RESISTIVITY SURVEY FOR GROUNDWATER IN PARTS OF ENUGU SOUTH LOCAL GOVERNMENT AREA, ENUGU STATE.

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Abstract

A geophysical survey for groundwater search was carried out in some selected locations in Enugu South Local Government Area of Enugu State to determine the groundwater potential and depth to the aquifer layers using vertical electrical resistivity (VES) method. Sixteen vertical electrical soundings were obtained using the Schlumberger electrode configuration with the aid of the OHMEGA terrameter. A computer programme (OFFIX) was used in the interpretation, which produced results used in the analysis of the vertical electrical sounding data. The results obtained from the interpretation revealed between four and six geoelectric layers with the top layers being lateritic (clayey) soil having thicknesses ranging from 1.90m to 3.20m. Five geoelectric layers were evident at VES 1, 3, 4, 7, 8, 9 and 11. Profiles VIES 5, 6, 10, 12, 13, 14, 15 and 16 indicated six geoelectric layers while VES 2 revealed four geoelectric layers. The water bearing rock in the survey areas are predominantly shaly mudstone and fractured shale. The tops of the aquifer layers were interpreted to exist at depths between 49m and 120m. The aquifers have resistivities ranging from 0.92<Tm to 41.31 Ωm. Some locations in the survey area have good prospect for groundwater development. Such locations includes VES 2, 3, 4, 5, 6, 8 and 10 (Akwuke, Amechi and Obeagu region). This is because the depth to the main aquifer (shaly mudstone) falls within the depth range (between 49 m and 120 m). These fairly correlate with some of the borehole logs obtained in the survey area. However, locations at VES 1, 7, 9, 11, 12, 13, 14, 15 and 16 are not strongly recommended for borehole drilling because the aquifer layers even though with appreciable thickness are composed of clay and coal. Clay is an aquitard which is not ready to give out its water during groundwater exploration. Existing data shows that boreholes drilled at those areas failed to yield significant quantities of water all year round because of the geological formation. The research work has shown that the selected survey area does not have good groundwater potential.

Keywords**:** Aquifer depth, Ground water potential, Resistivity.

1.0 Introduction

Resistivity methods employ an artificial source of current, which is introduced into the around through point electrodes or long line contacts. The procedure is to measure potentials at other electrodes in the vicinity of the current flow. From these measurements, it is possible to determine an effective or apparent resistivity of the subsurface.

In this regard the resistivity technique is superior, at least theoretically, to all the other electrical methods, because quantitative results are obtained by using a controlled source of specific dimensions. Electrical resistivity technique has been used for many decades in hydro geological mining and geotechnical investigation [1].

The electrical resistivity technique involves two basic procedures: lateral profiling and vertical sounding. These two procedures both test the flow of electric current in the ground. Electrical resistivity technique enables the determination of surface resistivity by driving a direct current signal or low frequency alternating current into the ground [2]. The resulting potential field generated is then recorded by sensitive detecting instrument at various locations on earth surface. From the data recorded information about the electrical properties of the earth pin be derived and geological property inferred.

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Acquisition of resistivity data therefore involves the deployment of an array of electrodes, which are connected to a control unit through cables. By evaluating the resistivity values obtained, an understanding of the subsurface materials can be developed. Also these resistivity values when plotted produce a numerical picture of the subsurface materials at a chosen depth across a horizontal plane.
The depth of investigation depends on the electrode separation and geometry, with the eater electrode separation yielding information about greater depths. The ability of a rock unit to conduct an electric current depends primarily on three factors: porosity, permeability and conductivity. Ground water in sedimentary rock is generally encountered in cracks, fissures, bedding planes, pore space and contract zones with intrusion [3]. The presence of water and its chemical characters are the principal control on the flow of electric current because "most rock particles offer high resistance to electrical current flow. Thus, resistivity decreases as porosity, water content and water salinity increases.
The objective of electrical resistivity technique is to deduce information about the subsurface resistivity distribution by making measurements on the ground surface [4]. This method considers the subsurface geological setting as series of electrical resistors that naturally inhibit the flow of an electric current. Current flowing vertical through layers of the earth I transverse each in series like resistors connected in series in an electrical circuit. Current flowing laterally will tend to take the path of least resistance and the layers will behave like resistor connected in parallel. The success of electrical resistivity lies in its ability to detect changes in the electrical field caused by these resistors and consequently to determine their locations, depth and thickness [5].

2.0 Location and Geology of the study area

The area under survey lies between longitudes 6°51' and 7°28' east of Greenwich meridian and latitudes 6°4.13' and 6°21' north of the equator as indicated in figure 1 which displays the -geological map of the Enugu South Local Government. The survey area covers about 121 square kilometres and lies in the Southern part of Enugu State. The global positioning system (GPS) receiver was used in the field to obtain the global grid positions of the vertical electrical sounding points, including the latitudes, longitudes and the elevations. This instrument receives its data from the GPS satellite. The GPS locations of field stations are shown on table 1. The study area has since assumed urban status and is easily accessible except the interior parts of the local government. It can be accessed through Enugu-Porthacourt express way Onitsha-Abakaliki express way through new market after Udi-Ngwo hill. The elevation is generally 150m above sea level.
The study area and its environs lie on the geological formation referred to as the Awgu-Ndeaboh formation. This formation is basically made up of fine medium grained sandstone, yellow in colour. The entire formation was deposited in a marine environment during the lower Cenomanian period of the Cretaceous era [6]. It runs from Cross River State to as far as Kogi and beyond through west of Markurdi. Awgu -Ndeaboh shale lies directly and conformably on the underlying Eze-Aku shale group, the dominant geological material around Abakiliki and its environs. It consists of mainly bluish grey well-bedded shale with occasionalintercalations of fine grained yellow-cretaceous sandstones and yellow limestone.
It was affected in the Awgu area by intracretaceous folding on a west-south axis passing h the Awgu sandstone and dipping gently to the west.
As a result of its vast age of over eight million years, the sandstone bodies are consolidated ice to long lasting over-burden pressure exerted by the younger overlying material.
As earlier mentioned, this formation is dominantly made up of shale, mudstones, and clay stones. This is not endowed with primary porosity. However, if fractured, the formation could veld water to bore holes.

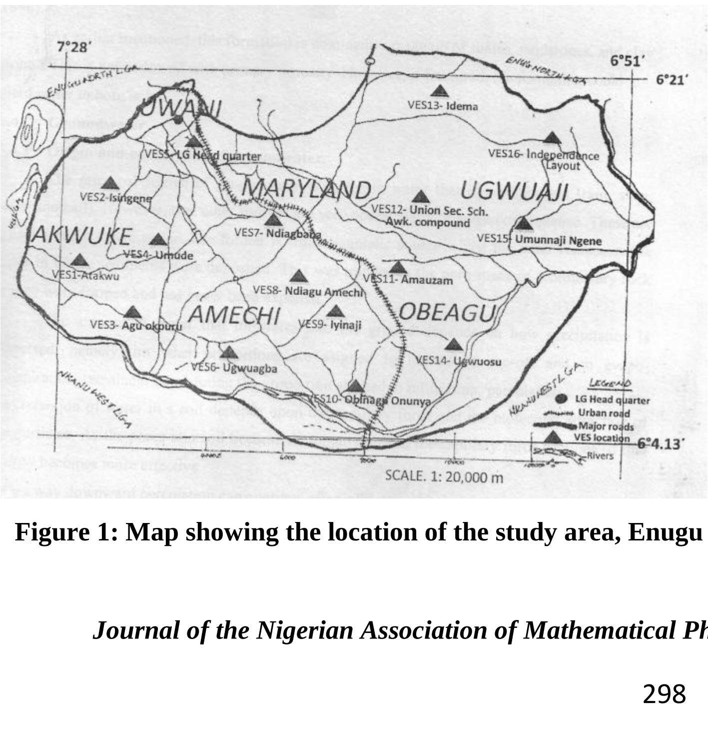

Figure 1: Map showing the location of the study area, Enugu South LGA and the VES points.

Table 1:The global grid positions and elevations of the profile centres

Profile No.	Location of profile	Latitude	Longitude	Elevation(m)
VES. 1	Atakwu	06^0 11.48'N	$7^0$27.40'E	197.60
VES. 2	Isingene	$06^0$17.08'N	$7^0$26.24'E	173.50
VES. 3	Agu Okpuru	$06^0$10.48'N	$7^0$22.29'E	174.50
VES. 4	Umude	$06^0$14.12'N	$7^0$20.31'E	183.40
VES. 5	Enugu South L.G.A Headquarter	$06^0$18.43'N	$7^0$17.50'E	177.20
VES. 6	Ugwuagba	$06^0$08.12'N	$7^0$17.03'E	193.50
VES. 7	Ndiagbana	$06^0$16.16'N	$7^0$11.10'E	261.40
VES. 8	Ndiagu Amechi	$06^0$11.41'N	$7^0$10.20'E	247.21
VES. 9	Iyinaji	$06^0$11.01'N	$7^0$08.18'E	205.00
VES. 10	Obinagu Onunya	$06^0$05.02'N	$7^0$06.21'E	216.30
VES. 11	Amauzam	$06^0$12.06'N	$7^0$05.19'E	210.50
VES. 12	Union Secondary Sch. Akwuanano compound	$06^0$17.09'N	$7^0$03.12'E	215.20
VES. 13	Idema settlement	$06^0$20.52'N	$7^0$02.30'E	176.00
VES. 14	Agwuosu settlement	$07^0$08.22'N	$7^0$01.51'E	187.05
VES. 15	Umunaji Ngene	$06^0$15.53'N	$6^0$56.03'E	142.00
VES. 16	Independence layout	$06^0$19.28'N	$6^0$54.20'E	197.61

3.0 Methodology

The most basic equipment required for field measurement in vertical electrical sounding survey includes suitable power source, terrameter, electrodes, cables and reels. Auxiliary equipment for the survey consist of a global positioning system (GPS) used for determining the resistivity survey locations and topography of the study area, geologic hammers for driving electrodes into the ground, two measuring tapes, cutlasses for clearing operation site and digging small holes where need be.

The power source for a resistivity survey conventionally is direct current (D.C) or a low frequency A.C supply. The A.C motor generator is useful in large scale work due to its great Current capacity despite the fact that the equipment is bulky and stressful to move about. The battery source is limited in capacity and has a short life span though it is portable, r. the course of this field work, a lead accumulator (car battery) was used.

The basic instrument for electrical resistivity survey is the terrameter. The design of terrameter varies in its circuit and depends on type of current used as well as the portability requirement. With DC or long-period commutated DC sources, the current is measured with a DC milliammeter, whose range should be from about 5 to 500mA, depending on the electrode spread, type of ground and power used. Potential is normally measured with a DC voltmeter of high input impedance (1MΩ or greater) and range 10mV to perhaps 20V.

A typical resistivity set with voltage and current meter is an instrument that measures the ratio of potential to current (resistance) usually associated with the trade name Megger has been frequently employed for resistivity work. The terrameter used in this research work is the OHMEGA signal averaging system (SAS 1000). This is a modern and compact system for resistivity measurement. It comprises of the power source that provides a steady current and it is capable of automatically measuring the ratio of potential difference (ΔV) to current (I) that is the resistance (R). The OHMEGA terrameter, SAS 1000 is made up of three major units. These include the transmitter, the receiver, and the micro-processor units. .The transmitter sends out regulated signal current to the ground through the wires and the electrodes. The receiver measures the potential difference at the position of interest. It is also connected to the ground through a pair of potential electrode and insulated wires. It is table of discriminating against signal noise such as self-potentials. The microprocessor unit automatically controls the operations of the instrument and displays the results.

The OHMEGA terrameter, SAS 1000 is designed to operate in different modes including resistivity mode, self-potential mode and induced-polarization mode.

With AC power source, all the electrodes may be steel, aluminium, or brass. Stainless steel is probably the best for combined strength and resistance to corrosion. Metal electrodes should be at least half metre long so that they can be driven into the ground several centimetres for good electricalcontact. In very dry surfaces, this contact may be improved by watering the electrodes. If DC power is used, the potential electrodes should be porous pots. Connecting wires, which must be insulated and as light as possible, are wound on portable reels. Plastic insulation is more durable than rubber against an abrasion and moisture.

Finally, a modern version of the resistivity survey equipment, the signal averaging system S 1000) was used. This instrument, according to the manufacturers' specifications, can discriminate against low frequency electrical noise due to natural origin. The system also makes series of automatically repeated measurements and displays the average value.

A total of sixteen sounding profiles were carried out within the selected communities or locations in the research area.

4.0 INTERPRETATION OF THE FIELD DATA.

Data Processing

Preliminary interpretation began in the field where the sounding data were reduced to apparent resistivity values ρ_a using equation below

$$\rho_a = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)\frac{\Delta V}{I} = GR \quad (1)$$

Where G is the geometric factor and R is the measured resistance.

It is important to give an estimate of errors in the calculated values of apparent resistivity, ρ_a.

If $u = f(x, y, z, \dots)$, then the standard error S_u in u is given by

$$S_u = \left[\left(\frac{\partial u}{\partial x}\right)^2 S_x^2 + \left(\frac{\partial u}{\partial y}\right)^2 S_y^2 + \left(\frac{\partial u}{\partial z}\right)^2 S_x^2 + \cdots\right] \quad (2)$$

The expression for apparent resistivity, $\rho_{a.}$ is $\rho_a = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right)R$. Hence $\rho_{a.}$depends on a, b, and R. using the formula in equation 2, it is easily shown that the standard error S_{ρ_a} in $\rho_a$is given by

$$S_{\rho_a}^2 = \left(\frac{2\pi aR}{b}\right)^2 S_a^2 + \left\{\pi R\left(\frac{a^2}{b^2} + \frac{1}{4}\right)\right\}^2 S_b^2 + \left\{\pi\left(\frac{a^2}{b} - \frac{1}{4}\right)\right\}^2 S_R^2 \qquad (3)$$

In

Interpretation in terms of various layers of actual resistivities and their depths

Computer program was used to interpret the sounding data. The resistivity and thickness parameters (ρ and h) believed to be closer to reality were input into the computer program. This was modified by trial and error until a very close match was attained between the calculated and the observed resistivity curves. The theoretically calculated apparent resistivity curves give the geoelectric model for the field curves. The OFFIX application software was used to interpret the sounding data. The software was programmed in such a way that it can interpret data obtained with any of the popular electrode arrays used in vertical electrical soundings and induced polarization. The program requires an experienced interpreter who can handle geological problems as it concerns fitting of sounding curves. The curves obtained with the computer interpretations for the various vertical electrical sounding points are shown are showing in figures 2, 3, 4, 5, 6, and 7.

The results of the computer interactive modelling were referred to in the final analysis of the sounding data. This is because the computer program is believed to be more efficient than the partial curve matching techniques.

Interpretation of actual resistivities in terms of subsurface geology and ground water condition

The results of the sixteen vertical electrical soundings of the selected areas indicated between four and six geoelectric layers. The thickness of the top layers vary between 1.09m and 3.20m, these are usually top laterite (Clayey) soil observed during the field work. The field curve of VES 1, 2, 12, 13, and 16 show a trend of continuous decrease in resistivity with depth though was inappreciable increase in VES 13 (Idema settlement) field curve. These persistent decrease in resistivities with depth could be attributed to increase in water saturated soil.

VES 7, 9, and 14 shows opposite field curve to VES 1, 2, 12, 13, and 16. The curves show steady increase in resistivity with depth. The field curves obtained from VES 11 and 15 show little decrease in resistivity and later increase in resistivity with depth, at a point the resistivity started decreasing with depth again.

In the field curves obtained from VES 3, 4, 5, 6, 8, and 10 initially revealed a decrease in resistivity and later increased resistivty with depth. The lower values encountered before the rise in resistivity could be attributed to the water saturated fractured shale and mudstone aquifer which are the major water bearing rocks in the survey area.

The geoelectric sections of the vertical electrical soundings are shown in figures 8 and 9, these sections are based on the number of layers interpreted by the computer. The various resistivities and thicknesses obtained from the interpretation of VES data using computer interactive program is shown in Table 2.

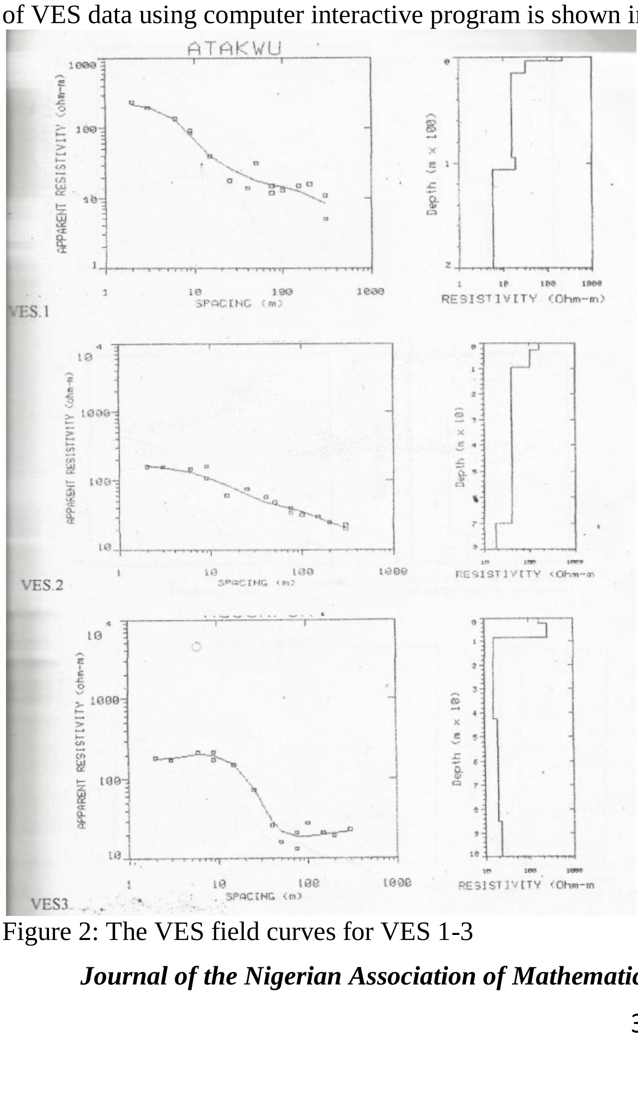

Figure 2: The VES field curves for VES 1-3

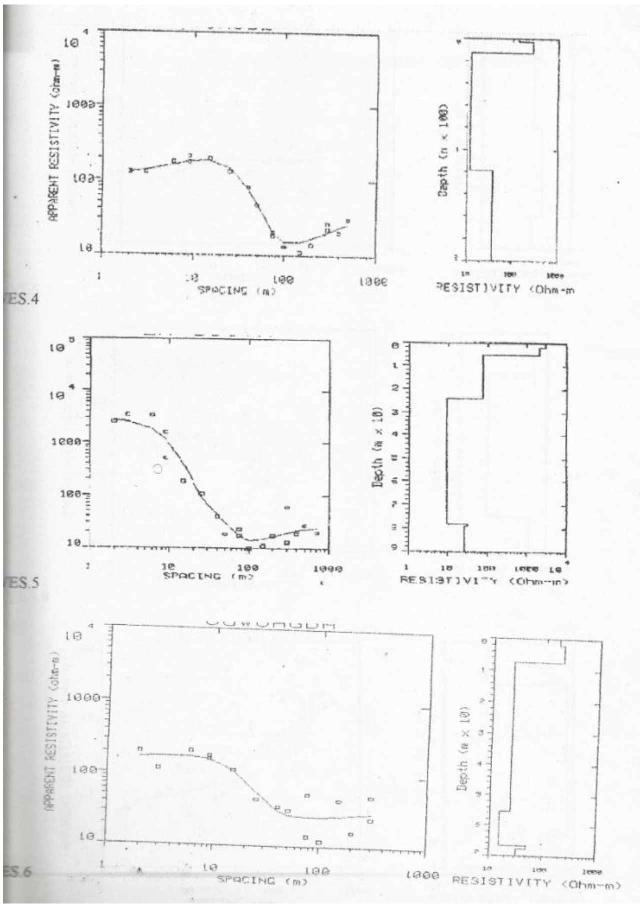

Figure 3: The VES field curves for VES 4-6

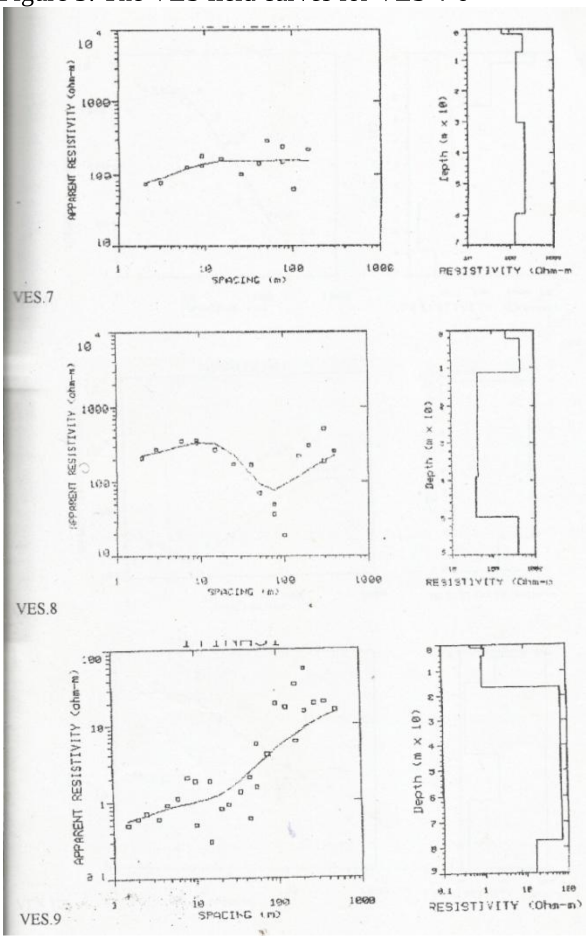

Figure 4: The VES field curves for VES 7-9

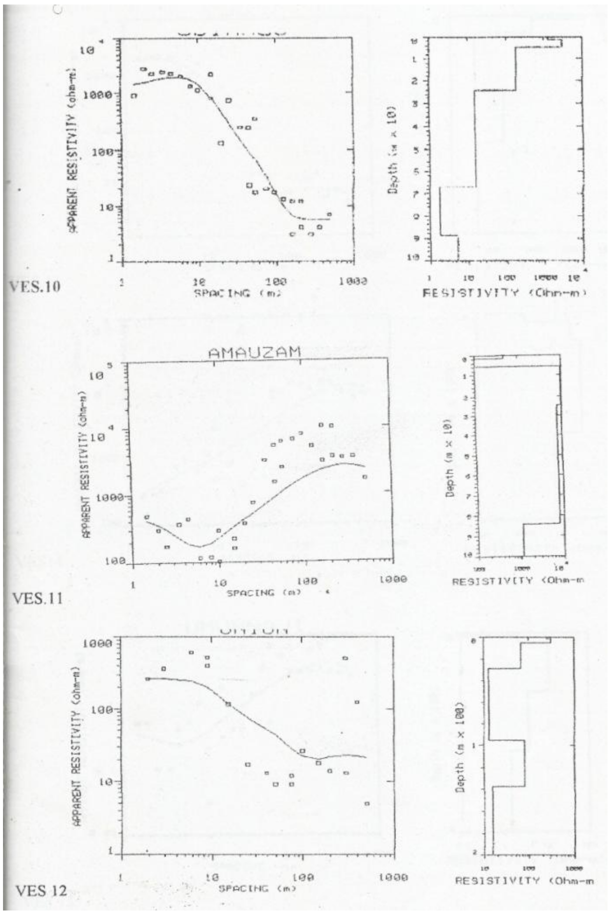

Figure 5: The VES field curves for VES 10-12

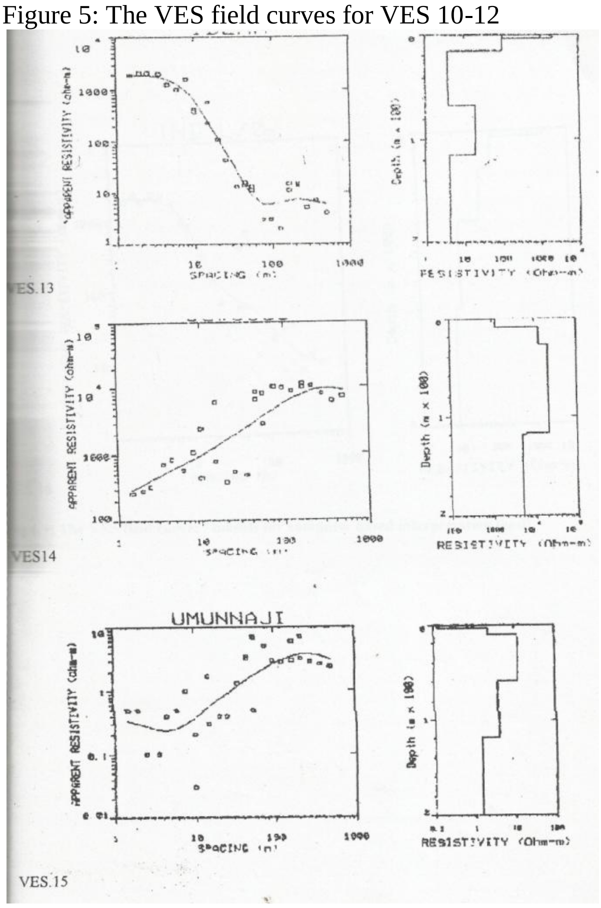

Figure 6: The VES field curves for VES 13-15

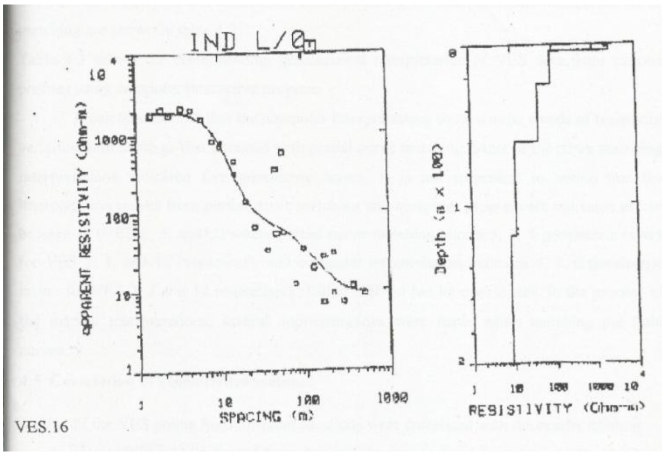

Figure 7: The VES field curve for VES 16

Correlation of geoelectric section

Six of the VES points from different locations were correlated with the nearby existing borehole data (Figure 10) collected from Atlantic Geophysical and Associates LTD, Abuja and borehole drilled by Geoprobe Nigeria Limited, Enugu at Amodu 5km from VES 8 after the geophysical survey (Table 3) was used to correlate the geologic sections and the inferred formations of VES 8. The following observations could be given:

A comparison of the log of the study area revealed that the lithology is basically the same in VES 2, 7, 8, 10, and not in VES 1 and 15.some layer thicknesses appear to be varying.

Water table depths as interpreted from the resistivity data are consistent with those of the wells to a good extent.

The borehole lithology from Geoprobe Nigeria Limited, and Atlantic Geophysical and Associates LTD, correlates well with the interpretation of the data for VES 1, 2, 8, 10, and 15 in terms of the geoelectric sections and rock-type formation.

The inferred geoelectric section and rock-type formation of VES points locations of the study area are shown in Figure 11. This was obtained by bringing the geoelectric sections of the vertical electrical soundings Figures 8 and 9 close to each other.

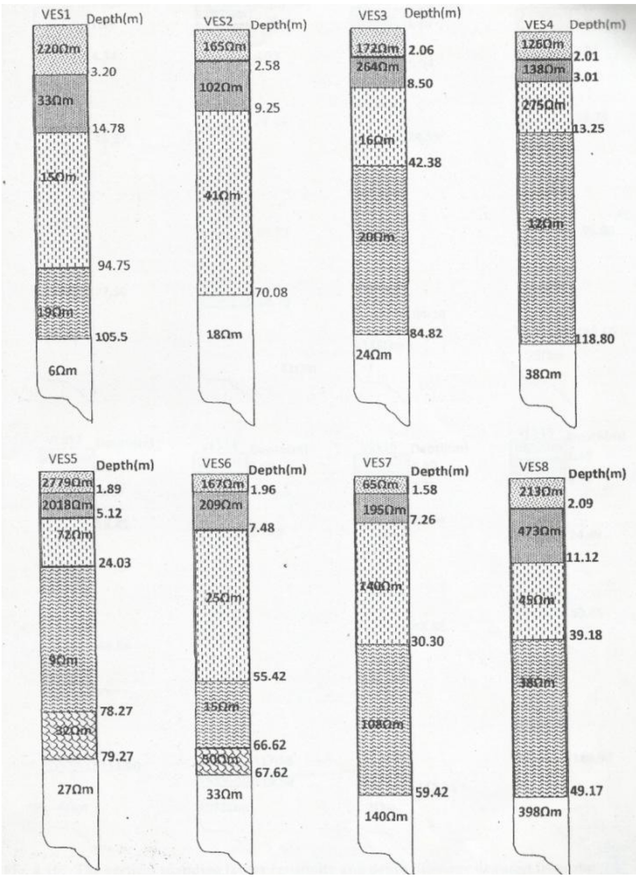

Figure 8: The VES layers and lithology for VES 1-8 deduced from computer interactive model

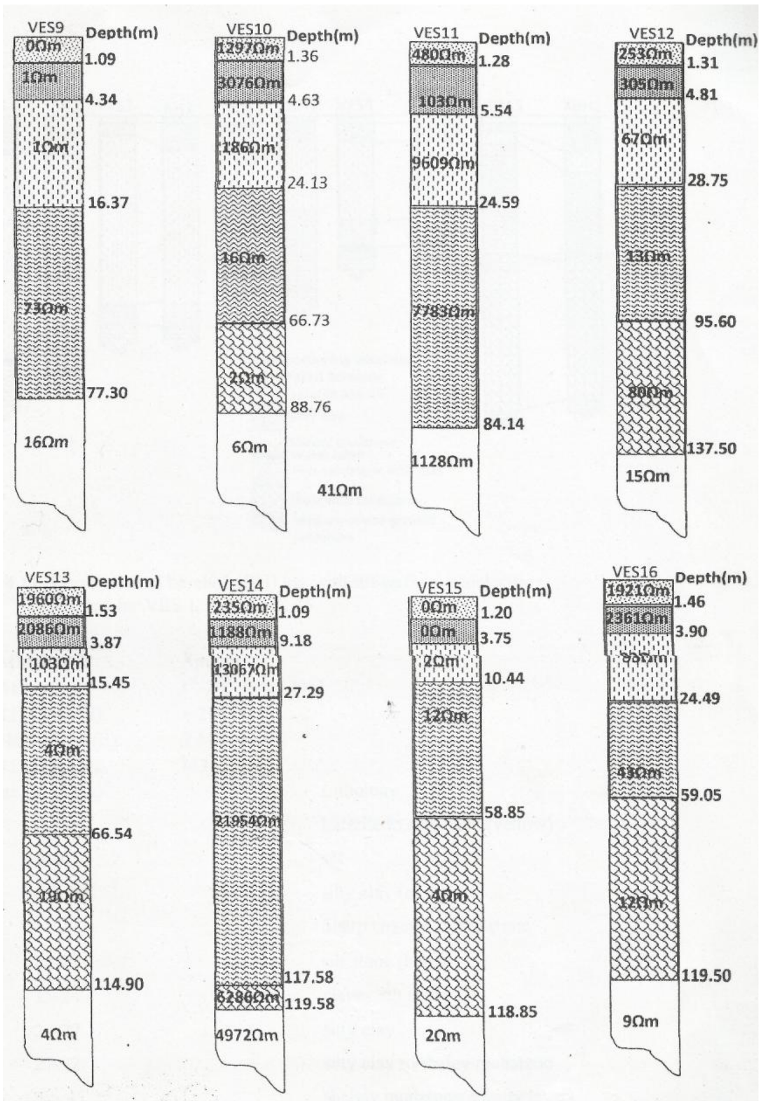

Figure 9: The VES layers and lithology for VES 9-16 deduced from computer interactive model

Table 2: Geoelectric interpretation of VES data using computer interactive programme

VES NO	Resistivity of geoelectric layers (Ωm)						Thickness (m)					Depth (m)				
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5		t_1	t_2	t_3	t_4	t_5	d_1	d_2	d_3	d_4	d_5
1	220	33	15	19	6		3.20	11.58	79.97	10.83		3.20	14.78	94.75	105.50	
2	165	102	41	18			2.58	6.67	60.83			2.58	9.25	70.08		
3	172	264	16	20	24		2.06	6.44	33.88	42.44		2.06	8.50	42.38	84.82	
4	126	138	275	12	38		2.01	0.996	10.24	105.60		2.01	3.01	13.25	118.80	
5	2779	2018	72	9	32	27	1.89	3.23	18.90	54.24	1.00	1.89	5.12	24.03	78.27	79.27
6	167	209	25	15	50	33	1.96	5.52	47.93	11.20	0.997	1.96	7.48	55.42	66.62	67.62
7	65	195	140	208	128		1.58	5.68	23.04	29.12		1.58	7.26	30.30	59.42	
8	213	473	45	38	398		2.09	9.03	28.06	10.52		2.09	11.12	39.18	49.70	
9	0	1	1	73	16		1.09	3.25	12.02	60.93		1.09	4.34	16.37	77.30	
10	1297	3077	186	16	2	6	1.36	3.27	19.49	42.62	22.01	1.36	4.63	24.13	66.73	88.76
11	480	103	9609	7783	1128		1.28	4.26	19.04	59.55		1.28	5.54	24.59	84.14	
12	253	305	67	13	80	15	1.31	3.49	23.94	66.84	41.90	1.31	4.81	28.75	95.60	137.50
13	1960	2086	103	4	19	4	1.53	2.34	11.57	51.09	48.40	1.53	3.87	15.45	66.54	114.90
14	235	1188	13067	21954	6286	4972	1.09	8.09	18.11	90.29	2.00	1.09	9.18	27.29	117.58	119.58
15	0	0	2	12	4	2	1.20	2.55	6.69	48.41	60.01	1.20	3.75	10.44	58.85	118.85
16	1921	2361	93	43	12	9	1.46	2.43	20.58	34.56	60.47	1.46	3.90	24.49	59.05	119.50

Table 3:

Depth range (m)	**Lithology**
0-3	Laterite to silty sand (yellow)
3-6	Silt
6-9	Silty clay (dark)
9-12	Sharp change to mudstone
12-15	Silt stone (hard)
15-24	Clayey silt stone
24-27	Silty clay
27-32	Silty clay to shaly mudstone
32-45	Shaly mudstone (aquifer layer)

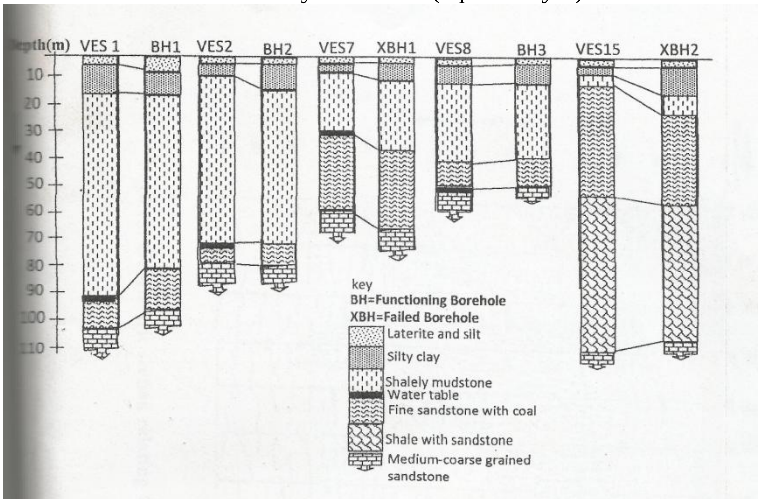

Figure 10: Correlation of borehole (BH) log with subsurface geoelectric sections of VES 1, 2, 7, 8, and 15

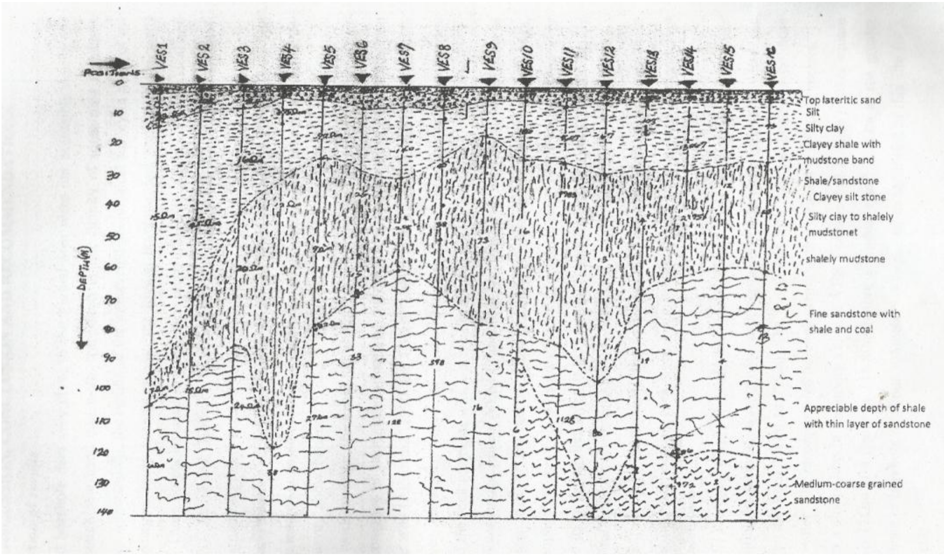

Figure 11: Geoelectric section relating VES points and lithology of the study area

5.0 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Discussion of results

Logged borehole data very close to the studied area were not accessible during the field work, though few hand dug wells were seen in the vicinity of some data collection points. This notwithstanding, the results of the interpreted geophysical survey in most of the investigated locations fairly correlated with the logged borehole data and hand dug wells from the area. These boreholes used in correlation were drilled by Atlantic Geophysical and Associates LTD, Abuja and Geoprobe Nigeria Limited, Enugu under the Enugu State Rural Borehole Construction Project in 2010.

The water bearing rock in the survey areas are predominantly shaly mudstone and fractured shale located at depth between 49 meters and 120 meters. The results, of most of the geophysical survey show between 5 and 6 geoelectric layers. The first layers are the top lateritic sand with average thickness of about 2.5 meters. The intermediate layers are suggested to comprise of shale, sandstones and mainly shale as reported in the literature on geology of the area [7,8]. It is suggested that the layers with relatively lower resistivity could be water bearing formations. This is because the conductivity of the rock increases with water saturation in porous strata.

At Atakwu village square, VES 1 (Table 2), the fifth layer with resistivity of 6Ωm at the depth greater than 105.50 meters could possibly be the water bearing rock. Though, because the geophysical curve shows a progressive decrease in resistivity with depth, no layer can be referred to as the aquifer layer. It may be clayey sand which retains water and hardly gives it out. Thus, borehole is not strongly recommended here.

In VES 2 (Isingene settlement), the fourth layer of resistivity 18Ωm at depth 70.08 meters could be the water bearing rock layer. Here, a borehole drilled to a depth of about 71m is expected to yield water.

In VES 3 (Aguokpuru), it could be observed that there is an increase in water saturation resulting in decrease in resistivity with depth seen before the fifth layer where the value gradually rose from 19Ωm to 24Ωm. The fourth and fifth layers appeared to be r saturated with water. The recommended borehole depth at this location is about 43 metres.

There is a sharp drop in resistivity value at VES 4 obtained at Umude market square from 275Ωm to 12Ωm at a depth of 118.80m before a gradual rise to 38Ωm at the greater depth layer. Hence, a borehole of about 118meters is expected to be better water yield.

From the six geoelectric layers encountered at Enugu South L.G Headquarters (VES5) there is indication that water saturated layer is the fourth layer of depth 78.27meter and resistivity 9Ωm. Here, a borehole of about 70 meter is expected to be drilled at this site. However, the water yield may not be enough to serve a community at the onset of dry season, because the layer is mixed with clay which is aquitard.

In VES 6 (Ugwuagba), the lower resistivities of the fourth layer probably indicate the presence of water saturated rock. The depth of the aquifer recommended for drilling here is estimated to be about 66.00meters.

The geophysical survey at Ndiagbana, Amechi west (VES 7) does not show an appreciably decrease in resistivity. It may be probably the aquifer layer may still be at the ■tear depth Drilling of borehole here is not strongly recommended.

In the result of the interpretation of the data obtained at Ndiagu Amechi, (VES.8) the resistivity' decreased from 213Ωm at the first layer to 38Ωm at the depth of 49.70meters for layer from the surface before a slight rise in resistivity. The recommended borehole depth at this location is about 49 meters.

In VES 9, obtained at Iyinaji settlement, the resistivity gradually increases from OΩm at thetop later tic soil to 73 Ωm at depth of 77.30 m. Low resistivity implies plenty of ground water potential. Here, borehole drilling is not recommended as the aquifer layer may n the probed depth.

The result of VES 10, obtained at Obinagu Onunya shows that the water saturated rock is at the fifth layer because of the drastic drop in the resistivity from 1297Ωm to 2Ωm at the depth of 88.76meters. Here, a borehole depth of about 89meters or more from the surface is recommended.

The result of VES 11 shows no appreciably decrease in resistivity. It may be probably the aquifier layer may still be at the greater depth. It is not advisable to carry out a borehole drilling exercise here without a more thorough geophysical survey.

In VES 12. It can be inferred that the water bearing rocks must be within the fourth and sixth layers where there are relatively low resistivities of about 13Ωm and 15Ωm respectively at the depth beyond 30 meters down to the infinite depth. A borehole depth of 95meters may yield a reasonable quantity of water.

From the six geoelectric layers encountered at Idema settlement, VES 13, the gradual decrease in resistivity at fourth and sixth layers show that the water bearing rock is likely tobe at the depth beyond 66 meters.

At Ugwuosu Settlement, VES 14, the interpretation result was different. The interpretation shows that the resistivity continuously increased from the first layer to the fourth layer. The resistivity sharply dropped from 21954Ωm to 6286Ωm and 4972Ωm in the fifth and sixth layers respectively. This shows that the aquifer layer may not be within the probed depth. Thus, drilling of borehole here is not recommended.

At Ugwuaji zone of the local government area, the geophysical survey results revealed six layers with top layer thickness less than 2 meters. The VES result from locations 15 and 16indicate that the aquifer layers are at greater depth. It can be observed from the continuous decrease in resistivities with depth in their geoelectric sections. Thus, borehole depth of 118mand 119.50m are recommended at the sites respectively.

Conclusion

These geophysical vertical electrical soundings were conducted in order to investigate groundwater potentials at some selected locations in Enugu South Local Government Area ofEnugu State. The survey was basically aimed at estimating and locating promising sites fordrilling of successful boreholes where potentially high producing aquifers are detected inorder to reduce the problems of water scarcity in the area. Sixteen VES were conducted usingthe Schlumberger electrode configuration. The data were acquired using the signal averagingsystem, OHMEGA terrameter (SAS 1000) which automatically displays the resistance of thesubsurface. The resistance was used with the geometrical factor to obtain the apparentresistivity in each case. The data were subjected to interpretation first with the aid of mastercurves and the auxiliary curves, using the method of partial curve matching. The parameterswere obtained to determine the resistivity and the thicknesses of the subsurface layers.

Secondly, the interpretations were done using computer software called OFF1Xsoftware whereby the interpreter adjusts the theoretically calculated curve to approximate the field data points. The results of most of the geophysical survey show between 5 and 6geoelectric layers. The first layers are the top lateritic sand with average thickness of about2.5 meters. The intermediate layers are suggested to comprise of silty clay, shaly mudstone, fine sandstones with coal and medium-coarse sandstone. The water bearing rock in the survey areas are predominantly shaly mudstone and fractured shale. The tops of aquifers layers were interpreted to exist at depths between 49m and 120m. The aquifers have resistivities ranging from 0.92Ωm to 41.3Ωm.

Therefore good prospect for groundwater development exist in some locations surveyed in the study area. Such locations includes VES 2, 3, 4, 5, 6, 8 and 10 (Akwuke, Amechi and Obeagu region of the survey area, see Figure 1). This is because the depth to the main aquifier (shaly mudstone) falls within the depth range (between 49 m and 120 m). These fairly correlate with some of the borehole logs obtained in the survey area.

However, locations at VES 1, 7, 9, 11, 12, 13, 14, 15 and 16 are not strongly recommended for borehole drilling because the aquifer layers even though with appreciable thickness are composed of clay and coal. Clay is an aquitard which is not ready to give out its water during groundwater exploration. Existing data shows that boreholes drilled at those areas failed to yield significant quantities of water all year round because of the geological formation. The research work has shown that the selected survey area does not have groundwater potentials.

Recommendations

In addition to drilling boreholes at the recommended sites, it is suggested that subsequent drilling of boreholes should not be embarked upon without geophysical investigations. Going by the scientific search for groundwater, the number of unproductive and abandoned boreholes will be reduced to the barest minimum. Furthermore, were commend the use of the frequency domain electromagnetic method (FEM) for groundwater survey. This method measures the apparent conductivity of the subsurface from the ratio of the secondary to the primary electromagnetic fields. Unlike the popular electrical resistivity survey method, it is a quick and easy method for determining changes in thickness of weathered zone or alluvium. The method can as well be used in basement rocks to help identify fractured zone [9], though it requires a very careful geological control.

Finally, precautionary measures should be taken in order to minimize the errors introduced in the vertical resistivity work as a result of non-straight line spread, poor metrical contact, erratic conductivities due to buried metallic objects and fences, and the errors due to rugged topography. In addition, the interpretation of the field profiles should be done with the assistance of a very experienced geologist.

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