Delineation of Aquiferous Zones in Some Parts of Umuahia and Uzuakoli Environs Using Vertical Electical Sounding Data

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DOI: https://doi.org/10.51583/IJLTEMAS.2024.130309

Received: 18 February 2024; Accepted: 09 March 2024; Published: 15 April 2024

Abstract

A delineation of aquiferous zones in some parts of Umuahia and Uzuakoli environs was carried out using Vertical Electrical Sounding (VES). A total of fourteen (14) VES data were acquired at different locations. Cross sections of the VES data were interpreted and correlated along profiles. The results showed that sands constitute the aquifer units while clay and shale made up the aquiclude. Aquifer units occur at shallow depths in some places such as Ibeku, Umule, Ohuhu, at 9m to 30m with thickness range of 9 m to 50m while some places such as Isingwu, Nkpa, Amachara, Ubakala, Lohum, Etitulo Bende areas have deep aquifer units with the depth to the top of aquifer ranging from 40m to 115m and the aquifer thickness ranges from 17m to 102m.The degree of the relationship of the aquifer parameters were investigated using some statistical analysis in which the coefficient of correlation between depth and resistivity is 0.6; From the analysis, it has been ascertained that there exist shallow and deep aquifer systems within the Ameki Formation and the depth to the top of these aquifers are in range of 40 m to 115m. The deep aquifer systems except the shallow units are confined. Recommended total drill depth (TDD) to guide a successful water borehole prospecting in the area should be 140m in the North, 180m in the south and west flank of the study area.

Keywords: Aquifer parameters, Borehole, Correlation, Delineation, Depth, Formation, Resistivity

1.0 Introduction

Sedimentary basins are known to have most prolific aquifers and their aquifer materials are often fairly homogeneous. The surface observations of the localities show disparity in rocks that makeup the subsurface of these areas. From south to north, top soil changes from coarse sands to gritty sandstone intercalating with clay and sometimes only clay. By this harnessing groundwater may not the same or uniform in every place within the study area. The study area comprises of three geologic Formations which can be investigated with geophysical methods to understand the lithologies of the different parts. However, of major concern for this study is to delineate the aquifer zones in Umuahia and the neighbouring towns. There has been some case of boreholes failing to yield enough water in certain areas within the sedimentary basin. This is however more prevalent in crystalline basements (Ajayi &Abegurin,1994).

The technique of using electrical resistivity to interpret rock units is of immense help in the search for groundwater, Nwugha et al., (2020). It will explore parameters such as aquifer resistivity, thickness as well as depths to water table. The thickness and depth of each unit has not been properly determined and this has caused a great financial loss and mismanagement in terms of groundwater development in this area. This may be due to lack of knowledge of the subsurface geology of the area. Also incessant abortive wells and numerous cases of re-drilling of boreholes before a successful one is achieved have necessitated the zeal to seek for a good understanding of the subsurface geology and the structural disposition of the subsurface layers. Vertical Electrical Sounding (VES) is a very good tool and aid accurate mapping of the subsurface geologic layers and the delineation of aquiferous zones in tectonically stable sedimentary basins (Eke,Cookey & Ejiogu 2018, Ejiogu et al.,2021).

This study which is aimed at delineating the aquifer zones in environs of Umuahia. The objectives include determining the distribution of the producing aquifers, establishing the direction in which the Formation thins out and proposes the optimum borehole depths for the study area. Vertical Electrical Sounding (VES) is a field experimental (science practical) method of acquiring resistance of rocks for geophysical analysis used in geologic interpret

2.0 Location and Geology of the Study Area

The study area is located in Southeastern part of Nigeria within latitudes 5° 25' N to 5° 41'N and longitudes 7° 25' E to 7°43'E. The major towns found in this area include: Umuda, Nkpa, Lohum, Afugiri, Ubani, Isingwu, Umuahia, lbeku and Ubakala., Figure 1.The

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue III, March 2024

area is drained by some perennial rivers such as lnyang river, Otenyi River, Eme River, Imo River, etc. The drainage pattern is dendritic. There are three Formations in the study area namely: Benin Formation in the southwestern part, Benin Formation, Pliocene in age consists of alternating layers of sands, sandstones and loams with clays. As the sandy component in most of the areas form more than 90% of the sequence of the layers, permeability, transmissivity and storage co-efficient are high. The Ogwashi Formation of the Pleistocene age is in the central region and Ameki Formation in the northern area. Ogwashi Formation consists of clay that is gritty, pebbly sandstone units and lignite seams. The Ameki Formation is of Eocene age, consisting of series of highly fossiliferous grayish- green sandy clay with calcareous concretions and white clay sandstones. Sandstones are associated with primordial radionuclides (Nwaka, et al., 2018). The thickness may attain as much as 1400m in some places (Lambert-Akhionbare, Ogbe & Oteze, 1977)

The beds dip gently between 5° to 7°S. Near Bende, the sandstones are almost horizontal. In general, Ameki strata show steeper dip than the overlaying strata, which is indicative of unconformable relationship (Wilson, 1925). Ameki Formation in South Nigeria Eocene is correlative with middle Eocene (Lutetian) of the Senegal Basin (Monciardin, 1966) and later subdivisions of the Togo-Dahomey sequences (Skanshy, 1962). It shares the common occurrence of phosphate with both Basins and the diagnostic Eocene pelagic foraminifera, Truncorotaloidsrohric Bronnimann and Bermedez with the Senegal Basins.

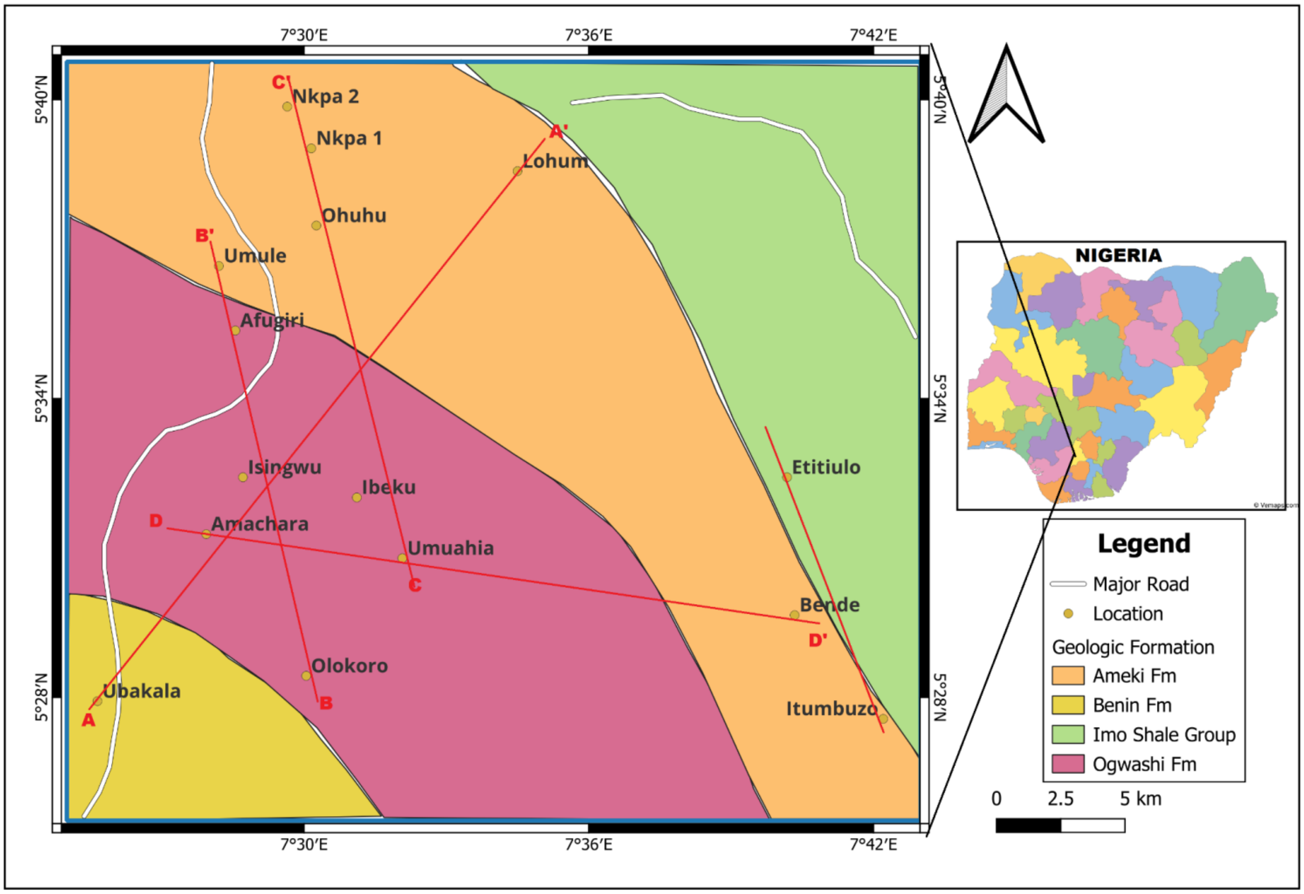


Fig 1 Geology map of the study area.

2.0 Materials and Methods

2.1 Principles of the electrical resistivity method

The electrical resistivity method is based on the measurement of electrical resistance of the ground which is dependent primarily on porosity, fracturing, degree of saturation and salinity of the pore water (Eke, Nwokocha, Nze & Eze, 2022).The method is widely used to determine, the thickness of sand/ gravel aquifers overlying bedrocks, subsurface characteristics and freshwater and saltwater interface (Zohdy, 1976).

Field measurements were obtained by introducing direct low frequency electric current into the ground through the electrodes (current electrodes), and the potential difference developed by the current is measured by a second pair of electrodes (potential

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue III, March 2024

electrodes). Both the current in milliamperes (mA) and the potential in millivolts (mV) measurements are used to calculate the apparent resistivity.

In the Schlumberger configuration, the four electrodes employed are arranged on a straight line with distance (AB) between the two outside current electrodes (C1, C2) Figure 2. This distance is equal to or greater than four times the distance (MN) between the inner potential electrodes (P1, P2) (AB greater than or equal to 4 MN). The array is widely used in measuring earth resistivities and is designed to measure approximately the potential gradient at a point. The current electrodes are constantly moved outwards after each reading, while the potential electrodes are kept constant and were only varied to obtain a satisfactory reading of the potential drop (Figure 2).

The apparent resistivity as given by

$$r = \pi R\left[\frac{\left(\frac{AB}{2}\right)^2}{(MN)} - \frac{(MN)}{4}\right]$$ (1) (Telford, Gredart, Sherriff & Keys, 1970).

Where AB is the distance between the two outer current electrodes,

MN is the distance between the two inner potential electrodes,

R is the resistance of the measured rock in Ohm (Ω),

$\rho_a$is the Apparent resistivity of measured rock in Ohm-m (Ωm).

The basis of the electrical resistivity method is that when current is passed into the ground through the electrodes, any subsurface variation in conductivity alters the current flow which in turn affects the distribution of electrical potential. It is usually possible to obtain information about the distribution of subsurface materials from measurement of electrical potentials made at the surface (Oteze, 1990; Uma, & Egboka, 1985; Vingoe, 1972).

Resistivity surveying helps in preventing unnecessary repetitive drilling due to dry It indicates the presence of rapid lateral changes which may be accessed even by a close spacing of drill holes.

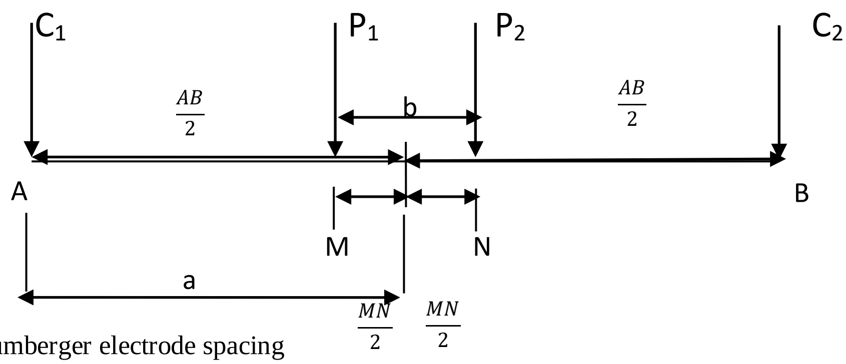


Fig.2 Schlumberger electrode spacing

2.2 Data acquisition

The field equipment used in collecting data include: Germin GPS 78 CSX for obtaining the coordinates and elevation of various locations; ABEM Terrameter (SAS 1000) which consist of transmitters, receiver and the microprocessor to determine the resistance of the subsurface at each location. The arrangement adapted for the data acquisition is the schlumberger electrodes configurations or arrays.

The data obtained in depth sounding is usually plotted as a graph of apparent resistivity against electrode separation (half the current electrode separation). This provides an idea of the depth of interfaces (Enuvie, 1999; Nwugha; Okeke & Emeronye, 2021). Depth estimation makes use of an approximation of the depth of interface is equal to two – third (2/3) of the electrode separation at which the point of inflection occurs. This approximation is a useful approximation in computer iterative modeling, (Nwugha et al., 2020).

The coordinates of various locations were plotted or superimposed on the geologic map (Fig 1). Each of the apparent resistivity sounding data was plotted on log-log graph, filtered and IP2WIN computer software was used to iteratively model the curves to get geoelectric layers of the probable lithologies.

Cross sections were drawn to establish four profiles of VES locations namely; A–A′, B–B′, C–C′ and D–D′. Strata 5, Golden software was used to draw the correlations of the vertical electrical sounding points and aquifer parameters such as aquifers thickness, the geometric sections and depth to aquifer. The statistical analysis of the depth and the aquifer resistivity as well as the test for significance was done. Profile A–A′ traversed through Umueleagwu Ibeku, Isingwu, Afugiri and Nkpa in the N – S direction. B–B′ is in the East – West direction, C–C′ in the NW – SE direction and D–D′ in the NE – SW direction.

One hypothesis guided the study.

H_o: There is no linear correlation between the aquifer depth, D and aquifer resistivity R.
The correlation between the depth of the aquifers and the aquifer resistivity was established from the product- moment coefficient of correlation designated by r which is derived from the formula

$$r = \sqrt{\frac{n\sum DR-(\sum D)(\sum R)}{[n\sum D^2-(\sum R)^2][n\sum D-(\sum R)^2]}} \qquad (2)$$

Where r is the correlation coefficient

D is the depth to aquifer

R is the aquifer resistivity

3.0 Results and Discussion

3.1 Vertical Electrical Sounding

There were fourteen (14) VES points in the study area. The data on current and, potential difference at various depths were used to evaluate the resistance of the earth's layers. Applying the geometric factor for the Schlumberger array using equation 1, the earth resistivity at various depths were determined. A plot of resistivity against the half electrode spacing on the log-log scale gave rise to the computer modelled curves (Figure 3).

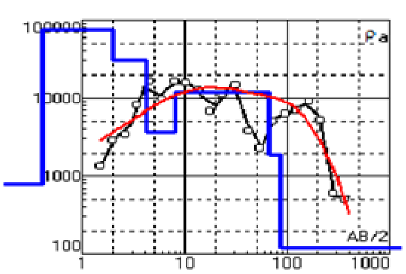
There were six profiles from the study area. Profile A–A′ (Figure 4)in the NE-SW direction passed through Mgbarakuma Ubakala, Amachara, Isingwu to Lohum. The depths to aquifers are 43.8m, 24.7m, 24.1m and 41.3m respectively (Figure 8). It can be deduced that the aquifers around Amachara and Isingwu are shallow at mean depth of 24.4m while the aquifer at Mgbarakuma Ubakala and Lohum are moderately deep with mean depth of 42.5 m. The aquifer thicknesses vary from greater than 104.2m to 44.1m (Table 1).

Profile B – B′ (Figure 5) in the NW-SE direction cuts through Olokoro, Isingwu, Afugiri;, and Umule. The subsurface lithology and depth to aquifer reveal sand and sandstone from surface with underlying clay/ shale. The corresponding aquifer depths are 23.9m, 24.1m, 17.8m and 2.3m respectively.

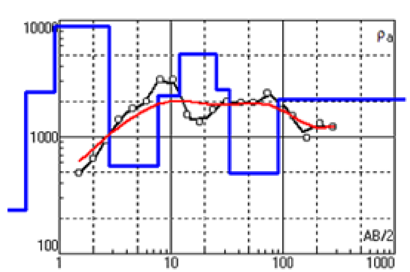
The C–C′ profile (Figure 6) is in the NW – SE direction passing through Nkpa, Umuezeagwu Ibeku to FMC Umuahia. The depth and thickness of the aquifers in the various locations are 64 m, 116 m, 117 m, 14.1 m; 39.2 m, 25.2 m; 94.8m respectively. Due to the clay/shale units occupying the middle zone of the subsurface in this area, there are two prospective zones identifiable near the ground surface to shallow depths and the deeper zone varying from 64m to 90.6m.

The D–D′ profile (Figure 7) is in the E–W direction traversing Amachara (VES 13), FMC Umuahia (VES 14) and Bende (VES 7). The subsurface consists of sand, siltysand, shalysand, sandyshale and shale. The depth to water in Amachara is 24.7m, FMC is 64m and Bende is 3.5m. The aquifer thickness varies from 44.1m to 116m

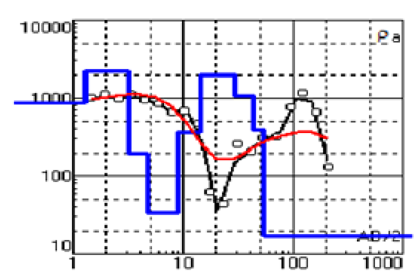
The aquifer parameters as summarized in Table 4.1 revealed that aquifer resistivities ranges from 253 Ωm at Umule to 2510 Ωm at Isingwu and Ubakala, depth to aquifer varies from 19.2 m to 148 m while aquifer thickness is between 9.3 m and 102.2 m (Table 1).



VES 1 at Lohum



VES 2 at Nkpa 1



VES 3 at Umuezeagwu Ibeku

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue III, March 2024

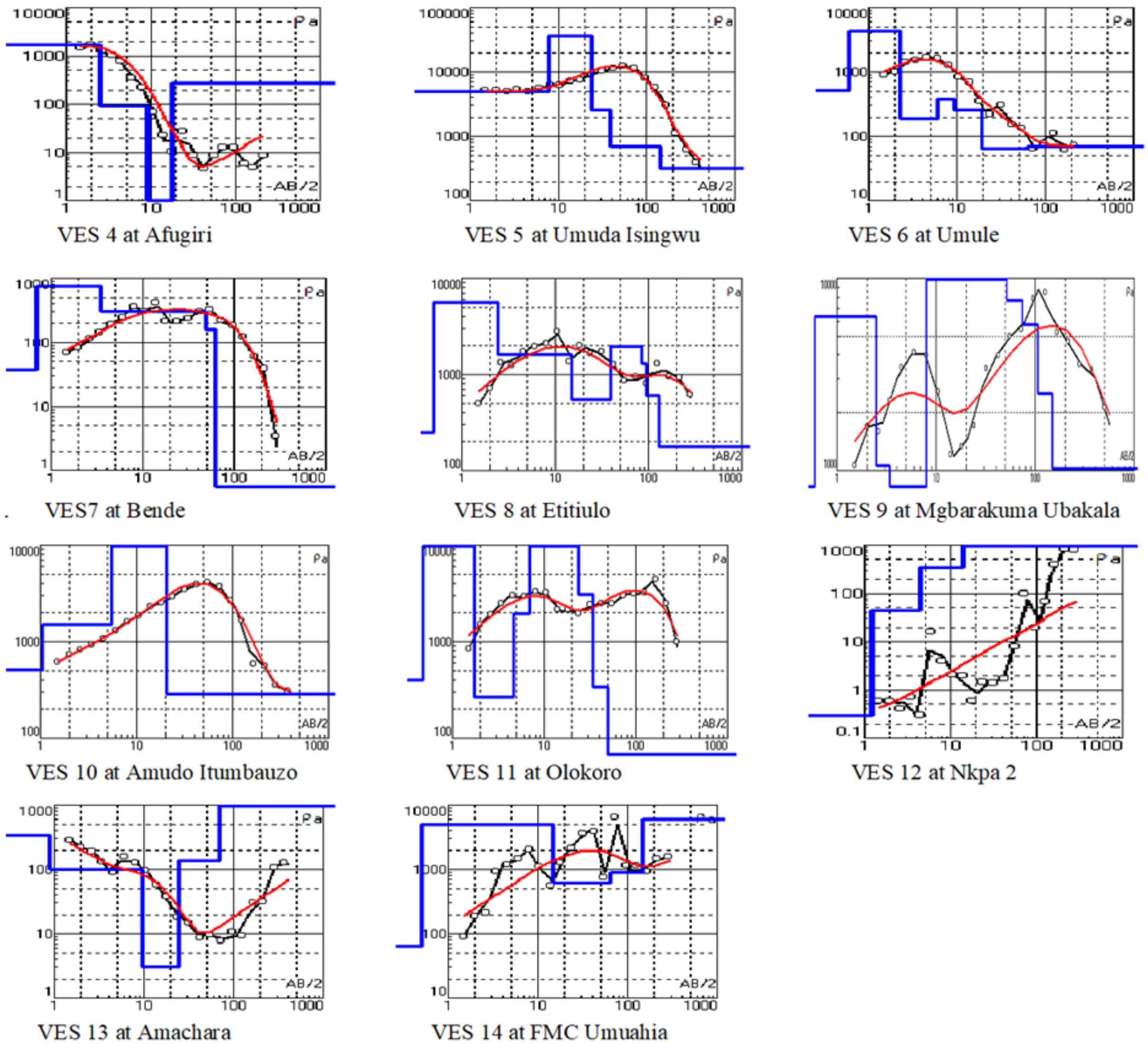


Fig 3. Computer modelled VES from the study are

Table 1: Summary of Aquifer Parameters in the Study Area

VES NO	LOCATION	DEPTH TO BOTTOM OF AQUIFER (m)	AQUIFER THICKNESS (m)	AQUIFER RESISTIVITY(Ωm)
1	Lohum	85.7	17.6	1880
2	Nkpa	117.0	26.4	485
3	Ibeku	43.8	14.3	1070
4	Afugiri	27.1	9.3	274
5	Isingwu	141.0	102.2	2510
6	Umule	19.2	9.2	253
7	Bende	48.0	44.5	306
8	Etitiulo	129.0	32.0	1310
9	Ubakala	148.0	42.0	2510
10	Itumbauzo	107.0	76.6	800
11	Olokoro	69.5	19.6	1650
12	Nkpa 2	138.5	23.5	1230
13	Amachara	92.0	23.2	1180

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14	FMC Umuahia	146.0	94.0	990

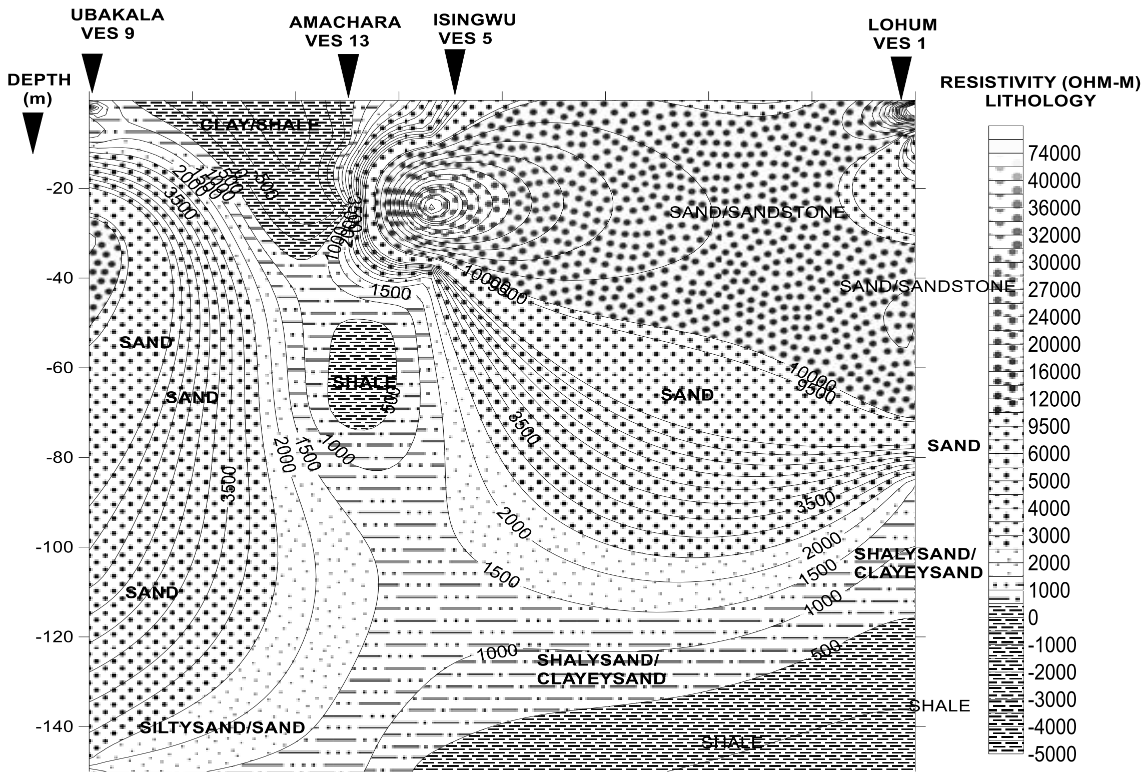

Fig. 4 Profile of A-A′

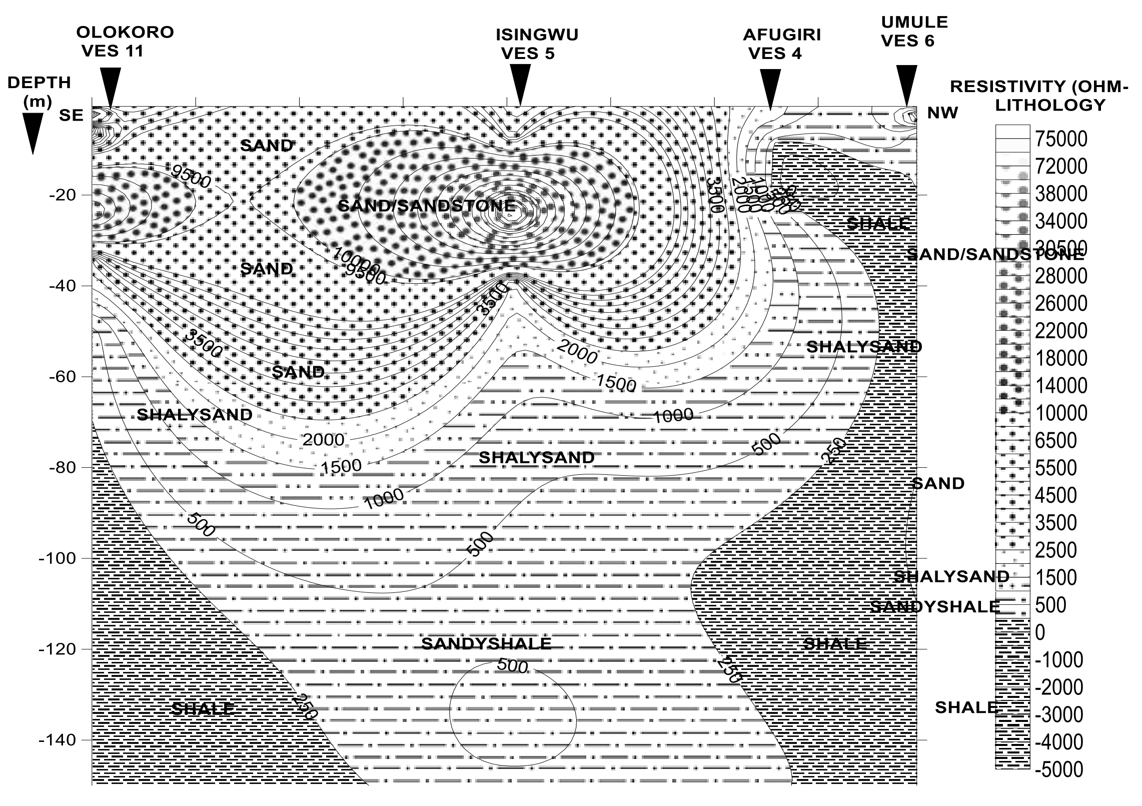

Fig. 5 The B′ – B′ profile

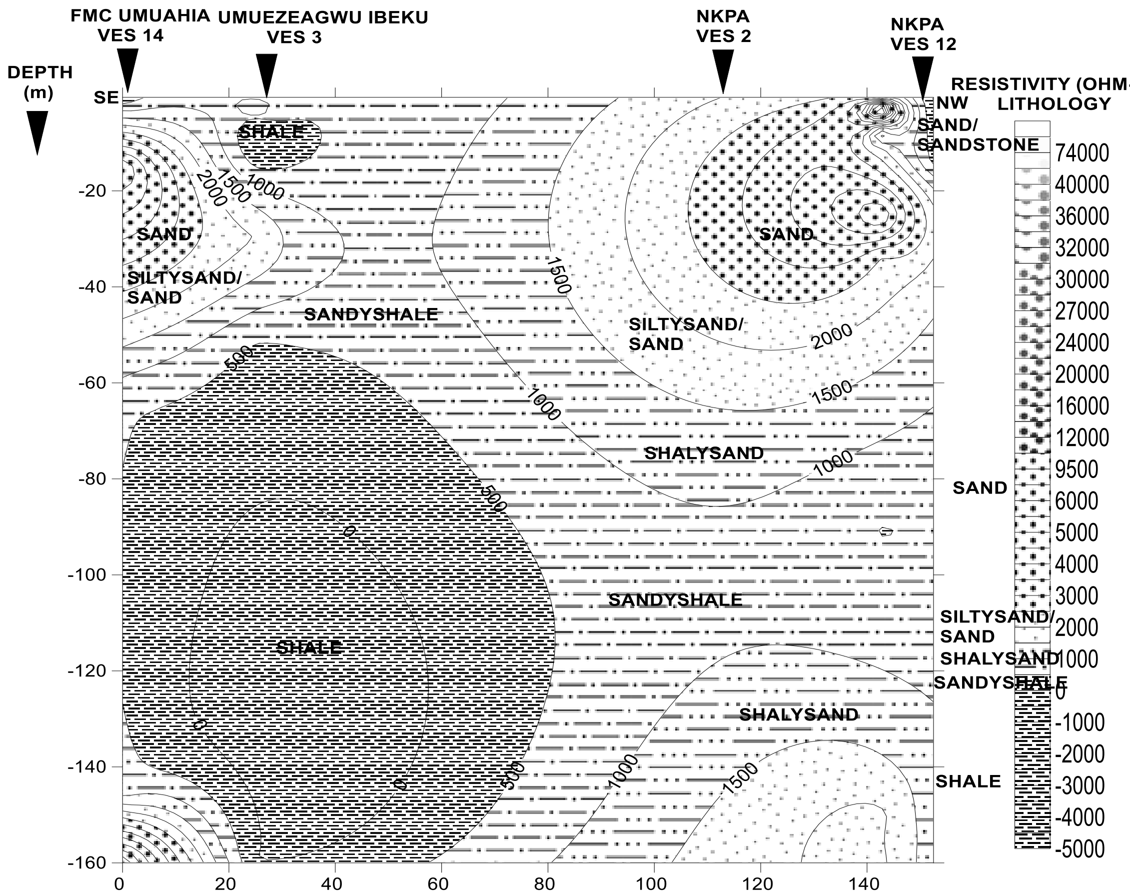

Fig. 6 The C – C′ profile

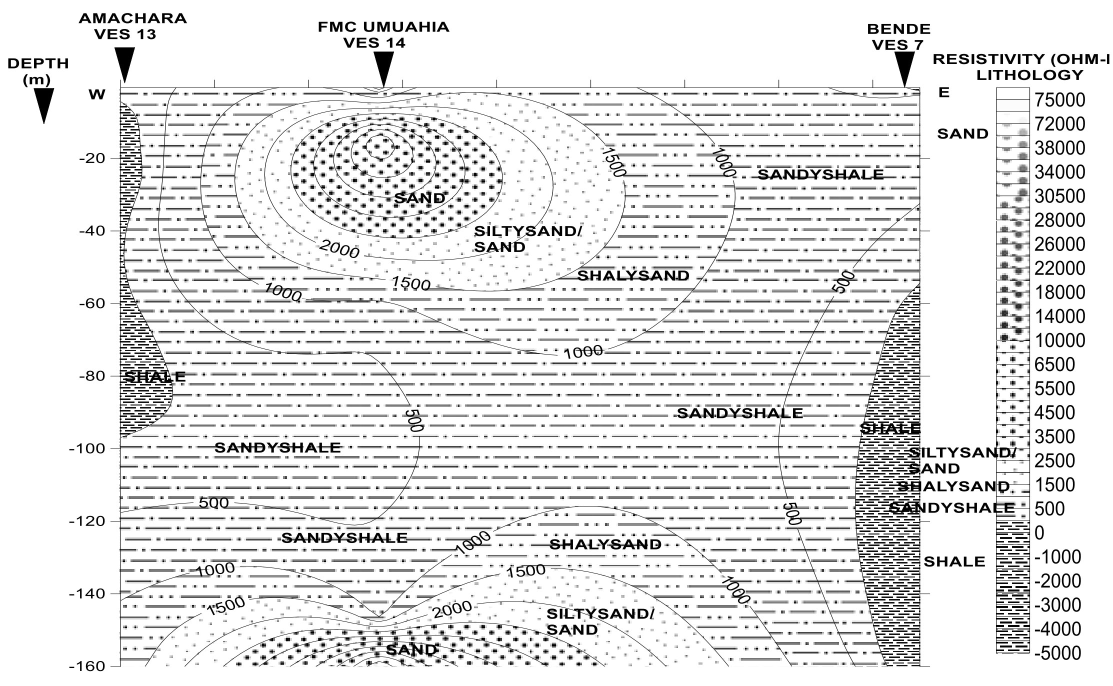

Fig. 7 The D – D′ profile

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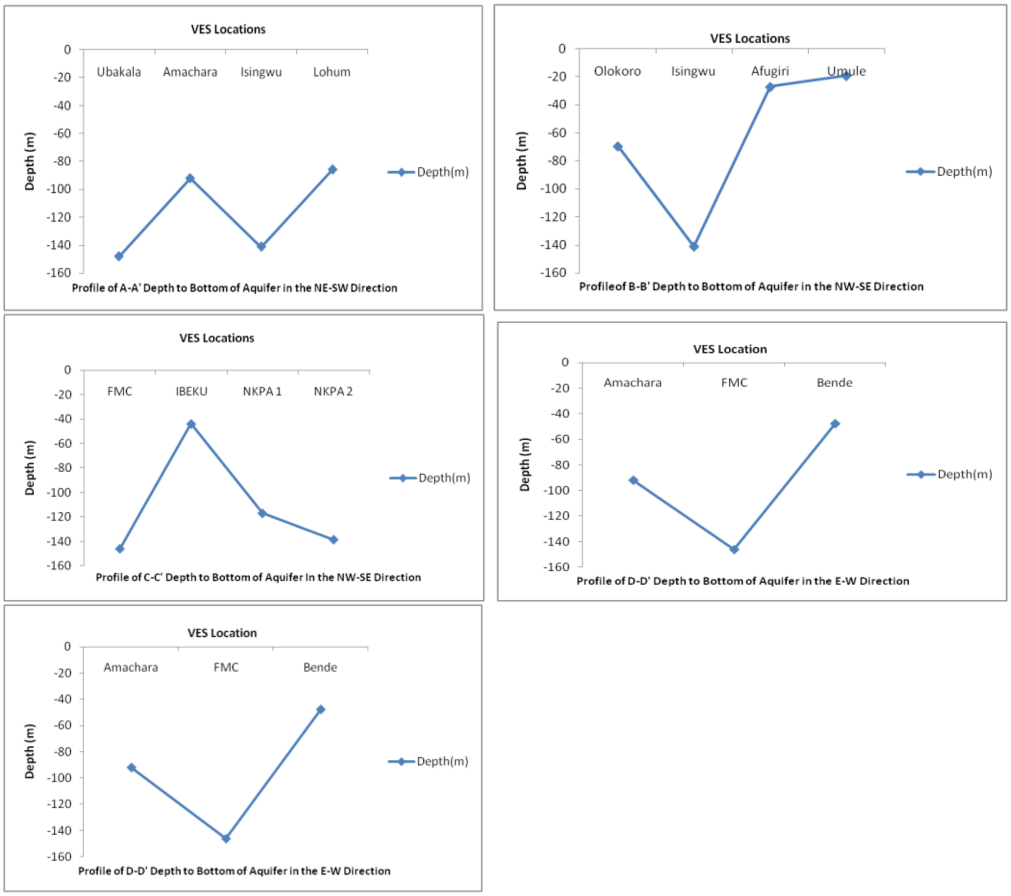

Fig. 8 Models of depths to bottom for aquifers of the profiles within the study area

3.2 Statistical Analysis

From Table 2, let depth be represented by D and resistivity as R, and n=14 as in equation 2 gives a coefficient of correlation r as 0.6. A test of significance of r with null hypothesis, H_o, P=0 (there is no linear correlation between D and R) and alternative hypothesis, H_1: P=0 (there is linear correlation between D and R) at 0.05 level of significance reveal that H_1>0.05 which implies that there is a linear relationship between D and R.

Table 2 The relationship between depth to aquifer and aquifer resistivity

DEPTH (D)	RESISTIVITY (ℓ)	D^2	$ℓ^2$	D ℓ
85.7	1880	7344.49	35344	16111.6
117	485	13689	235225	56745
43.8	1070	1918.44	1144900	46866
27.1	274	734.41	75076	7425.4
141.0	2510	19881	6300100	353910
19.2	253	368.64	64009	4857.6
48	306	2304	93636	14688
129	1310	16641	1716100	168990
148	2510	21904	6300100	371480
107	800	11449	640000	85600
69.5	1650	4830.25	2722500	114675
138.5	1230	19182.25	1512900	170355
92	1180	8464	1392400	108560
146	990	21316	980100	144540
1311.8	**16448**	**1720819**	**2.71E+08**	**21576486**

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue III, March 2024

4.0 Conclusion

The correlation of the geoelectric layers from the modeled Vertical Electrical Soundings revealed a systematic arrangement of the stratigraphy in this area. There are high magnitude alternations of sands and clays/shale. The topsoil in the area is composed of laterite that varies in depth from 5m to 20m.The deeper geoelectric layers have slightly high resistivities alternating with low resistivity values interpreted as shalysands/siltysands and sandyshale respectively as aquifers. Sand, shale and silts are associated with radiation emission in an environment. Aquifer resistivities vary from 253Ωm to 2510Ωm, which implies that some aquifers can have low resistivities less than 1000Ωm while some locations yield water at resistivity greater than 1000Ωm. The lithology of areas with low resistivities is composed of intercalations of clay/ shale units with sand as sandyshale or clayeysands/shale sand layers and sands for areas with high aquifer resistivities respectively. Two aquifer systems are identified as shallow occurring mainly along Umuagwu Ibeku, Umule and Ohuhu areas between 9 m and 30 m. The deep aquifers are located at Isingwu, Nkpa, Amachara, Ubakala and Etitiulo at depths of 40 m to 115 m.

The aquifer thicknesses of shallow aquifers are between 9 m and 50 m and deep aquifer thicknesses in the range of 17 m to 102 m. Most of the aquifers are confined especially the deep ones and they tend to thin out towards the southwestern part of the study area. There is obvious relationship between depth to aquifer and the aquifer resistivity, with the coefficient of correlation, $r = 0.999$. This shows that Formations with clay and shale as dominant rocks have aquifer medium as sands at depths that are directly proportional to the resistivity. There is need to investigate the natural terrestrial background radiation within the study area to ascertain if the lithology of the area has much effect on radionuclides of the area and radiochemistry of drinkable water in the study area.

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