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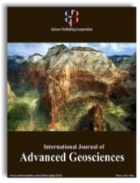
Research paper



Evaluation of groundwater resources within Ankpa and environ, north central Nigeria

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Abstract

Geophysical and Geochemical assessment of groundwater in part of Northern Anambra Basin has been evaluated. The groundwater potentials, aquifer characteristics and groundwater quality within the study area have been delineated. This is aimed is at establishing the depth to watertable and potability of the groundwater within the area. Twenty-(20) vertical electrical soundings (VES) were acquired with a maximum half current electrode spacing of 150 metres using ABEM 4000 SAS Tetrameter. Hydrogeochemical analysis was carried out using HANA Model Hi 83200 multi parameter ion specific meter to evaluate the basic anions and cations in the water samples. Piper, Durov and Schoeller semi-logarithmic plots were drawn to characterize the water types. Results from the geo-electric sections revealed the presence of five to seven geo-electric layers. The depth to water table ranges between 20m and 161.1m. The depth to Watertable is deepest around Ogene area with depth of 161.1m. The result of the geophysical analysis correlates with the borehole data acquired from the study area. Results from hydrogeochemical studies revealed that the concentrations of ions are in the order of Ca^{2+}> Na^{2+}>K^{+}>Mg^{2+} and HCO_3->NO_3^->SO_4^{2-}>Cl^- in Anyigba area, Na^{2+}>K^{+}> Ca^{2+}>Mg^{2} and Cl^- >HCO_3->NO_3^->SO_4^{2-} Ankpa area while in Ejule area Mg^{2+}> Na^{2+}>K^{+}> $Ca^{2+}$and Cl^- >HCO_3->NO_3^->SO_4^{2-}. These fall within the WHO (2006) drinking water standard. It is recommended that an average depth of 75m should be drilled for borehole within the northern part of the studied area and a depth of about 100m in the southern part of the study area. In addition, the water is recommended for domestic use.

Keywords: *Groundwater Potentials; Water Types; Aquifer Characterization; Piper Diagram and Potability.*

1. Introduction

Groundwater availability is also as important as portability since water is of great economical value. Hence, there is a great need to evaluate the groundwater resources of the study area (Omali., 2014 and Alile, et al 2008). Consequently, the increase in population of people as a result of increase in Industrial, Educational and Agricultural activities and inaccessibility of the inhabitants to potable water necessitates this study.

The study area falls within the Northern Anambra basin. It is bounded by Longitudes $7^{0}\,00^{1}00^{11}$N and $7^{0}45^{1}00^{11}$N and latitudes $6^{0}45^{1}00^{11}$E and $07^{0}45^{1}00^{11}$E (Fig.1). There are available surface water such as Okura, Ofu and Mabolo rivers among others which are tributaries to the River Niger. Water supply to the growing population is mainly by surface water schemes because of limited boreholes. It is against this background that the study becomes necessary.

The objectives include: Determination of the geo-electrical and hydro-geological characteristics of the aquifers, geochemical assessment of the surface and groundwater, delineation of the water types, aquifer thickness and their geometries, determination of potential aquiferous layers and boundaries from the geo-electric sections, correlate the geo-electric sections/VES curves with various rock lithologies from well logs and relate them to aquifer potentials and to compare the differences in the hydraulic properties of the geologic formations underlying the study area.. Again, there are scanty literature and very limited or no detailed data on water resources and long term yield capabilities of aquifers within the study area. Most of available water schemes in the area are obsolete, making the accessibility to groundwater resources within the area in terms of availability and quality to be very difficult.

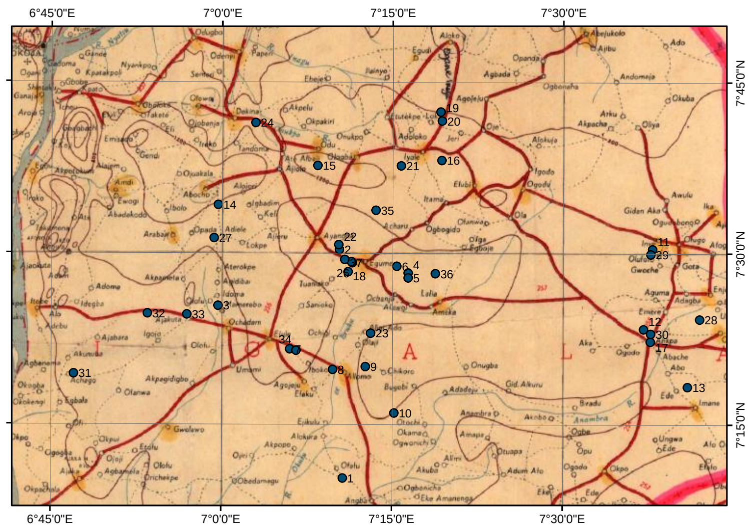


Fig. 1: Accessibility Map of the Study Area (Omali, Et Al, 2018).

2. Geology and hydrogeology of the study area

The Anambra Basin is one of the Nigerian's most important sedimentary basins and comprises an almost triangular shaped embayment covering an area of about 30,000 Km^2 (Offodile,2002) (Fig. 2). The sequence of depositional events demonstrates a progressively deepening of the Anambra basin, from lower coastal plain shoreline deltas to shoreline and shallow marine deposits. According to Obaje (2009), sedimentation in the Anambra Basin commenced with the Campanian – Maastrichtian marine paralic shales of the Enugu/Nkporo Formations.

The fluvio – deltaic sandstones of the Ajali and Owelli Formation which lie on the Mamu Formation constitute its lateral equivalents in most places. The sandstone unit is white in colour, coarse grained and poorly sorted. Constituent pebbles are well rounded while finer grains are sub – rounded. The composite thickness of the Owelli Formation is approximately 50m around Owelli. The most important aquiferous formation in the Anambra Basin is the Ajali Formation, consisting of a heterogeneous lithological sequence. The Anyigba area is overlain by the Ajali Formation. The sandstone beds of the Ajali Formation are confined in places and have produced artesian conditions. According to Kogbe (1989), the Nsukka Formation overlies the Ajali Formation conformably. Good exposures of the Nsukka Formation are rare except around some of the areas west of Nsukka and it consists of an alternating sequence of laminated, very fine sandstone and siltstones. There are also brown and grey shales and sandy shales and mudstone with numerous coal seams at various horizons. The Nsukka Formation was not noticed in the study area, is overlain conformably by the Ajali sandstone (Upper Maastrichtian). These Formations collectively consists of the following lithologic units in the study area: shale, clay, whitish sand, reddish sand, brownish sand, laterites, ferruginised sandstones and alluvial deposits.

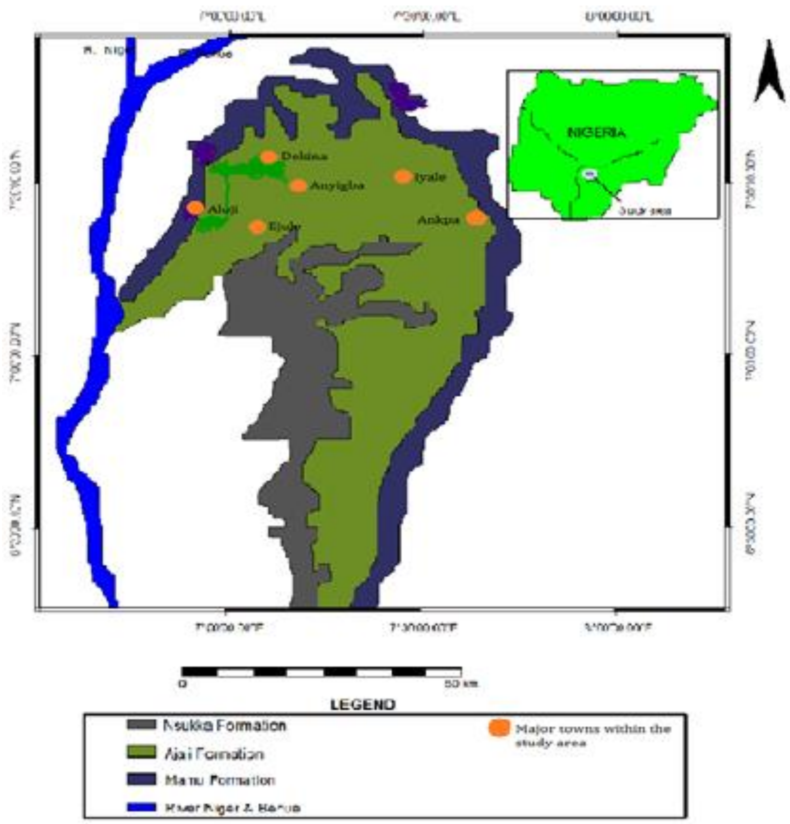


Fig. 2: Geological Map of Anambra Basin Showing the Study Area (modified from Umeji, 2005).

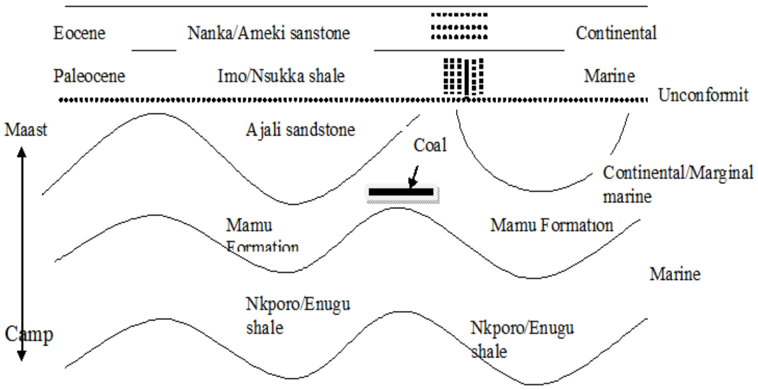


Fig. 3: Stratigraphic Successions in the Anambra Basin (After Obaje, 2009).

3. Method of study

Groundwater assessment within part of Kogi East, Northern Anambra Basin has been carried out using Geophysical and Geochemical techniques. Geophysical investigation was done using vertical electrical sounding (Schlumberger method) to delineate the subsurface resistivity by sending an electrical current into the subsurface and measuring the potential field generated by the current on the resistivity meter (Tetrameter). Vertical Electrical Sounding (VES) was conducted at twenty-two stations in the study area using Schlumberger configuration. The maximum half-current electrode spacing (AB/2) ranges from 250 to 500m. The survey was conducted along the existing major and minor roads with good stretch and at the vicinity of existing boreholes in the study area.

Vertical Electrical sounding using Schlumberger array was carried out by keeping the electrode array centered over a field station while increasing the spacing between the current electrodes and consequently increasing the depth of investigation. The potential difference (ΔV) and the electrical current (I) are measured for each electrode spacing and the apparent resistivity (ρ_a) is calculated by the equation 1 below.

$$\rho_a = G\frac{\Delta v}{I}(ohm - m) \quad (1)$$

Where, ρ_a = Apparent resistivity of the aquiferous layer; G = the geometric factor of the electrode arrangement; Δv = potential difference; I = current

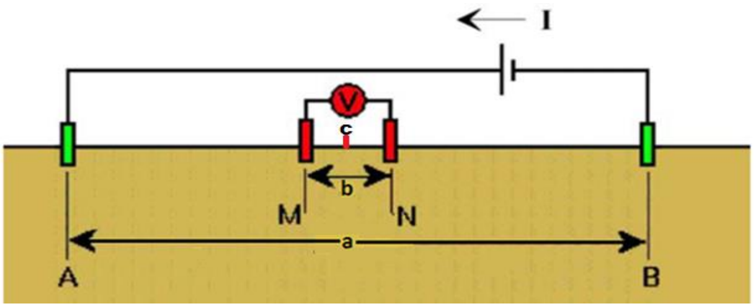


Fig. 4: Diagrammatic Representation of Schlumberger Array.

By repeating the Schlumberger measurements with the entire setup moved one step to the side, vertical electrical sounding (VES) were performed continuously and the resistivities of the subsurface layers were measured. A plot of apparent resistivity (ρ_a) against current electrodes spacing was plotted on a bilogarithimic graph.

The apparent resistivity data are associated with varying depths relative to the distance between the current and potential electrodes and can be interpreted qualitatively and quantitatively in terms of lithologic and or geo-electric models.

23 samples of Groundwater were collected from boreholes within the study area at the peak of the dry season to prevent dilution effect of precipitation and contamination associated with storm water runoff (Thomson, 1996). Each sampling bottle was allowed to get filled to the brim and capped. Parameters such as Temperature, colour, Total Dissolved Solid (TDS), Dissolved Oxygen (DO), pH and Electrical conductivity were taken at each location in the field for all the water samples using HANA model HI 83200 multi parameter ion specific meter, pH meter and conductivity meter respectively. Furthermore, 0.5 liters of water samples were taken for laboratory analyses. The samples were protected from heat and contamination by chemicals. Cationic compositions were determined using Atomic Absorption Spectrophotometer (model 210 VGP) at the Department of Earth Sciences, Kogi state university Anyigba. The concentration of anions such as No_3^- and Cl^- were determined by titrimetric method in the Geochemistry laboratory of the University. Results of the analyses are presented in tables 4, 5 and 6. The chemistry of the water samples are plotted on Piper, Durov and Schoeller diagrams (figures 9-17).

4. Results, interpretation, and discussion

4.1. Geophysical results and interpretations

The interpretation of the resistivity data of the twenty (20) stations represented as V1-V20 shows basically five to six geo-electric horizons. However eight (8) out of the twenty VESs were made at the sites of the existing boreholes for comparative purposes to check the efficiency of this method. Below are detailed descriptions of some of the VES results.

VES 1: (Fig. 5 and Table 1) has five geo-electric layers. The sounding curve at this station is of AKH model. The first layer comprises the topsoil, 5.5m thick and has resistivity of 169Ωm. The second layer is composed of laterite of thickness and depth 12.2m and 17.2 respectively. The resistivity of this layer is 394.2Ωm. The third layer can be interpreted as sandstone, the depth of this zone is 55m, with thickness of 37.8m and resistivity of 2801.3Ωm. The fourth layer is interpreted as fairly saturated to saturated sandstone to a depth of 126m with thickness of 71.0m and resistivity of 1002.9m. Underlying this unit has a high conductivity value and it is interpreted as impermeable clay.
VES 4: The first layer consists of topsoil which has a thickness of 2.5m and resistivity of 257.92Ωm. The second layer is composed of laterite with thickness of 5.0m at a depth of 2.5m and resistivity of 13051.7Ωm. The third layer is mainly sandstone with thickness of 33.8m at a depth of 38.8m and resistivity value of 11876.Ωm. This is followed by the fourth layer which is fairly saturated sandstone layer with thickness of 37.9m and at a depth of 54.2m and resistivity value of 59967.3Ωm. Underlying which is the fifth layer is a compacted saturated sandstone layer with a resistivity of 56301.9Ωm.
VES 7: Six horizons are delineated in Fig. 7 and Table 3. The uppermost layer has a resistivity value of 198.9Ω-m and 1.95m thick. It is interpreted as top lateritic soil. The second layer has a resistivity value of 535.9Ω-m and a thickness of 7.26m which is interpreted as sandy clay. The third layer has a resistivity value of 3364.7Ω-m with thickness of 3.0m and interpreted as clayey sand. The forth layer has a very high resistivity value of 53356Ω-m with thickness of 140.22 m. It is interpreted as dry sandstone. The fifth layer has a thickness of 20m and has moderate resistivity value of 2231Ω-m. It is interpreted as water saturated sandstone which is the prospective aquifer of interest. The sixth layer whose base was not reached has a resistivity value of 621Ω-m and interpreted as clayey sand.
VES 16: Six geo-electric sections were delineated in this location (Fig.8 and Table 4). The topmost layer has a resistivity value of 721.0Ω-m which is 0.5m thick and interpreted as top lateritic soil. The second layer has a high resistivity value of 1121Ω-m and a thickness of 0.8 metres which is interpreted as sandstone. The third layer has a resistivity value of 1321Ω-m with thickness of 57m and interpreted as sandy shale. The forth layer has a very high resistivity value of 19813Ω-m with high thickness of 30m. It is interpreted as dry sandstone. The fifth layer has a thickness of about 30m and has a relatively moderate resistivity value of 2210Ω-m. It is interpreted as water saturated sandstone which is the prospective aquifer of interest. The last layer whose base was not reached has low resistivity value of 431.2Ω-m and interpreted as sandy clay.

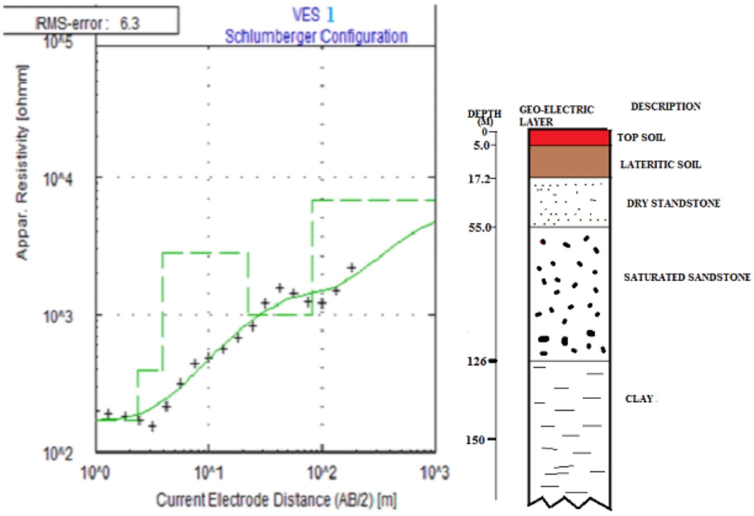


Fig. 5: Sounding Curve and Descriptive Section for VES 1 (AKH-Type).

Table 1: Geo-Electric Section of VES 1

VES 1 Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth	Remarks
1	I69	5.0	5.0	Top soil
2	394.2	12.2	17.2	Lateritic sand
3	2801.3	37.8	55.00	Dry sandstone
4	1002.9	71.0	126	Water Saturated Sst.
5	1,125	Base Not Reached		Clayey

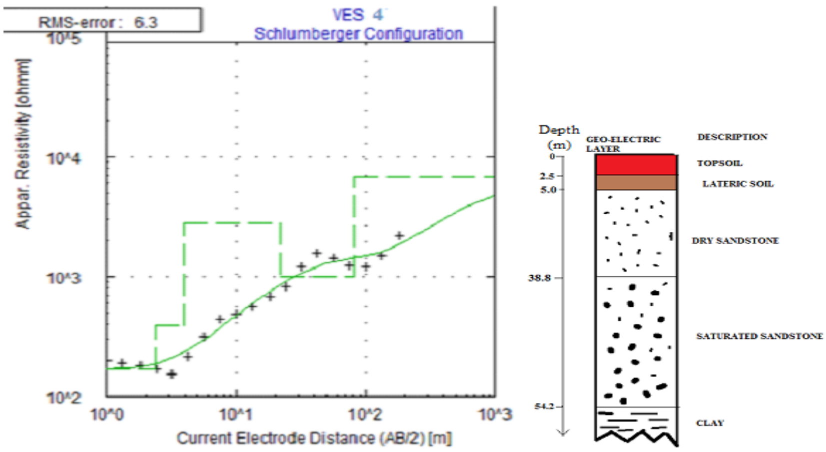


Fig. 6: Sounding Curve and Descriptive Section for VES 4 (KHA-Type).

Table 2: Geo-Electric Section of VES 4.

VES 4 Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth	Remarks
1	257.92	0.5	0.5	Top soil
2	13051.7	1.9	2.4	Lateritic sand
3	11876.5	13.8	16.2	Dry sandstone
4	9967.3	37.9	54.2	Water Saturated Sst.
5	56301.9	Base Not Reached		Clayey Sandstone

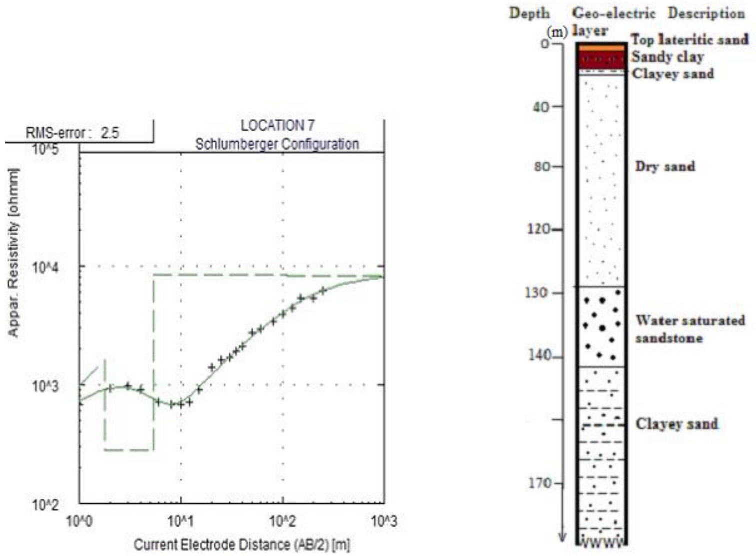


Fig. 7: Sounding Curve and Descriptive Section for VES 7 (K-Type).

Table 3: Geo-Electric Section of VES 7

VES 7 Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth(m)	Remarks
1	198.9	1.95	1.95	Top lateritic sand
2	544.9	7.26	9.21	Sandy clay
3	3244.7	3.00	12.21	Clayey sand
4	61356	140.13	158.34	Dry sand
5	2161	20.0	178.34.0	Water Saturated sand
6	621	Base Not Reached		Clayey sand

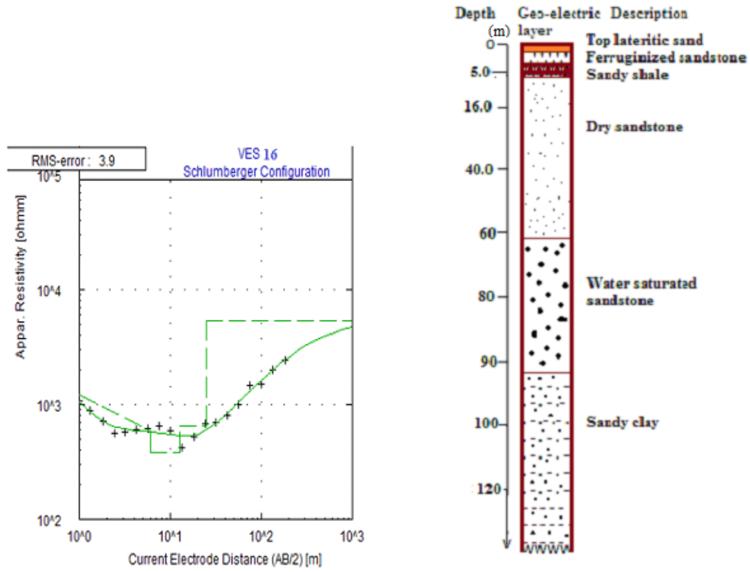


Fig. 8: Sounding Curve and Descriptive Section for VES 16 (K-Type).

Table 4: Geo-Electric Section of VES 16

VES 16 Layer	$\rho_a(\Omega m)$	Thickness(m)	Depth(m)	Remarks
1	721.0	0.50	0.50	Lateritic sand
2	1121	0.8	1.30	Ferruginised Sst.
3	1321	3.7	5.0	Sandy shale
4	19813	57.0	62.0	Dry Sandstone
5	2210.0	30.0	92.0	Water Saturated sand
6	431.2	Base not Reached		Sandy Clay

5. Geochemical analysis of the water samples

5.1. Hydrogeochemical result (facies)

The results of the physio-chemical analysis of water samples collected from Anyigba, Ankpa and Ejule areas are presented in tables 5, 6 and 7 below.

Table 5: Summary of Physical and Chemical Parameters of Groundwater in Anyigba Area.

Locations	Borehole Sources Specific Eatary	Ajetachi	K.S.U Main Borehole	Egume	Ogene	Ijoji	Who Standards (2006)		Nigeria Standard (2005)
G.P.S Readings	N7'29' 16.6'' E7'10' 42.5''	N7'29' 43.0'' E7'10' 18.0''	N7'29' 06.0'' E7'10' 51.0''	N7'28' 15.8'' E7'16' 25.6''	N7'28' 51.2'' E7'15' 26.2''	N7'27' 450.2'' E7'16' 47.6'	High Desirable Level	Maximum Permissible Level	Maximum Permitted Level
Colour	Clear	Clear	Clear	Clear	Clear	Clear	5	50	15
Ph	6.6	6.5	6.5	6.6	6.5	6.6	7.0 – 8.5	6.5 – 9.2	6.5 – 8.5
Temp ^{O}c	28.5	28.0	27.5	28.0	28.5	28.0	Na	Na	Ambient
Electrical Conductivity µc/Cm	0.02	0.02	0.01	0.03	0.03	0.02	Na	250	1000
T.D.S Mg/L	14	23	16	22	20	19	500	1500	500
D.O	3.05	3.06	3.26	3.02	3.18	3.16	Na	Na	Na
Cations (Mg/L)									
K^+	0.18	0.20	0.22	0.20	1.12	1.09	10	15	Na
Mg^{2+}	0.05	0.04	0.07	0.20	0.12	0.05	50	150	0.20
Fe^{2+}	0.05	0.04	0.07	0.20	0.12	0.05	0.1	1.0	0.3
Na^{2+}	0.31	0.47	0.23	0.24	0.25	0.20	150	200	200
Cu^{2+}	0.03	0.03	0.04	0.03	0.03	0.04	0.05	1.5	1
Ca^{2+}	0.92	0.87	1.02	1.10	1.10	0.85	75	200	Na
Zn^{2+}	Nd	Nd	Nd	Nd	Nd	Nd	5.0	15	3
Anions (Mg/L)									
No_3-	10.30	10.34	10.21	10.70	11.13	10.23	45	50	50
So_4^{2-}	7.01	7.98	8.63	8.02	7.09	6.82	200	400	100
Cl-	0.065	0.067	0.068	0.066	0.072	0.069	200	600	250
Hco_3^-	98.11	99.86	101.95	99.01	91.06	89.42	200	600	Na

NA= Not applicable ND= Not detected.

Table 6: Summary of Physical and Chemical Parameters of Groundwater in Ankpa Area.

Locations	Borehole Source					Spring Source		Shallow Water Source			Who Standards (2006)		Nigeria Standads (2005)
	Ankpa	Coe	Sabima	Itodo Compd.	Munaja	Ikebe	Imane	Ojede 1	Ojode Ii	Sabon Gari	High Desirable Level	Maximum Permissible Level	Maximum Permitted Level
Colour	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	5	50	15
Ph	6.0	6.5	6.80	6.1	6.21	6.95	6.98	5.58	5.56		7.0 – 8.5	6.5 – 9.2	6.5 – 8.5
Temp ^{O}c	26	26	25	25.5	26	24	25	27	27		Na	Na	Ambient
Electrical Conductivity µs/Cm	1277	0.52	211	103	.59	.17	.15	283	202		Na	250	1000
T.D.S Mg/L	84.2	0.51	0.43	0.43	0.39	164.0	164.1	.51	169.0		500	1500	500
D.O	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd		Na	Na	Na
Cation (Mg/L)													
K^+	26.15	0.066	1.330	0.203	0.286	0.127	0.126	1.997	1.770	0.811	10	15	Na
Mg^{2+}	6.692	0.119	0.682	0.181	0.283	0.073	0.065	0.892	0.827	0.592	50	150	0.20
Fe^{2+}	0.015	0.016	0.013	0.015	0.014	0.009	0.007	0.007	0.016	0.012	0.1	1.0	0.3
Na^{2+}	49.6	1.144	5.556	0.479	0.566	0.328	0.324	10.48	3.967	2.825	150	200	200
Cu^{2+}	0.003	0.011	0.006	0.006	0.021	0.001	0.001	0.000	0.001	0.001	0.05	1.5	1
Ca^{2+}	16.44	0.515	2.269	5.296	1.436	0.495	0.466	3.405	4.273	1.801	75	200	Na
Zn^{2+}	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.0	15	3
Anions (Mg/L)													
No_3-	0.98	0.24	0.21	0.31	0.49	1.84	1.80	0.42	1.69	0.43	45	50	50
So_4^{2-}	21.6	11.0	10.1	11.2	12.3	49.6	44.5	2.1	48.6	11.2	200	400	100
Cl-	112.2	62.3	80.1	64.2	46.1	204.2	202.0	76.1	212.4	69.5	200	600	250
Hco_3^-	104.1	0.81	0.69	0.98	1.08	212.2	201.2	1.16	214.1	1.02	200	600	Na

NA= Not applicable ND= Not detected.

Table 7: Summary of Physical and Chemical Parameters of Groundwater in Ejule Area.

Locations	Borehole Source Marist College Ejule	Ejule Town	Iboko	Ofabo	Who Standards (2006)	Nigeria Standard (2005)

G.P.S Readings	N7'29' 16.6'' E7'10' 42.5''	N7'29' 43.0'' E7'10' 18.0''	N7'29' 06.0'' E7'10' 51.0''	N7'28' 15.8'' E7'16' 25.6''	High Desirable Level	Maximum Permissible Level	Maximum Permitted Level
Colour	Clear	Clear	Clear	Clear	5	50	15
Ph	6.32	6.33	6.50	6.50	7.0 – 8.5	6.5 – 9.2	6.5 – 8.5
Temp ^{O}c	25•C	25.5•C	26.0•C	26•C	Na	Na	Ambient
Electrical Conductivity μs/Cm	0.71	0.66	0.52	0.47	Na	250	1000
T.D.S Mg/L	102.0	96.2	101.5	88.2	500	1500	500
D.O	Nd	Nd	Nd	Nd	7.0 – 8.5	6.5 – 9.2	6.5 – 8.5
Cations (Mg/L)							
K^+	4.6	4.3	4.8	3.8	10	15	Na
Mg^{2+}	15.8	15.1	14.7	14.3	50	150	0.20
Fe^{2+}	0.02	0.02	0.03	0.03	0.1	1.0	0.3
Na^{2+}	3.4	3.0	3.3	3.8	150	200	200
Cu^{2+}	0.012	0.013	0.008	0.006	0.05	1.5	1
Ca^{2+}	12.2	11.6	12.8	13.1	75	200	Na
Zn^{2+}	Nd	Nd	Nd	Nd	5.0	15	3
Anions (Mg/L)							
No_3-	12.86	11.92	10.77	13.31	45	50	50
So_4^{2-}	8.22	7.91	6.89	7.46	200	400	100
Cl-	52.10	53.5	38.6	44.8	200	600	250
Hco_3^-	7.73	8.02	9.66	9.05	200	600	Na

NA= Not applicable.
ND= Not detected.

5.2. Water quality and usability

5.2.1. Physical parameters

pH of groundwater samples in Anyigba area ranges between 6.5 to 6.6, in Ankpa and environs it varies from 5.56 to 6.98 whereas, in Ejule area, the water samples recorded pH values of between 6.32 and 6.50. These values fall within the World Health Organization (WHO) and Standard Organization of Nigeria (SON) maximum permissible level for drinking water. The electrical conductivity values in these areas range between 0.01 to 0.03μs/cm, 15 to 127703μs/cm and 0.47 to 0.7103μs/cm respectively. These values are within the WHO (250μs/cm) and SON (1000μs/cm) permitted levels.
In addition, the total dissolved solids (TDS) in the sampled areas recorded values ranging from 14mg/l to 23mg/l in Anyigba area, 0.39mg/l to 169mg/l in Ankpa axis and 88.2mg/l to 102mg/l in Ejule area. These Fall below WHO and SON guidelines for potable water (tables 5, 6, and 7)

5.2.2. Cationic concentration

Cationic concentrations in the water samples from Anyigba area include; Potassium K^+ 0.18 to 1.12mg/l, Magnesium Mg^{2+}, 0.04 to 0.12mg/l, Iron Fe^{2+} 0.0 to 0.12mg/l, sodium Na^{2+}, 0.20 to 0.47mg/l, and Calcium $Ca^{2+,}$ 0..85 to 1.10mg/l. All the analyzed cations fall within the standards for potable water by WHO and SON. This also applies to the samples collected from Ankpa and Ejule areas (tables 6 and 7).

5.2.3. Anionic concentration

Nitrate (NO_3^-) concentration varies from 10.23 to 11.13mg/l in water samples collected from Anyigba area. In Ankpa area it ranges from 0.21 to 1.8mg/l, while in Ejule area, it recorded values ranging from 10.77 to 13.31mg/l. These values are in tandem with the maximum permissible levels of 50mg/l stated in the tables above. Also, bicarbonate (HCO_3^-) concentrations range between 89.42mg/l to 101.95mg/l, , 0.69 to 214.1mg/l and 7.73 to 9.66mg/l respectively. These cations and others including sulphate ($SO_4^{2-)}$ and Chloride (Cl^-) in the areas studied are within the acceptable limits for both the WHO and SON for drinking water. Hence, the groundwater in the study area is fit for domestic use.

5.3. Results of piper diagrams, durov diagrams and schoeller semi-logarithmic plots

Piper trilinear, Durov and Schoeller diagrams were generated for groundwater within the study area (Fig. 9 to 17). Hence, the groundwater and the surface water composition and character were determined. Akakuru et al (2015) noted that during groundwater movement along its path, from recharge to discharge areas, a variety of chemical reactions with solid phases take place. They maintained that these chemical reactions vary spatially and temporally, depending on the chemical nature of the initial water, geological formations, and residence time. The resulting concentrations of major ions of groundwater can be used to identify the intensity of rock–water interaction and chemical reactions.
From the hydrochemical plots in figures 9 to 17, different chemical characters have been established. The groundwater from Anyigba area indicated Ca-HCO_3^- water type. This represents recently recharged water of meteoric origin that resulted from the dissolution of allumino-silicates. In Ankpa area, the groundwater sample indicated Na+K-Cl water type. This reflects fossil water whose origin is natural and anthropogenic
In Ejule and environs, Ca-Cl and Mg-Cl water types have been established from plots on piper and Durov diagrams. This reflects water of intermediate compositions that evolved by simple hydrochemical mixing and reverse ion exchange. Also, the presence of chloride (Cl^-) is an indication of the old water contained in a deep aquifer.
However, changes in the chemistry of groundwater occur as the water moves from shallow zones of acting flushing through intermediate zones into zones where the flow is very sluggish and the water is old. However, this sequence must be looked into in terms of the scale and geology of the area, with allowances for interruption and incompletion.

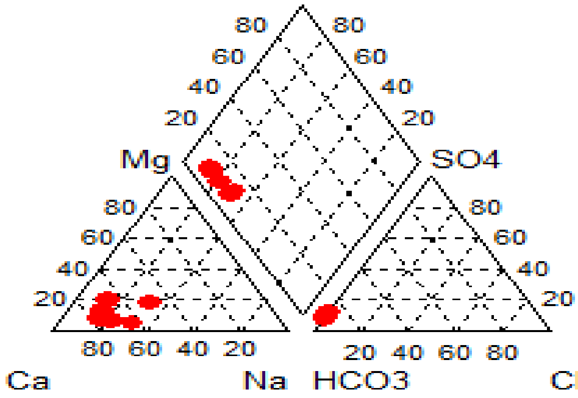
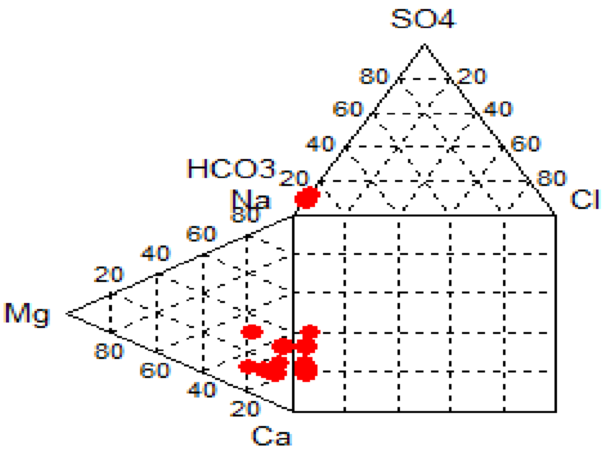


Fig. 9: Piper Trilinear Diagram Plot of Water Samples in Anyigba Area Showing Ca- HCO_3 Water Type.



Fg 10: Durov Diagram Plot of Water Samples in Anyigba Area Showing Ca-HCO_3 Water Type.

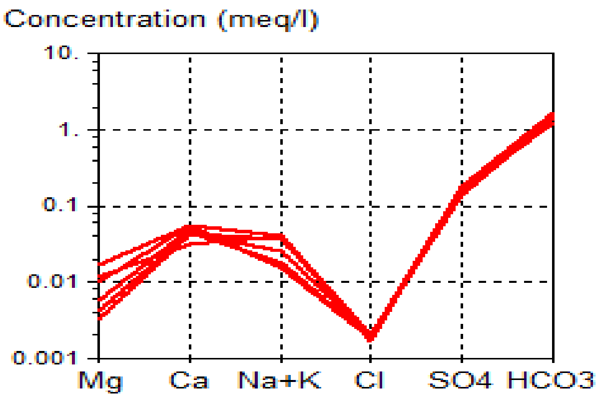


Fig. 11: Schoeller Semi-Logarithmic Plot of Water Samples in Anyigba Area Showing A Trend of Hco_3 > So_4 > Ca> Na+K > Mg> Cl.

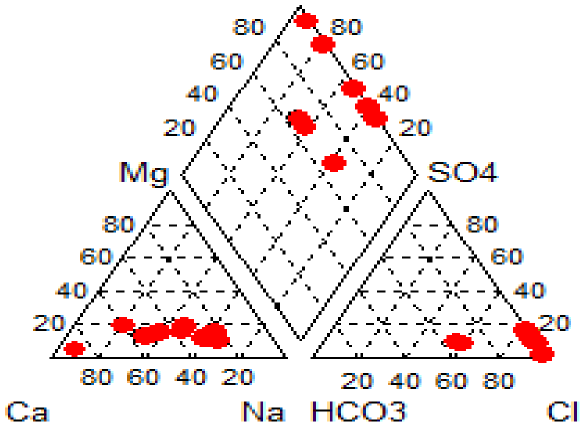


Fig. 12: Piper Trilinear Diagram Plot of Water Samples in Ankpa Area Showing Na+K-Cl Water Type.

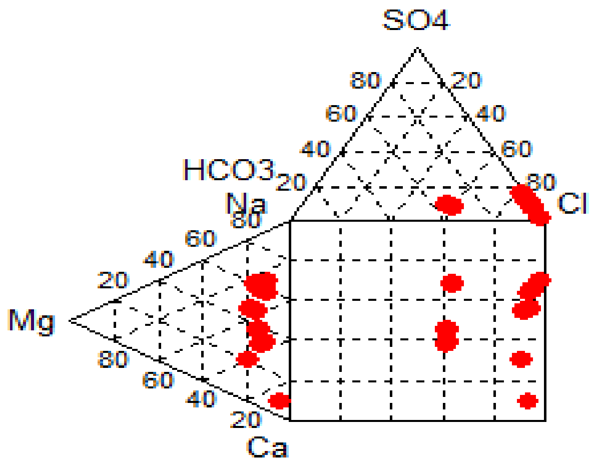


Fig. 13: Durov Diagram Plot of Water Samples in Ankpa Area Showing Na^{+}+K-Cl Water Type.

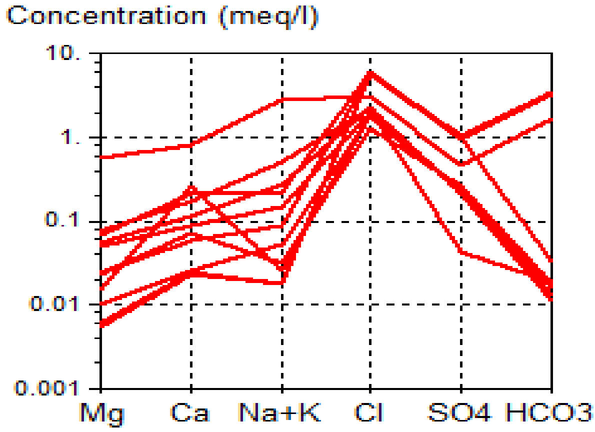


Fig. 14: Schoeller Semi-Logarithmic Plot of Water Samples in Ankpa Area Showing A Trend of Cl> HCO_3> SO_4 > Na+K > Ca> Mg.

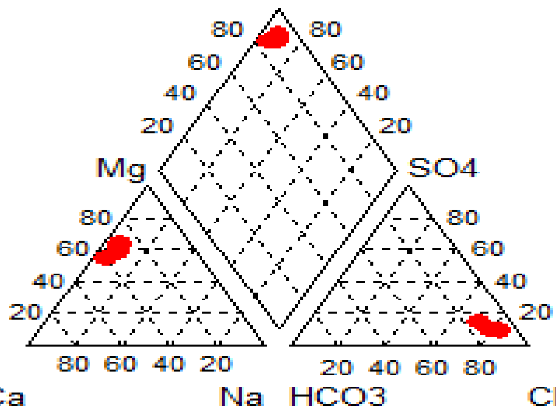


Fig. 15: Piper Trilinear Diagram Plot of Water Samples in Ejule Area Showing Ca-Cl Water Type.

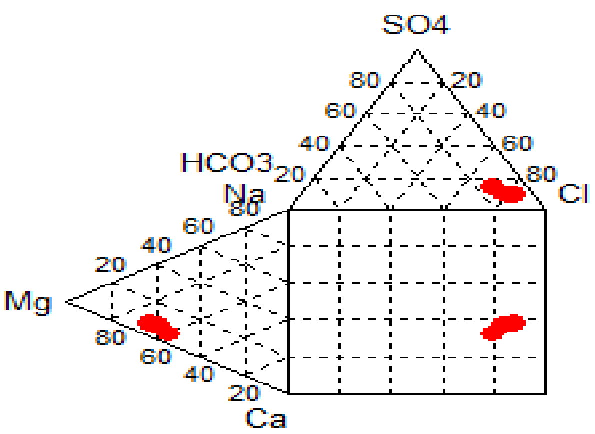


Fig. 16: Durov Diagram Plot of Water Samples in Ejule Area Showing Mg-Cl Water Type.

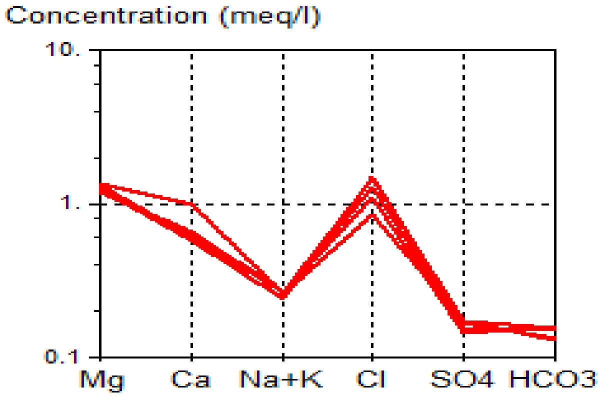


Fig. 17: Schoeller Semi-Logarithmic Plot of Water Samples in Ejule Area Showing A Trend of Cl>Mg >Ca> Na+K > SO_4 >HCO_3

6. Conclusions and summary

Analysis from the hydrogeochemical studies reveals that the concentration values of Na^{2+}, Ca^{2+}, Zn^{2+}, SO_4^{3-}, Cl^- and NO_3^- in the three water samples analyzed fall within the WHO (2006) drinking water standard. From the hydrogeochemical plots, there exist similarity in water type, between the water sources; this suggests that similar geochemical processes may be controlling major ion chemistry in these aquifers, and that the waters had the same or similar origins. Schoeller semi logarithm diagram shows that the surface water in the study area is not of one dominant type. The close to parallel lines of the Schoeller diagram for groundwater portrays it to be composed of equal ratio of ions, thus of one dominant type, while the surface water is not.

The modeled interpretation from computer analysis revealed the presence of five to seven geo-electric layers. The layer resistivity is a function of porosity, moisture content present in the pore spaces and the rock matrix. The depth to water table in the study area varies between 20m and 151.1m and the aquifer thickness was revealed to be highest in Ogene, Acbocho and Egume areas. The depth to Watertable is deepest around Ogene area.

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