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# Geoelectric Investigation of Groundwater in Some Villages in Ohafia Locality, Abia State, Nigeria

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## ABSTRACT

Geoelectric investigation for underground water in some part of Ohafia was done using the Vertical Electrical Sounding (VES) method. Twenty vertical electrical sounding data were acquired within the locations in the study area. These were used in delineating the geoelectric sections. The study was carried out using the Schlumberger electrode configuration and computer-aided Resist software method of interpretation was adopted. The interpretation of the VES data obtained from the study area within the geology terrain often referred to as sedimentary environment indicates that the area around VES stations 12, 13, 10 and 8 have been chosen as the most viable locations for the development of a water borehole for groundwater resources in the study area. The thickness and resistivity of the aquifers at these VES stations, which shows very good potential for groundwater, indicates that VES 12 has the highest aquifer thickness depth of 494.9m. The geologic sections of some VES stations were delineated and this also corroborated with the geological description of the area.

*Keywords: Vertical electrical sounding; groundwater; geoelectric section; aquifer; resistivity; modeled curves;*

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## 1. INTRODUCTION

Inadequate supply of portable water in Ohafia has been a chronic problem for many years. The major source of water for all purpose in life in the area is surface water, which has grossly become inadequate because of rapidly increasing demand for water due to urbanization. Prospecting for steady and reliable water supply from subsurface or ground water will rescue the area from acute shortage of water.

Ground water is characterized by a certain number of parameters which are employed in geophysical methods such as electrical resistivity methods, seismic methods, magnetic methods, gravity methods, etc in locating them. Electrical resistivity method employs the conductivity of ground water to locate its occurrence. Records show that the depths of aquifers differ from place to place because of variational geo-thermal and geo-structural occurrence (Ekine and Osobonye, 1996; Okwueze, 1996). Electrical resistivity method for conducting a vertical electrical sounding (VES) has proved very popular with groundwater studies due to the simplicity of the technique, the ruggedness of the instrumentation and because the resistivity of rock is very sensitive to its water content.

An excellent example of the use of the technique was shown by Oseji et al. (2005) in the geoelectric investigation of the aquifer characteristics and groundwater potential in Kwale, Delta state Nigeria. Before the vertical electrical soundings were used a failure rate of over 82% was recorded for boreholes. With the geophysics and a combination of geological and photogeological inspection this was dramatically reduced to less than 20% failure. Van-Overmeeren (1989) showed the use of electrical measurements in mapping boundary conditions in an aquifer system in Yemen. Beeson and Jones (1988), Olayinka and Barker (1990), Hazell et al. (1988, 1992) and Carruthers and Smith (1992) all have demonstrated the use of electrical techniques for sitting wells and boreholes in crystalline basement aquifers throughout sub-Saharan Africa. Other similar examples are given by Igboekwe et al. (2006) and Yang et al. (1994).

## 2. MATERIALS AND METHODS

### 2.1 Location and Physiography of the Study Area

The study area is located along Umuahia Arochukwu road from Umuahia the Abia State capital. It lies between latitude 5°30´ N to 5°45´ N and longitude 7°45´ E to 7°55´ E. The climate of the study area usually alternates with the dry and rainy season. The area which lies within the south-eastern part of Nigeria has a total annual rainfall of over 1400mm spread over the mouth of March to October. The highest amount of rainfall is observed in the mouth of Jun. The dry season is from November to February. Also the temperature is very high throughout the year, with an annual range of 23°C to 32°C, with the hottest period of the year during the dry season. The vegetation of the area is that of the rainforest which comprises of various species of shrubs and high forest plants all over the area – both at the hilly and depressed areas. The study area consists of few flat terrains and so many gentle hills and valleys.

The area is drained by very few scattered rivers and streams e.g. Obayi River which flows south-east direction, Muri River which flow also in the south-east direction and very few others. The area has a scattered drainage pattern which is a function of the hilly nature of the area.

## 2.2 Geology of the Area

Ohafia area falls in south-eastern part of the Anambra basin. The south-eastern part of the Anambra basin is a part of the scarplands of south-eastern Nigeria. The north-south trending of Enugu escarpment forms the major watershed between the lower Niger drainage system to the west, and the Cross-River and Imo drainage systems to the east (Ibe et al., 1998). It is an asymmetrical ridge stretching in a sigmoid curve for over 500 km from Idah on the river Niger to Arochukwu on the Cross-River.

The geology of Ohafia local government area falls within the Deltaie marine sediment of Cretaceous to recent age. There are essentially three principal geological formations in the area namely: the Ajali (false bedded sandstones) formation, Bende-Ameki formation and the Asata Nkporo shale formation.

The Ajali formation of Cretaceous age consists of red earth sands which form the false bedded sandstones. These in turn consist of great thickness of friable but poorly sorted sandstones. The formation spans through narrow country in Abia state from Isuochi north in Isuikwuato local government area, through Eluama, Ovim and Alayi where it narrows down to south of Nguzu before running south. It is overlain by Bende-Ameki formation. The Bende-Ameki formation of Eocene to Oligocene age consist of medium to coarse-grained white sandstones which contain pebbles, gray-green sandstones, bluish calcareous sit with mottled clays and thin limestone. Indeed, there is a considerable lateral variation in lithology in the area. The Asata-Nkporo shale in north of Uturu in Abia State stretches laterally up the Agwu sandstones. In east of Uturu, the shale increases in thickness and have their greatest development along eastern limb of the anticlinorium where Nkporo village is located. The formation consists mainly of blue or dark grey shale mudstones with occasionally sunstones.

The main water-bearing geological formation in the area is the late Maastrichitan Ajali formation (Hoque and Ezepue, 1977; Ibe et al., 1998). The formation consists of a quartz arenite, loose angular to sub-bounded grains. The grain size of the area has a multi-model distribution (Ibe et al., 1998). The Ajali is underlain by a shaly rock unit, which belongs to the Mamu formation. The shaly unit of the Nsukka formation overlies it. The Ajali formation is a confined aquifer in most locations in the area. The Ajali formation is very permeable. The groundwater flows from the recharge areas in the east and northeast to southwest below the younger formations over which artesian conditions develop (Offodile, 1992). At locations where artesian condition develops, springs usually occur. Prominent among such springs include Muri and Obayi River.

## 2.3 Resistivity Theory

Electrical resistivity (ρ) is an inherent property of all earth materials. Resistivity is the reciprocal of electrical conductivity and thus is a measurement of a material resistance to the flow of an electrical current. In most porous rock systems, ionic conduction by interstitial fluids and surface conduction at the interface between the solid rock matrix and the electrolyte solution are responsible for the major part of electrical current flowing through a formation (Pfannkuch, 1969). Clay minerals, however, are capable of conducting current both electronically and through the electrolyte interface, due to high cation exchange properties. Clay minerals typically have much lower resistivity than other silicate minerals or carbonate minerals. Because resistivity in a porous rock system is predominantly the result of the electrical properties of ionic solutions and porosity of the rock matrix, the quality of water in the system can be evaluated by using resistivity measurements obtained at land surface, assuming geology of the area is known. These measurements are obtained by introducing a direct current into the ground through a pair of current electrodes and measuring the potential difference between a pair of potential electrodes.

## 2.4 Study Methods

Variation of electrical conductivity is investigated here with the help of electrical resistivity soundings. Twenty schlumberger vertical electrical soundings (VES) were collected using a maximum current electrode separation of AB/2 of 500m. Digital averaging equipment, ABEM SAS 4000 Terrameter, was used for direct current (dc) resistivity work. The instrument displays directly the apparent resistivity of the subsurface under probe. It is powered by a 12-volts dc battery. Four stainless metal stakes were used as electrodes.

All the sounding data were collected from the study area as shown in figure 1.

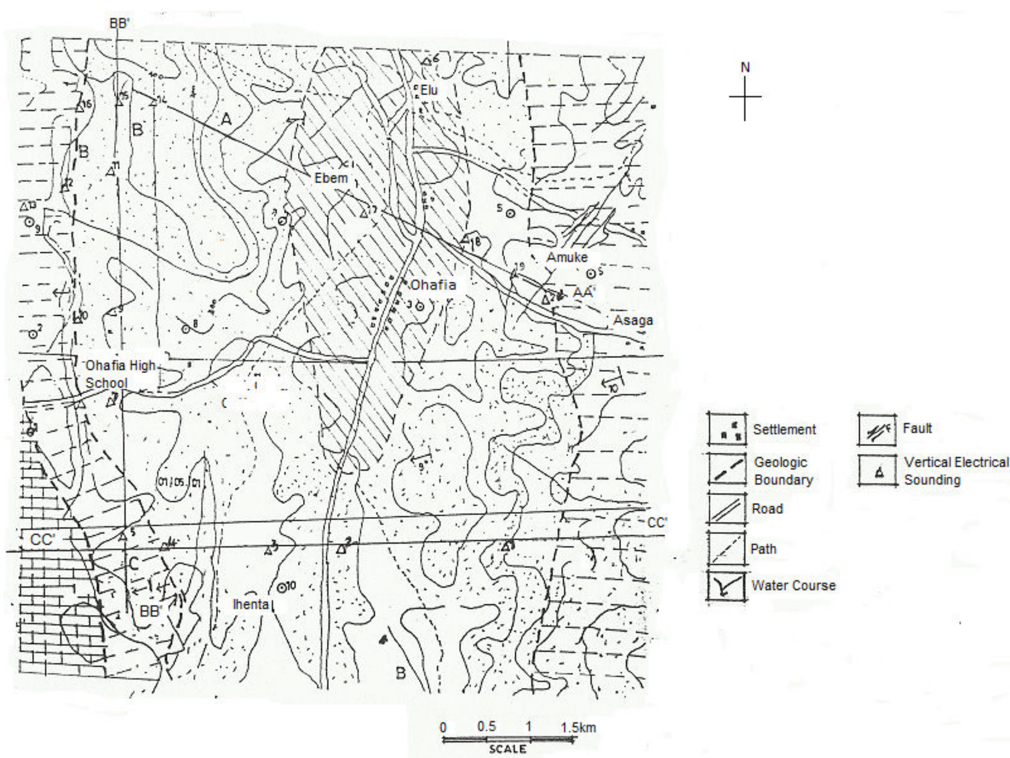



**Fig. 1: Geologic map of the area showing VES stations**

The Schlumberger electrode configuration was used in all the soundings. In the Schlumberger configuration, all the four electrodes are arranged collinearly and symmetrically placed with respect to the centre (Kearey and Brooks, 1984). In this array the potential electrode separation is very small compared to the current electrode separation (less than 1/5). The distance between the potential electrodes is increased only when the signal is too small to measure.

**Table 1: Vertical electrical sounding data for VES stations 1 to 10**

| VES NOS | LOCATION | HEIGHT (m) | LATITUDE | LONGITUDE | NUMBER OF LAYERS | Resistivity/ Depth | P1h1 | P2h2 | P3h3 | P4h4 | P5h5 | P6h6 | P7h7 | P8h8 | P9h9 | TOTAL(m) | FITTING ERRORS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VES 1 | EAST BARRACK S 1 | 171 | 5° 36' 6.25 "N | 7° 49' 47.85"E | 8 | ρ(Ωm) | 5860 | 6545.1 | 10250 | 4277.0 | 8773 | 23408 | 15505 | 4421.2 | ….. | 183 | 2.4 |
| | | | | | | h(m) | 0.5 | 1.6 | 3.3 | 6.7 | 14.6 | 37.7 | 118.2 | ….. | ….. | | |
| VES 2 | EAST BARRACK S 2 | 156 | 5° 36' 10.4"N | 7° 49' 32.7"E | 8 | ρ(Ωm) | 1996 | 4804.0 | 4094.4 | 3287.8 | 3654 | 18072.0 | 7535 | 3115.6 | ….. | 189 | 2.5 |
| | | | | | | h(m) | 0.5 | 2 | 2.8 | 4.6 | 9.3 | 50.5 | 119.1 | ….. | ….. | | |
| VES 3 | EAST BARRACK S 3 | 126 | 5° 36' 8.8"N | 7° 49' 6.9"E | 8 | ρ(Ωm) | 605.0 | 597.0 | 48.7 | 149.6 | 15.2 | 249.1 | 2121 | 120.5 | ….. | 496 | 9.8 |
| | | | | | | h(m) | 0.5 | 2.3 | 5.0 | 8.7 | 23.1 | 28.8 | 427.5 | ….. | ….. | | |
| VES 4 | EAST BARRACK S 4 | 115 | 5° 36' 10.4"N | 7° 48' 45.2"E | 8 | ρ(Ωm) | 1420 | 2816.0 | 3241.8 | 6113.8 | 3891 | 3788.6 | 3564 | 2197.9 | ….. | 775 | 2.4 |
| | | | | | | h(m) | 0.5 | 3.8 | 5.4 | 31.5 | 84.2 | 149.8 | 499.6 | ….. | ….. | | |
| VES 5 | EAST BARRACK S 5 | 81.7 | 5° 36' 14.07"N | 7° 31' 48.1"E | 9 | ρ(Ωm) | 4029 | 7039 | 4381.1 | 27435.0 | 355.2 | 1034.5 | 272.1 | 3898.7 | 3519.0 | 218 | 7.4 |
| | | | | | | h(m) | 0.5 | 2.1 | 3.8 | 10.7 | 7.5 | 106 | 47.7 | 135.2 | ….. | | |
| VES 6 | ELU OHAFIA | 62.8 | 5° 39' 32.9"N | 7° 49' 2.5"E | 9 | ρ(Ωm) | 1395 | 1988 | 3446.7 | 2785.0 | 4672 | 7189.0 | 9210 | 13707.9 | 28183 | 207 | 5.6 |
| | | | | | | h(m) | 0.5 | 2.2 | 3.1 | 10.1 | 22.0 | 45.9 | 46.5 | 76.9 | | | |
| VES 7 | UDUMA RIVER OHAFIA 1 | 79.4 | 5° 37' 26.06"N | 7° 48' 31.81"E | 8 | ρ(Ωm) | 1405 | 794.4 | 1268.6 | 680.5 | 302.3 | 282.4 | 225.3 | 1287.0 | ….. | 126 .0 | 2.7 |
| | | | | | | h(m) | 0.6 | 2.2 | 3.8 | 5 | 9.5 | 28.0 | 77.3 | ….. | ….. | | |
| VES 8 | UDUMA RIVER OHAFIA 2 | 78.7 | 5° 37' 26.02"N | 7° 48' 15.61"E | 7 | ρ(Ωm) | 1236 | 906.5 | 1091.4 | 287.1 | 6723 | 845.8 | 265.4 | ….. | ….. | 168 | 2.5 |
| | | | | | | h(m) | 0.5 | 3.1 | 6.2 | 13.4 | 32.7 | 112.5 | ….. | ….. | ….. | | |
| VES 9 | UDUMA RIVER OHAFIA 3 | 82.8 | 5°.37' 37.08"N | 7°.48' 31.81"E | 9 | ρ(Ωm) | 753.4 | 781.1 | 1294.1 | 152.1 | 7387 | 2240 | 254.0 | 316.8 | 574.8 | 448 | 4.5 |
| | | | | | | h(m) | 0.5 | 2.5 | 6.8 | 16.6 | 41 | 40.7 | 113.6 | 225.9 | ….. | | |
| VES 10 | UDUMA RIVER OHAFIA 4 | 74.5 | 5° 37' 37.08"N | 7° 48' 15.61"E | 8 | ρ(Ωm) | 690.7 | 768.9 | 946.8 | 558.1 | 532.2 | 547.7 | 968.5 | 747.9 | ….. | 346 | 4.5 |
| | | | | | | h(m) | 0.4 | 1.4 | 5.0 | 15.2 | 66 | 87.8 | 169.7 | ….. | ….. | | |

**P* and ***h*** *represents the apparent resistivity and the depth of the layer from the subsurface respectively*

## Table 2: Vertical electrical sounding data for VES stations 11 to 20

| VES NOS | LOCATION | HEIGHT (m) | LATITUDE | LONGITUDE | NUMBER OF LAYERS | Resistivity/ Depth | P1h1 | P2h2 | P3h3 | P4h4 | P5h5 | P6h6 | P7h7 | P8h8 | P9h9 | TOTAL(m) | FITTING ERRORS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VES 11 | UDUMA RIVER OHAFIA 5 | 70.3 | 5°.38' 29.06"N | 7°.48' 31.81"E | 8 | ρ(Ωm) | 615.8 | 998.2 | 218.0 | 648.4 | 632.6 | 456.8 | 625.7 | 1145.0 | ….. | 298 | 3.6 |
| | | | | | | h(m) | 0.6 | 10.8 | 5.7 | 22.7 | 39.7 | 72.0 | 146.2 | ….. | ….. | | |
| VES 12 | UDUMA RIVER OHAFIA 6 | 70.4 | 22° 38' 22.01"N | 7° 48' 10.85"E | 8 | ρ(Ωm) | 595.1 | 967.6 | 322.9 | 954.3 | 506.3 | 725.8 | 863.9 | 978.9 | ….. | 348 | 3.6 |
| | | | | | | h(m) | 0.5 | 9.2 | 17.9 | 36.8 | 93.2 | 190.0 | 494.9 | ….. | ….. | | |
| VES 13 | EBEM ASAGA NDI-IBE 1 | 75.7 | 5°.38' 21.18"N | 7°.48' 6.88"E | 8 | ρ(Ωm) | 200.3 | 276.5 | 544.5 | 2331.4 | 911.7 | 1547.9 | 1098 | 1393.9 | ….. | 573 | 5.4 |
| | | | | | | h(m) | 0.4 | 3.6 | 20.6 | 62.2 | 39.2 | 146.4 | 300.1 | ….. | ….. | | |
| VES 14 | EBEM ASAGA NDI-IBE 2 | 77.7 | 5° 39' 23.17"N | 7° 48' 45.51"E | 8 | ρ(Ωm) | 384.3 | 384.0 | 97.7 | 810.9 | 8050 | 1426.4 | 6270 | 1674.3 | ….. | 414 | 11 |
| | | | | | | h(m) | 0.5 | 1.7 | 3.8 | 5.7 | 37.1 | 67.9 | 297.4 | ….. | ….. | | |
| VES 15 | EBEM ASAGA NDI-IBE 3 | 81.1 | 5° 39' 23.17"N | 7° 48' 36.56"E | 8 | ρ(Ωm) | 171.9 | 2044 | 30023 | 1639.2 | 480.4 | 2885.6 | 3228 | 2362.2 | ….. | 565 | 8.6 |
| | | | | | | h(m) | 0.5 | 0.5 | 5.8 | 9.8 | 43.2 | 122.3 | 399.1 | ….. | ….. | | |
| VES 16 | EBEM ASAGA NDI-IBE 4 | 77.1 | 5° 39' 12.18"N | 7° 48' 23.48"E | 8 | ρ(Ωm) | 3578 | 8020 | 8622.4 | 23234 | 6262 | 6900.5 | 13896 | 10207 | ….. | 678 | 2.8 |
| | | | | | | h(m) | 0.5 | 3.0 | 5.9 | 15 | 32.8 | 120.7 | 500 | ….. | ….. | | |
| VES 17 | EBEM ASAGA NDI-IBE 5 | 72.2 | 5° 38' 28.11N | 7° 49' 20.81"E | 8 | ρ(Ωm) | 210.5 | 3102 | 492.1 | 150.9 | 73.3 | 166.7 | 214.1 | 112.3 | ….. | 720 | 4.5 |
| | | | | | | h(m) | 0.6 | 2.6 | 2.6 | 26.7 | 72.5 | 108.6 | 506.8 | ….. | ….. | | |
| VES 18 | AMA-UKE 1 | 50.2 | 5° 38' 21°.39"N | 7° 49' 40.85"E | 7 | ρ(Ωm) | 866.2 | 2727 | 859.6 | 2582 | 5911 | 5982.5 | 2230 | ….. | ….. | 248 | 5.6 |
| | | | | | | h(m) | 0.5 | 2.1 | 10.8 | 37.3 | 43.6 | 153.4 | ….. | ….. | ….. | | |
| VES 19 | AMA-UKE 2 | 48.8 | 5° 38' 21.06"N | 7° 49' 51.86"E | 7 | ρ(Ωm) | 76.7 | 67.7 | 215.4 | 375.3 | 483.2 | 427.1 | 375.9 | ….. | ….. | 514 | 2.4 |
| | | | | | | h(m) | 0.5 | 3.8 | 13.6 | 37.3 | 159.4 | 299.4 | ….. | ….. | ….. | | |
| VES 20 | AMA-UKE 3 | 45.7 | 5° 37' 42.08"N | 7°.49' 52.77"E | 7 | ρ(Ωm) | 51.8 | 269.4 | 19.3 | 2 | 3.2 | 18.3 | 16.1 | ….. | ….. | 191 | 5 |
| | | | | | | h(m) | 0.6 | 2.1 | 1.9 | 7.4 | 16.6 | 162.3 | ….. | ….. | ….. | | |

**P and h represents the apparent resistivity and the depth of the layer from the subsurface respectively*

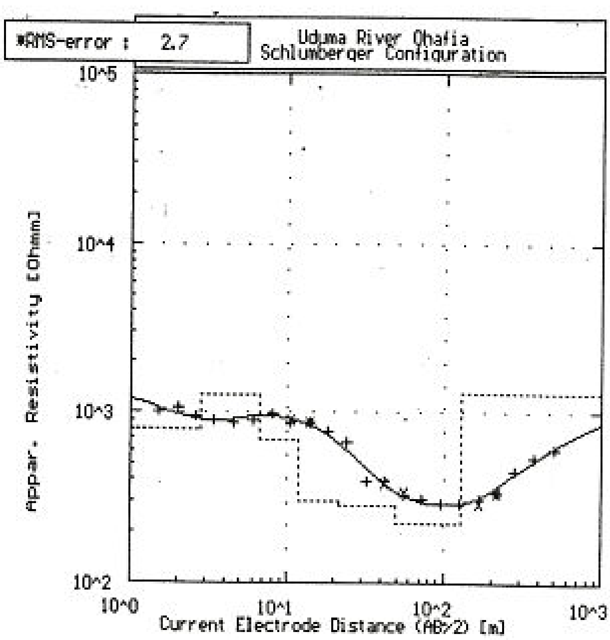
Apparent resistivity $\rho_a$ is given by

$$\rho_a = \pi \left\{ \frac{\left[\frac{AB}{2}\right]^2 - \left[\frac{MN}{2}\right]^2}{MN} \right\} \frac{V}{I} \quad \text{.................. } 1$$

Where AB/2 is half current electrode separation and MN/2 is half potential electrode separation. The apparent resistivity was plotted against half current electrode spacing on a double logarithmic paper. This preliminary interpretation and initial estimation of the number of geoelectric layers, was later used as a starting models for a fast computer-assisted interpretation.

## 3. RESULTS AND DISCUSSION

The Resist computer programme was employed in the modeling of the VES data. The result of this computer modeled curves for some selected stations are presented in figures 2, 3, 4, 5, 6 and 7. Tables 1 and 2 show the following information about the various VES stations: the field name of the VES station; height of the station with respect to sea level; the geographical location of each VES station; the number of geological layers present at the subsurface of each station; the total depth of each station and the fitting error of the Resist software in analyzing the data from each VES station.

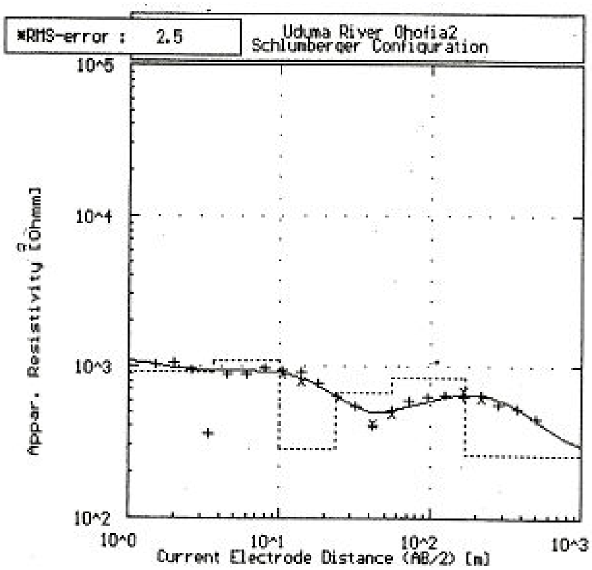



| No | Res | Thick | Depth |
|---|---|---|---|
| 1 | 1405.2 | 0.6 | 0.6 |
| 2 | 794.4 | 2.2 | 2.8 |
| 3 | 1268.6 | 3.8 | 6.6 |
| 4 | *680.5 | 5.0 | 11.6 |
| 5 | 302.3 | 9.5 | 21.1 |
| 6 | 282.4 | 28.0 | 49.1 |
| 7 | 225.3 | 77.3 | 126.4 |
| 8 | 1287.0 | -.- | -.- |

* RMS on smoothed data

VES7

**Fig. 2: Results of computer modeled curve for VES 7**

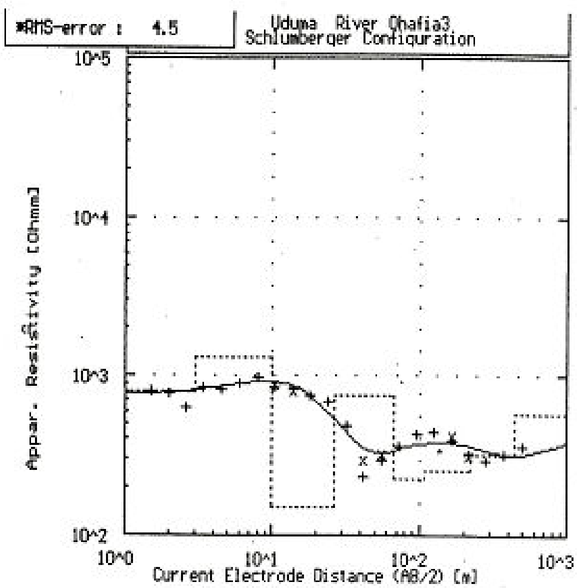



| No | Res | Thick | Depth |
|---|---|---|---|
| 1 | 1236.4 | 0.5 | 0.5 |
| 2 | 906.5 | 3.1 | 3.6 |
| 3 | 1091.4 | 6.2 | 9.8 |
| 4 | 287.1 | 13.4 | 23.2 |
| 5 | 672.3 | 32.7 | 55.9 |
| 6 | 845.8 | 112.5 | 168.4 |
| 7 | 265.4 | -.- | -.- |

* RMS on smoothed data

VES 8

**Fig. 3: Results of computer modeled curve for VES 8**




| No | Res | Thick | Depth |
|---|---|---|---|
| 1 | 753.4 | 0.5 | 0.5 |
| 2 | 781.1 | 2.5 | 3.0 |
| 3 | 1294.1 | 6.8 | 9.8 |
| 4 | 152.1 | 16.6 | 26.3 |
| 5 | 738.7 | 41.0 | 67.3 |
| 6 | 224.0 | 40.7 | 108.0 |
| 7 | 254.0 | 113.6 | 221.6 |
| 8 | 316.8 | 225.9 | 447.5 |
| 9 | 574.8 | -.- | -.- |

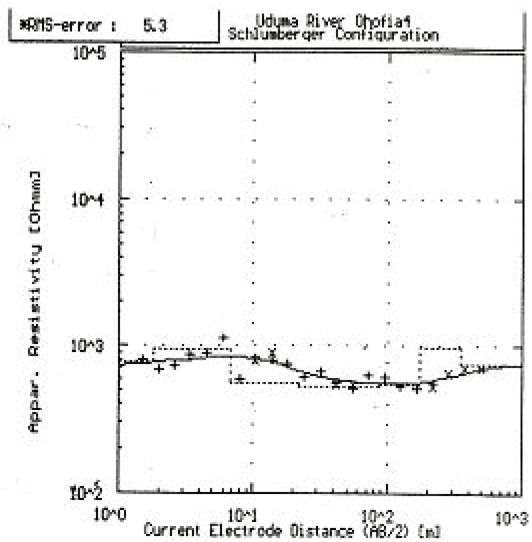
* RMS on smoothed data

VES 9

**Fig.4: Results of computer modeled curve for VES 9**

## 3.1 Interpretation of Apparent Resistivity Data

The first step in the interpretation of a resistivity sounding survey is to classify the observed apparent resistivity curves into types. This classification is primarily made on the basis of the shapes of the curves, but at the same time it is related to the geological situation in the subsurface. The shapes of a VES curve depend on the number of layers in the subsurface, the apparent resistivity value and on the thickness of each layer. The clay/conducting layer has resistivity ρ of less than 400Ωm, while the fine-medium coarse grained sands (Aquifer) has resistivity between 401Ωm and 1350Ωm. The resistivity of the undifferentiated laterite is seen to lie between 1351Ωm and 2650Ωm while that of the top soil is greater than 2650Ωm (Igboekwe et al., 2006).

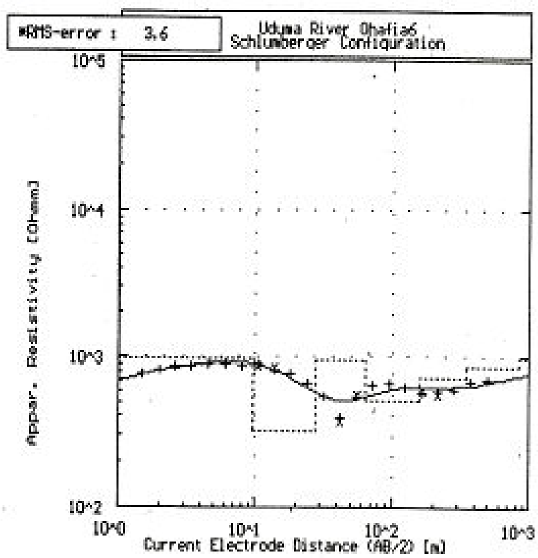



| No | Res | Thick | Depth |
|---|---|---|---|
| 1 | 690.7 | 0.4 | 0.4 |
| 2 | 769.9 | 1.4 | 1.8 |
| 3 | 946.8 | 5.0 | 6.8 |
| 4 | 558.1 | 15.2 | 22.0 |
| 5 | 532.2 | 66.0 | 88.0 |
| 6 | 547.7 | 87.8 | 175.8 |
| 7 | 968.5 | 169.7 | 345.5 |
| 8 | 747.9 | -.- | -.- |

* RMS on smoothed data

VES 10

**Fig. 5: Results of computer modeled curve for VES 10**




| No | Res | Thick | Depth |
|---|---|---|---|
| 1 | 595.1 | 0.5 | 0.5 |
| 2 | 967.6 | 9.2 | 9.8 |
| 3 | 322.9 | 17.9 | 27.7 |
| 4 | 954.3 | 36.8 | 64.4 |
| 5 | 506.3 | 93.2 | 157.7 |
| 6 | 725.8 | 190.0 | 347.7 |
| 7 | 863.9 | 494.9 | 842.7 |
| 8 | 978.9 | -.- | -.- |

* RMS on smoothed data

VES 12

**Fig. 6: Results of computer modeled curve for VES 12**

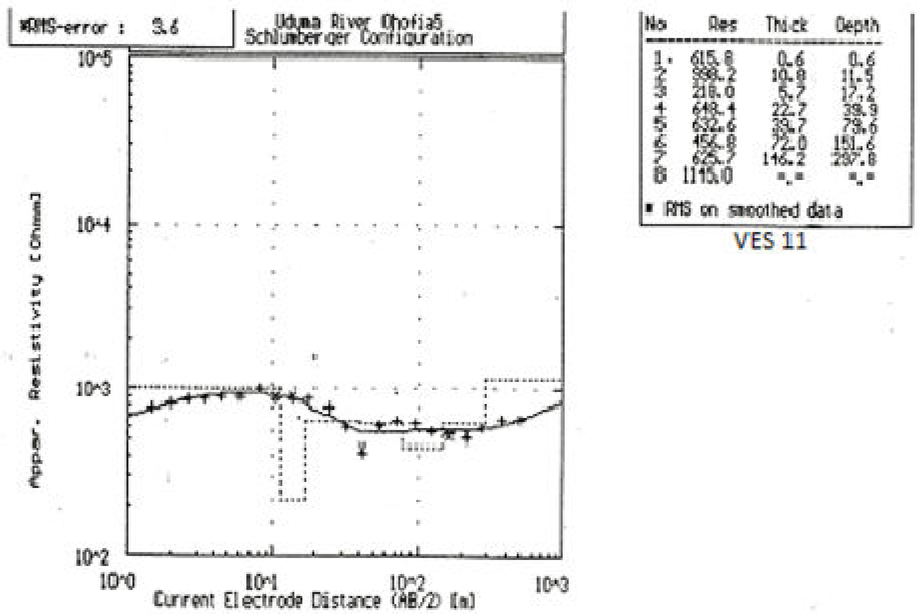



**Fig. 7: Results of computer modeled curve for VES 11**

### 3.1.1 VES points along BB' line

VES 5 and 9 has nine geoelectric layers each; VES 5 is a AH typed while VES 9 is a QKA type. VES 7, 11 and 15 has eighty layers each; VES 7 is a QA type: VES 11 is a QA curve and VES 15 is KA type. The interpreted sounding curves and presented as a geoelectric section in figure 8. The first geoelectric layer corresponds to the top soil with apparent resistivity value ranging from 171.9Ωm to 4028.6Ωm. It is composed of moisture, sand, clay and shale. The thickness varies between 0.5m and 0.6m. VES 5 has an aquifer bearing sixth layer with an apparent resistivity value of 1034.5Ωm and is 10.6m thick. VES 7 has the second, third and fourth geoelectric layers as aquifer bearing layers. The apparent resistivity of these layers ranges from 680.5Ωm to 1268.6Ωm and total thickness of 11.0m; they are located just 0.6m deep and therefore will be susceptible to pollution. But the eighth layer with apparent resistivity valued of 1287Ωm with an infinite thickness, because it is the last layer, and is located at about 126.4m deep constitute a good confined aquifer. VES 9 has an unconfined aquifer from the first geoelectric section to the third geoelectric section. The apparent resistivity value of this aquifer ranges from 753.4Ωm to 1294.1Ωm. A clayey aquitard of apparent resistivity value of 152.1Ωm and 16.6m thick occupying the fourth layer separates the third geoelectric section from the aquiferous fifth geoelectric section with an apparent resistivity value of 738.7Ωm and is 41m thick. The ninth layer with apparent resistivity value of 574.8Ωm with an infinite thickness, because it is the last layer, and is located at about 447.5m deep constitute a good and profitable confined aquifer. Almost all the geoelectric layers of VES 11 are aquifer bearing layers except the third layer which is a clayey aquitard zone with apparent resistivity value of 218Ωm and is 5.7m thick. The apparent resistivity values of all geoelectric layers of VES 11 ranges from 456.8Ωm to 1145Ωm. The total thickness from the fourth layer down to the eighth layer is over 258m. VES 15 has only the fifth layer as an aquiferous layer. It has an apparent resistivity value of 480.4Ωm and is 43.2m thick.

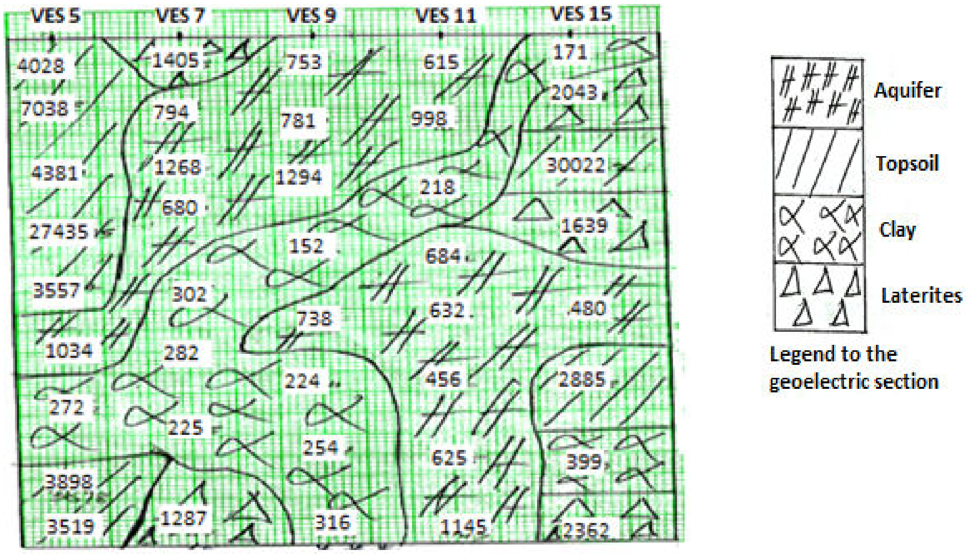



**Fig. 8: Geoelectrical section along BB'**

The resistivities, thickness and curve types of some randomly selected VES stations lying in the watershed of Muri River shows VES stations with good aquifer characteristics. VES 8, 10, 12 and are among these stations. The proximities of VES 7 and 8, VES 9 and 10 and VES 11, 12 and 13, which all lie within the watershed of Muri River, shows an area for a profitable water borehole.

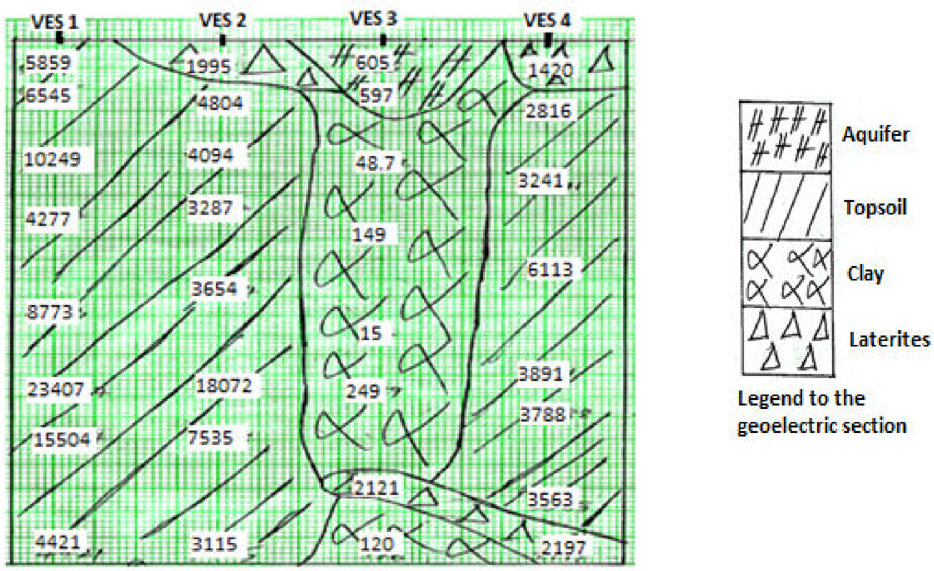



**Fig. 9: Geoelectrical section along CC'**

**3.1.2 VES points along CC' line**

VES 1 and 2 are an eight layer KK type curve. VES 3 is an eight layer H type curve. While VES 4 is an eight layer A type curve. The interpreted modeled curves are presented as a geoelectric section in figure 9. The first layer corresponds to the top soil with apparent resistivity value raging from 605Ωm to 5859.5Ωm reflecting the various compositions and moisture constant of the top soil, it is composed of sand, clay, silt and decomposed organic materials, the thickness is approximately 0.5m. Except the first layer (with resistivity value of 605Ωm) and second layer (with resistivity value of 597Ωm) of VES 3, there is no other layer with apparent resistivity value of an aquifer bearing range. The lithology of these VES points mainly consists of sand, shale, silt, sandstones and clay.

**3.1.3 VES points along AA' line**

VES 14 is an eight-layer HQ type curved while VES 17 is an eight-layer KA type curve. VES 18, 19 and 20 are seven-layer curves; VES 18 is a KK type; VES 19 is an A type while VES 20 is a KA type.

The interpreted sounding curves are presented as a geoelectric section in figure 10. The topsoil geoelectric layer has apparent resistivity value which ranges from 51.8Ωm to 866.20Ωm; its thickness varies from 0.5m to 0.6m and is composed mainly of shale, organic matters and silt. The fourth layer of VES 14 constitutes the first aquifer. It has an apparent resistivity value of 810.9Ωm and is 5.7m thick. The seventh geoelectric layer has apparent resistivity value of 627Ωm and is about 297.4 m thick. This constitutes an aquifer of very good quality and is located at about 116.7m deep and it won't be susceptible to pollution. The third layer of VES 17 has an apparent resistivity value of 492.1Ωm with thickness of 2.6m and is located 3.2m deep. It will be susceptible to pollution and is of small quantity.

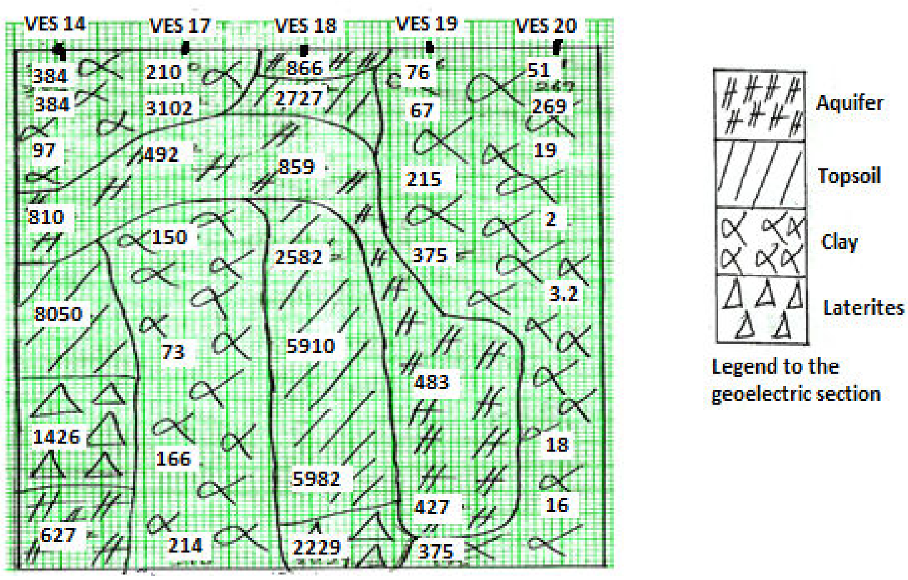



**Fig. 10: Geoelectrical section along AA'**

VES 18 has an aquifer bearing third layer, with an apparent resistivity value of 859.6Ωm and is 10.8m thick; it is located just 2.6m deep. VES 19 has a promising aquiferous fifth and sixth layer. Their apparent resistivity values ranges from 427.1Ωm to 483.2.Ωm. Their combined thickness is 458.8m. They are located at about 55.2m deep. VES 20 has no aquifer bearing layer.

## 4. CONCLUSION

This research has provided information on the depth to the groundwater and the thickness of the aquifer unit in the study area. This information is going to be relevant to the development of an effective water scheme for the area.

Based on all the findings made in the interpretation of the VES data, VES stations along the line BB' westwards towards VES 12, 13, 10 and 8 have been chosen as the most viable locations for the development of groundwater resources in the study area. The thickness and resistivity of the aquifers at these VES stations indicates a very good potential for groundwater. Conclusively, the study area has a high potential for groundwater development. Despite all the limitations of the VES technique, it has been found to be reliable for groundwater exploration in the study area particularly when using the schlumberger configuration and combining it with adequate geologic mapping and using computer aided interpretation for survey data.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

Beeson, S., Jones, C. R. C. (1988). The combined EMT/VES Geophysical Method for Sitting Boreholes. Ground Water, 26(1), 54-63.

Carruthers, R. M., Smith, I. F. (1992). The Use of Ground Electrical Methods for Siting Water Supply Boreholes in Shallow Crystalline Basement Terrains. In E. P. Wight and W. G. Burgess, (eds). The Hydrology of Crystalline Basement Aquifers in Africa. Geological Society Special Publication, 66, 203-220.

Ekine, A. S., Osobonye, S. (1996). Surface Geo-electric sounding for the determination of Aquifer characteristics in parts of Bonny Local Government Area of Rivers State. Nig. J. Phys., 85, 93-97.

Hazell, J. R. T., et al. (1992). The hydrogeology of Crystalline Aquifers in Northern Nigeria and Geophysical Techniques used in their Exploration. In E. P. Wight and W. G.

Burgess, (eds). The Hydrology of Crystalline Basement Aquifers in Africa. Geological Society Special Publication, 66, 155-182.

Hazell, J. R. T., et al. (1988). The Location of Aquifers in Crystaiiine Rocks and Alluvium in Northern Nigeria using Combined Electromagnetic and Resistivity Techniques. Quarterly Journal of Engineering Geology, 21, 159-175.

Hoque, H. M., Ezepue, M. C. (1977). Petrology & Palaeogeography of the Ajali sandstone, Nigeria. Journal of Minning & Geology, 14, 16-22.

Ibe, K. K. et al. (1998). Natural fluoride levels in some springs and streams from the Late Maastrichtian Ajali Formation in Ohafia- Arochukwu area of South Eastern Nigeria. Odonto-Stromatologie Tropicale, 87, 1998.

Igboekwe, M. U. et al. (2006). Delineation of Potential Aquifer Zones from Geoelectric Soundings in KWA-IBO River Watershed, Southeastern, Nigeria. Journal of Engineering and Applied Sciences, 1(1), 410-421.

Kearey, P., Brooks, M. (1984). Introduction to geophysical Exploration (2nd Edition). Blackwall Scientific Publication, Oxford.

Offodile, M. E. (1992). An approach to Groundwater study & development in Nigeria. Mecon Services Ltd Jos, Nigeria.

Okwueze, E. E. (1996). Preliminary findings of the groundwater resource potentials from a regional geo-electric survey of the Obudu basement area. Nig. Global J. Pure Appl. Sci., 2(2), 201-211.

Olayinka, A., Barker, R. (1990). Borehole Sitting in Crystalline Basement Areas of Nigeria with a Microprocessor Controlled Resistivity Traversing System. Groundwater, 28, 178-183.

Oseji, J. O., et al. (2005). Geoelectric investigation of the aquifer characteristics and groundwater potential in Kwale, Delta state Nigeria. J. Appl. Sci. Environ. Mgt., 9(1), 157-160.

Pfannkuch, H. (1969). On the correlation of electrical conductivity properties of porous systems with viscous flow transport coefficients. International Association of Hydraulic Research, ed., Fundamentals of Transport Phenomena in Porous Media, 1972. Elsevier., 42-54.

Van-Overmeeren, R. A. (1989). Aquifer boundries explored by geoelectric measurements in the coastal plain of Yemen: a case of equivalence. Geophysics., 54(1), 38-48.

Yang, C., et al. (1994). Locating groundwater at selected sites by geoelectric methods, Annual Meeting Abstracts, Society of Exploration Geophysics, 652-654.

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