Characterization of Aquifer Potential in Ohafia Area of Abia State, Nigeria

Adindu Ruth U, Igbokwe Kelechi K

Department of Physics,
Abia State Polytechnic, Aba

***Abstract*: Vertical Electrical Sounding (VES) using Schlumberger electrode configuration was employed in the characterization of aquifer potential in Ohafia Area of Abia State. A total of 5 vertical electrical sounding (VES) was occupied with maximum current electrode spacing of AB / 2 = 300 m. The data was acquired and processed using ABEM Terrameter and WinRESIST software respectively. 5–7 geo-electrical layers were delineated. The area is characterized majorly by sand materials while aquifer resistivity ranged from 441.30 Ωm – 1898.00 Ωm. Aquifer thickness ranged from 77.94 m – 97.84 m. Depth to water table varied from 27.76 m – 68.36 m indicating shallow aquifer system. Aquifer layers were delineated in the third and fourth layers. The area showed high Transverse resistance ranging from 41702.850 Ωm^2 – 185700.320 Ωm^2 implying high aquifer yield. Groundwater potentials of the area were categorized into moderate, good and high potentials. VES 3 (Ndiaku) showed minimal potential while the maximum groundwater potential was delineated at VES 5 (Akanu). High Transverse resistance for shallow aquifers indicates the possibility of surface contaminant migration and circulation in the aquifer system of the area. Therefore, it is recommended that the quality of the groundwater of the area be evaluated.**

***Keywords*: VES, Aquifer Potentials, Groundwater, Resistivity, Ohafia**

1. Introduction

Groundwater is considered to be the largest reservoir of drinkable water. It plays a major role in augmenting the water supply to meet the ever increasing demands for domestic, agricultural and industrial usage (Amos-Uhegbu *et al*., 2013). However, its distribution in the sub-surface is not even due to variations in the amount of precipitation, topography, porosity and permeability of subsurface rocks. Other factors include surface water available for recharge, size of aquifer, nature of over burden materials.

In crystalline basement complex terrain, the occurrence of groundwater is largely dependent on secondary porosity and permeability of fractured or weathered rocks. But in sedimentary terrains, primary sedimentary porosity determines the storage and permeability of a sedimentary rock material to a great extent. Hence groundwater can be found in the sedimentary pore spaces of subsurface geo-materials or in a saturated, permeable, geologic unit that can transmit significant amount of groundwater under an ordinary gradient to a well (aquifer). Hydro-geological characterization of a sedimentary rock formation has become essential in the evaluation of aquifer parameters as it identifies aquifer nature in terms of its type, thickness, depth, number of layers as well as the hydraulic conductivity of the aquifer and its groundwater quality. This identification can be done through the electrical resistivity method.

The Vertical electrical Sounding technique has become one of the most adopted techniques in groundwater exploration and also in aquifer evaluation owing to its simplicity, cost effectiveness, usefulness in deep subsurface mapping and its ability to image large expanse of land through geo-electrical parameters (Adagunodo *et al*, 2018). It has been applied in Aquifer characterization in Auchi Polytechnic, Edo State, Nigeria and in Geophysical characterization of aquifer systems in Demsa, northern Nigeria (Babaiwa *et al*., 2020; Saleh and Satendra, 2020); in the estimation of Potentials of Groundwater Aquifers in Karang Anyar of Tarakan City, Indonesia (Asta and Abdul, 2020). Layade *et al*. (2017) and Jayeoba *et al*. (2013) used it in the Hydro geophysical evaluation of Groundwater in Hard Rock Terrain of Southwestern Nigeria and for groundwater development at Gbongudu area, Akobo Ojurin, Ibadan respectively. While Aluko *et al*., (2017) used 2-D resistivity survey in groundwater aquifer delineation in a sedimentary terrain.

Electrical resistivity measurement is based on the physical properties of rocks against the current that is injected into the ground. The technique measures the properties of an earth material in relation to hydraulic parameters. The success of the method is lies in the fact that variation of conductivity within the earth's subsurface layers affects the distribution of electric potential. The degree of this effect depends on the shape, size, location and also the bulk electrical resistivity of the subsurface layers. The bulk electrical resistivity depends on the mineralogy of the rocks and its contained fluids (Iserhien-Emekeme *et al*., (2017). The working principle of electric resistivity is measuring the resistivity to the flow of electric current applied into the subsurface rock through the current electrode and the corresponding potential voltage across the potential electrodes. The ultimate goal of VES probe is to obtain a true resistivity model similar to a well log at a locality, without actually drilling the well. This study therefore aimed at using the VES technique to characterize the aquifer system in Ohafia area of Abia State, Nigeria.

The study area lies between latitude 5° 30´ N to 5° 45´ N and longitude 7° 45´ E to 7° 55´ E (Figure 1). Ohafia area falls in south-eastern part of the Anambra basin. (Ibe *et al.*, 1998). The geology of Ohafia local government area falls within the Deltaic marine sediment of Cretaceous to recent age. There are essentially three principal geological formations in the area namely: the Ajali (false bedded sandstones) formation, the Mamu and Asata Nkporo shale formations (Figure 2). 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 Manu formation is a mid Senonian paralic sedimentary formation made up of tin grained sandstones and shale (Kogbe, 1976). The shales are conspicuously dark colored and are observed along streams and rivers valleys in the eastern and central parts of the area. The Asata-Nkporo shale 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).

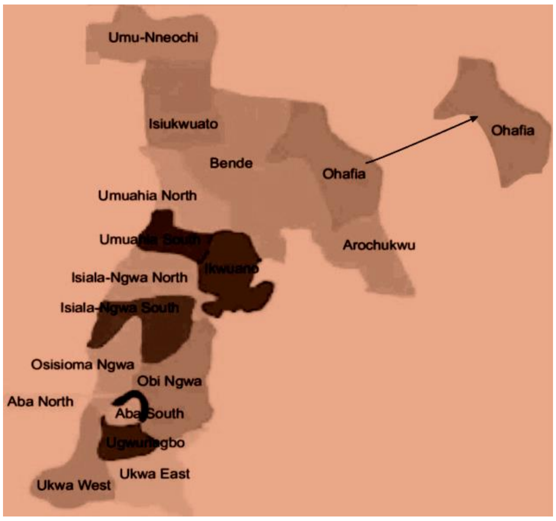


Figure 1: Location Map of the Study Area

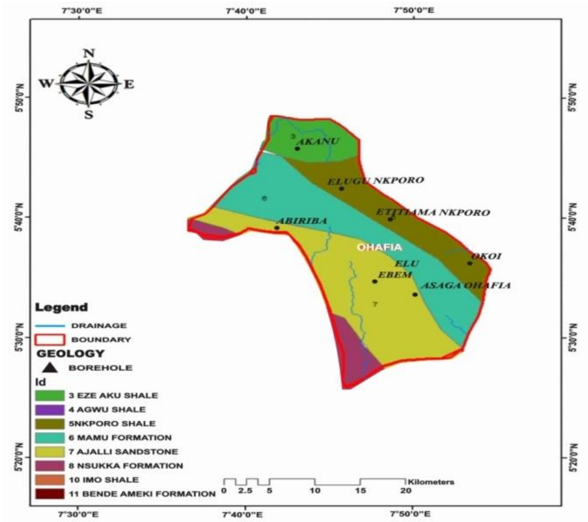


Figure 2: Geology Map of the Study Area

2. Method of the Study

Five Vertical Electrical Sounding (VES) were obtained using the Schlumberger electrode array. A maximum spread of AB / 2 = 300 were adopted. Two sets of current electrode A and B and another set of potential electrode M and N were driven into the soil, and subsequently connected to the ABEM Terrameter SAS 3000. On each location, current was sent into the subsurface through the current electrodes and the resulting potential difference between M and N was measured. The ratio of the current (I) to the measured potential difference (p.d) gives the resistance (R_a) of the soil material to the flow of current according to the equation;

$$R_a = V / I \qquad \dots (1)$$

Measurements of resistance were taken progressively from the smallest spacing to the maximum spread of AB / 2 = 300, and MN / 2 = 50. When the ratio of the distance between A and B and that between M and N becomes so large, the potential electrodes were expanded with respect to the mid-point so that accurate measurement of the potential difference will be made. The apparent resistivity (*r_a*) of the soil material for each of the locations was calculated by multiplying the values of R_a by the geometric factor G. r_a is then given by:

$$\rho_a = \pi \left[\frac{\frac{(AB)^2}{2} - \frac{(MN)^2}{2}}{MN} \right] \frac{V}{I} \qquad \dots (2)$$

Where AB = distance between the two current electrodes
MN = distance between the potential electrodes,
R_a = apparent electrical resistance

Where 'G' the geometric factor is given by:

$$G = \pi \left[\frac{\frac{(AB)^2}{2} - \frac{(MN)^2}{2}}{MN} \right] \qquad \dots (3)$$

Values of the apparent resistivity for each location were then processed using a computer software, the WinRESIST to obtain geo-electric layer parameters, such as the true resistivity (r), thickness of the layer, and depth of the investigated geologic layer. The Dar'Zarrouk parameters (total transverse resistance and total longitudinal conductance) were derived from the primary parameters and were used for further interpretations of groundwater potentials and vulnerability. According to Adekunle *et al.,* (2007),

Total Longitudinal Conductance (S)

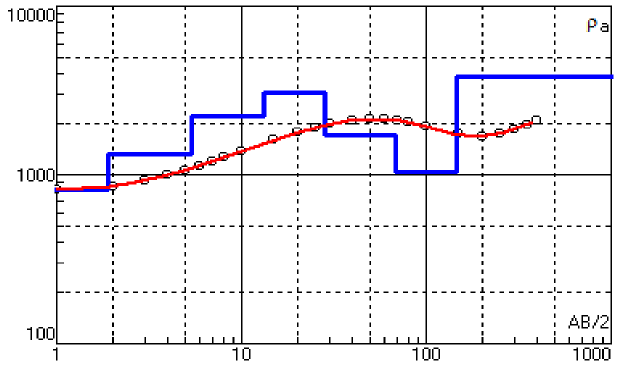
$$S = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \cdots + \frac{h_n}{\rho_n} \quad \ldots (4)$$

Total Transverse Resistance (T)

$$T = h_1\rho_1 + h_2\rho_2 + h_3\rho_3 + \ldots + h_n\rho_n \quad \ldots (5)$$

3. Results

A typical VES curve in the area is presented in Figure 3 while the geo-electric parameters and the aquifer characteristics of the VES stations are presented in Tables 1 and 2. These show the aquifer depth, aquifer resistivity, aquifer thickness, longitudinal conductance and transverse resistance of each location.



Resistivity (Wm)	Thickness (m)	Depth (m)
812.9	1.96	1.96
1324.0	3.41	5.37
2228.0	7.87	13.24
3069.0	15.09	28.33
1717.0	40.30	68.36
1041.0	77.94	146.30
3825.0	-	-

Figure 3: Typical VES Curve in the Area (VES1 - Abiriba)

Table 1: Geo-electric Parameters of the VES Stations

Location	VES Station	Layer Number	Resistivity (Wm)	Thickness (m)	Depth (m)	Lithology
Abiriba	VES 1	1	812.90	1.96	1.96	Lateritic Topsoil
		2	1324.00	3.41	5.36	Sand
		3	222.80	7.87	13.24	Sand
		4	3069.00	15.09	28.33	Sand
		5	1717.00	40.30	68.36	Sand
		6	1041.00	77.94	146.30	Sand
		7	3825.00	-	-	-
Ndiaku	VES 2	1	45.49	1.94	1.94	Shaley Topsoil
		2	116.40	4.00	6.39	Sand
		3	441.30	26.21	32.60	Sand
		4	1274.00	94.80	127.40	Sand
		5	3680.00	-	-	-
Amaekpo	VES 3	1	835.00	1.98	1.98	Lateritic Topsoil
		2	1936.00	3.73	5.71	Sand
		3	1020.00	13.69	19.40	Sand
		4	631.00	25.50	44.50	Sand
		5	3194.00	79.80	124.70	Sand
		6	1297.00	-	-	-
Ebem	VES 4	1	209.80	1.94	1.94	Lateritic Topsoil
		2	414.40	4.12	6.06	Sand
		3	818.60	27.86	33.92	Sand
		4	1823.00	90.68	124.60	Sand
		5	980.00	-	-	-
Akanu	VES 5	1	506.00	1.97	1.97	Lateritic Topsoil
		2	923.00	3.97	5.94	Sand
		3	1898.00	22.36	27.76	Sand
		4	3325.00	97.84	126.60	Sand
		5	1823.00	-	-	-

Table 2: Aquifer Characteristics of the VES Stations

Location	VES No.	Lat. (°N)	Long. (°E)	Elev. (m)	No. of Layers	Aquifer Resist. (Ωm)	Aquifer Thickness (m)	Aquifer Depth (m)	Transverse Resistance (Ωm²)	Longitudinal Conductance (mhos)	VES Curves
Abiriba	1	5° 43' 4"	7° 43' 9"	180	7	1717.0	77.94	68.36	132,105.98	0.04481	KHK
Ndiaku	2	5° 40' 3"	7° 47' 5"	96	5	441.3	94.50	32.60	41,702.85	0.21414	AAA
Amaekpo	3	5° 1' 29"	7° 49' 41"	221	6	631.0	79.80	44.90	50,358.80	0.12646	KHKQ
Ebem	4	5° 37' 33"	7° 49' 53"	199	5	818.6	90.68	33.92	74,230.64	0.11077	AAA
Akanu	5	5° 35' 46"	7° 45' 27"	182	5	1898.0	97.84	27.76	185,700.32	0.05154	AAA

4. Discussion

Table 1 presents the primary geo-electric parameters from each of the five VES points in the study area. It shows the total number of layers, thickness, depth and resistivity range delineated in each of the locations. 5–7 geo-electric layers were delineated across the area. Resistivity values ranged from 45.49 Wm to 3825.0 Wm across the stations, thickness ranged from 1.96 m to 97.84 m while a maximum depth of 146.3 m was delineated. The lithology of the area consists of lateritic top soil and sand materials while the elevation of the area ranged from 96 m to 221 m implying fairly upland area.

The first layer has resistivity ranging from 45.49 Wm – 835.0 Ωm and thickness varying from 1.94 m – 1.98 m. This layer is a thin layer consisting of lateritic topsoil. The second layer has resistivity values ranging from 116.4 Ωm – 936.0 Ωm and thickness value varying from 3.41 m – 4.12 m. It is delineated as a thin layer of sand. The third and fourth layers are also sand layers with characteristic resistivity values ranging from 222.8 Ωm – 1898.0 Ωm and 631.0 Ωm – 3325.0 Ωm respectively. Their layer thicknesses ranged from 7.87 m – 27.86 m and 15.09 m – 97.84 m respectively. In the fifth layer and sixth layers, resistivity ranged from 980 Ωm – 3680 Ωm and 1041.0 Ωm – 1297.0 Ωm respectively whereas thicknesses ranging from 40.0 m – 79.0 m and 77.94 m – 97.84 m were delineated respectively. Aquifers were delineated in the third and fourth layers.

Table 2 summarizes both the primary and secondary aquifer parameters in the study area. The elevation of the area implies an area dominated by uplands. Depth to groundwater table follows the topography of an area and aquifer parameters show variability across the region. Generally, aquifer resistivity was categorized into; low (441.30 Wm) at VES 2, moderate (631.0 – 818.60) Wm at VES 6 and VES 4 respectively and high (1717 – 1898) Ωm at VES (1 and 3). However, the values indicate sand materials and less clay material in the litho-units. Sand materials have high porosity and permeability which encourage infiltration and recharge of ground water (Ezeh, 2012), thereby signifying good ground water potential in the area. The characteristic lithologic formation in this area is attributed to the geology (the Ajali sandstones) of the area.

Aquifer thickness in the study area is large, ranging from 77.94 m – 97.84 m. This indicates the ability of the aquifer system to store and yield sufficient groundwater the wells. Depth to water table in the area is low. It ranged from 27.76 m – 68.36 m indicating shallow aquifer system. Shallow depth to water table could have negative implication on the ground water quality of the area because of the proximity of the aquifers to the surface (Ehirim and Ebeniro, 2010).

Transverse resistance is estimated by taking the product of aquifer apparent resistivity and aquifer thickness. The transverse resistance (T) is considered a unique factor in hydrological classification of an area since it is a product of aquifer thickness (h) and resistivity (ρ) and is closely related to transmissivity. Therefore areas where the total transverse unit resistance values are high, are expected to correlate with areas having the highest transverse resistance (T) and storage coefficients whereas areas with low values of total transverse unit resistance) are expected to have the least transmissivity and permeability values (Ugada *et al.*, 2013). Transverse resistance in the study area is high. It ranged from 41,702.85 Ωm² – 185,700.32 Ωm². It is categorized into moderate in VES 2 and VES 3 for a value range of (41,702.85 – 50,358.80) Ωm², good (> 50,358.80 – 74,230.64) Ωm² in VES 4 and high (132,105.98 – 185,700.32) Ωm² in VES (1 and 5). However, the minimum value is delineated in VES 2 whereas VES 5 has maximum value. This indicates fair groundwater potentials in VES 2 and VES 3, good groundwater potentials in VES 4 and high groundwater potentials in VES (1 and 5). High transverse resistance of shallow aquifers has implication on the viability of the boreholes for portable water supply in the area.

Low longitudinal conductance is delineated across the study area. It ranges from 0.04481 mhos – 0.21414 mhos implying poor aquifer protective overburden material. This is indicative of insufficient shale/clay materials and more sand in the aquifer overburden. Sand materials in the overburden indicate unconfined aquifers and the tendency of surface contaminant fluid migration into the aquifer system of the area.

5. Conclusion

Aquifer potentials in Ohafia area of Abia State, Nigeria has been characterized using the Schlumberger electrode configuration. A total of 5 VES sounding points were occupied. The results show 5 – 7 geo-electric layers across the area. Generally, aquifer resistivity varies from low at VES 2, moderate VES 6 and VES 4 respectively and high at VES 1 and VES 5. The lithology of the area consists of lateritic/alluvial top soil and sand. Aquifers were delineated in the third and fourth layers.

Aquifer thickness in the study area is high indicating sufficient groundwater storage and yield to wells whereas depth to water table in the area is low indicating shallow aquifer system.

Transverse resistance in the study area is categorized into moderate**,** good and high. It is minimum at VES 2 and maximum at VES 5. The area indicates fair, good and high groundwater. Ground water development is therefore encouraged in the area.

Low longitudinal conductance is delineated across the study area owing to sufficient sand materials in its lithology. Insufficient shale/clay materials were delineated in the area signifying poor aquifer protective overburden. Poor aquifer protective overburden signifies the tendency of surface contaminant fluid migration into the aquifer system of the area.

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