INTERNATIONAL JOURNAL OF NATURAL AND APPLIED SCIENCES (IJNAS), VOL. 2, NO. 2(2007); P. 95 – 104, 4 TABLES, 4 FIGS.

Seasonal variation of physicochemical parameters of groundwater in sandstone – shale – intrusive aquifers in part of Mamfe embayment southeastern Nigeria.

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ABSTRACT

Water samples were collected from twenty two (22) locations in the Embayment across the periods of dry (January), dry-wet (March), wet (June), wet-dry (September), to highlight the micro-climatic conditions between January to September 2005. The main objectives of this work were to carry out hydrogeochemical studies and assessment of the sandstone – shale – intrusive aquifers in part of Mamfe embayment South Eastern Nigeria and evaluate the seasonal variation of groundwater and asses the contamination of the aquifers using Anion, Cation, NO_3 and Coliform to assess the contamination of the aquifer and identify source of the contaminant. In this study, the relationship between various elements has been studied using physico-chemical/ biological parameters. The data in the stiff diagram shows variation of Anion, Cation in the three different formations with the micro seasonal period of dry, dry-wet, wet and wet-dry. In intrusive there was an increase of Bicarbonate and Magnesium in the dry-wet period and a reduction of the same element as the rain intensify, an indication of dilution while there was an increase of bicarbonate in the dry-wet period showing precipitation. In Asu-River Group, bicarbonate and Magnesium decreases in dry-wet period but rather increase it quantity during the wet period while Na+K was deceasing and this may be due to precipitation of carbonate and leaching of Na+k which continued after wet period into dry-wet period. In Eze-Aku Formation, there was an increase of Ca^+ and Mg^+ in the dry-wet period and a drastic reduction of Ca^+ in wet period. Bicarbonate was being reduced as the period move from dry period to wet-dry period; this is due to rock type (sandstone) which helps in high infiltration of runoff. The data also show that the formations were more contaminated in the wet period in some areas than dry period while in some areas the wet period reduces the contamination due to dilution from runoff and this is evidence that the contamination of the study area is control by infiltration and runoff. And these goes further to show that the aquifers in the study area are mostly recharged by precipitation. The data also prove that the aquifers in the study area are not contaminated by nitrate, but are rather contaminated by faecal coliform due to water from runoff that infiltrate into the aquifer from the vodoze zone during precipitation in the area.

INTRODUCTION

Hydrogeochemical processes reveal the zones and quality of water that are suitable for drinking, agricultural and industrial purposes. They also help to understand the changes in water quality due to rock–water interaction as well as anthropogenic influences. The geochemical properties of groundwater also depend on the chemistry of water in the recharge area as well as the different geochemical processes that are occurring in the subsurface. These geochemical processes are responsible for the seasonal and spatial variations in groundwater chemistry (Matthess 1982). Groundwater chemically evolves by interacting with aquifer minerals or internal mixing among different groundwater along-flow paths in the subsurface (Domenico 1972; Wallick and Toth 1976; Toth 1984). Schuh *et al.* (1997) indicated that increases in solute concentrations in groundwater result from seasonal variable recharge, governed by micro topographic controls.

Generally, groundwater at the discharge zones tend to have higher mineral concentration compared to that at the recharge zones due to the longer residence time and prolonged contact with the aquifer matrix (Freeze and Cherry 1979). The weathering of primary and secondary minerals also contributes to cations and silica in the groundwater system (Jacks 1973; Bartarya 1993) and areas that are replenished at a high rate are generally more contaminated than those replenished at a slower rate. Unconfined aquifers that do not have a cover of dense material are susceptible to contamination. Similarly, bedrock areas with large fractures are also susceptible by providing pathways for the contaminants. In contrast, deep aquifers tend to be better protected with a dense layer of clay material (Kim and Hamm 1999).

Ground water pollution is caused by a variety of substances originating from many different activities. Most of the contaminants that commonly cause concern originate above ground, often as the result of human activities.

After release at the land surface, the contaminant may infiltrate downward through the soil, vadose zone, and saturated zone and into the aquifer.

Soil overlying the water table provides the primary protection against groundwater pollution, because, sediment and other insoluble forms of contamination become trapped within the soil pores.

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Some chemicals are absorbed or react chemically with various soil constituents, thereby preventing or slowing the migration of the pollutants into the groundwater. In addition, plants and soil microorganism use some potential pollutants such as nitrogen, as nutrients for growth, thereby depleting the amount that reaches the groundwater (Hearne *et al.,* 1992).

Study area

The study area lies between latitudes $5^0$15' and $6^0$15'N and longitudes $7^0$45' and $8^0$45'E (Fig 1). It is located within the sub-equatorial climatic region of Nigeria with a total annual rainfall of between 300 and 400m. The annual temperature ranges from 25^0C to 28^0C. The area experiences two seasons. these are the wet season which lasts from April to September with a peak in June and July and the dry seasons that lasts from October to March(Iloeje,1991). The elevation of the study area ranges from 14m to 170m above sea level. The occurrence of the low-lying plain is occasionally broken by inselbergs of granite and basalts in the southern part of the study area. In the sediment- filled sections, the plains are also occasionally broken by flat topped hills of sandstone ridges and igneous intrusives with highly ferroginized sandstones and gravels resulting from uplifts.

The area is drained by the Cross River with major tributaries like, Udip, Ukong, Lakpoi, Okwo, and Okpon. These rivers form a network of dendritic drainage system. The minor streams that feed the major ones are perennial and originate from the Enugu escarpment or the Cameroon highlands.

Geology and Hydrogeology

The study area is underlain by two major lithologic units: Precambrian crystalline basement rocks and Cretaceous sediments (Fig.1). The crystalline basement rocks occupy the extreme south of the study area. There are also igneous intermediate rocks scattered in patches around Obubra, Iyamayong, Iyamitet, Ikom, Nkpani and Usumutong(Fig.1) The Cretaceous sediments cover about 85% of the study area. The Asu River Group is the basal and oldest of the sedimentary rock units. The Eze - Aku Formation is of middle Cenomanian – Turonian age. It flanks the Asu River Group dipping away to the NW and SW (Offodile, 1992). This geologic formation outcrops on the northern flank, stretching centrally to the west and it consist mainly of shallow water grayish shale and siltstone with interbedded sandstone and sparingly thin layers of limestone. Rocks of the Eze-Aku Formation are texturally similar to those of Asu River Group and were also deposited under more or less similar oxygen-deficient low energy water environment.(Offodile, 1992). The Asu River Group is dominated by bluish gray/black to olivine brown shale and sandy shale, fine - grained micaceous calcareous sandstone and siltstone with limestone lenses. The shale is often carbonaceous and pyritic which indicates that the sediments were deposited under a poorly oxygenated shallow water environment of restricted circulation (Petters *et al.,* 1987). Cross River Basin Development Authority (CRBDA, 1982) identified and grouped the study area into four convenient hydrogeologic provinces namely; basement and intrusive rocks, shale - sandstone, shale, and alluvial. In basement provinces groundwater occurrence depends exclusively on discontinuities like fractures, joints, fissures, and weathered litho - zones. The fissures of crystalline rocks are limited to shallow depths, and water movement is lateral in the direction of the gradient downwards to the drainage area. Fracturing and fissuring is a common phenomenon in basalts because of the tectonic chilling effects on them, which develops fractures.

About 60% of ground water is habited in weathered fresh bedrock transition with aquifer yields of 0.2 - 3.5 l/sec. (CRBDA (1982). According to Petters (1989), recharge to the weathered zones and joints system is greatly retarded in significantly lateritic cover areas. This is attributed to the high content of impermeable clay in the laterite. CRBDA (1982) put the yield for (weathered zones) at 84.4 - 345.6 m^3/day. Static water level (SWL) is between 4.6 - 19.8 m in Obubra and 12.2 - 21.4 m for part of Ikom in the study area. Borehole depths range between 25 and 47m.

Shale - sandstone or shale/siltstone province is the largest hydrogeological province in the study area, occupying about 60% of the study area and cutting across locations like Obubra, Apiapum, Nko, Ekori, Ugep, Ochom, and Agara Ekureku underlain by the Asu River Group and Eze – Aku formation. The sediments are slightly folded and at times broken by faults. Fractures, fissures and joints commonly occur in sandstones and sandstone affiliated sediments, but are commonly restricted to shallow depths of 20 - 50 m.

Permeability in the study area is influenced by the nature and texture of the sediment type. For example permeability is moderate in porous, fissured and fractured sandstone/shale but very low in impervious shale and siltstones. Shale/siltstones province record very low aquifer yield of 0.05 - 0.5 l/sec, while fracture sandstone/shale record up to 2.02 l/sec. (CRBDA, 1982).

MATERIALS AND METHODS

Water samples were collected from various locations within the study area (Table 1, Fig 1). The groundwater samples were collected to cover four (4) microclimatic conditions (Table 2)using pre-washed, 2L polythene plastic bottles for chemical and biological analysis while 250 ml polythene plastic was used to collect samples for heavy metals. The samples for heavy metals analysis were acidified to pH of 2 using nitric acid. The physical parameters (color, oxygen, pH, conductivity and temperature) were determined in the field using standard field equipment

(Table3). The groundwater samples were analyzed using standard methods (Table 3). The statistical summary of the groundwater analysis for the different sampling period is given in Table 4.

Table 1. Sampled locations

s/n	location name	latitude	longitude	Northing	Easting
1	Ikom	5056.805	8043.343	657160	469113
2	Ikom	5057.123	8043.26	657747	468960
3	Ochon stream	5055.759	8026.659	655257	438334
4	Ochon	5055.656	8026.567	655066	438165
5	Edondon	5051.922	8025.608	648185	436385
6	Iyamoyong	5057.95	8021.164	659304	428200
7	Iyamitet	5052.889	8020.13	649981	426280
8	Obubra	6004.092	8020.379	670623	426766
9	Apiapum	5059.806	8016.985	662734	420493
10	Ofudua	5058.539	8015.508	660402	417769
11	Ababene	5057.208	8015.654	657949	418035
12	Onyadama	5056.281	8014.492	656245	415889
13	Nko	5052.281	8011.238	648883	409875
14	Ekpenti	5053.287	8007.356	650747	402714
15	Ekori	5052.381	8007.165	649078	402361
16	Ugep	5048.252	8004.736	641476	397864
17	Ebom	5050.803	8058.194	646197	385799
18	Usumutong	5049.847	8001.074	644430	391113
19	Adim	5043.796	8002.494	633272	393715
20	Agwugune	5040.929	8000.719	627997	390428
21	Abini	5041.325	8003.86	628711	396209
22	Igbo Ekureku(Agbara)	5059.283	8001.266	661813	391497

Table 2. Microclimatic condition covered by the study

s/n	Microclimatic Type	Abbreviation	Months	Average Rainfall(mm)	Average Temperature (0c)
1	Dry	D	Jan-March	4.07	33
2	Dry-Wet	DW	April-June	13.84	30.93
3	Wet	W	July-Sept	19.94	27.9
4	Wet-Dry	WD	Sept -Dec	6	30.53

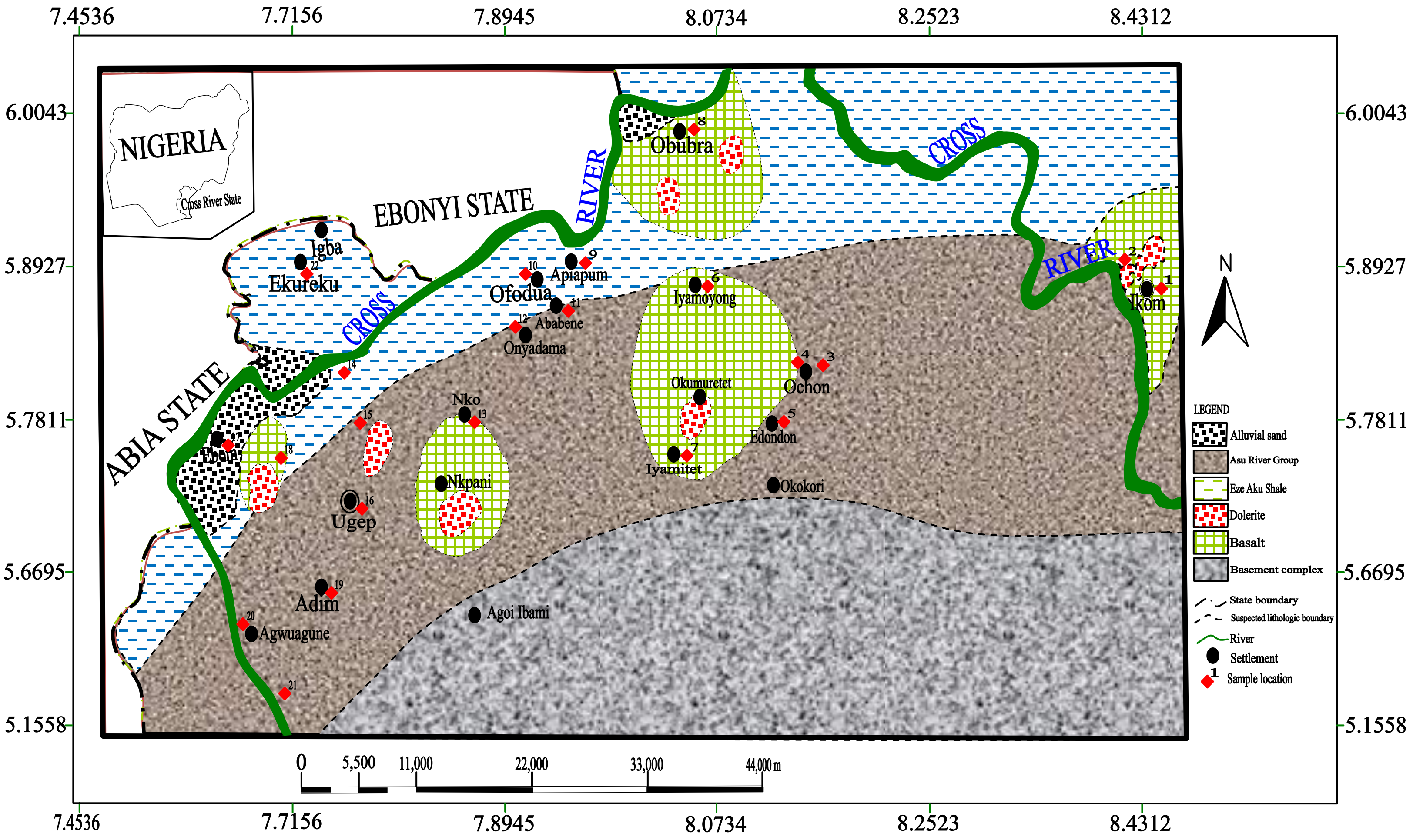

Fig.1. Geologic/sample location map

Table 3. Parameters of the groundwater and equipment used for their determination in the field/laboratory.

Parameter	Method / Equipment	Location	Type of sample
Temperature/conductivity	WTW LF 91 meter	Field	Groundwater
pH	WTW ph 90 meter	"	
Dissolved Oxygen DO)	WTW oximeter 96	"	
Color	Lau bond comparator	"	
Alkalinity	Titrimetric method	University of Calabar	
Total hardness	"	"	
Calcium	"	"	
Magnesium	"	"	
Chlorine	"	"	
Potassium	"	"	
Sodium	"	"	
THB	Counting of Aerobic mesophilic Bacteria	Dept. of Biology, University of Calabar	
Faecal Coliform	"	"	
Total Coliform	"	"	
Ammonium salt	DR/4000u Spectrophotometer	Oceanography University of Calabar	
Nitrate	"	"	
Nitrite	"	"	
Phosphate	"	"	
Sulphate	"	"	
Iron	"	"	
Zinc	"	"	
Manganese	"	"	

Table 4. Statistical summary of the groundwater analysis for the different sampling period

Parameters	Range	Lowest mean	Highest mean
Temperature (^{0}C)	24.00 – 32.2	27.84(W)	29.34(DW)
conductivity(µsm/cm)	27.4 - 1141	191.73(D)	352.45(WD)
pH	4.1 - 9.1	5.93(W)	7.34(DW)
Color(Pt-Co)	0 – 825	6.86(D)	76.18(DW)
DO(mg/l)	0 – 6-6	2.4(D)	5.2(DW)
BOD(mg/l)	0 - 2.8	0.004(W)	1.13(DW)
Total hardness	12 – 2188mg/l CaCO$_3$	105.82(WD)	653.82(DW)
Alkalinity(ppm)	30 – 1090	168.18(W)	364.77(D)
Na$^+$(mg/l)	9.2 - 386.2	29.82(W)	130.59(D)
K$^+$(mg/l)	0.3 - 12.1	0.92(W)	4.04(D)
Ca^{2+}(mg/l)	2.4 - 347.9	20.59(WD)	125.25(DW)
Mg^{2+}(mg/l)	0 - 534	13.52(WD)	88.15(W)
NH$_4^+$ (mg/l)	0.01 – 10.5	0.74(D)	1.42(WD)
HCO$_3^-$(mg/l)	36 - 1308	210(W)	437.73(D)
Cl$^-$(mg/l)	14.2 - 603.5	45.83(W)	201.90(D)
SO$_4^{2-}$(mg/l)	0 - 0.68	0.07(WD)	0.09(D)
NO$_2^-$(mg/l)	0 - 8	0.07(DW)	0.23(D)
NO$_3^-$(mg/l)	0.32 - 4.8	1.97(W)	2.78(DW)
PO$_4^{3-}$(mg/l)	0.03 - 2.41	0.22(D)	0.42(W)
Total Fe(mg/l)	0 – 2.40	0.05(D)	0.17(DW)
Total Mn(mg/l)	0 - 24	2.47(DW)	5.93(W)
Zn(mg/l)	0 – 0.14	0(D)/(WD)	0.0096(W)
THB(x10^{3}cfu/ml)	0.2 – 25.47	1.26(D)	3.26(WD)
Faecal Coli (/100ml)	0 - 20	0.81(W)	3.3(DW)
Tatal Coli(/100ml)	0 - 15	5.09(W)	14.93(DW)

W = wet period (June), WD = wet-dry period (September), D = dry period (January) and DW = dry-wet period (March)

RESULTS AND DISCUSSIONS

The seasonal variations in levels of the groundwater parameters are presented in Table 4. The mean temperature ranged from 27.84^{0}C to 29.34^{o}C with the lowest mean temperature 27.84^{0}C during wet period and highest value of 29.34^{0}C in the dry-wet period. These values are consistent with the ambient temperature of the study area in Table 2. Temperature is a variable parameter and is dependent on various factors such as time of sampling and prevailing weather condition at the time of sampling. The water temperature was generally within the WHO limit of 30^{0}C for drinking water (WHO 2001) except during the following period, location 18 (dry)(32.2^{0}C), location 3(dry–wet)(32^{0}C), and location 10(wet) (31^{0}C) were however higher than the tolerable limit, and is due to the factors mentioned above.

Conductivity or specific conductance is a measure of the ability of water to conduct an electrical current. It is related to the amount of dissolved substances in water, but it does not give an indication of which minerals are present. Changes in conductivity over time may indicate changing water quality. The conductivity varied from 27.4 µS/cm to 1141µS/cm with the lowest mean value of 191.73 µS/cm obtained in the dry period while the highest mean value of 352.45 µS/cm was in the wet – dry period. The relatively high values at locations 10 (dry-wet period) and 22(wet period) indicate an abundance of free ions in the water which could be attributed to equilibrium between the water and the soluble rock type (Hem, 1986). In any case the values are below the WHO limit of 1400 µS/cm for drinking water (WHO 2001).

The pH varied from 4.1 to 9.1 with the lowest mean value of 5.93 obtained in the wet period while the highest mean value of 7.34 was obtained in the dry-wet period. About 40 percent of the pH values were not within the WHO standard values of 6.5 – 8.5. The acidic nature of water in the wet period is attributed to humic acid resulting from decomposition of vegetative materials and biodegradable organic wastes from the environment as well as the river discharge characteristics which drain the area.

The level of dissolved oxygen in water serves as an indicator of the microbial activity (Carlson, 2001). Dissolved oxygen concentration varied from 0 to 6.6mg/l with the lowest mean value of 2.4mg/l obtained in the dry period while the highest mean value of 5.2mg/l was obtained in the dry-wet period. The mean value for the dry period is lower than the WHO standard of 5mg/l for drinking water and this could be attributed to bacteriological activities which used up the available dissolved oxygen, while those slightly above the standard value could be due to low organic matter content, low microbial activities or dilution from the rain. BOD values ranged from 0 to 2.8mg/l with the lowest mean value of 0.04mg/l in the wet period while the highest mean value of 1.13mg/l occurred in dry – wet period.

The values for colour varied from 0pt-Co to 825pt-Co, with the lowest mean value of 6.86pt-Co in the dry period while the highest mean value of 76.18pt Co was in the dry-wet period. Generally, the colour values are above the WHO standard of 15pt-Co due probably to the infiltration of runoff into the water table through the soil zone.

Total hardness range from 12 to 2188mg/l $CaCO_3$ with the lowest mean value of 105.82mg/l $CaCO_3$ in the wet-dry period while the highest mean value of 653.82mg/l $CaCO_3$ was recorded during the dry-wet period. The mean values were all above the WHO standard and could be attributed to the types of bedrock or mineral composition of the aquifer in the study area, which are mostly shale/limestone lenses. Hardness in water is caused mostly by dissolved calcium and magnesium, primarily the result of dissolving limestone or dolomite from soil and rock materials. Alkalinity is a measure of the water's ability to neutralize acids, and so is related to pH. It results primarily from dissolving limestone, dolomite or other carbonate minerals in the aquifer. Alkalinity and total hardness are usually nearly equal in concentration (when they are both reported in mg/l $CaCO_3$ (calcium carbonate), because they form from the same minerals. If alkalinity is much higher than total hardness in an unsoftened sample, consider testing for sodium but if alkalinity is much lower than total hardness, it shows the presence of chloride, nitrate, and sulphate (Spurlock, 2005).The lower the alkalinity, the more likely water is corrosive. High alkalinity in water (greater than 150 mg/l) may contribute to scale (lime) buildup in plumbing. Alkalinity ranged from 30mg/l to 1090mg/l with the lowest mean value of 168.18mg/l in wet period while the highest mean value of 364.77mg/l was recorded in dry period. The decrease in alkalinity in the wet period is due to dilution from the rain/runoff. Sodium concentration ranged from 9.2mg/l to 386.2mg/l with the lowest mean value of 29.82mg/l in the wet period while the highest mean value of 130.59mg/l was in the dry period. This is due to dilution in the wet season through infiltration of rain water into the groundwater through the soil zone.

Potassium concentration ranged from 0.3mg/l to 12.1mg/l with the lowest mean value of 0.92mg/l in the wet period while the highest mean value of 4.04mg/l was in the the dry period. The low value in the wet period is due to dilution from the rain/runoff.

Calcium value ranged from 2.4mg/l to 347.9mg/l with the lowest mean value of 20.59mg/l in wet-dry period while the highest mean value of 125.25mg/l was recorded in the dry-wet period. The high concentration of calcium in the dry-wet period could be due to infiltration of rain water and surface runoff through the vadose zone, since the zone are not yet saturated with water at this time of the period (Spurlock, 2005). Magnesium value ranged from 0 to 534mg/l with the lowest mean value of 13.52mg/l in wet-dry period while the highest mean value of 88.15mg/l was recorded in wet period. High increase in the wet period could be due to leaching of mineral of porous media by the rain water during this period. Ammonium is another cation in the water and its value ranged from 0.01mg/l to 10.5mg/l and the lowest mean value of 0.74mg/l in dry period and highest mean value of 1.42mg/l in wet-dry period. High concentration of NH_4^+ in the wet-dry period could be due to degradation of organic matter by micro organisms. Bicarbonate value ranged from 36mg/l to 1308mg/l with the lowest mean value of 36mg/l in wet period while the highest mean value of 1308mg/l was obtained in dry period. Chlorine value ranged from 14.2mg/l to 603mg/l with the lowest mean value of 45.83mg/l in the wet period while the highest mean value of 201.90mg/l was recorded in dry period. Sulphate value ranged from 0mg/l to 0.46mg/l with the lowest mean value of 0.07mg/l in wet-dry period and highest mean value of 0.09mg/l in the dry period. Sometimes results of nitrate and nitrite are reported together (Feig, 1981,Gregory and Sneed 1996). Nitrate ranged from 0.4mg/l to 4.8mg/l with the lowest mean value of 1.97mg/l in the wet period while the highest mean value of 2.78mg/l was recorded in the dry-wet period. Nitrite value ranged from 0 to 1.5mg/l and the lowest mean value of 0.07mg/l was recorded in the dry-wet period while the highest mean value of 0.22mg/l was obtain in the dry period. Phosphate value ranged from 0.03mg/l to 2.41mg/l with the lowest mean value of 0.22mg/l in the dry period and highest mean value of 0.42mg/l in the wet period.

The increase of some of the cations and anions in dry-wet, wet and wet-dry is usually due to leaching of the minerals of the aquifer material by the rain water. Other possible sources may be the salt in the environment carried by the rain water and the runoff.

However, geochemical processes along the flow system have a role to play in the nature of the geochemical constituents. For example, as water passes through the sandy clay aquitard, the sodium ion in the clay is exchanged for calcium ion. The process of cation exchange may either lead to a decrease or an increase in the levels of these ions, depending on which ion is replacing the other. The predominant ionic species in rain water include HCO_3^-, SO_4^{2-}, Cl^-, Mg^{2-},Ca^+ and Na^+ which are released into the groundwater as infiltration occurs (Hem, 1986).

Total iron concentration ranged from 0 mg/l to 2.4mg/l with the lowest mean value of 0.05mg/l in dry period while the highest mean value of 0.17mg/l was recorded in the dry-wet period. The high level in the dry-wet period could be attributed to the leaching of iron (Fe) which had been absorbed onto the soil material from the water table as the water level increases with an increase in precipitation, while the low level in the dry period could be due to precipitation of iron compound as the water level recedes with a decrease in rainfall. Iron is slightly above the WHO standard value of 0.03mg/l in the dry-wet period . Hem (1986) has shown that the solubility of iron is affected by pH - Eh (redox potential).

The lowest mean concentration of 0 mg/l of zinc was obtained in dry/wet-dry period and the highest mean value of 0.0096mg/l was obtained in wet period. Total manganese lowest mean concentration of 2.47mg/l was obtained in dry-wet period and the highest mean concentration of 5.93mg/l was obtained in wet period. Total manganese value is higher than the WHO standard value of 0.1mg/l and this could be due to hydrolysis which can lead to the precipitation of the mineral in the dry period and due to leaching of the aquifer formation in the wet period. Total heterotrophic bacteria (THB) ranged from 0.2cfu/ml to 25.47cfu/ml with the lowest mean value of 1.26cfu/ml in dry period and highest mean value of 3.26cfu/ml in the dry-wet period. The increase of THB in the dry-wet, wet and wet-dry period could be due to high organic material introduced into the aquifer due to infiltration and runoff through the soil zone. Total coliform concentration ranged from 2cfu/ml to 134cfu/ml with lowest mean value of 5.1cfu/ml in wet period and highest mean value of 14.9cfu/ml in the dry-wet period. Coliform do not usually cause disease. However, their presence indicates that fecal wastes may be contaminating the water and that pathogenic (disease-causing) organisms could be present. If human or animal wastes are contaminating the water, gastrointestinal diseases, hepatitis, or other diseases may result. Fecal coliform bacteria, e. coli concentration ranged from 1cfu/ml to 16cuf/ml with the lowest mean value of 0.82cfu/ml in the wet period and the highest mean value of 3.3cfu/ml in the dry-wet period. The presence of e. coli in a water sample is more conclusive evidence of fecal contamination which represents an even greater health risk than the presence of total coliform bacteria. (Hem, 1986).

Figures 2 -4 are stiff diagrams showing variations in the three different formations with the micro season of dry, dry-wet, wet and wet-dry period.

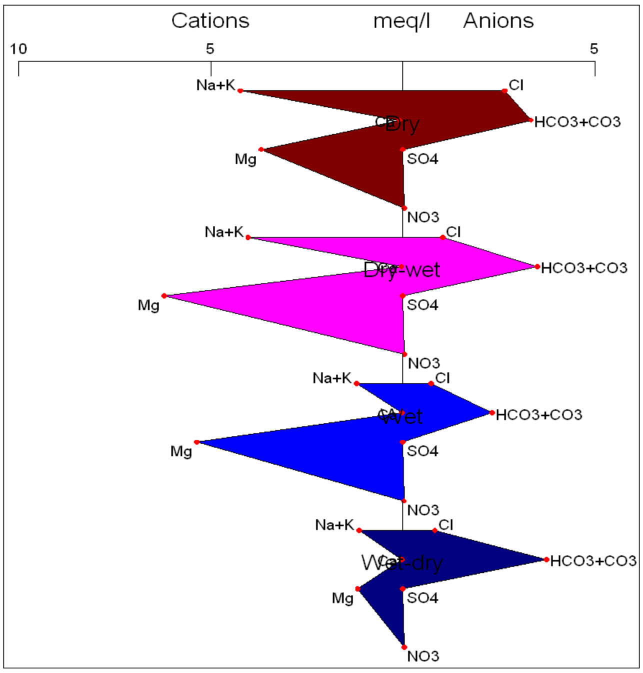

Fig: 2 Stiff diagrams showing seasonal variation of major anion/cation for Intrusive

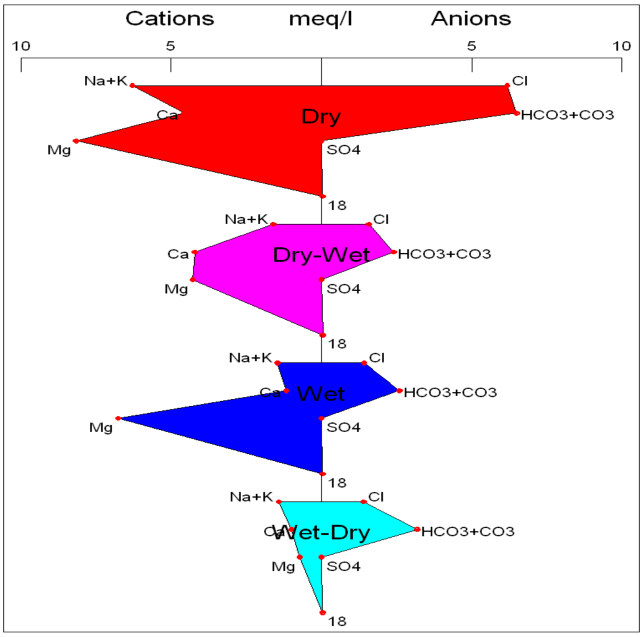

Fig: 3 Stiff diagrams showing seasonal variation of major anion/cation for Asu River Group

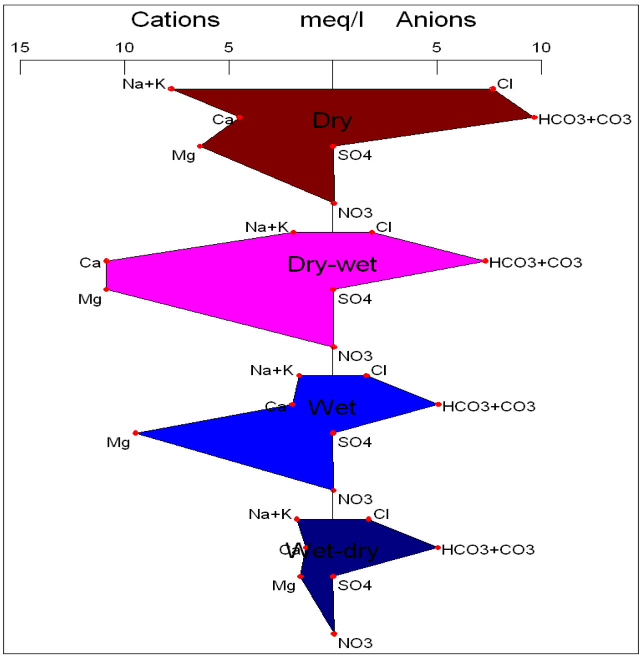

Fig: 4 Stiff diagrams showing seasonal variation of major anion/cation for Eze-Aku Formation

In intrusive there was an increase of bicarbonate and magnesium in the dry-wet period and a reduction of the same element as the rain intensify, an indication of dilution. But there was an increase of bicarbonate in the dry-wet period showing precipitation (Fig 2). In Asu-River Group, bicarbonate and magnesium decreases in dry-wet period but rather increase it concentration during the wet period while Na+K was deceasing (Fig. 3) and this could be due to precipitation of carbonate and leaching of Na+k which continued after wet period into dry-wet period (Fig. 3). In Eze-Aku Formation, there was an increase of Ca$^+$ and Mg$^+$ in the dry-wet period and a drastic reduction of Ca$^+$ in wet period. Bicarbonate was being reduced as the period move from dry to wet-dry (Fig. 4), these is due to rock type (sandstone) which help in high infiltration of runoff.

CONCLUSION

Baseline data on hydrogeochemical studies of sandstone – shale – intrusive aquifers in part of Mamfe embayment which previously had not been documented have been assembled and analyzed in this work. The present levels of physico-chemical parameters and biological have been used to assess the seasonal variation of sandstone – shale – intrusive aquifers in the study area. In physiochemical parameters, more than 70% of the parameters are below the W.H.O standard unit for drinking and domestic purposes. More than 65% of biological parameters are below W.H.O standard while the other percentage of more than 25% are higher than W.H.O standard and was noticed to increased during wet and wet-dry period and reduces during dry period which show an increase due to infiltration. It was also noticed to increase from Asu River group to Eze-Aku Formation. It was also observed that the Eze-Aku Formation was more contaminated to coliform than the Asu-River Group followed by the Intrusive. The data also show that the formations were more contaminated in the wet period in some area than dry period while in some area the wet period reduces the contamination due to dilution from runoff and this is evidence that the contamination of the study area is control by infiltration and runoff. And these goes further to show that the aquifer in the study area is mostly recharged by precipitation. The data also show that the aquifers in the study area are not vulnerable to nitrate, but are rather vulnerable to faecal coliform due to water from runoff that infiltrate into the aquifer from the vodoze zone during precipitation in the area.

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