Mn), iron (Fe), salinity, dissolved oxygen (DO), chromium (Cr), zinc (Zn), copper (Cu), cyanide (C), nickel (Ni), lead (Pb), cobalt (Co), biological oxygen demand (BOD_5), bicarbonate (HCO_3^-), fluoride (F) were analyzed in the laboratory. Bacteriological investigations of faecal coliform count (FCC/100ml), total coliform count (TCC/100ml) and total heterotrophic count (THC/100ml) were also carried out in the laboratory using nutrient agar medium.

Triplicates of each analysis were performed and mean values were computed. Statistical evaluations were carried out with the aid of statistical package for social sciences (SPSS 10.0). Results were compared to the World Health Organization (WHO, 2011a). Magnesium adsorption ratio (MAR), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) were computed using appropriate equations for salinity evaluation. Piper diagram was used to classify the groundwater.

RESULTS AND DISCUSSIONS

The results of the physicochemical and bacteriological analysis of the water samples are given in Table 1. The average pH value was 4.49, below the WHO (2011a) permitted range, suggesting that the groundwater is acidic and not appropriate for drinking (pH 6.5-8.9). High acidic waters in the research area have been attributed primarily to gas flares. The mean temperature was found to be 29.14 ^oC, which is within the WHO (2011a) limit. The mean hardness value of 4.30 mg/l indicates that the water is soft (0-50 mg/l) and below WHO (2011a) limit of 300 mg/l. The average electrical conductivity (EC), potassium (K+), calcium (Ca^{2+}), magnesium (Mg^+), chlorine (Cl^-), cupper (Cu^+), iron (Fe), Chromium (Cr), bicarbonate (HCO_3^{2+}), alkalinity, turbidity, Nitrate (NO_3^-), nitrite (NO_2^-) and total dissolved solid (TDS) concentration values were found to be 45.3 µs/cm, 2.490 mg/l, 13.140 mg/l, 0.740 mg/l, 4.070 mg/l, 0.034 mg/l, 0.160 mg/l, 0.025 mg/l, 1.35 mg/l, 2.40 mg/l, 0.40 mg/l, 17.71 mg/l, 0.018 and 21.6 mg/l, respectively, and were found to be below the WHO (2011a) permissible limits (Table 2). The mean biological oxygen demand (BOD_5) value of 5.82mg/l, with some locations having values high as 23.1 mg/l, was above WHO (2011a) permissible limit (5mg/l). This indicates that there is significant organic activity and sewage contamination in these areas. The average phosphate concentration is 12.00 mg/l, which is above the acceptable limit of 0.1mg/l. The high phosphate content observed could be attributed to domestic, industrial, and farming activities in the area. Sulphate (SO_4^{2-}) was observed in two locations with concentrations of 17mg/l and 22mg/l. The values fall below the permissible limits (250 mg/l). Salinity, sulphate, copper and lead concentrations in some locations were below detectable limit of the equipment used. Results of the bacteriological analysis revealed the aquifers are contaminated. This may be caused by unhygienic circumstances or the presence of excessive levels of organic pollutants (APHA, 1992; Beka et al., 2014, WHO, 2011a). Bivariate correlation was utilized to evaluate the relationship among the various parameters using Spearman's correlation matrix (Table 3).

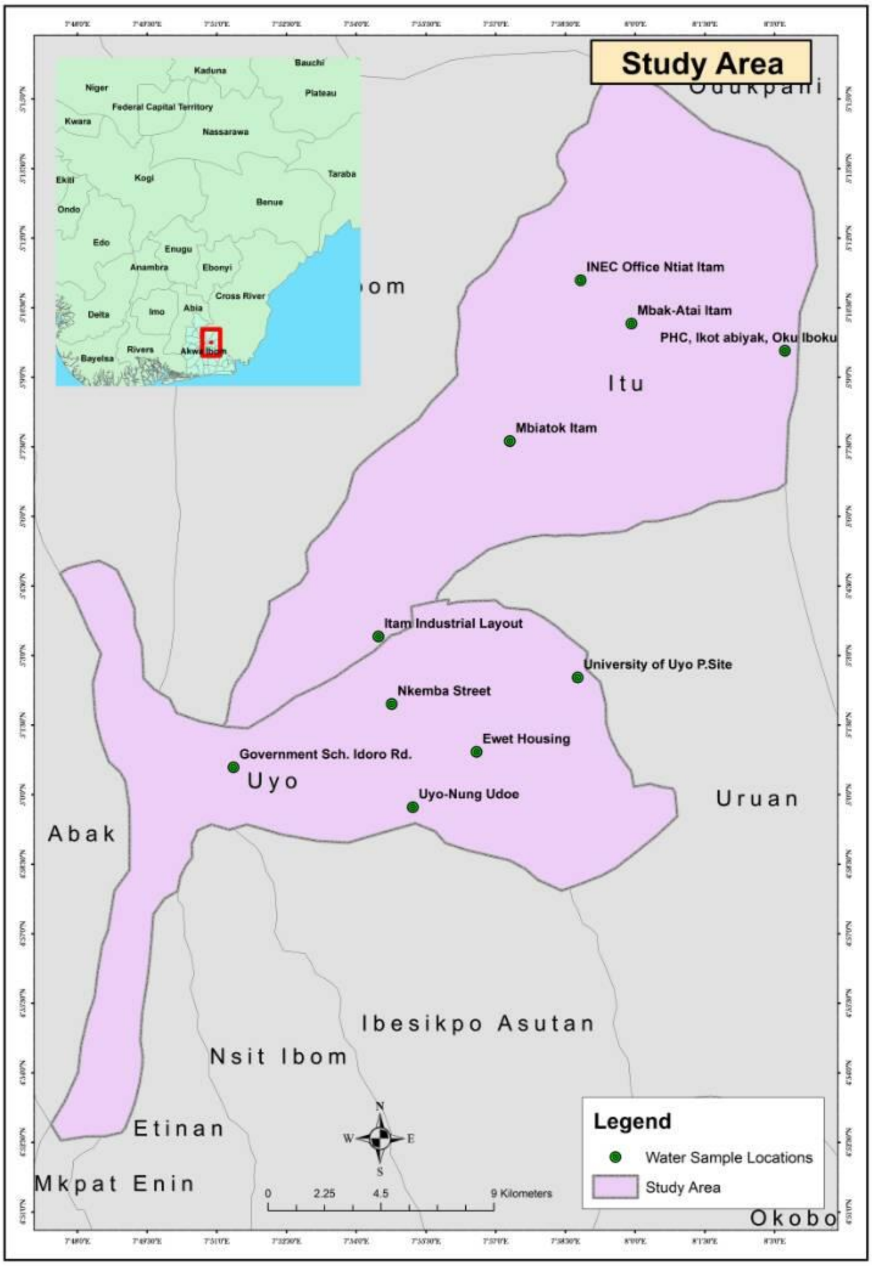

Figure 2. Map showing sample location (Udousoro and Umoren 2014)

Table 1. Result of physicochemical and bacteriological analyses of water samples in the study area in comparison with WHO (2011a)

Parameter/ Unit	BH 1	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8	BH 9	BH 10	WHO (2011a)
Temperature (°C)	27.100	28.900	28.800	28.200	27.900	30.300	31.400	29.700	29.200	29.900	27 – 29
pH	4.730	4.820	5.410	4.480	3.900	5.550	3.890	4.030	3.930	4.130	6.5-8.5
Conductivity (µs/cm)	10.000	12.500	20.000	10.500	90.000	10.000	110.000	40.000	140.000	10.000	1000
TDS (mg/l)	5.000	6.000	10.000	5.000	40.000	5.000	50.000	20.000	70.000	5.000	600
Total Hardness (mg/l)	2.540	3.760	3.510	3.710	4.830	4.220	5.190	4.340	7.330	4.380	300
Turbidity (NTU)	0.370	0.380	0.480	0.620	0.355	0.389	0.377	0.352	0.345	0.339	4
Chloride (mg/l)	1.200	1.500	2.600	1.700	6.800	1.500	7.900	4.500	10.500	2.500	250
Sulphate (mg/l)	BDL	BDL	BDL	BDL	BDL	17.00	BDL	BDL	BDL	22.000	250
Nitrate (mg/l)	8.800	1.100	4.600	1.300	10.300	0.100	8.600	53.400	76.800	12.100	50
Bicarbonates (mg/l)	1.610	1.910	1.310	1.540	1.730	1.150	1.770	1.840	1.720	1.950	-
Phosphate (mg/l)	1.930	2.500	9.740	4.820	1.090	6.140	8.330	19.080	55.380	11.010	0.1
Nitrite (mg/l)	0.001	0.006	0.006	0.008	0.055	0.003	0.003	0.039	0.051	0.004	3
Ammonia (mg/l)	0.130	0.170	0.130	0.160	0.130	0.120	0.150	0.190	0.090	0.150	-
Calcium (mg/l)	6.180	18.240	9.060	9.360	18.000	10.380	17.820	23.220	6.270	12.840	250
Magnesium (mg/l)	0.360	0.520	0.450	0.350	0.830	0.840	1.370	1.120	1.060	0.540	250
Potassium (mg/l)	2.300	1.600	4.500	2.080	3.340	1.950	2.140	2.660	1.600	2.700	250
Alkalinity (mg/l)	2.060	1.300	2.630	3.000	2.340	2.500	2.370	2.430	2.330	2.520	200
Salinity (ppt)	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.000	0.100	0.000	-
BOD_5 (mg/l)	0.610	23.100	5.660	2.880	4.140	1.920	6.400	3.220	5.810	2.500	5.0
DO (mg/l)	6.000	8.000	15.000	7.000	14.000	6.000	19.000	13.000	16.000	11.000	3.0
Copper (mg/l)	0.250	BDL	0.050	BDL	BDL	0.010	0.010	BDL	BDL	0.020	2.0
Chromium (mg/l)	BDL	0.041	0.019	0.030	0.101	0.020	0.001	0.009	0.002	0.003	0.05
Zinc (mg/l)	0.140	0.120	0.140	0.110	0.140	0.140	0.140	0.150	0.160	0.140	-
Cobalt (mg/l)	0.005	0.001	0.007	0.007	0.002	BDL	BDL	0.001	0.007	BDL	0.05
Cyanide (mg/l)	0.008	0.004	0.002	0.005	0.004	0.003	0.008	0.007	0.003	0.020	0.01
Nickel (mg/l)	0.244	0.179	0.394	0.266	0.202	0.132	0.181	0.161	0.124	0.113	0.07
Lead (mg/l)	BDL	BDL	BDL	0.002	BDL	BDL	BDL	BDL	BDL	BDL	0.01
Manganese (mg/l)	0.015	0.026	0.053	0.025	0.168	BDL	0.035	0.065	0.107	BDL	0.1
Iron (mg/l)	0.010	0.030	0.150	0.040	0.230	0.130	0.040	0.220	0.400	0.340	0.3
THC/100ml	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	0.00
TCC/100ml	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	0.00
FCC/100ml	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	0.00

BDL = Below Detection Limit; BH = Borehole; WHO = World Health Organisation;
TNTC = Too Numerous to Count; THC = Total Heterotrophic Count; TCC = Total Coliform Count; FCC = Faecal Coliform Count

Table 2. Results of statistical analysis of water samples

Parameter	Unit	Mean	Median	Min	Max	SD	Varian	WHO (2011a)
Temp	Oc	29.140	29.050	27.100	31.400	1.252	1.567	27-29
Ph		4.490	4.310	3.900	5.550	0.624	0.389	6.5-8.5
EC	Us/cm	45.300	16.250	10.000	140.000	49.268	2427.289	1000
TDS	mg/l	21.600	8.000	5.000	70.000	23.500	552.267	600
Hardness	mg/l	4.300	3.600	2.540	7.330	2.023	12.279	300
K^+	mg/l	2.490	2.220	1.600	4.500	0.884	0.782	250
Ca2+	mg/l	13.140	11.610	6.180	23.220	5.840	34.160	250
Mg2+	mg/l	0.740	0.690	0.350	1.370	0.354	0.126	250
Cl-	mg/l	4.070	2.550	1.200	10.500	3.250	10.590	250
Fe	mg/l	0.160	0.140	0.010	0.400	0.137	0.019	0.30
Pb	mg/l	0.001	0.000	0.000	0.002	0.001	0.000	0.01
Ni	mg/l	0.190	0.180	0.110	0.390	0.081	0.007	0.07
Cu2+	mg/l	0.034	0.010	0.010	0.250	0.078	0.006	2.0
HCO3-	mg/l	1.450	1.390	1.310	1.950	0.625	0.391	-
SO42-	mg/l	19.500	0.000	0.000	22.000	8.305	68.989	250
NO3	mg/l	17.710	8.700	0.100	76.800	25.908	671.259	50
Mn2+	mg/l	0.049	0.310	0.000	0.170	0.528	0.003	0.1
P2O5	mg/l	12.000	7.240	1.090	55.380	16.152	260.898	-
Cr	mg/l	0.025	0.019	0.000	0.100	0.032	0.001	0.05
NH3	mg/l	0.142	0.140	0.090	0.190	0.028	0.001	-
Zn	mg/l	0.138	0.140	0.110	0.160	0.014	0.000	
Co	mg/l	0.004	0.000	0.000	0.007	0.005	0.000	0.05
Cy	mg/l	0.006	0.005	0.002	0.020	0.007	0.000	0.01
Turbidity	NTU	0.400	0.375	0.340	0.620	0.087	0.008	4.0
BOD5	mg/l	5.820	3.680	1.920	23.100	6.269	39.303	5.0
DO	mg/l	11.500	12.000	6.000	19.000	4.600	21.167	3.0
Salinity	Ppt	0.002	0.000	0.000	0.100	0.004	0.000	-
Alkalinity	mg/l	2.450	2.460	1.330	3.000	0.112	0.026	200
Nitrite	mg/l	0.018	0.001	0.001	0.055	0.003	0.002	3

Table 3. Bivariant correlation of the physicochemical parameters

Vaiance	pH	EC	TDS	K	Ca	Mg	Cl	HCO3	SO4	NO3	Hardness	Turbidity	P2O5	BOD	DO
Ph	1.000														
EC	0.706	1.000													
TDS	0.694	0.981	1.000												
K	0.763	0.893	0.959	1.000											
Ca	0.425	0.551	0.544	0.841	1.000										
Mg	0.564	0.595	0.675	0.725	0.455	1.000									
Cl	0.784	0.898	0.894	0.693	0.626	0.669	1.000								
HCO3	0.939	0.681	0.675	0.868	0.603	0.564	0.766	1.000							
SO4	0.395	0.613	0.535	0.43	0.009	0.069	-0.282	0.225	1.000						
NO3	0.673	0.460	0.506	0.466	0.987	0.394	0.620	0.758	0.757	1.000					
Hardness	0.455	0.379	0.369	0.663	0.952	0.600	0.345	0.385	0.981	0.855	1.000				
Turbidity	0.564	0.528	0.350	0.738	0.651	0.479	-0.413	0.673	0.516	0.867	0.603	1.000			
P2O5	0.651	0.379	0.340	0.894	0.907	0.491	0.517	0.511	0.582	0.515	0.934	-0.406	1.000		
BOD	0.358	0.755	0.732	0.532	0.467	0.489	0.486	0.467	0.683	0.881	0.511	0.881	0.881	1.000	
DO	0.669	0.880	0.891	0.554	0.675	0.571	0.924	0.565	0.360	0.486	0.403	0.413	0.474	0.675	1.000

HYDROGEOCHEMICAL ASSESSMENT OF GROUNDWATER

Hydrogeochemical characteristics of minor and major ions were assessed using Piper trilinear diagrams (Fig. 3). Two basic types of water are prevalent, based on varying ionic concentrations. These include the calcium sulphate water ($Ca^{2+} – Mg^{2+} – SO_4^{2-} – Cl^-$), typical of gypsum groundwater, and calcium bicarbonate water ($Ca^{2+} – Mg^{2+} – HCO_3^-$), typical of shallow fresh groundwater (Erguvanili and Yuzer, 1986 Freeze and Cherry, 1979). Groundwater in the Uyo area is of the calcium sulphate specie while groundwater in Itu area is of the calcium bicarbonate species. This showed that there are two aquiferous units that make up the subsurface water in the area, each of which possesses a unique chemistry. The cation triangle showed that all the groundwater plotted in the calcium type zone while on the anion triangle, the water samples plotted in the chloride, bicarbonate and sulphate zones. Nitrate was the predominant anion with mean value of 17.71 mg/l, followed by phosphate (12.00 mg/l), chloride (4.07 mg/l), sulphate (3.90 mg/l) and bicarbonate (1.45 mg/l), (Fig. 4); meanwhile, calcium was the predominant cation, at 13.14 mg/l, followed by potassium (2.49mg/l) and magnesium (0.74mg/l) (Fig. 5). The relationship between the ionic concentrations (Table 4) revealed that Mg/Ca values were less than 5.0 meq/l (0.03 meq/l to 0.18 meq/l) and Cl/HCO_3^- ranged from 0.14 meq/l to 1.36 meq/l (Fig. 6), suggesting an inland origin for the groundwater in the area with no level of intrusion (Gimenez and Morell, 1997).

MECHANISM CONTROLLING GROUNDWATER CHEMISTRY

Gibbs (1970) plot of total dissolve solid (TDS) against Cl/(Cl+HCO3) (Fig. 7) recognizes rainfall dominance and rock dominance as the distinct mechanisms influencing the groundwater chemistry in the area. This suggests that the subsurface water chemistry is as a result of precipitated water and dissolution of rocks that makes up the aquifer. The quality of the groundwater was further evaluated for irrigation purposes with sodium adsorption ratio (SAR), magnetic adsorption ratio (MAR) (Fig. 8) and residual sodium bicarbonate found to range from 0.6-3.0 meq/l, 2.77-14.46 mg/l and -15.38-2.43 meq/l respectively (Table 4), suggesting that the water is excellent and suitable for agricultural purposes (Todd, 1980, Jajali, 2009).

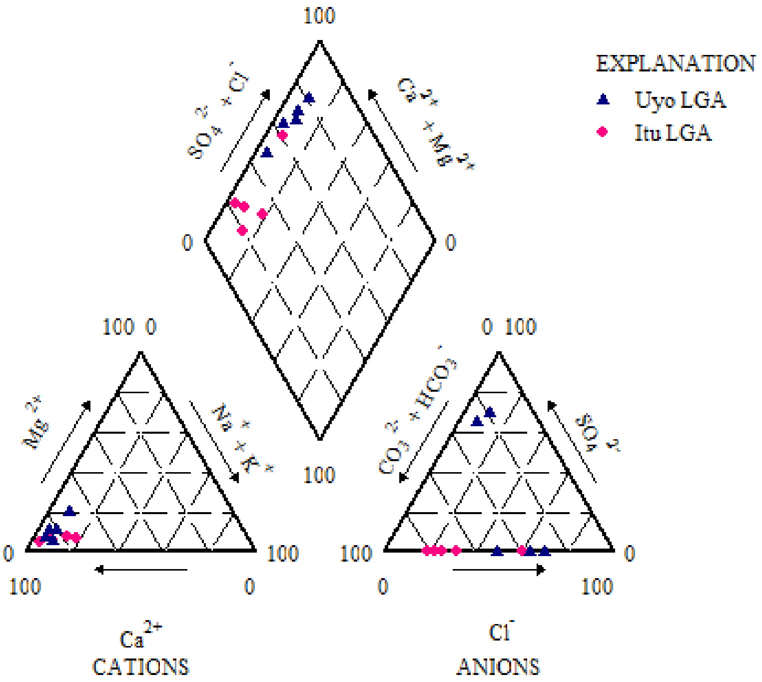

Figure 3: Piper trilinear diagram for the groundwater samples in the study area

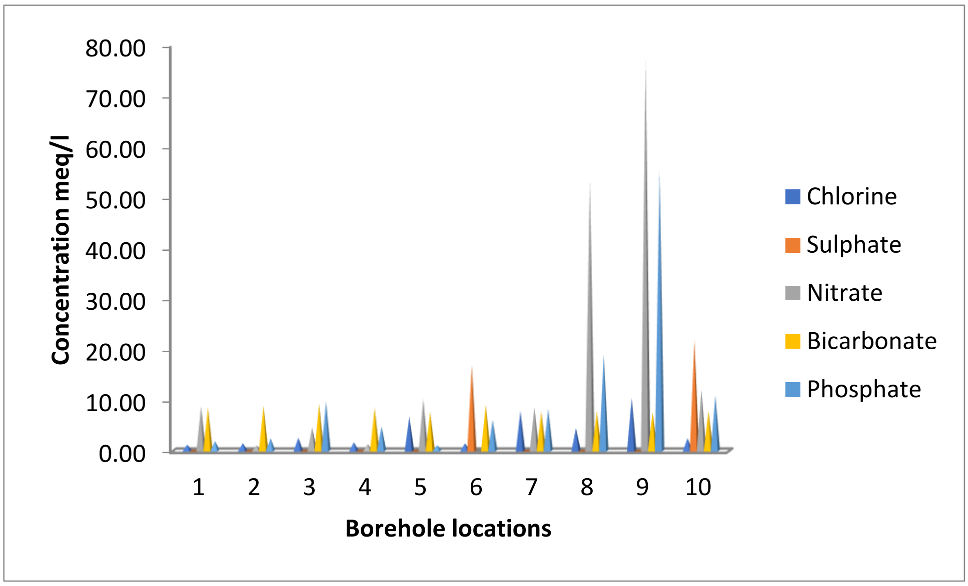

Figure 4. Concentration of basic anions in the study area

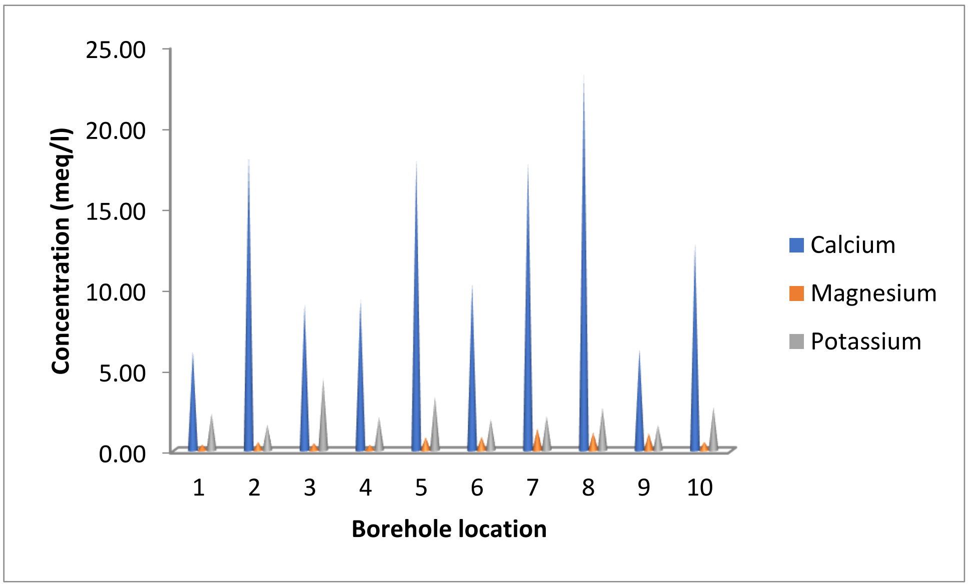

Figure 5. Concentration of the basic cations in the study area

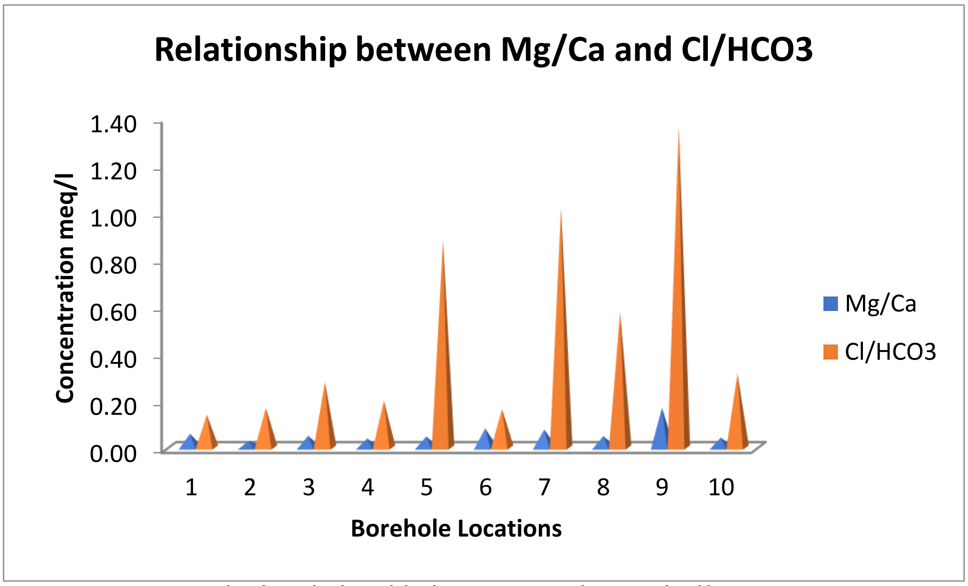

FIG 6: ionic relationship between Mg/Ca and Cl/HCO_3

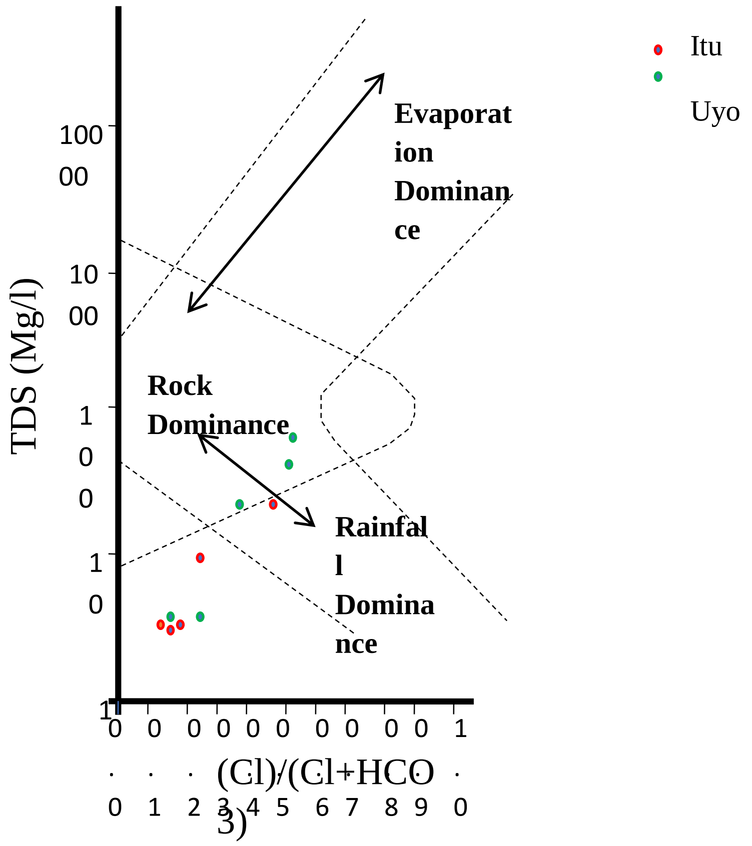

Figure 7. Gibbs plot of groundwater mechanism

HYDROGEOCHEMICAL ASSESSMENT OF GROUNDWATER

Hydrogeochemical characteristics of minor and major ions were assessed using Piper trilinear diagrams (Fig. 3). Two basic types of water are prevalent, based on varying ionic concentrations. These include the calcium sulphate water (Ca^{2+} – Mg^{2+} – SO_4^{2-} – Cl^-), typical of gypsum groundwater, and calcium bicarbonate water (Ca^{2+} – Mg^{2+} – HCO_3^-), typical of shallow fresh groundwater (Erguvanili and Yuzer, 1986 Freeze and Cherry, 1979). Groundwater in the Uyo area is of the calcium sulphate specie while groundwater in Itu area is of the calcium bicarbonate species. This showed that there are two aquiferous units that make up the subsurface water in the area, each of which possesses a unique chemistry. The cation triangle showed that all the groundwater plotted in the calcium type zone while on the anion triangle, the water samples plotted in the chloride, bicarbonate and sulphate zones. Nitrate was the predominant anion with mean value of 17.71 mg/l, followed by phosphate (12.00 mg/l), chloride (4.07 mg/l), sulphate (3.90 mg/l) and bicarbonate (1.45 mg/l), (Fig. 4); meanwhile, calcium was the predominant cation, at 13.14 mg/l, followed by potassium (2.49mg/l) and magnesium (0.74mg/l) (Fig. 5). The relationship between the ionic concentrations (Table 4) revealed that Mg/Ca values were less than 5.0 meq/l (0.03 meq/l to 0.18 meq/l) and Cl/HCO_3^- ranged from 0.14 meq/l to 1.36 meq/l (Fig. 6), suggesting an inland origin for the groundwater in the area with no level of intrusion (Gimenez and Morell, 1997).

MECHANISM CONTROLLING GROUNDWATER CHEMISTRY

Gibbs (1970) plot of total dissolve solid (TDS) against Cl/(Cl+HCO3) (Fig. 7) recognizes rainfall dominance and rock dominance as the distinct mechanisms influencing the groundwater chemistry in the area. This suggests that the subsurface water chemistry is as a result of precipitated water and dissolution of rocks that makes up the aquifer. The quality of the groundwater was further evaluated for irrigation purposes with sodium adsorption ratio (SAR), magnetic adsorption ratio (MAR) (Fig. 8) and residual sodium bicarbonate found to range from 0.6-3.0 meq/l, 2.77-14.46 mg/l and -15.38-2.43 meq/l respectively (Table 4), suggesting that the water is excellent and suitable for agricultural purposes (Todd, 1980, Jajali, 2009).

Table 4. Relationship among ionic concentration in the study area

LOC	Mg/Ca	Cl/HCO$_3$	Ca/Cl	Mg/Cl	Ca/HCO$_3$	BOD$_5$/No$_3$	SAR	MAR	RSBC
BH 1	0.06	0.14	5.15	0.30	0.72	0.30	2.28	5.50	2.43
BH 2	0.03	0.17	12.16	0.35	2.05	21.00	0.60	2.77	-9.33
BH 3	0.05	0.28	3.48	0.17	0.97	1.23	3.00	4.73	0.25
BH 4	0.04	0.20	5.51	0.21	1.10	2.22	1.44	3.60	-0.82
BH 5	0.05	0.88	2.65	0.12	2.33	0.40	1.20	4.41	-10.27
BH 6	0.08	0.16	6.92	0.56	1.13	19.20	1.16	7.49	-1.23
BH 7	0.08	1.02	2.26	0.17	2.29	0.74	0.75	7.14	-10.05
BH 8	0.05	0.57	5.16	0.25	2.96	0.60	0.75	4.60	-15.38
BH 9	0.18	1.36	0.60	0.10	0.81	0.08	1.38	14.46	1.45
BH 10	0.04	0.31	5.14	0.22	1.62	0.21	1.36	4.04	-4.89

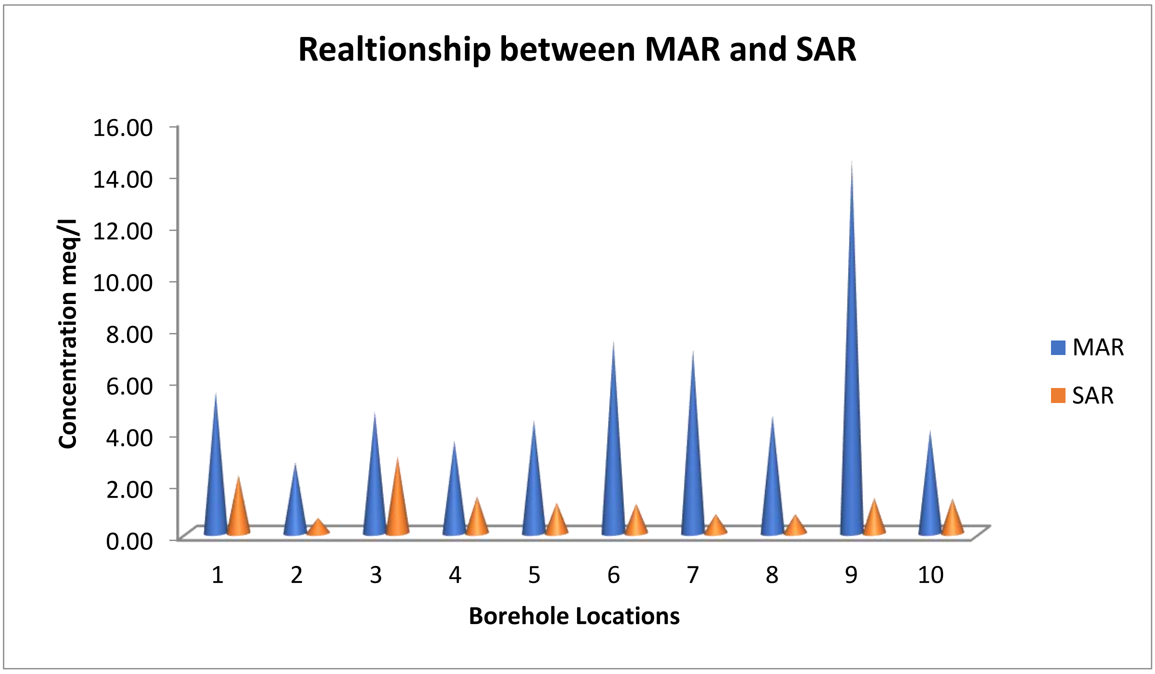

Figure 8: Relationship between MAR and SAR

CONCLUSIONS

Physicochemical and bacteriological tests of groundwater in Itu and Uyo have raised concerns about the quality of water in the area. Most of the physicochemical parameters, including electrical conductivity, total dissolve solids, potassium, calcium, magnesium, chlorine, iron, copper, bicarbonates, sulphate, nitrate, and alkalinity, were found to be below the WHO (2011a) standard for drinking water. Nickel (Ni), phosphate, biological oxygen demand, and dissolved oxygen showed concentrations that were higher than the WHO-permitted limits (2011a).

The pH results show that the groundwater is acidic (3.9 – 5.5). Bacteriological analysis revealed the occurrence of faecal coliform, total coliform and total heterotrophic count in the groundwater. This is an indication that the aquifers feeding the boreholes are contaminated, which may be caused by unhygienic circumstances or the presence of significant amounts of organic debris. Piper trilinear diagram revealed two basic types of water based on varying ionic concentrations. These are the calcium sulphate and calcium bicarbonate water types.

Magnesium adsorption ratio, sodium adsorption ratio and residual sodium bicarbonate indicate that the groundwater is excellent and suitable for irrigation. Findings from this research showed that the groundwater in Uyo and Itu areas is acidic and not potable for drinking; but it can be used for irrigation.

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