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Vertical Electrical Sounding for Aquifer Characterization around the Lower Orashi River Sub-Basin Southeastern Nigeria

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Abstract. The different aquifer units within the Lower Orashi River Sub-Basin Southeastern Nigeria were delineated using the Vertical Electrical Sounding (VES) technique. Twenty two (22) VES soundings were carried out using the ABEM SAS 4000 Terrameter. The data generated were analyzed using the Zohdy software which outputted modeled curves in terms of depth and resistivity. Six profiles were taken in the Northeast–Southwest and Northwest–Southeast directions to cover the entire area of study. Four to six geo-electric layers comprising the top soil, clayey sand, dry sandstone, saturated sandstone, shaley sand and sandy shale were delineated with the later usually occurring as the last layer. The third and fourth layers underlying dry sandstone form the aquiferous unit. This unit was found to have an average resistivity value range of 10.7 – 6060Ωm and an average thickness of 32m. It was observed that most of the aquifer units within the area are unconfined with static water level varying between 10.6 to 62.8m. Some of the aquifer units are shallow with static water level less than 40m while others are deeper with static water level occurring at over 60m below the surface. It was advised that care ought to be taken in drilling and casing at shallow aquiferous areas to maintain proper sanitary condition so as to reduce the risk of groundwater contamination.

Keywords: Aquifer, Benin Formation, Orashi River, SAS, Schlumberger.

This paper is presented in loving memory of Late Prof. Kas M. Ibe (Dee Kas). The"German Hill" explorer.

1. INTRODUCTION

Geophysical methods are increasingly being used for subsurface characterization. They offer the potential to derive basic characteristics, state variables and properties of geological formations (Vereecken et al 2005).This is feasible because of the rapid advances in computer softwares and associated numerical modeling solutions. The Vertical Electrical Sounding (VES) has proved very popular with groundwater prospecting and engineering investigations due to simplicity of the technique. The electrical geophysical survey method is the detection of the surface effects produced by the flow of electric current inside the earth (Ekwe et al 2006). The electrical techniques have been used in a wide range of geophysical investigations such as mineral exploration, engineering studies, geothermal exploration, archeological investigations, permafrost mapping and geological mapping (Ibe and Uzoukwu 2004, Igbokwe 2006, Khalil, 2009). Electrical methods are generally classified according to the energy source involved, i.e., natural or artificial. Thus, self potential (SP), telluric current come under natural source methods, while resistivity, electromagnetic (EM) and induced polarization (IP) methods are artificial source methods (Miller 2006). The electrical d.c resistivity method used in carrying out the present survey is of artificial source using the ABEM terrameter (SAS 4000).

2. THE STUDY AREA

The area lies within latitudes $5^o38'$N to $5^o50'$N and longitudes $7^o00'$E to $7^o24'$E. It is located towards the northern part of Imo State. The area is bounded to the northwest by Anambra State, to the northeast by Okigwe and to the south by Owerri. The main rivers that traverse the study area are Njaba, Orashi and Ogidi Rivers which are tributaries to the Imo River. The terrain of the study area is characterized by two types of landforms viz: high undulating ridge and flat topography. These undulating ridges and flat lands are somewhat related to the bedrock underlying the area. Borehole lithologic logs reveal that the undulating hills and ridges are underlain by a succession of thick unconsolidated sandstones and relatively thin clay unit belonging to the Benin Formation. The ridges trend in the north-south direction and have an average elevation of about 122m above sea level. In between these ridges and valleys of the Orashi River, Njaba River and their tributaries further south, the ridges give way to clearly flat topography. The flat southern part is underlain by thick unconsolidated sand and minor clay lenses and stringers. The area has two seasons, namely rainy and dry seasons. The mean annual rainfall is between 200m and 2250m and the annual rainfall is usually heavy. On a monthly basis, the rainfall amount at any location is not uniform but exhibits a marked seasonality. The date of the onset of the rainy season is usually between February and March and ends around October and November, whereas the onset of the dry season is between November and December and ends between March and April (Iloeje 1991).

The rainfall distribution consists of two minima and two maxima. The first minima are in November and December while the second minimum is in August which is usually associated with August break. From February, total rainfall increases sharply to primary maxima in June and July. The second maximum is in September which increases sharply and subsequently decreases in November and December (NIMET 2012). The area comprises of true rainforest, characterized by an abundance of plant species. A storeyed sequence of canopies may be found in most part of the forest.

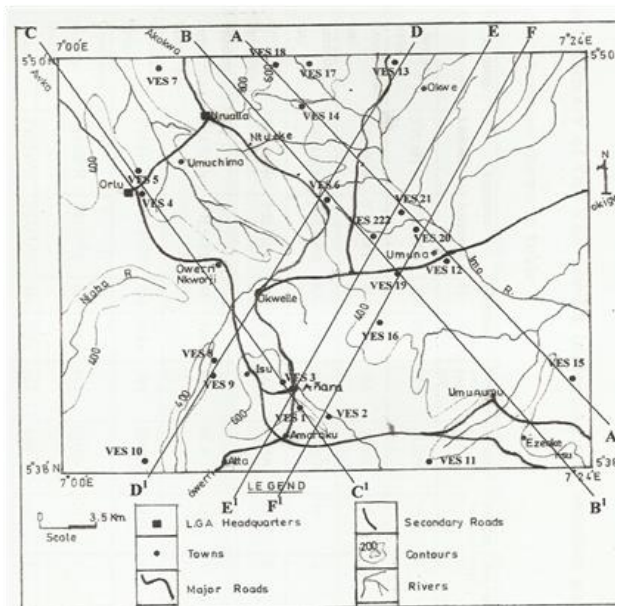

Figure 1. Location Map of the Study Area showing VES points

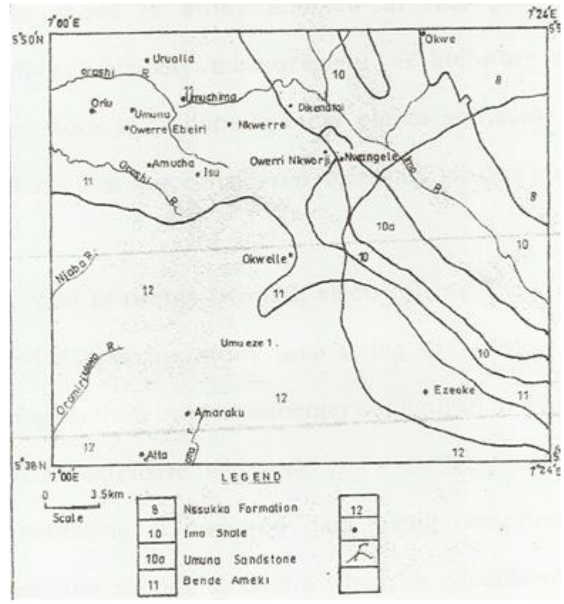

Figure 2. Geologic Map of the Study Area

3. GEOLOGY OF THE AREA

The area is part of the Benin Formation (Figure 2). The geology of the Benin Formation has been given by Short and Stauble 1967, Reyment 1965, Hospers 1965 among others. The Benin Formation is made up of friable sands and minor intercalation of clay. The sand units are mostly coarse grained, pebbly, poorly sorted and contain lenses of fine grained sands (Short and Stauble, 1967, Onyeagocha, 1980). Benin Formation is one of the three recognized subsurface stratigraphic units in the modern Niger Delta. It is a fresh water bearing massive continental sand and gravel deposited in an upper deltaic environment. It was formerly designated as coastal plain sands (Reyment, 1965). As the study component in most areas form more than 90% of the sequence of the layers, permeability, transmissivity and storage coefficient are high. The Formation starts as a thin edge at its contact with Ogwashi/Asaba Formation in the north of the area and thickens seawards. The Benin Formation conformably overlies the Ogwashi/Asaba Formation. The Ogwashi/Asaba Formation (Lignite series) is also predominantly sandy with minor clay units. The Formation is characterized by lignite seams at various levels. The lignite Formation has thickness of about 300m. This is underlain by the Ameki Formation with thickness of 1460m, which is in turn underlain by Imo shale and Nsukka Formations successively.

Table 1. Stratigraphic succession in the area (adapted from Uma and Egboka 1985).

Tertiary	**AGE**	**FORMATION**	**LITHOLOGY**
	Miocene-Recent	Benin Formation	Medium-coarse grained poorly consolidated sands with clay lenses and stringers.
	Oligocene-Miocene	Ogwashi Asaba	Consolidated sands with lignite seams at various layers.
	Eocene	Ameki Formation	Clayey sandstone and sandy claystones
	Paleocene	Imo shale	Laminated clayey shale
	Danian	Nsukka Formation	Sandstones intercalated with shales and coal beds

4. MATERIALS AND METHODS

The methods utilized in this study involve both Geological and Geophysical approaches. The Geological method includes the identification of rock units in the area taking their attitudes and relating these to regional geology. Such outcrops helped in inferring the signals on the geophysical records. In other to evaluate the geo-structural setting of the concealed bedrock and possible fracture pattern, a geophysical survey involving the use of electrical resistivity was employed.

4.1 Theory

The electrical resistivity method is an active geophysical method. It employs an artificial source which is introduced into the ground though a pair of electrodes. The procedure involves measurement of potential difference between other two electrodes in the vicinity of current flow. Apparent resistivity is calculated by using the potential difference for the interpretation. The electrodes by which current is introduced into the ground are called Current electrodes and electrodes between which the potential difference is measured are called Potential electrodes.

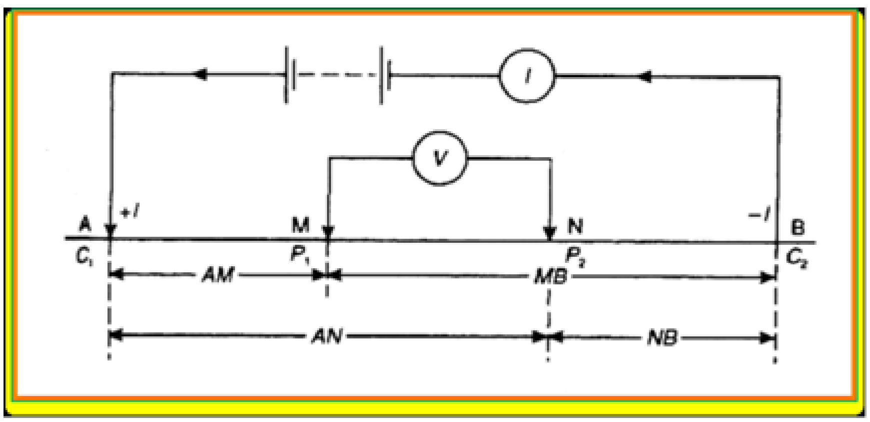

Figure 3.Generalized Electrode configuration for Electrical Resistivity

A and B are current electrodes; M and N are potential electrodes.

In Schlumberger configuration, MN<<AB.

Potential at M,

$$V_1 = \frac{\rho_a I}{2\pi}\left(\left(\frac{1}{AM}\right) - \left(\frac{1}{MB}\right)\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Potential at N,

$$V_2 = \frac{\rho_a I}{2\pi}\left(\left(\frac{1}{AN}\right) - \left(\frac{1}{NB}\right)\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Potential Difference $\Delta V = \frac{\rho_a I}{2\pi}\left\{\left((\frac{1}{AM}) - (\frac{1}{MB})\right) - \left((\frac{1}{AN}) - (\frac{1}{NB})\right)\right\}$............(3)

Basically we use direct currents but we can also use low frequency alternating currents to investigate the electrical properties (resistivity) of the subsurface. Current is injected into the ground using two electrodes (from A and B) and the resulting voltage is measured using the remaining two electrodes (from M and N) (figure 3). The fundamental equation is derivable from Ohm's laws. The electric potential, Vr at any point, P distance, r from a point electrode emitting an electric current, I in an infinite homogenous and isotropic medium of Resistivity, ρ is given by

$V_r = \frac{\rho I}{2\pi r}$................................(4)

For a semi-finite medium, this is the simplest Earth model, and with both current and potential point-electrodes placed at the Earth's surface.

$\rho = \frac{V(2\pi r)}{I}$ ....(5)

Irrespective of surface location and electrode spread, the resistivity is constant in a homogenous and isotropic ground. However, it does vary with the relative positions of electrodes when there is presence of subsurface inhomogeneities and any computed value is known as apparent resistivity

$\rho_a = \frac{\Delta v(2\pi r)}{I}$ ....(6)

For schlumberger arrangement

$G = \frac{\pi\left((\frac{AB}{2}) - (\frac{MN}{2})\right)^2}{2\,(\frac{MN}{2})^2}$ ....(7)

$\rho_a = \frac{\Delta VG}{I} = R.G$ ....(8)

This can generally be written as

ρ_a = $\pi(a^2/b - b/4)$ R …………………(9)

where

ρ_a = apparent resistivity in Ohm-m

a = AB/2, the Half Current Electrode Separation in meters

b = MN, Potential electrode separation in meters

R = Instrument reading in Ohms

G is the Geometric Constant which is a function of the electrode configuration employed during the survey. The data collected in the field were presented by plotting the apparent resistivity (ρ_a) values against the electrode spacing (AB/2) on bi-log graph. Quantitative interpretation of the VES curves involved partial curve matching and computer iteration technique. As a good fit, (up to 95% correlation) was obtained between field and model curves, interpretation was considered as right. A total of twenty two (22) VES were carried out. The maximum spread was 250-300m for AB/2 (m) and the data were acquired under favourable weather condition.

5. RESULTS AND DISCUSSION

The results of the twenty two (22) Vertical Electrical Sounding (VES) are presented in Table 3 while their interpretation and subsequent analysis to suite the content of this work are as presented hereunder.

5.1 CORRELATION OF DIFFERENT AQUIFER UNITS

The different aquifer units delineated within the study area were correlated along six (6) major profiles denoted as AA^1, BB^1, CC^1, DD^1, EE^1 and FF^1 (Figures 4-9).

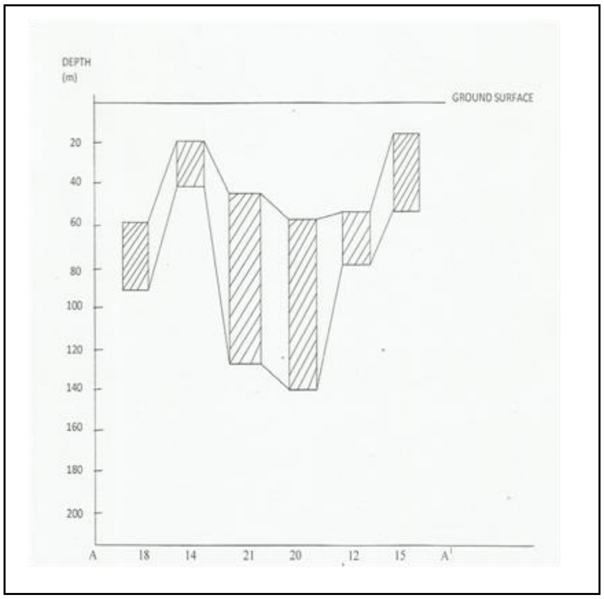

Figure 4. Correlation of Aquifer Units along Profile AA1

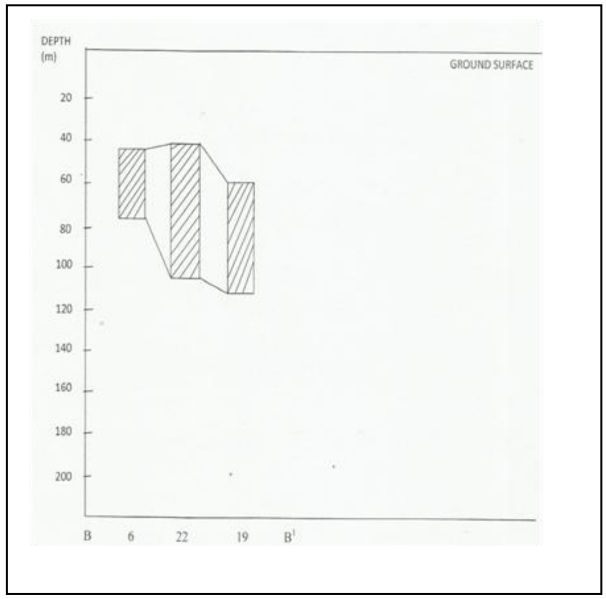

Figure 5. Correlation of Aquifer Units along Profile BB1

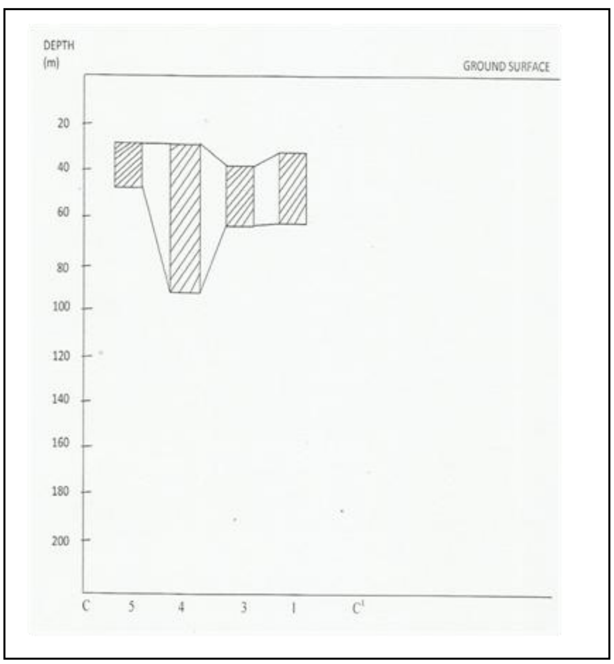

Figure 6. Correlation of Aquifer Units along Profile CC1

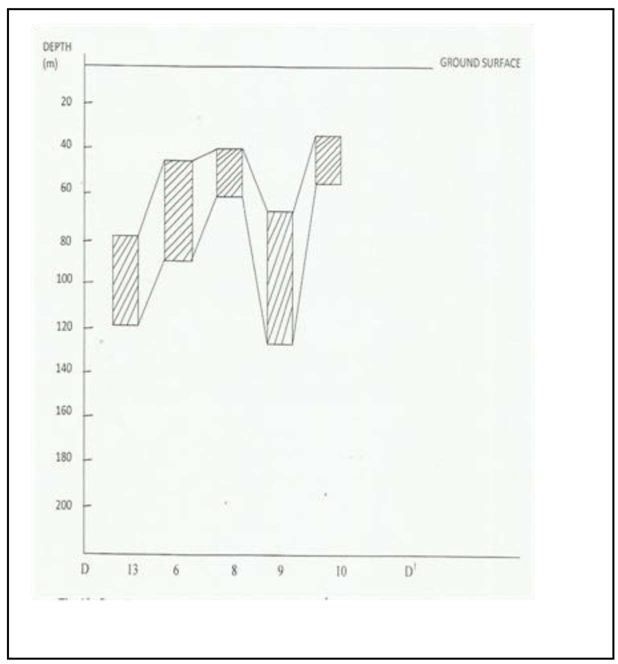

Figure 7. Correlation of Aquifer Units along Profile DD1

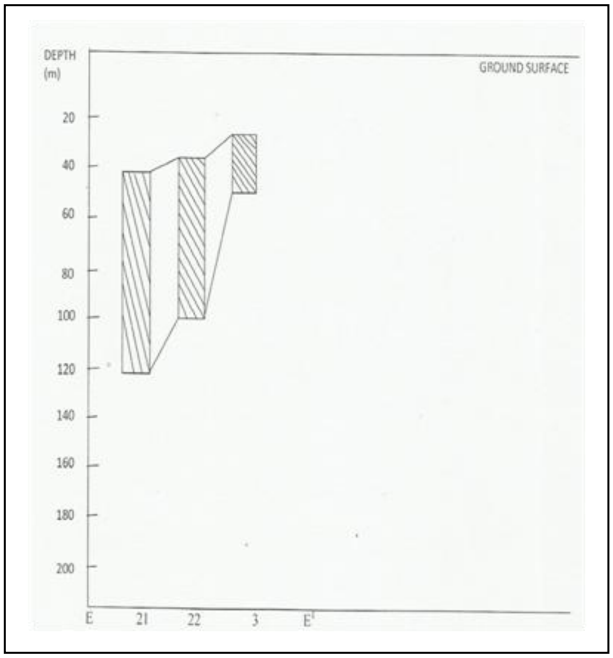

Figure 8. Correlation of Aquifer Units along Profile EE[1]

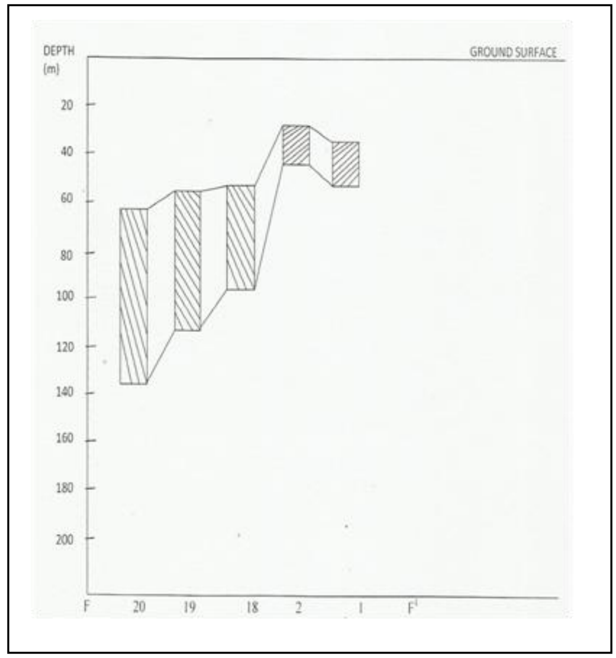

Figure 9. Correlation of Aquifer Units along Profile FF[1]

5.2 DISCUSSION OF RESULTS ALONG THE SIX (6) PROFILES

Profile AA[1] was taken along Northwest-Southeast direction in the study area traversing six (6) VES points numbered VES 18, VES 14, VES 21, VES 20 VES 12 and VES 15 (Figure4). From this it was observed that the deepest aquifer was encountered around VES 21 and VES 20 with the aquifer units mapped between 45.2m – 126.5m and 58m – 130m respectively. These units were observed to have resistivity of 1900Ωm (VES21) and 1010Ωm for VES 20. The shallowest aquifer unit along this profile was observed to fall at VES 15 with depth to water table of 20.7m; aquifer unit of VES 15 could be said to be of low potential because of the possibility of shale intercalations within the sandy unit of the aquiferous zone. This is evident in the low aquifer resistivity observed. Profile BB[1] was taken along NW – SE. It traversed only three VES points denoted as VES 6, VES 22 and VES 19 (Figure 5). The deepest aquifer unit was mapped at VES 19 with depth to water table occurring at 52.2m, aquifer thickness and resistivity of 54.8m and 2650Ωm respectively. The shallowest is 39.9m. The thickness and resistivity of the aquifer units are 38.5m and 2980Ωm respectively. Profile CC^1 was equally taken in the same direction as profiles AA^1 and BB1 (Figure 1). It traverses via four (4) VES locations labeled VES 5, VES 4, VES 3 and VES 1 (Figure6). Near surface aquiferous units were observed at a depth of 26m and the shallowest at a depth of 19m. The aquifer thickness is very thin ranging from 15m to 23m. The deepest of all was observed at VES 4 with thickness of approximately 51.9m. Profile DD^1 was taken along Northeast–Southwest direction. It passed through five (5) VES locations labeled VES 13, VES 6, VES 8 VES 9 and VES 10 (Figure7). The deepest and thickest aquifer units along this profile was observed at VES 9 with depth to water table and depth to the end of the prospective zone occurring at 63.1m and 113m respectively with resistivity of 6060Ωm. This zone was believed to be composed of sand and sand stone of good aquifer yielding potential. The shallowest aquifer was observed at VES 10 with depth to water table occurring at 20m, aquifer thickness and resistivity being 12.6m and 539Ωm respectively. Similarly too this aquifer unit would be of low yield sequel to the presence of shaley lenses dominating the unit as depicted by low resistivity value within the unit. Profile EE^1 was taken along Northeast–Southwest direction. It traversed across three (3) VES locations only (Figure 8). The deepest aquifer unit occurred at VES 21 with thickness and resistivity of 45.8m and 1900Ωm respectively. Profile FF^1 was taken in the same direction as profile DD1 and EE1 (Figure 1). It traversed via five (5) VES points dented as VES 20, VES 19, VES 16, VES 2 and VES 1 (Figure 9) with thickness of 71.1m, 54.8m, 42m, 15.9m and 23m respectively. The deepest aquifer unit was encountered at VES 20 with depth to water table occurring at 58.9m. The shallowest aquifer occurred at VES 2 with the water table occurring at 19.3m.

Table 2. Classification of Aquifer Units in the area based on depth to water table.

Location Name	VES Notation	Depth to water Table (m)	Profile(s) Traversing through	Aquifer classification based on Depth to water table <40m
Okohia	14	22.4	AA^1	
Okpuala	15	20.7	AA^1	
Dikenafai	6	39.9	BB^1 and EE^1	
Umuna	22	39.5	BB^1 and EE^1	
Mgbee	5	18.3	CC^1	
UgwuOrlu	4	18.1	CC^1	SHALLOW
Anara	3	26.0	CC^1 and EE^1	
Anara II	1	21.6	CC^1 and FF^1	
Uloano	8	36.1	DD^1	
Orodo	10	20.0	DD^1	
Anara III	2	19.3	FF^1	
Arondizuogu	18	56.3	AA^1	
Umuezeala I	21	45.8	$AA^1$and EE^1	DEEP
Umuezeala II	20	58.9	$AA^1$and FF^1	
Onuimo	12	50.4	AA^1	
Okai	19	52.2	$BB^1$and FF^1	
Umuchiri	13	72.9	DD^1	
Chief Marcus	9	63.1	DD^1	
Umuduru	16	82.0	FF^1	

Table 3. Summary of the VES results indicating real location names and other hydraulic parameters.

VES	Location	Coordinates		Elevation		Depth to water table (m)	Aquifer Resistivity (Ωm)	Aquifer thickness (m)	No of layers	Possible total drill depth (m)	Aquifer Material	Longitudinal conductance	Transverse resistance
		Latitude	Longitude	Ft	m								
1	Anara prof's house	5°42.081'N	7°10.2118'E	671	204.5	21.6	111.00	23	5	60	Sand	0.059	49506
2	AnaraMbano road	5°42.125'N	7°10.2118'E	601	183.2	19.3	1120.0	15.9	6	55	Sandstone	0.058	39424
3	AnaraOrlu road	5°42.125'N	7°10.049'E	651	198.4	26.0	1010.2	19	6	60	Sand	0.073	45955
4	Dump Site UgwuOrlu	5°42.416'N	7°10.562'E	558	170.1	18.1	3190.0	51.9	4	85	Sandstone	0.028	226171
5	Umudaramgbee (Don's House) Orlu	5°42.811'N	7°10.540'E	407	124.1	18.3	3190.0	51.9	4	85	Sandstone	0.028	2915.4
6	DikenafaiIdeato South	5°42.729'N	7°10.846'E	445	135.6	39.9	86.0	15.6	5	50	Sandy shale	0.527	233632
7	UmuokwaraAkokwa, Ideato North	5°42.911'N	7°10.837'E	891	271.6	26.17	2980.0	38.5	4	90	Sandstone	0.064	86856
8	UloanoNdugbaIsu L.G.A	5°42.853'N	7°10.173'E	426	129.8	36.1	2310.0	10.9	6	50	Sandstone	0.030	977920
9	Chief Marcus House	5°42.243'N	7°02.285'E	434	132.3	63.1	6060.0	49.9	5	128	Sandstone	0.050	684780
10	OrodoMbaitoluL.G.A	5°42.151'N	7°01.567'E	457	139.3	20.0	539.0	12.6	4	47	Sandstone	0.090	17571.4
11	Agbaja, IsialaMbano	5°38.010'N	7°20.361'E	389	118.6	63.0	237.0	53	4	125	Sand/sst	1.089	274.92
12	UmunaOnumo	5°38.001'N	7°20.361'E	360	109.7	50.4	1200.0	24.3	4	47	Sand/sst	0.312	89640
13	OkohiaUmuchiri	5°49.972'N	7°49.972'E	510	155.4	72.9	260.0	37.1	4	120	Sandy shale	1.222	10375.2
14	OkohiaUmuchiri II	5°48.673'N	7°48.673'E	571	174.0	22.4	60.0	16.9	4	50	Sandy shale	2.465	2381.58
15	OkpualaAboh	5°40.784'N	7°40.784'E	312	95.0	20.7	10.7	31.2	4	63	Sandy	5.023	555.33

											shale		
16	UmuduruEgbeAguru	5°42.681'N	7°19.631'E	401	122.2	82.0	5070.0	42	4	133	Sandy shale	0.126	628680
17	NdiamazuArondizuogu	5°49.972'N	7°12.113'E	542	165.2	95.0	940.0	53	4	138	Shaly sand	0.193	120320
18	Arondizuogu	5°49.992'N	7°11.932'E	602	183.4	56.3	2340.0	36.6	4	105	Sand stone	0.053	217386
19	Okaiumuna	5°43.921'N	7°20.002'E	372	113.4	52.2	2650.0	54.8	4	115	Sand stone	0.064	283550
20	Umuezeala Umuna	5°44.231'N	7°20.242'E	307	93.6	58.9	1010.0	71.1	4	140	Sand stone	0.155	131300
21	Umuezeala EzifuokeUmuna	5°44.230'N	7°19.922'E	310	94.5	45.8	1900.0	81.2	4	135	Sand stone	0.112	241300
22	Aforezihu Umuna	5°44.230'N	7°18.021'E	301	92.0	39.5	30.5	61.5	4	112	Sandy shale	7.228	3080.5

6. CONCLUSION AND RECOMMENDATION

Having carried out this research work up to this level it could be necessary to conclude that the areas around the Lower Orashi River Sub-Basin have good aquifer systems. Most of these aquifer units are shallow while some are deep (Table 2). It was observed that the shallow aquifer systems were obtained towards the south characterized by the dominant Benin Formation whereas the deeper aquifer systems were observed to occur in the areas underlain by the Ameki and Imo Shale Formations. Similarly too, the hydraulic conductivity decreases towards the south indicating high groundwater productive potentials as one traverses southwards and vice versa. We hereby recommend that exploitation for groundwater in those areas delineated to have deeper aquifer units should be carried out with the aid of high powered hydraulic rig machine. The use of seismic rotary method is not in any way recommended in these areas. The seismic method can be used to exploit the shallow aquifer units. Also the design of the casing system of those shallow aquiferous areas must be carefully completed and properly grouted to avoid contamination of the groundwater system. The casing design must be carefully followed in both cases as to tap almost all the aquifer units (in case of areas with multi-aquifer systems).

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