Journal of Scientific Research & Reports
3(2): 366-383, 2014; Article no. JSRR.2014.009

SCIENCEDOMAIN ***international***
www.sciencedomain.org

Aquifer Characteristics and Groundwater Quality Assessment in Ikwuano Area of Southeastern Nigeria

C. Amos-Uhegbu[1*], M. U. Igboekwe[1], G. U. Chukwu[1], K. O. Okengwu[2] and K. T. Eke[3]

[1]Department of Physics (Geophysics), Michael Okpara University of Agriculture, Umudike,P.M.B 7267 Umuahia, Abia-State, Nigeria.
[2]Department of Geology, University of Port Harcourt, P.M.B 5323 Port Harcourt, Nigeria.
[3]Department of Physics/Electronics, Abia State Polytechnic P.M.B 7166 Aba, Abia-State, Nigeria.

Authors' contributions

Authors may use the following wordings for this section: Authors CAU and MUI designed the study and wrote the protocol while author CAU wrote the first draft of the manuscript. Authors CAU, GUC and KOO managed the analyses of the study. Authors CAU, GUC and KTE managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

Received 15th August 2013
Accepted 9th October 2013
Published 22nd November 2013

ABSTRACT

The present work is a review on the geoelectrical characteristics, and a study of physico-chemical parameters of groundwater in parts of Ikwuano Local Government Area of Abia State, Nigeria. The aim was to collate, synthesize and analyse geoelectrical parameters from available literature together with physico-chemical parameters in order to evaluate the geophysical and geochemical character of the aquifer systems; and subsequently determine the quality of groundwater in the area. The study shows that aquifer thickness varies from 24.5m to about 201.1m, the Formation Factor ranges from 2.02 to 13.53, and the groundwater is naturally potable. Total Hardness (TH) values range from 17.86mg/l to 46.91mg/l. The concentrations of major cations and anions are far below the permissible limit for drinking and domestic purposes recommended by World Health Organisation (WHO). With respect to agricultural and irrigation purposes, using the values of Sodium

**Corresponding author: E-mail: nenyemos@yahoo.com;*

Absorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Electrical Conductivity (EC), the groundwater samples are excellent.

Keywords: Geo-physical and Geo-chemical characteristics; formation factor; groundwater quality; Irrigation.

1. INTRODUCTION

Michael Okpara University of Agriculture, Umudike; and National Root Crop Research Institute, Umudike are located within 7km east of the capital city of Abia State 'Umuahia' in present day Ikwuano Local Government Area of Abia state.

The presence of these institutions has undoubtedly added to a great increase in the population of the area.

Rapidly increasing population, rising standards of living and exponential growth in industrialization and urbanization tends to add pressure on natural resources [1].

The proximity of Government College Umuahia, and the Umuahia (Agricultural) campus of Abia State University to Ikwuano Local Government Area also added to an increase in population of the area.

This resultant increase in population and the non-acceptance of surface water; together with the comatose nature of the municipal water supply has made almost every sector in the area to depend on groundwater for their various purposes.

Water beneath the ground surface in soil pore spaces and in the fractures of rock formations is usually referred to as Groundwater.

A unit of rock or a layer of porous substrate that contains groundwater and transmits it in appreciable amounts (yield a usable quantity of water) is called an aquifer.

Groundwater is considered to be the largest reservoir of drinkable water and plays a major role in augmenting the water supply to meet the ever increasing demands for domestic, agricultural and industrial usage. Due to the long retention and residence time of groundwater and natural filtration capacity of aquifers; groundwater is less contaminated as compared to surface water. Over-dependence on it for many purposes and the indiscriminate disposal of domestic, industrial or agricultural waste slowly makes groundwater susceptible to pollution [2,3].

Water is said to be polluted when water in its original sources is contaminated to such an extent that the usage is rendered unacceptable [3].

Contaminants that may be in untreated water include microorganisms such as viruses and bacteria; inorganic contaminants such as salts and metals; organic chemical contaminants from agricultural practices and industrial processes [2,3]. Consumption of contaminated or polluted water can give rise to many diseases and even death [4,3].

Therefore, groundwater quality assessment of the area is essential.

Also, the presence of these research institutions, their associated steady population growth and other related factors will greatly stress the groundwater resources and since the emphasis on the availability and quantity of groundwater has extended to the quality of groundwater [5,6]; thus, an understanding of the hydrogeological conditions of the area is essential.

1.1 Location of the Study Area

Ikwuano Local Government Area is geologically situated in the Eastern Niger Delta and lies within latitudes 5º20' and 5º32' N, and longitudes 7º32' and 7º40'E (Fig 1). It has high relative humidity values over 70%, and is characterized by high temperatures of about 29º – 31ºC.

The area is part of the sub-equatorial belt with average annual rainfall of about 4000mm per annum.

The wet season starts from Mid-April to October and dry season from November to Mid-April, and has double maxima rainfall peaks in July and September with a short dry season of about three weeks between the peaks locally known as the August break.

The geology of Ikwuano area falls within two out of eleven geologic units in Abia State. They are Bende-Ameki Formation and Benin Formation as shown in Fig. 1, but this study is centred on Benin Formation.

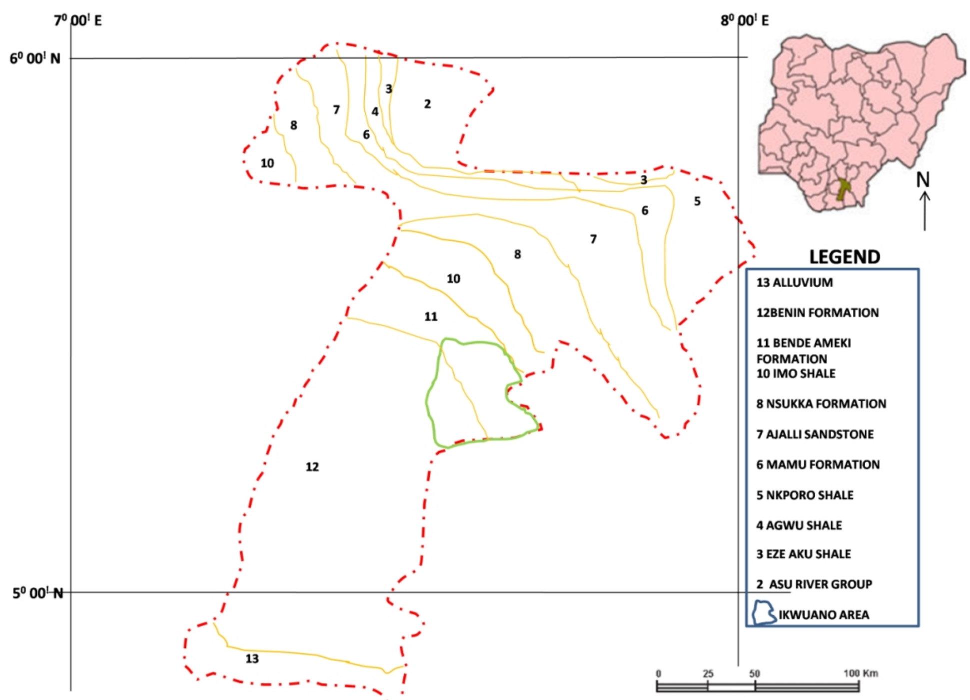

Fig. 1. Geologic Map of Abia State showing Ikwuano the study area

Ikwuano Local Government Area of Abia state, Nigeria is bounded in the north and north-east by Bende, in the north by Umuahia-North, in the north-west by Umuahia–South, in the west by Isiala-Ngwa North Local Government Areas respectively; and in the east and the south by Akwa-Ibom state of Nigeria (Fig 2).

The area is endowed with natural springs and streams including Onu-Inyang River which flows from Bende (the northern boundary) through the study area in a south-westerly direction; while Iyinta-Ocha River flows from the central part (Isiala) through south-western part (Ogbuebule) into Akwa-Ibom state on the western flank.

On the other hand, Anya River traverses the entire western flank of Ikwuano and joins with Ahi (the westernmost counterpart). This confluence together with others is a main tributary of the great Kwa Ibo River of Akwa Ibom and Cross River States of Nigeria (Fig 2).

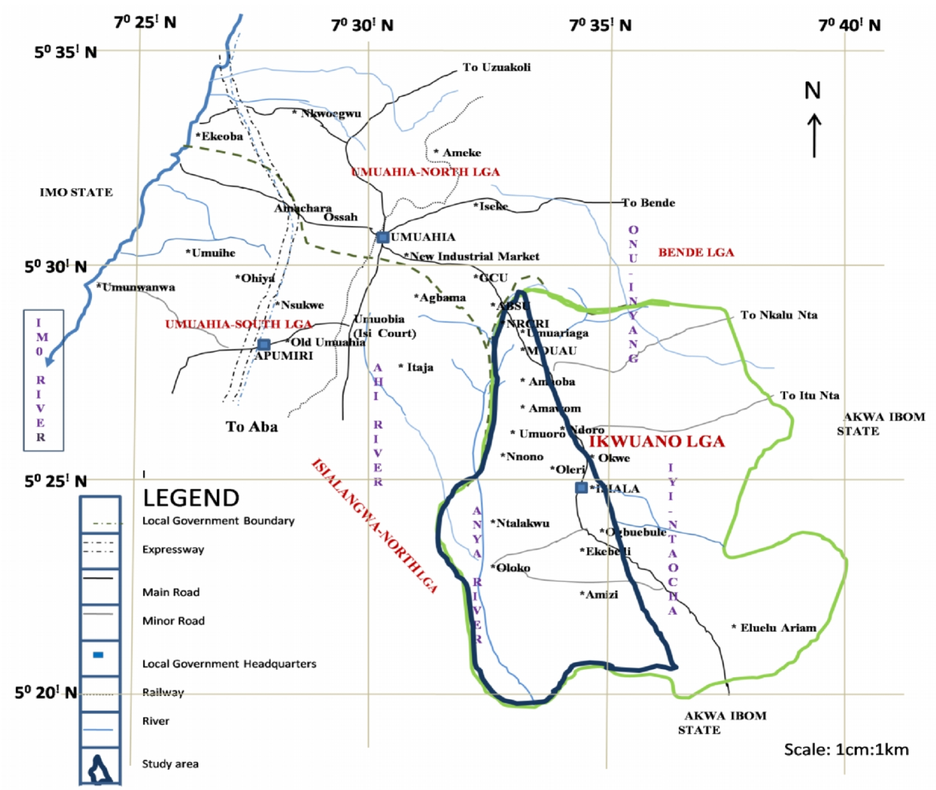

Fig. 2. Map of Ikwuano area showing Benin Formation the Study area.

1.2 Geology and Hydrogeology

Benin Formation is one of the stratigraphic units in the modern Cenozoic Niger Delta. Niger Delta complex which has been extensively described [7,8]; thus indicating that there are three lithostratigraphic units in Niger Delta. These units are Marine Akata Formation, Paralic Agbada Formation, and the Continental Benin Formation (Fig 3).

The overall thickness of these Tertiary sediments is about 10,000 meters. The Akata and Agbada Formations are the source and reservoir rocks respectively for petroleum in the Niger Delta.

However, all boreholes in the Tertiary Niger Delta tap water from the Benin Formation.

Benin Formation occurs across the whole Niger Delta from Benin-Onitsha area in the north to beyond the present coastline [8]. It is probably a product of upper deltaic depositional environment with identifiable structural units such as point bars, channel fills, natural levees, back swamp deposits and ox-bow fills.

The age of Benin Formation is Oligocene to Recent in the subsurface and also as surface outcrop in the northern parts of Western Niger Delta basin and also in some parts of Umuahia area of the Eastern Niger Delta. This upper part of Benin Formation is known as Ogwashi-Asaba Formation; while the younger southern part which is Miocene to Recent in age is known as Coastal Plain Sands.

Benin Formation consists of thick unconsolidated sands with lignite streaks and wood fragments. The sands are sub-angular to well-rounded, mostly medium to coarse-grained, pebbly, and moderately sorted with inter-fingering of local lenses of poorly cemented sands and clay, thus giving rise to multi-aquifer systems separated by aquitards.

The petrography analysis shows that the rocks composition is about 95-99% of quartz grains; 1-2.5% of Na+K mica; 0.5-1.0% of feldspar, and 2.3% of dark-coloured minerals [9].

Five regional levels of aquifers in the Niger Delta have been delineated using lithological and geophysical logs [10].

The first aquifer occurs under phreatic conditions between depths of 0 and 45 m. The second and third aquifers are semi-confined occurring within the depth of 45 to 130m and 130 to 212m respectively. The forth aquifer is 219 to 300m deep while the fifth level of aquifer is more than 300m deep.

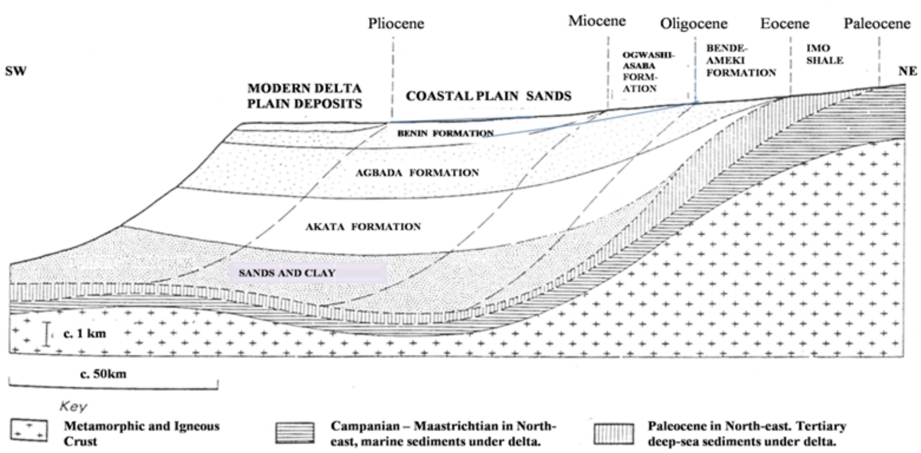

Fig. 3. A schematic longitudinal cross section showing the diachronous nature of common lithofacies of Anambra basin and Niger Delta

**Curved broken lines represent successive positions of the delta front with time.*

2. MATERIAL AND METHODS

The study area (Benin Formation of Ikwauno area) lies within lies within latitudes 5º20' and 5º32' N, and longitudes 7º35' and 7º37'E (Fig 2). An understanding of the quality of groundwater of an area is as important as its quantity because it is the main factor determining its suitability for domestic, drinking, agricultural and industrial purposes.

Water quality being the physical, chemical and biological characteristics of water is mainly assessed with reference to a set of standards; and for the fact that the emphasis on the availability and quantity of groundwater has extended to the quality; hence this study. Accounting fully for the physical, chemical and biological interactions between soil, water, nature and society is quite complex; therefore the parameters for water quality are determined by a specific usage and interest such as human consumption, agricultural use, industrial use, etc.

In other words, water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter since it is dependent on the local geology and ecosystem, as well as human uses such as sewage dispersion, agricultural / industrial pollution and over-exploitation. So, it is variable both in time and space, and requires routine monitoring to detect spatial patterns and changes over time.

A range of chemical, physical, and biological components affect the quality and quantity of water, thus many variables could be examined and measured. Some of the variables provide a general indication of the characteristics of aquifers (yield and quality) thus aiding in determining and predicting changes for sustainable beneficial management practices.

2.1 Geolectrical Data Acquisition

In this present work, geoelectrical aquifer parameters from previous works were taken for this study as shown in Table 1 [11,12]. Also taken for this study as shown in Table 1 are the Unpublished PhD theses, Michael Okpara University of Agriculture, Umudike-Nigeria (G.U Chukwu, 2010 and C. Amos-Uhegbu, in view).

Common to all these data acquired is the use of Vertical Electrical Sounding (VES) method of electrical resistivity which employed the Schlumberger electrode configuration involving four electrodes spacing with two current electrodes (maximum half electrode spacing 'AB/2' of 500m) widely spaced outside and two potential electrodes (maximum half electrode spacing 'MN/2'of 55m) closely spaced within them all along the survey line (Fig. 4).

$$\rho_a = \pi R \left(\frac{L^2 - l^2}{2l}\right)$$

Where

ρ_a = Apparent resistivity.
L = 'AB/2' = Half current electrode spacing (m).
l = MN/2 = Half potential electrode spacing (m).
R = Resistance in ohms.

$$\pi\left(\frac{L^2-l^2}{2l}\right) = \text{Geometric factor (K).}$$

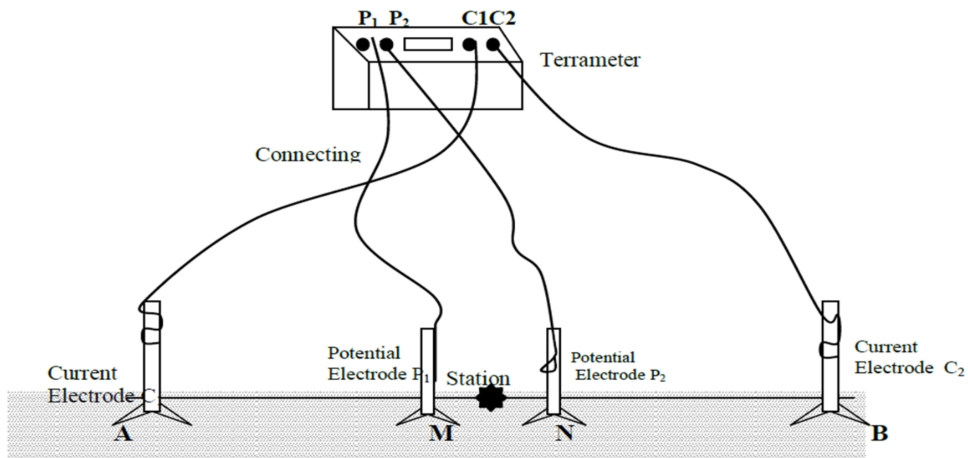

Fig. 4. Schlumberger Array for Vertical Electrical Sounding

Also common in the data acquisition of the geoelectrical parameters were that the aim of the various surveys were for delineation of aquifer systems in the area and the use of RESIST software package for computer iteration.

The theories of both the electrical resistivity survey and the Schlumberger electrode configuration are well documented in the standard texts [13,14].

Table 1. VES location points and their corresponding Aquifer Characteristics

VES Station Location	GPS Reading			Aquifer Resistivity (Ωm)	Aquifer Thickness (m)	Longitudinal Conductance S (Siemens)	Aquifer Conductivity σ (mho/m)	Aquifer Transverse Unit Resistance R (Ωm^2)	Source
	Elevation (m) m.s.l	Latitude ºN	Longitude ºE						
MOUAU	125.2	5º28.826'	7º32.765'	ρ = 611	t = 94.0	S = 0.1538	σ = 0.0016	R = 57434	Amos-Uhegbu (in view)
Amaoba	135.0	5º28.150'	7º33.008'	ρ = 1350.0	t = 138.3	S = 0.1024	σ = 0.0007	R = 186705	,,
Umuoro	143.5	5º25.715'	7º33.928'	ρ =1120.1 ρ = 688.3	t = 199.0 t =?	S_3 = 0.1777	σ = 0.0009 σ = 0.0015	R = 222899.9	,,
Isiala	135.0	5º24.345'	7º34.088'	ρ = 1058 ρ = 829.9 ρ = 577.0	t =100.5 t = 180.1 t =?	S = 0.0950 S = 0.2170	σ_4 = 0.0009 σ_5 = 0.0012 σ_6 = 0.0017	R = 106329 R = 149464.99	,,
Oloko	117.0	5º22.022'	7º34.097'	ρ = 910	t =24.5	S = 0.0269	σ = 0.0011	R = 22295	,,
Amawom	187.0	5º27.570'	7º33.531'	ρ = 1338	t =139.0	S = 0.1039	σ = 0.0007	R =185982	Chukwu (2010)
Umuariga	146.0	5º26.760'	7º32.886'	ρ = 720	t = 89.1	S = 1238	σ = 0.0014	R = 64152	,,
Nnono	150.0	5º26.028'	7º32.797'	ρ = 1026.0	t = 97.5	S = 0.0950	σ = 0.0010	R = 100035	,,
Amizi	-	5º22.022'	7º34.097'	ρ = 544.7	t = 201.1	S = 0.3692	σ = 0.0018	R = 109539	Igboekwe et.al (2006)
Ndoro	140.4	5º26.032'	7º33.097'	ρ = 1141.3	t = 200	S = 0.1752	σ = 0.0009	R = 228260	Mbonu et.al (1991)

2.2 Physico-chemical Data Acquisition

Ten physico-chemical parameters of groundwater samples were acquired from the unpublished PhD Thesis of Amos-Uhegbu, C (in view) Michael Okpara University of Agriculture.

The method stated for data acquisition indicated that collection and analysis of water samples were done during the cold Harmattan period in the month of January, hot temperature period of the month of March, transitional season period of the month of May and the rainy season period of July. While the average values of the samples were used in order to maintain neutrality in seasonal variation of parameters thus covering the dry season, transitional season and wet season. The work further stated that Pre-washed and clean 500ml screw cap plastic containers were used to collect water samples from the selected boreholes after pumping the wells for about five minutes thus ensuring stable laminar flow conditions; and all boreholes were located within 1km radius of nearest VES stations of same locality.

Also indicated was that due to the sensitivity of groundwater to environmental changes, the following parameters temperature, colour, pH and electrical conductivity were determined *in situ*. While thereafter, the samples were immediately taken to the Soil and Water Laboratory Department, Federal Ministry of Agriculture and Water Resources, km 5 Ikot-Ekpene Road, Umuohu-Azueke Ibeku Umuahia (Nigeria) for further laboratory analyses.

As shown in Table 2, the parameters with physical (temperature, electrical conductivity, total dissolved solids and pH), basic cation (sodium, potassium, calcium and magnesium) and anions (chloride, bicarbonate, sulphate and nitrate) that fall within the study area were selected; and then used to determine or assess their suitability for domestic, industrial and agricultural applications with reference to international standards [15], [16], [17].

3. RESULTS AND DISCUSSION

3.1 Aquifer Resistivities, Groundwater Resistivities and Formation Factor

The aquifer resistivity obtained from various VES surveys ranges from 544.7 to 1350Ωm and the reciprocal of resistivity is conductivity. Correspondingly as shown in Table 1, the aquifer conductivity of the study area ranges from 0.0007 to 0.0018mho/m.

An inventory of the boreholes was carried out as shown in Table 3 whereby Groundwater resistivities in the area were determined from the obtained measurements of specific conductance of groundwater at wells by taking the reciprocal of groundwater specific conductance.

The result was further used in determining the values of formation factor of each borehole. Formation Factor (FF) is calculated using the aquifer resistivity (ρ) estimated from VES and water resistivity of the formation (ρw) using Archie's law [17].

$$FF = \rho/\rho_w \tag{1}$$

Where ρw = resistivity of water.

The water resistivity is calculated by using the equation

$$\rho_w = 10{,}000/\text{electrical conductivity of water} \tag{2}$$

Table 2. Physico-Chemical Parameters of Groundwater samples in the study area

Data Location	Temp (oC)	Cond. (µs/cm)	pH	TDS (mg/l)	TSS (mg/l)	Fe2+ (mg/l)	Ca2+ (mg/l)	Mg2+ (mg/l)	Na2+ (mg/l)	K+ (mg/l)	HCO3 (mg/l)	Cl- (mg/l)	SO4^{2}- (mg/l)	NO^{3-} (mg/l)	Source
MOUAU	29.6	88.3	6.32	68.0	0.42	0.17	6.75	0.24	5.00	3.15	28.00	1.30	3.51	0.10	Amos-Uhegbu (in view)
Umuariga	29.8	106.5	6.30	2.90	0.26	0.20	8.00	1.88	3.85	2.67	13.05	2.30	4.30	0.08	,,
Amaoba	30.0	100.2	6.22	3.00	0.30	0.16	5.90	2.40	3.55	2.45	11.50	3.20	4.20	0.07	,,
Amawom	30.0	100.2	6.22	2.60	0.20	0.16	6.12	1.40	4.70	2.30	11.50	3.20	4.20	0.09	,,
Umuoro	29.7	29.4	6.30	3.21	0.25	0.18	8.21	5.10	4.00	2.15	13.50	1.50	4.35	0.11	,,
Isiala	29.4	36.6	6.15	3.00	3.50	NS	7.91	4.88	4.08	2.33	18.50	1.31	4.80	0.10	,,
Oloko	29.8	38.5	6.32	3.88	4.10	NS	8.84	6.05	4.27	1.85	13.50	4.40	4.60	0.06	,,
Nnono	29.4	36.6	6.15	3.00	3.50	NS	7.91	4.88	4.08	2.33	18.50	1.31	4.80	0.08	,,
Amizi	29.7	48.0	6.22	12.40	1.20	0.18	7.40	3.84	4.91	2.41	16.00	2.00	4.30	0.07	,,
Ndoro	29.8	36.0	6.10	3.00	0.22		8.00	4.94	4.85	1.72	19.30	2..30	4.92	0.14	,,
WHO LIMITS	25	< 500	6.5-8.5	50-750	10-25	< 0.3	<500	< 50	< 5	<75	<250	< 50	< 400	45	

**NS = Not Stated*

Table 3. Aquifer parameters of the study area

VES Station/Data Locality	Aquifer Resistivity (Ωm)	Aquifer Thickness (m)	Longitudinal Conductance S (Siemens)	Aquifer Conductivity σ (mho/m)	Transverse Resistance R (Ωm^2)	Electrical Conductivity (µs/cm	Resistivity of water (Ωm)	Formation Factor	Total Hardness
MOUAU	ρ = 611	t = 94.0	S = 0.1538	σ = 0.0016	R = 57434	88.3	113.3	5.39	17.86
Umuariga	ρ = 720	t = 89.1	S = 1238	σ = 0.0014	R = 64152	106.5	93.9	7.67	27.71
Amaoba	ρ = 1350	t = 138.3	S = 0.1024	σ = 0.0007	R = 186705	100.2	99.8	13.53	24.60
Amawom	ρ = 1338	t =139.0	S = 0.1039	σ = 0.0007	R =185982	100.2	99.8	13.41	21.04
Umuoro	ρ =1120.1	t = 199.0	S_3 = 0.1777	σ = 0.0009	R = 222899.9	29.4	340.1	3.29	41.44
	ρ = 688.3	t =?		σ = 0.0015				2.02	
Isiala	ρ = 1058	t =100.5	S_4 = 0.0950	σ = 0.0009	R = 106329	36.6	273.2	4.09	39.78
	ρ = 829.9	t = 180.1	S_5 = 0.2170	σ = 0.0012	R =			3.04	
	ρ = 577.0	t =?		σ = 0.0017	149464.99			2.11	
Oloko	ρ = 910	t =24.5	S = 0.0269	σ = 0.0011	R = 22295	38.5	259.7	3.50	46.91
Nnono	ρ = 1026	t = 97.5	S = 0.0950	σ = 0.0010	R = 100035	36.6	273.2	3.76	39.78
Amizi	ρ = 544.7	t = 201.1	S = 0.3692	σ = 0.0018	R = 109539	48.0	208.3	2.61	34.24
Ndoro	ρ = 1141.3	t = 200	S = 0.1752	σ = 0.0009	R = 228260	36.0	277.8	4.11	40.25

3.2 Determination of Groundwater Quality for Drinking and Domestic Purposes

3.2.1 Physical Parameters

Table-2 illustrates the various physico-chemical parameters of groundwater of in parts of Ikwuano Local Government Area. The temperature ranged from 29.6°C to 30.0°C during the study period.

The pH values of groundwater ranged from 6.10 to 6.32 with an average value of 6.23. This shows that the groundwater of the study area is slightly close to the 6.5 to 8.5 permissible limit prescribed by World Health Organization [18]. Acidic water corrodes pipe and plumbing materials of iron and steel thus clogging the distribution pipes which may stain clothes and rust cooking utensils, and also cause objectionable taste of drinks and food. Exposure to extreme pH values results in irritation to the eyes, skin, and mucous membranes. In sensitive individuals, gastrointestinal irritation may also occur.

Total Dissolved Solids (TDS) indicate the salinity behaviour of groundwater and all the samples are below 100mg/l, thus indicating that the groundwater of the area is recharged mainly through rainfall. Water containing more than 500 mg/l of TDS is not considered desirable for drinking, and all samples fall within the standard permissible limit.

Electrical conductivity (EC) is a measure of the ability of water to conduct electricity. It signifies the amount of total dissolved salts in the water. The value of EC varied from 29.4µs/cm to 106.5µs/cm. All samples are within the WHO permissible EC standard for drinking water.

3.2.2 Chemical Parameters

Also outlined in Table-2 is the hydrogeochemical parameter of the study area. Dissolved minerals at times affect the suitability of water for a range of industrial and domestic purposes. For example, the presence of ions of Calcium and Magnesium can interfere with the cleaning action of soap, and can form hard sulphate and soft carbonate deposits in water heaters or boilers; and the water is referred to as Hard. The softening process often substitutes Sodium cations and since health problems have been associated with excess Sodium together with Calcium and Magnesium deficiencies. Hard water may therefore be preferred to soft water for human consumption.

This shows that water quality though it is assessed with reference to a set of standards; as earlier on stated is neither a static condition of a system, nor can it be defined by the measurement of only one parameter as outlined subsequently.

3.2.2.1 Cations

The dominant cation in the water samples of the study area is Calcium (Ca^{2+}) followed by Sodium except at Isiala, Oloko and Nnono where Magnessium (Mg^{2+}) dominated Calcium (Ca^{2+}) dominated. Potassium (K^{+}) is also present in all the samples. So the sequence is as follows: $Na^{2+} > Ca^{2+}$ **>** K^{+} **>** Mg^{2+}. In all the samples, all cations including Iron Fe^{2+} met the WHO standard for drinking water.

3.2.2.2 Anions

The major anion in all the samples is the Carbonate group (CO_3^{2-}) followed by the Sulphate group ($SO_4^{\ 2-}$), Chloride (Cl^-) and Nitrate (NO_{3-}); and all the levels are satisfactory whereby no sample exceeded the permissible limit. Chloride (Cl^-) contents greater than 40.0mg/l in aquifers indicate salt water contamination [19], and salt water intrusion has been reported in coastal aquifers of the Niger Delta [20].

Chloride (Cl^-) is known in the maintenance of acid - base balance, and hence excess of it may cause oedema and laxative effects [21].

Sulphate ($SO4^{\ 2-}$) and Nitrate (NO_3^-) concentrations are found naturally in groundwater, and human activities can introduce them, therefore their low levels in all samples used for the study is an indication that the groundwater samples have not been contaminated.

3.2.2.3 Total hardness

Hardness of water mainly depends on the amount of calcium or magnesium salts; it is the concentration of Calcium and Magnesium ions expressed as equivalent of Calcium carbonate. This property of water prevents formation of lather with soap and increases the boiling points and can be calculated by using the formula:

$$(CaCO3) = 2.5(Ca^{2+}) + 4.1\ (Mg^{2+}) \qquad (3)$$

Total Hardness (TH) values range from 17.86mg/l to 46.91mg/l. The borehole at Oloko which has the highest value of Calcium and Magnesium has also the highest value of hardness.

The World Health Organization (WHO) International Standard for Drinking Water (2004) classified water with a total hardness of CaCO3 < 50mg/l as soft water, 50 to 150 mg/l as moderately hard water and above 150 mg/l as hard. Based on this classification, all the water samples are soft water.

3.3 Determination of the suitability of the groundwater for Agricultural Purposes

3.3.1 Electrical Conductivity (EC)

EC is a good measure of salinity hazard to crops. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil [22]. All the groundwater samples are suitable for irrigation purposes with minimal likelihood that soil salinity will develop (Table 4).

Table 4. Quality of irrigation water based on Electrical Conductivity

Salinity Hazard Class	Specific Conductance (μmho/cm)	Characteristics	Samples
Low	0-250	Low-salinity water can be used for irrigation on most soil with minimal likelihood that soil salinity will develop.	All Samples
Medium	251-750	Medium-salinity water can be used for irrigation if a moderate amount of drainage occurs.	Nil
High	751-2,250	High-salinity water is not suitable for use on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required.	Nil
Very high	More than 2,250	Very high-salinity water is not suitable for irrigation under normal conditions.	Nil

3.3.2 Sodium absorption ratio (SAR)

SAR is also an important parameter for determining the suitability of groundwater for irrigation because it is a measure of sodium hazard to crops. SAR can be estimated by the formula [23]:

$$SAR = [Na^+] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2} \quad (4)$$

Where all ionic concentrations are expressed in meq/l.

SAR values ranges from 0.33 to 0.78 with an average value of 0.46. All the sampling stations fall in the excellent category because none of the samples exceeded the value of SAR = 10 (Table 5). So, the samples are suitable for all types of soils.

Table 5. Sodium-Hazard Classification based on SAR values

SAR	Water-suitability for irrigation
0-10	Suitable for all types of soils except for those crops which are highly sensitive to Sodium
10-18	Suitable for coarse-textured or organic soil with good permeability. Relatively unsuitable in fine-textured soil.
18-26	Harmful for almost all types of soils. Requires good drainage, high leaching and gypsum addition.
>26	Unsuitable for irrigation

A further classification system to evaluate the suitability of water for irrigation use is graphically plotted with the values (EC and SAR) on the US salinity diagram [24]. The plots of groundwater chemistry of study areas in the USSL diagram are shown in Figure 5. The range of values on the horizontal axis starts from 100 (Low) to 5000 (Very High) μmho/cm, while the vertical axis values range from 0 (Low) to 30 (Very High).

The analytical data plotted on the US Salinity diagram illustrates that all the groundwater samples are indicating low alkalinity hazard S1 and very low salinity hazard and so could not be plotted in diagram. The results therefore indicate that all the water samples can be used for irrigation on almost all types of soil with little danger of exchangeable Sodium.

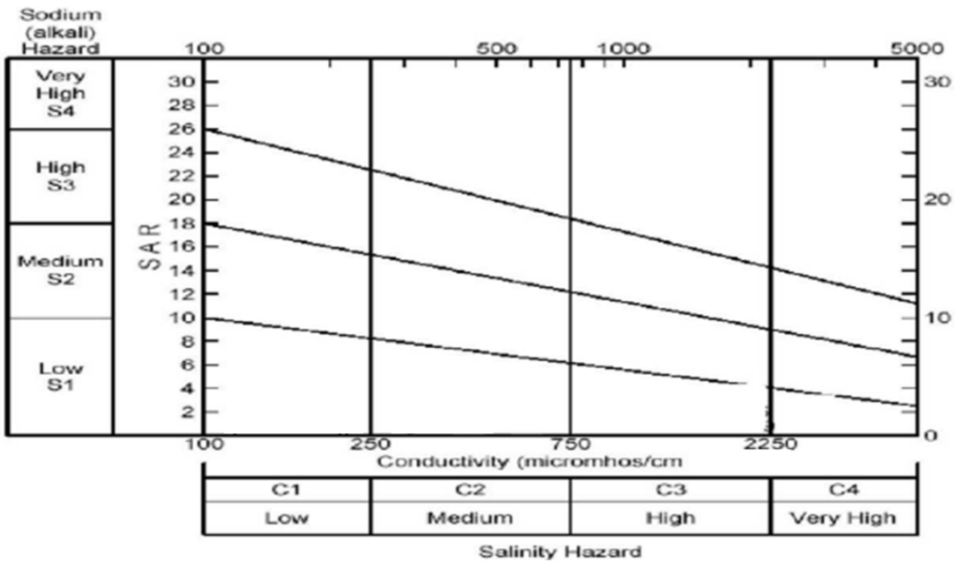

Fig. 5. Classification of irrigation waters using U.S. Salinity diagram

3.3.3 Residual sodium carbonate (RSC)

Residual Sodium Carbonate (RSC) has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose [25] and has been determined by the formula:

$$RSC = [HCO_3^{2-} + CO_3^{-}] - [Ca^{2+} + Mg^{2+}] \quad (5)$$

Where all the ionic concentrations were reported in meq/l.The classification of irrigation water according to the RSC values is presented in Table 6. According to the US Department of Agriculture, water having more than 2.5 epm of RSC is not suitable for irrigation purposes while those having 1.25-2.5 epm are marginally suitable and those with less than 1.25 epm are safe for irrigation (Table 6) and the results shows that all the samples are suitable for irrigation.

Table 6. Quality of groundwater based on Residual Sodium Carbonate

RSC	Remark the quality	Samples
>2.5	Unsuitable	Nil
1.25-2.5	Doubtful	Nil
< 1.25	Good	All

Table 7. The Values of SAR and RSC

Samples	SAR	RSC
Opposite MOUAU	0.73	1.02
Umuariaga	0.45	0.08
Amaoba	0.44	0.07
Amawom	0.63	0.15
Umuoro	0.38	-0.17
Isiala *	0.38	0.17
Oloko	0.38	-0.28
Nnono	0.40	0.11
Amizi	0.51	0.10
Ndoro	0.33	0.14

4. CONCLUSION

Based on geoelectrical characteristics (aquifer conductivity and depth), more than one aquifer system exist in the study area. Also, based on the geoelectrical (VES) and groundwater characteristics (aquifer resistivity and groundwater resistivity), a range of values for areas of similar geologic setting and water quality have been observed (Formation Factor).

From the observation, it may be concluded that naturally the groundwater of the study area is potable except for the slightly acidic nature of the samples.

Though the presence of Nitrate (NO_3^-) and Sulphate ($SO4^{2-}$) are at times from anthropogenic sources, they are also naturally occurring in groundwater and their concentrations together with other cations and anions being far below WHO permissible limit indicates that the groundwater of the study area is safe for domestic and drinking purposes. Thus, the presence of these institutions, their activities and associated increase in population has not impacted negatively on the groundwater of the area.

Also, from the observation, it may be concluded that all the sampling stations considered are suitable for irrigation uses according to EC, SAR and RSC values. Therefore, the groundwater samples of the study area are naturally satisfactory for agricultural (irrigation) purposes.

ACKNOWLEDGEMENTS

The contributions of two anonymous reviewers which greatly improved the manuscript is hereby acknowledged.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Amos-Uhegbu C. An investigation to determine the suitability of the Groundwater of Aba Metropolis for Agricultural purposes. Archives of Applied Science Research. 2012;4(5):2027-2033
2. Forster S, Hirata R Groundwater Pollution Risk Assessment: A methodology using available data. A publication of Pan American Center for Sanitary Engineering and Environmental Sciences (CEPIS), Lima Peru. Environmental Health Program of Pan American Health Organization/ World Health Organization. 1988,79pp.
3. Amos-Uhegbu C, Igboekwe MU. Characterization and Quality Assessment of Groundwater in parts of Aba Metropolis Southern Nigeria. Archives of Applied Science Research. 2012;4(5):1949-1957.
4. Bartram J, Balance R. Water Quality Monitoring: A practical guide to the design and implementation of fresh water quality studies and monitoring programmes. In E and F. N. Spoon, (London,). 1996,115pp.
5. Edet A, Okereke C. Hydrogeological and hydrochemical character of the regolith aquifer, Northern Obudu Plateau, southern Nigeria. Hydrogeology Journal. 2005;13:391–415
6. Amos-Uhegbu C, Igboekwe MU, Chukwu GU, Okengwu KO, Eke TK. Hydro geophysical Delineation and Hydrogeochemical Characterization of the Aquifer Systems in Umuahia-South Area, Southern Nigeria. British Journal of Applied Science & Technology 2012,2(4):406-432
7. Asseez LO. Review of the Stratigraphy, Sedimentation and Structure of the Niger Delta". In: Kogbe, C.A. (ed.). Geology of Nigeria. Elizabeth Publ. Co.: Lagos, Nigeria. 1976,259–272.
8. Short KC, Stauble AJ. Outline of the Geology of the Niger Delta. AAPG Bull. 1967;51: 761-769.
9. Onyeagocha AC. Petrography and Depositional Environment of the Benin Formation,Nig. J. Min. Geol; 1980;17(2):147-151.
10. Etu – Efeotor JO, Akpokodje EG. Aquifer Systems of the Niger Delta. J. Min. Geol. 1990,26(2):279-294.
11. Mbonu PDC, Ebeniro JO, Ofoegbu CO, Ekine AS. Geoelectric sounding for the determination of aquifer characteristics in parts of the Umuahia area of Nigeria, Geophysics, 1991;5:284–291.
12. Igboekwe MU, Okwueze EE, Okereke CS. Delineation of Potential Aquifer Zones from Geoelectric Soundings in KWA IBO River Watershed, Southeastern, Nigeria. Journal of Engineering and Applied Sciences 2006,1(4):410-421.
13. Griffiths DH, King RF. Applied Geophysics for Geologists and Engineers: In:*The* Elements of Geophysical Prospecting. Pergamon Press Ltd., Headington Hill Hall, Oxford OX3 OBW, England. 1983, 230pp.
14. Kearey P, Brooks M. An Introduction to Geophysical exploration. 2nd Edition. Blackwell Science, Cambridge University Press. 1991, 254pp.
15. International Standard Organization (ISO) Water quality determination of sum of Calcium and Magnesium. (Geneva 1990).
16. United Nation Environmental Programme (UNEP). Environmental Data Report, 3rd ed., 1996;58-60.
17. Archie GE. The electrical resistivity log as an aid in determining some reservoir characteristics. Amer.Inst. Min. Met. Eng., Tech. Pub. 1422, Petroleum Technology. 1942,8pp.

18. World Health Organization. Guidelines for Drinking Water Quality, Health Criteria and Other Supporting Information; 2004. 3rd Ed; Recommendations, Geneva. 1.
19. Trembley J, D'Cruz J, Anger H. Saltwater intrusion in the Summerside Area, P.E.I.Groundwater.; 1973;11:4.
20. Udom GJ, Acra EJ. Hydrochemical characteristics of groundwater in Andoni Local Government Area, Rivers State. Jour of Research in Physical Sciences. 2006;2(1):35-41.
21. Ekpete OA. Determination of Physico-Chemical Parameters in borehole water in Odihologboji community in Rivers State. Afr. J. Interdiscip. Stud. 2002;3(1):23-27.
22. Saleh A, Al-Ruwaih F, Shehata M. Hydrogeochemical processes operating within the main aquifers of Kuwait. J Arid Environ. 1999;42:195–209.
23. Karanth KR. Ground water assessment, development and management. Tata McGraw Hill, New Delhi, India. 1987;720pp.
24. Richards LA. Diagnosis and improvement of Saline and Alkali Soils. Agric. Handbook 60, U.S. Department of Agriculture, (Washington, D.C. 1954;160.
25. Eaton FM. Significance of carbonates in irrigation waters. Soil Science. Nature and Science 8:10. 1950;69:123-133.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=317&id=22&aid=2587