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Research Article

GROUND WATER AQUIFER DELINEATION OF AKWA IBOM STATE, NIGERIA

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ABSTRACT

Aquifer delineation and hydrogeochemicalcharacterizationof groundwater resources in Akwa Ibom State was carried out in order to delineate aquifers for the drilling of productive boreholesand evaluate the groundwater quality. Detailed analysis of borehole lithologic samples shows a multi-aquifer system, with a sub-regional trend of upper unconfined aquifer and locally restricted subjacent second and third aquifers. The regionally extensive upper unconfined aquifer was logged across boreholes in Abak, Etim Ekpo, Etinan, Ibiono Ibom, Ikono, Ini, Itu, Nsit Atai, Nsit Ibom, Obot Akara, Okobo, Oron, Uruam and Uyo.. Groundwater flow direction shows northwest – southeast trends in consonance with the regional groundwater flow trend in the Niger Delta. Thirty two groundwater samples were analyzed for their physico–chemical and microbiological properties, using standard methods. Detailed interpretation of gross hydrogeochemical data suggest that the prevailing hydrogeochemical processes responsible for the groundwater chemistry are attributable to ion exchange, carbonate and silicate weathering, precipitation and dissolution from rocks, through which the water infiltrates. The study provides an applicable scenario in hydrogeochemical evaluation and aquifer delineation towards sustainable groundwater management in the study area.

INTRODUCTION

The quality of water usually available for exploitation is often limited by the geography and geology of the area under consideration. There are discharge areas, where groundwater rises to the surface, and recharge areas, where rain and run-off percolate down to replenish supplies. The groundwater movement is affected by the type of rock comprising the aquifer; water moves quickly through loosely packed layers of rock, slowly through more impermeable ones. Shallow unconfined aquifers are more vulnerable to contamination than are deep ones protected by overlying layers of rock. Everyday activities of people in an area can bring about possible pollution of groundwater, activities like changing of used engine oil which are left to be washed away by the next rain, others are herbicide, fertilizer, deliberate dumping of waste, leaks from underground tanks (mainly gasoline), septic tanks. It is therefore imperative to determine the suitability of groundwater before use. The chemistry of groundwater in any geological environment is controlled by several factors viz: the chemistry of the infiltrating water at the recharge source, the chemistry of the porous medium including the interstitial cement or matrix of the aquifer, the rate of groundwater flow, in the aquiferous medium and hence the permeability of the aquifer and the travel time of the water through the environment.

The quality of water for various purpose, viz: domestic, irrigation and industry, depends on the concentration of these substances. Results of water quality are usually compared with establishment by international regulatory bodies such as the World Health Organizations (WHO), Federal Environmental Protection Agéncy (FEPA) and National Agency For Food, Drugs And Administrative Control (NAFDAC). This research work is prompted by the ever increasing population in the study area, that depend heavily on groundwater and the fear that continual abstraction could lead to environmental problems such as saltwater Intrusion, subsidence or water crisis.

LOCATION OF STUDY AREA

The location of study for this research project is AkwaIbom State. The state occupies part of the southeastern corner of Nigeria. It is located between latitudes $4^0$30’and $5^0$30’ North and longitudes $7^0$30’ and $8^0$20’ East.

Akwa Ibom State shares boundary on the north with Cross River and Imo States, on the south with the Atlantic Ocean, to the east with Cross River State and to the southwest with Rivers and Imo States.

AIM OF THE STUDY

The aim of the study is to to use borehole data to delineate the aquifers in the study area.To determine local groundwater flow direction, To evaluate the hydro geochemical characteristics of groundwater in AkwaIbom State with a view to assessing its suitability with internationally accepted standards for specific uses.

(a)Water quality: Groundwater quality can be affected by both natural and anthropogenic activities. In aquifers unaffected by human activities, the groundwater results from geochemical reactions between the water and the rock matrix as the water moves along flow paths from areas of recharge to areas of discharge. In general the longer groundwater remains in contact with soluble materials, the greater the concentrations of dissolved materials in the water. The quality of the water can be directly affected by the infiltration of anthropogenic compounds or indirectly affected by alternation of flow path or geochemical conditions (Guler and Thyne, 2004).

A wide range of different elements can become dissolved in groundwater as a result of interactions with the atmosphere, the superficial environment, soil and bedrock. Groundwater usually tend to have much higher concentrations of most constituents than do surface waters, and deep groundwater that have been in contact with bedrock for a long time tend to have higher concentrations than shallow younger aquifers. It is therefore,relevant to note major dissolved components the predominant cations and anions in groundwater These dissolved constituents are typically expressed in mg/l.

COMPONENT	POSSIBLE SOURCE
Calcium (cations)	Amphiboles, feldspars, gypsum, aragonite, calcite, pyroxenes, dolomite, clay minerals
Magnesium (cations)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals
Sodium (cations)	Feldspars, clays, halite, mirabilite, industrial wastes
Potassium(cations)	Feldspars, feldspathoids, some micas, clays
Bicarbonate/Carbonate (anions)	Limestone, dolomite
Sulphate (anions)	Oxidation of sulphide ores, gypsum, anhydrite
Chloride (anions)	Sedimentary rock, igneous rock

Table 1: Major Dissolved Components in Groundwater and their Possible Sources

(b) Literature Review: Not much research has been done on water quality status of groundwater in the study area, although several studies have shown effects of increase in human and industrial activities in the Niger

Delta (Odigi, 1989; Amadi and Amadi, 1990; Udom, 2004). Uzoukwu (1981) reviewed the importance of groundwater in Nigeria and highlighted inadequate supply of potable water as the main factor limiting human and economic activities in many parts of Nigeria, particularly in the eastern Niger Delta. Etu-Efeotor and Odigi (1983) discussed the groundwater quality problems of the eastern Niger Delta. This was an expansion of the findings of Etu-Efeotor (1981) on the groundwater hydro -geochemistry in parts of the Niger Delta.

Aquifers frequencies have been used to delineate the different units within the multi-layered aquifer system of the Niger Delta (Etu-Efeotor and Akpokodje, 1990; Akpokodje et al, 1996).The variations in frequency of aquifers with depth shows that all the aquifers are generally overlain by sands/silt clay or clay at their respective surfaces, with the exception of coastal beach islands. The stratigraphic sequences of the Niger Delta Basin with aquifer prospectivety are shown in Table 2.

A thick clay layer below overlies the regional aquifer. The thick clay layer below the perched aquifer is partially continuous laterally, and therefore, constitutes a semi-confining aquitard with very small pressure head (0.6m above the base of clay).

AGE	STRATIGRAPHIC UNITS	LITHOLOGIC UNIT	AQUIFER PROSPECT
Quaternary	Alluvium	Gravelly sands, sands, silt and clay	Good
	Meander belt deposit	Gravelly sands, sands with thin clay units	Good
	Wooded backswaps and freshwater Swamp deposits	Mainly silt and silty clays with clayey intercalations	Poor
	Mangrove Swamp deposits	Fine sands to silt and silty clay and clays with organic matter	Poor (Saline Water)
	Sombreiro Deltaic Plain Sediments	Coarse to fine grained sand, silt and clays	Medium

Table 2: Ngah (1990) identified three (3) Aquiferous zones in the Niger Delta, namely

Edet (1993) presented an assessment of the groundwater quality of the parts of Akwa Ibom State. After reviewing some hydrogeochemical data from the area, he concluded that there was an occurrence of slightly saline water in certain areas which was as a result of hydrologic processes, rather than sea water intrusion.

Udom et al (1999, 2002), investigated the hydrogeochemistry of some groundwaters in parts of the Niger Delta and the results show that the water in these areas are soft and low in dissolved constituents (Fe, Zn, Ca, Mg, Na, and K) except Fe. Salt water encroachment is evidenced in these areas from geoelectrical studies (Etu-Efeotor et al., 1989; Oteri, 1990).

(c) Geomorphology of the Study Area The study area of Akwa Ibom State in this hydrogeochemical research is located in the onshore southeastern Niger Delta. The geomorphological nature of the study area is therefore, reflective of the relief features of this part of the Niger Delta **.**The Niger Delta progrades and changes its shape by the process of channels which occur simultaneously at the different parts of the delta. The delta has been recognized by Allen (1665) as having various types of depositional and morphological units which include the coastal flats, rivers, lagoon beaches, flood plains, swamps, sand bars and flats, rivers, lakes, ancient and modern seas.

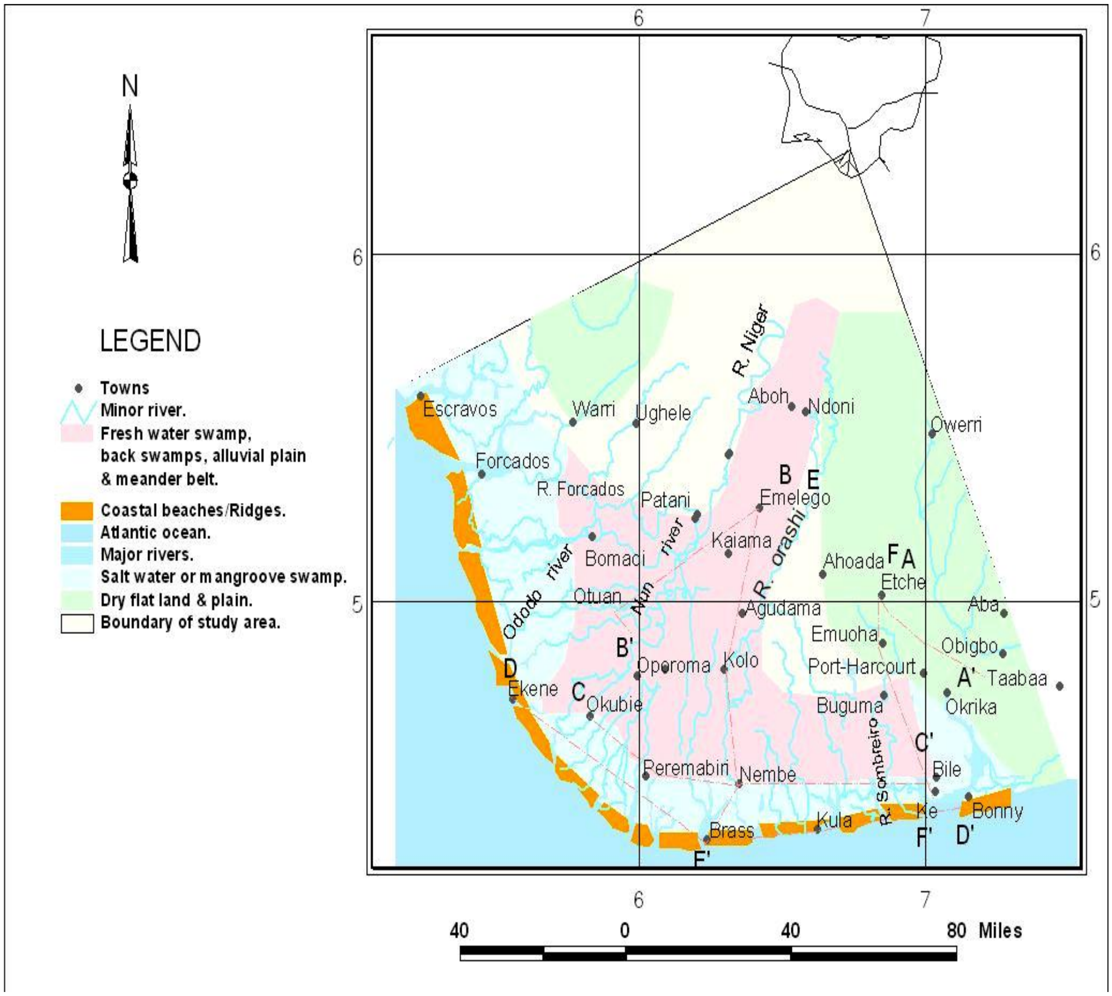

Figure 1: Major Morphological Units of the Niger Delta (modified after Short and Stauble, 1967 and Akpokodje, 1989).

Akwa Ibom State is a low-lying coastal plain which lies within the fifth geomorphological unit (Figure 1) that is, the dry flat land and plain. The closeness of some parts of the study area to the sea is marked by localized saltwater/ mangrove swamps to the extreme south.

The state is drained by the Cross River on the east, Imo River on the south west, and Qua Iboe River in the south central parts. These rivers flow from the northern highlands of the state and drain in to the Atlantic Ocean in the south.

The rainy season is followed by the dry season, which begins in November through March. During this period, there is harmattan dust haze (locally known as "ekarika") between December and January. The dry season is ushered in by dry Northeast Trade Wind which blows across the Sahara desert into the area.

This cold wind also blows from the northeast, with tiny particles of dust. The humid tropical climate in Akwa Ibom State is characterised by high humidity. Mean yearly temperature in the area is about 27^{0}C (Inyang, 1975), and monthly maximum temperatures deviate from this mean by about 10 – 12 degrees. The highest temperature in the area occurs in the months of March and April, and lowest in July and August (Amadi et al, 1985). According to these authors, minimum relative humidity lies between 70 and 80 (%) percent and maximum between 95 and 100 (%) percent. Minimum humidity is experienced in the month of December and maximum values from May to October.

METHODOLOGY

The study involves field sampling, data acquisition and interpretation of results obtained. This chapter considers instrumentation, measurement procedures, constraints and resolutions. Detailed sampling protocol was carried out. This is a very important step in collecting samples. The analytical method employed in this research consists of three (3) phases namely the field sampling phase, data collection phase and the laboratory phase. Physico-chemical analysis of groundwater samples and lithological logging of borehole samples from each of the thirty one (31) Local Government Areas Akwa Ibom State were carried out

(i) Sample Collection: Samples were collected in three (3) labeled, well drained plastic containers, tightly corked. The choice of plastic containers is to minimize contamination that could alter the water constituents. The first container was 250ml for microbial test. The second (1 litre container) was acidified with two (2) drops of concentrated Nitric acid (HNO_3) for cations determination, in order to homogenize and prevent absorption/adsorption of metals to the wall of the plastic container.. These samples were preserved in coolers to keep the temperature below 20^{0}C for eventual transfer to the laboratory for analysis within the standard period of twenty four (24) hours.

The static water level (SWL) in each of the sampling locations as well as the total depth penetrated by the boreholes was equally recorded, where possible. The SWL level map was produced by loading the measured value and the respective coordinates into the database in the SURFER 8 Software. The point measurements were then automatically gridded and contoured to obtain the static water level map for the study area.

(ii) Laboratory Analyses: The analysis of physico-chemical parameters was done at POCEMA Laboratory (Port Harcourt), Anal Concept Laboratory, Port Harcourt and University of Port Harcourt laboratories using standard techniques. The analytical methods used in the determination of water chemistry are in accordance with the American Standard. The laboratory results obtained in the study are compared with WHO (2006) and NSDWQ (2008)).

PRESENTATION OF RESULTS

DATA ANALYSES:

The results presented for each parameter per study location is the value for the location. The statistically analyzed values showing the range in values and the mean values for each parameter averages for all the study locations are presented in Table 3.

LGA	HCO_3/Cl	Na/Ca	Na/Cl	Ca/Cl	Mg/Cl	K/Cl	SO4/Cl	Mg/Ca	Ca/SO_4	Ca/HCO_3
Abak	2.44	0.24	0.31	1.28	0.51	0.31	0.70	0.40	1.84	0.52
Eastern Obolo	5.56	11.13	1.56	0.14	0.48	0.64	1.91	3.37	0.07	0.03
Eket	0.73	21.77	0.17	0.01	0.04	0.04	0.11	4.83	0.07	0.01
Esit Eket	3.00	1.91	1.53	0.80	1.00	0.85	0.00	1.25	0.00	0.27
Essien Udim	1.63	0.79	0.57	0.72	0.53	0.28	0.73	0.73	0.99	0.44
Etinan	0.75	0.36	0.38	1.06	0.95	0.14	0.62	0.90	1.70	1.40
Etim Ekpo	2.62	0.89	0.64	0.72	0.47	0.29	0.75	0.66	0.96	0.27
Ibeno	0.96	0.57	0.10	0.17	0.27	0.13	0.05	1.60	3.13	0.17
Ibesikpo Asutan	0.68	0.10	0.09	0.89	0.30	0.13	0.55	0.34	1.61	1.32
Ibiono Ibom	1.71	0.24	0.31	1.28	0.51	0.31	0.70	0.40	1.84	0.75
Ika	5.05	0.63	1.30	2.07	1.15	0.19	0.99	0.55	2.08	0.41
Ikono	1.19	0.10	0.09	0.89	0.30	0.13	0.55	0.34	1.61	0.55
Ikot Abasi	0.68	1.07	0.88	0.83	0.51	0.30	1.02	0.62	0.81	1.22
Ikot Ekpene	0.76	0.07	0.07	1.06	0.45	0.02	0.86	0.43	1.22	1.40
Ini	0.47	0.39	0.35	0.90	0.54	0.20	0.69	0.60	1.30	1.91

Itu	2.07	0.04	0.33	7.42	0.16	1.07	1.09	0.02	6.82	3.59
Mbo	1.10	0.20	0.03	0.16	0.04	0.01	0.08	0.25	1.90	0.14
Mkpat Enin	0.46	0.04	0.04	1.09	0.66	0.24	0.98	0.61	1.11	2.39
Nsit Atai	2.67	2.13	3.41	1.60	1.33	1.20	0.00	0.83	0.00	0.60
Nsit Ibom	0.37	0.63	1.30	2.07	1.15	0.19	0.99	0.55	2.08	5.65
Nsit Ubium	1.24	1.63	1.11	0.69	0.57	0.43	0.00	0.83	0.00	0.55
Obot Akara	1.20	0.10	0.15	1.58	0.64	0.04	0.29	0.40	5.36	1.31
Okobo	2.14	0.43	0.76	1.76	0.97	0.18	0.85	0.55	2.07	0.82
Onna	0.25	0.09	0.03	0.27	0.17	0.01	0.06	0.62	4.81	1.06
Oron	0.39	0.83	0.80	0.96	0.78	0.32	1.03	0.81	0.93	2.46
Udung Uko	0.61	0.57	0.06	0.11	0.37	0.53	0.15	3.29	0.76	0.18
Ukanafun	2.75	0.33	0.42	1.29	0.33	0.20	0.64	0.26	2.02	0.47
Uruan	1.86	0.21	0.04	0.21	0.29	0.10	0.11	1.34	1.93	0.12
Urue Offong - Oruko	0.88	0.22	0.40	1.78	1.31	0.23	0.68	0.74	2.61	2.02
Oruk Anam	0.44	0.86	0.84	0.98	0.56	0.16	0.58	0.58	1.67	2.23
Uyo	1.19	0.43	0.76	1.76	0.97	0.18	0.85	0.55	2.07	1.48

Table 3: Relationship Between Various Ionic Ratios Of Groundwater in The Study Area

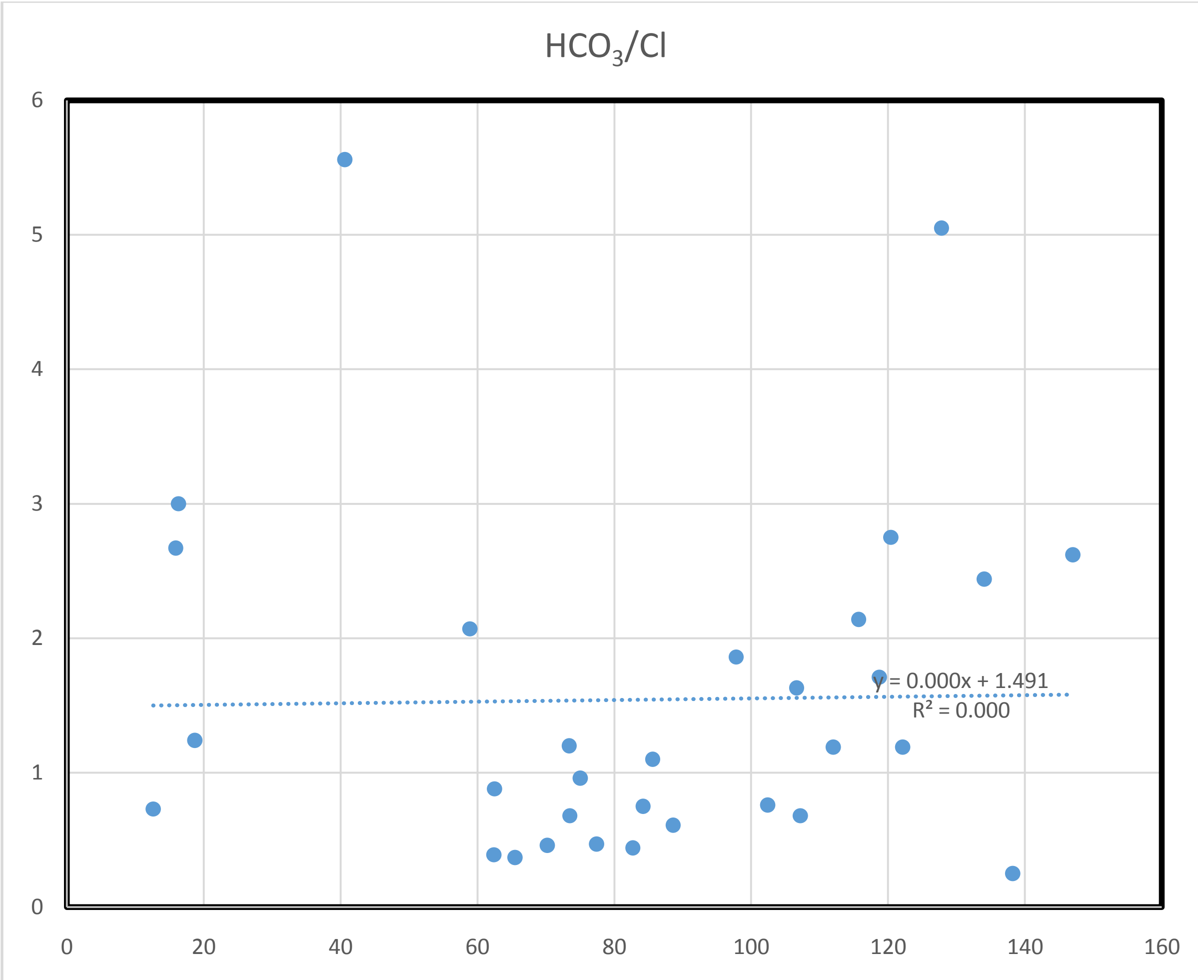

Figure 2: Ionic Ratio of HCO_3/Cl against TDS

(iii) Total dissolved solids: Total dissolved solids are a measure of the sum of organic and inorganic solutes in water. Typical TDS values for water of different sources are shown in Table 4.

Types of Water	Total Dissolved Solids (mg/l)
Freshwater	0-1000
Brackish water	1,000-10,0000
Saline Water	10,000-100,000
Brine Water	>100,000

Table 4: Types of water based on TDS (Richards, 1954)

The TDS concentration ranges from 12.6mg/l to 147.0mg/l and has an average value of 84.32mg/l within the study area. This shows that groundwater in the area is fresh in most of the locations. The TDS values correlate well with conductivity values. The highest TDS values of 147mg/l and 138.2mg/l were recorded in Etim Ekpo and Onna Local Government Areas, respectively. These areas with the highest Total Dissolved Solids values show corresponding highest Electronic Conductivity values. The WHO (2006) and the NSDWQ (2008)permissible limits for TDS is 500mg/l for potable drinking water. Thus, from results obtained the groundwater samples are potable with respect to TDS. According to Richards (1954), more that 1000mg/l TDS is good for dying textiles and the manufacture of pulp, paper, plastics and rayon

RESULT AND DISCUSSION

BOREHOLE DATA:

Data from 32 boreholes spread across Akwa Ibom State are discussed and presented in this section. The data include lithologic logs, Static Water Levels and elevation.

The lithologic logs. reveal major lithologies within the coastal plain sands and alluvial deposits. The lithologies are made up of sand and clay deposits, interbedded in some areas by clayey sand aquitards with occasional streaks of peat/ lignite in some sections.

(i) SANDS: Sands are the water-bearing permeable rocks in which aquifers occur in this setting. One to three aquifers have been identified in the study area as a result of clay intercalations within these formations. The upper one is in most cases unconfined, but is confined in few locations. The second aquifer is unconfined in Ikot Abasi, Ibiono Ibom, Ikono, Nsit Atai, Obot Akara, Uyo, but is confined at Ibeno, Ibiono Ibom, Ikono, Itu, Okobo, Oron, and also in Uyo. The third aquifer is confined all through the few locations where it is identified.

(a) First Aquifer Horizon: This aquifer extends regionally with a span that covers over 90 percent of the study area. This aquifer is generally unconfined, but in Uruan (JBL26) and Eket and Ibeno (JBL7 and JBL8) it appears to be confined. The aquifer is laterally extensive and varies in thickness across the study area. It has its highest thickness at Abak (JBL1) and thinnest at Uyo (JBL31). A layer of clayey sand separates the first aquifer horizon from the second.

(b) Second Aquifer Horizon: The second aquifer which occurs between 30 and 138 meters and is noticed in some of the boreholes studied. It is commonly overlain by clayey sand and mostly underlain by clayey sand or a lignitic layer. This aquifer varies in thickness from 83meters at Ibeno (JBL8) to 10 meters at Itu (JBL16).

(c) **Third AquiferHorizon:** occurs in Uyo at JBL28 and Ibeno (JBL7), and was not been penetrated at the study depths of other boreholes. There is a possibility that other wells bored could show this horizon at greater depths. The aquifer is generally confined as seen from the lithologic logs.

North to south and east to west correlations of the study aquifers and other lithologic units representing the north to south correlation, it can be seen that the first aquifer zone is thickest at the central area of the state (Abak) and thins out in the north and south directions. The second aquifer shows at Ikono and the third horizon absent. A correlation in the east to west direction shows varying thicknesses for the first aquifer. However, the second aquifer increases eastward towards Itu and decreases in thickness towards Ikono. The third aquifer does not appear in the logged section but may likely occur at greater depths.

(ii) Clays: Within the Benin Formation and the Quarternary alluvium, the clay horizons and lenses occur in places and produce a multi-aquifer system in these formations. A multi-aquifer system within the Benin Formation has been reported elsewhere in the Niger Delta by Etu-efeotor (1981), Udom et al (1998), and others. The clay layers have also locally given rise to confined aquifers in some parts of Ibeno, Uyo, Oron and Ikono. For the boreholes studied ,clay lenses are noticed in JBL 7, JBL 8, JBL 14, JBL24, JBL 27, JBL 28 and JBL29. In JBL7, the first clay layer occurs at a depth of eight meters and is twelve (12) meters thick; while the second layer, which is three (3) meters thick, is met at 36 meters. In JBL 8, the first clay layer occurs at nine meters depth and it is 24 meters thick, while the second layer occurs at a depth of forty two (42) meters and is five (5) meters thick. In Ikono the clay is deeper and thicker than at JBL8 (Ibeno). In JBL 9 it occurs at a depth 75 meters and is 15 meters thick. In JBL24 (Oron) a clay layer is noticed at a depth of 20 meters and is about 17 meters thick. In Uyo JBL27 one clay layer is noticed at a depth of 35meters with a thickness of about four meters. Also in Uyo, JBL28 and JBL29 show one and three clay layers, respectively. In JBL 28, the first clay layer occurs 35meters below the ground surface and is about 7 meters thick, the second at 35meters with a thickness of nine meters, while the third occurs 82 meters below the surface of the ground and is 18 meters thick. Thus, in the study area clay horizons/ lenses vary in thickness from three (3) meters to 45 meters and occur at a depth bracket of 8 to 120 meters for the maximum depth of about 130 meters penetrated by the boreholes studied.These clay layers, as well as sandy clay or clayey sand, separate one aquifer from the other in the study area. Also the clay horizons give rise to confined aquifers while the clayey sand or sandy clay aquitards lie above some of the second aquiferous layers in the area.

(iii) LIGNITE AND PEAT: This horizon is noticed at JBL9 (Ibiono Ibom), JBL 16 (Itu), JBL 23 (Okobo) and JBL 32 (Ikono)at various depths between 14 and 98 meters, where it commonly underlies the first aquifer. However, in Uruan it occurs at a shallower depth 14- 35 meters after the lateritic zone, where it locally confines the first aquifer in the area. In jbh9 and jbh21, it acts also as a confining material for the second aquifer.

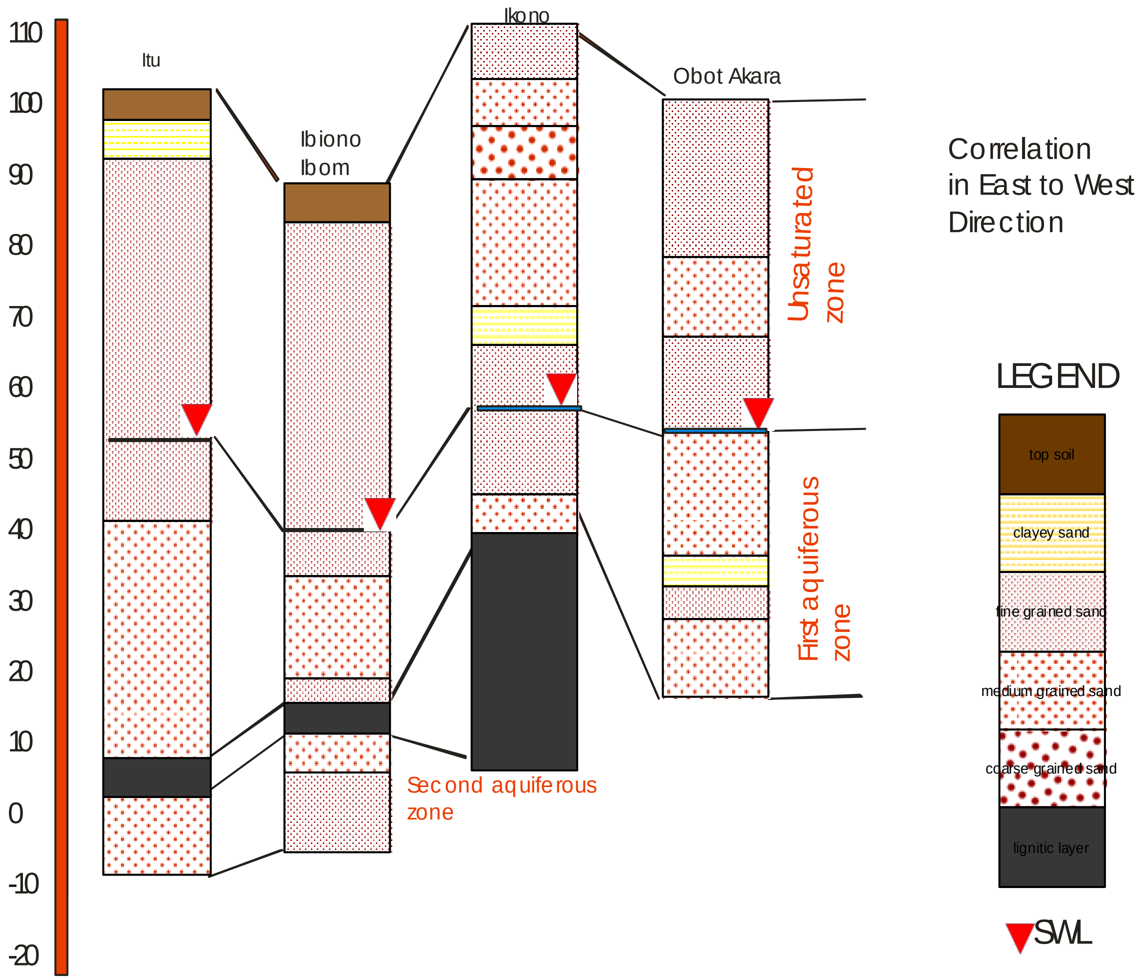

Figure 3: East to West Correlation of 4 Boreholes in the Study Area

HYDROCHEMICAL INDICES:

The following ionic relationships were studied to check the salinity and origin of the groundwater in the study area. These include: Mg/Ca, Cl/HCO_3, and the Cation Exchange Value (CEV= [Cl – (Na+K)]/Cl). Mg/Ca values were all less than 5. ranging from 0.02meq/l to4.83meq/l. According to the interpretation of this index, the groundwater in the study area appears to be slightly of inland origin, because waters under marine influence would have values of five (5) (Morell et al., 1986) except where other processes such as cation exchange take place. If this happens, the values would be below four (4) or less.

The Cl/HCO_3 values range from 0.01 - 5.65. Revelle (1994) recommended the Chloride – bicarbonate ratio as a criterion to evaluate intrusion. Values of this hydrogeochemical index given for inland waters are between 0.1 and 5 and that for seawater lies between 20 and 50 (Custodio, 1987). In general, the CEV for seawater ranges from +1.2 to +1.3 (Custodio, 1987), where low-salt inland waters give values close to zero, either positive or negative. The CEV values for Groundwater in Akwa Ibom State are generally below 0.7472 (table 4.9), ranging from 0.7472 to 0.0506, indicating that the groundwater is inland in some locations with respect to provenance. These results agree with the findings of Bolaji (2009

GROUNDWATER FLOW DIRECTION:

Local groundwater flow directions were determined at six locations in the state during this study using borehole data. These locations were Abak, Eastern Obolo, Eket, Ikono, Ikot Ekpene, and Ini. Groundwater flow direction in Eket, Ikot Ekpene, Uyo,Eastern Obolo and

Ikono is from northwest to southeast. Generally, the flow directions of groundwater in these areas are in consonance with Esu et al, (1999) and with the regional groundwater flow in the Niger Delta which is from the northern highlands southwards towards the Atlantic Ocean. The flow directions are related to the hydraulic heads which are higher at the northern part of the state and decrease gradually to the south. However, this work has identified some localized southwesterly and southeasterly flow trends within the study area.

Knowing the direction of ground water movement has become increasingly important because of the danger of contaminated groundwater supplies. Sewage or other contaminants can enter the groundwater systems, hence the flow direction of groundwater would help to know the direction of flow of the contaminant plume. This further indicates the significance of determining groundwater flow direction vis-à-vis the direction of flow of the contaminant plume.The l groundwater flow direction in the study area (Abak L.G.A) is shown in figure 4.

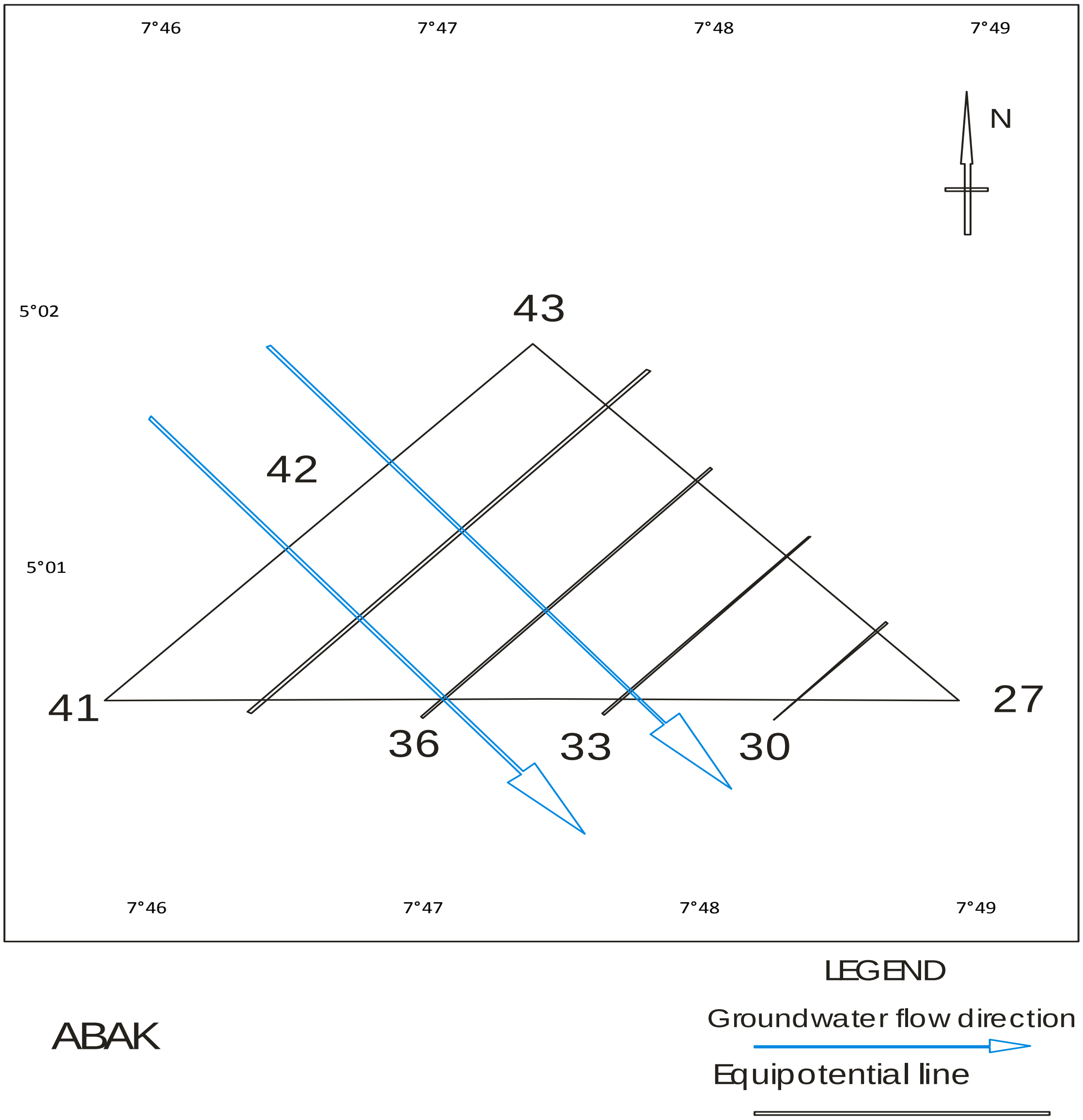

Figure 4: Groundwater Flow Direction in Abak LG

CONCLUSION

A number of practical aspects have come to light in the study. These findings help to explain the aquifer delineation and hydrochemical characterization of groundwater encountered in the area. Directly, deriving from this study the following conclusions maybe presented:

Detailed analysis of Lithologic Logs show the presence of multi-layered aquifer system delineated into three (3) aquifer horizons across the study area.Unlike most of the previous studies ,this work examined the factors controlling groundwater quality and also inferred the origin on the basis of their compositions. Moreso, significant interpretations have been extracted from hydrochemical data using multivariate statistical methods to evaluate groundwater quality.The concentrations of ions present in the groundwater were determined and the geochemical processes were idenitfied. The diagnostic chemical characteristics of the groundwater system were determined with the application of the hydrochemical facies, which enabled a convenient subdivision of water compositions by identifiable categories.

The physico-chemical analyses show that the groundwater is soft to moderately hard and weakly acidic to slightly alkaline.

The tested physico-chemical parameters in this research generally fall within permissible limits of the WHO (2006) and NSDWQ (2008) for potable water with the exception of iron (Fe) and total coliform count in some study locations.

The general groundwater direction is from the North-West to South-East. This trend is further indicative of potential contaminant plume flow directions in the study area.

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