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DELINEATION OF PROLIFIC AQUIFER DEPTH USING VERTICAL ELECTRICAL SOUNDING IN EBEM OKPO-IHECHIOWA, AROCHUKWU AREA, SOUTHEASTERN NIGERIA

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The depth at which economically viable quantities of groundwater could be obtained has been a problem for dwellers within Ebem Okpo-Ihechiowa Area, Southeastern Nigeria due to inadequate empirical subsurface investigation to depth of aquifer before drilling. Therefore, Vertical Electrical Sounding (VES) was carried out at four different locations across the area using the Schlumberger Array Configuration to obtain geophysical field data in order to investigate the occurrence of groundwater in relation to the depth and thickness of viable aquifer. To obtain sounding curve, the measured field data by SAS 1000 terrameter were plotted in a bi-log graph. The iterated results from sounding curves showed that the area has homogeneous subsurface strata with K, KH and HKH curve types. The geoelectric layers generated from sounding curves of the VES data show six to eight distinct sub-layers with lithogic sequence consisting of thick sandstone beds alternating with thin beds of saturated shale. The correlation of the geoelectric sequence of the four VES curves revealed prolific aquiferous zone at the depths of 145m, 81m and 151m with thicknesses of 129.8m, 336m and 913.5m within Ebem Okpo (VES 1), Amaeri Okpo (VES 2) and Obichie Okpo (VES 3), respectively. This implies that water seems to be everywhere in Ebem Okpo-Ihechiowa although a shallow surface perched aquifer occurs at depth of 1.7 to 10.2m in Amiyi Okpo (VES 4). Thus, this study provides insights into depths at which the aquifers should be targeted for a sustainable supply of groundwater to wells within the area.

INTRODUCTION

The growing demand for potable water supply as a result of rapid industrialization, population growth, agricultural related activities, and natural climatic imbalance have forced the dwellers of Ebem Okpo-Ihechiowa area to drifted from ordinary search for surface water to ground water through boreholes. However, delineating the depth to a prolific aquifer that will supply an economically feasible quantity of water to a well has become concern issue attracting increasing attention of many researchers in Southeastern Nigeria (Akpan et al, 2013). This is because of the geologic formation of the area as it has been established that characteristics of aquifers are greatly influenced by formation strata and terrain type (Akpokodje and Etu-Efeoto, 1987). Moreover, groundwater characteristics are greatly determined by the properties of the immediate geologic formations (Akankpo and Igboekwe 2011). Hence, the acquisition of viable deep wells mainly depends on the adequate and reliable empirical knowledge of geology of the area and the depth to aquifer (Okolie 2011).

Basically, groundwater in lithological formations is usually identified by several geophysical parameters of the subsurface using geophysical methods such as electrical resistivity methods, seismic methods, magnetic methods, and gravity methods (Lowrie 2002). Electrical resistivity method for conducting a Vertical Electrical Sounding (VES) has proved very popular with groundwater studies due to the simplicity of its technique, the ruggedness of its instrumentation and sensitive of rock's resistivity to water content (Kearey and Brooks 1991). Therefore, many extensive studies have been done on investigation of subsurface lithology and prolific aquifer using VES in Nigeria (Okolie et al. 2005; 2012; Obianu et al. 2014), but study on the determination of aquifer depth using Vertical Electrical Sounding (VES) within the study area is limited. Okolie et al. (2011) successfully carried out VES surveys on delineation of formation strata and groundwater distribution in the basement complex of Ifon area, Edo State. They found that rocks of the basement complex exhibit A, H and KH curve types with prolific aquifer depths ranging from 30 to 35 m. Okolie and Akpoyibo (2012) investigated the subsurface lithology and prolific aquifer in Edjekota area using VES. They pointed out that AAK, KHAA, AKHA, and KQHQ curve types predominant, implies the area has fairly homogenous subsurface stratification with average depth of 45 m to groundwater. Igboekwe et al. (2012) successfully determined the very shallow depths to aquifer at 16 - 30 m with a predominant curve of K and KH using field data of 8 VES surveys in Eket area of Akwa Ibom State. These findings suggested that the depths to aquifer differ from places due to variation in geostructural occurrence (Frohlich and Urish 2002).

In this study, the field data measured by VES were plotted in bi-log graphs and analyzed qualitatively and quantitatively by curve matching and computer iteration using the Win RESIST software to obtain the formation strata and the actual depth of viable aquifer. The results from the analysed field data were interpreted to obtain the geoelectric layers from which the subsurface lithology and hydrogeology were stratified for effective citing of reliable boreholes for optimal harnessing of groundwater from prolific aquifer in Ebem Okpo-Ihechiowa area. With regards to the results of the above analysis, the purpose of this research is to delineate the subsurface stratification and determine the depth to a prolific aquifer for sustainable groundwater supply to the dwellers of Ebem Okpo-Ihechiowa area.

STATEMENT OF THE PROBLEM WITHIN THE STUDY AREA

The study area is made up of predominantly rural dwellers who are mostly farmers. They make use of water from streams and springs (Figure 1) that are located at various points in their community for drinking and other domestic purposes. There is usually water scarcity especially in the dry season when most of the streams and springs dry up. Unfortunately, potable water is limited to many people due to improper subsurface investigation on depth to prolific aquifer before drilling borehole. Because of the unavailability of functional boreholes, they use water from streams and springs for their day to day domestic activity and expose themselves to risk of consumption of low quality water. This has led to development of various health challenges such as guinea worm, cholera, typhoid, stomach disorder and so on. The need therefore arises for a systematic study such as this, aimed at determining the depth using Vertical Electrical Sounding (VES) to hit prolific aquifer that will supply an economically feasible quantity of water continuously to the dweller in the area. This study will provide insights into depth at which groundwater could be obtained to borehole drillers or clients on the best place and depth to consider for drilling in Ebem Okpo-Ihechiowa area.

Figure 1. Contact springs in the study area

GEOLOGY OF THE STUDY AREA

Ebem Okpo-Ihechiowa is situated in the Southeastern part of Nigeria. Geographically, it is bounded by latitude 5°25'N and 5°30'N and longitude 5°51'E and 5°56'E (Figure 2), and is underlain by Middle Maestichtian Mamu Formation and Upper Maestrichtian Ajali Formation of the Afikpo sub-basin (Offodile 1975; Reijers 1997; Okoro and Igwe 2014). The Coal bearing part of the formation is predominantly made of freshwater and low salinity sandstone, shales, mudstones and sandy shales; coal seams occur at several levels (Nwajide and Reijers 1996). Based on the lithologic, structural and stratigraphic of the study area, the outcrops encountered include fine to coarse grained sandstones, sandstones interbedded with shales, fine grained sandstones and ferruginized sandstones lithofacies, which are designated into four lithostratigraphic units, namely: (1) Fine to coarse-grained sandstone unit (Unit A); (2) Sandstone interbedded with shale unit (Unit B); (3) Coarse-grained to pebbly sandstone unit (Unit C); and (4) Ferruginized sandstone unit (Unit D) as shown in Table 1 and Figure 2. The vegetation of the study area has been described as part of the lowland rainforest region of southeastern Nigeria (Igbozuruike 1975), controlled by the drainage, topography, lithology and rainfall (Ofomata 1981). The mapped area is also characterized by undulating hills. While the plains and lower part of the hills are mostly underlain by shales, the irregular ridges and gentle sloping hills are underlain mostly by sandstones and siltstones. The study area is drained by very few scattered rivers and streams e.g. Rawra River which flows in the southerly direction and very few others. The drainage pattern is generally dendritic with tributaries generally in a southerly direction (Figure 2).

Table 1. Lithostratigraphic succession of rocks in the study area

Age	Formation	Unit	Lithofacies
	Ajali	D: Ferruginized sandstone	Fine to coarse grained, Brownish to reddish, highly ferruginized sandstones and mudstones.
		C: Coarse to pebbly sandstone	Sandstones with randomly emplaced sandstone boulders.
	Mamu	B: Sandtones/shale	Whitish sandstone and dark-grey shale.
		A: Fine to coarse grained sandstone	Whitish to yellowish sandstone and mudstones.

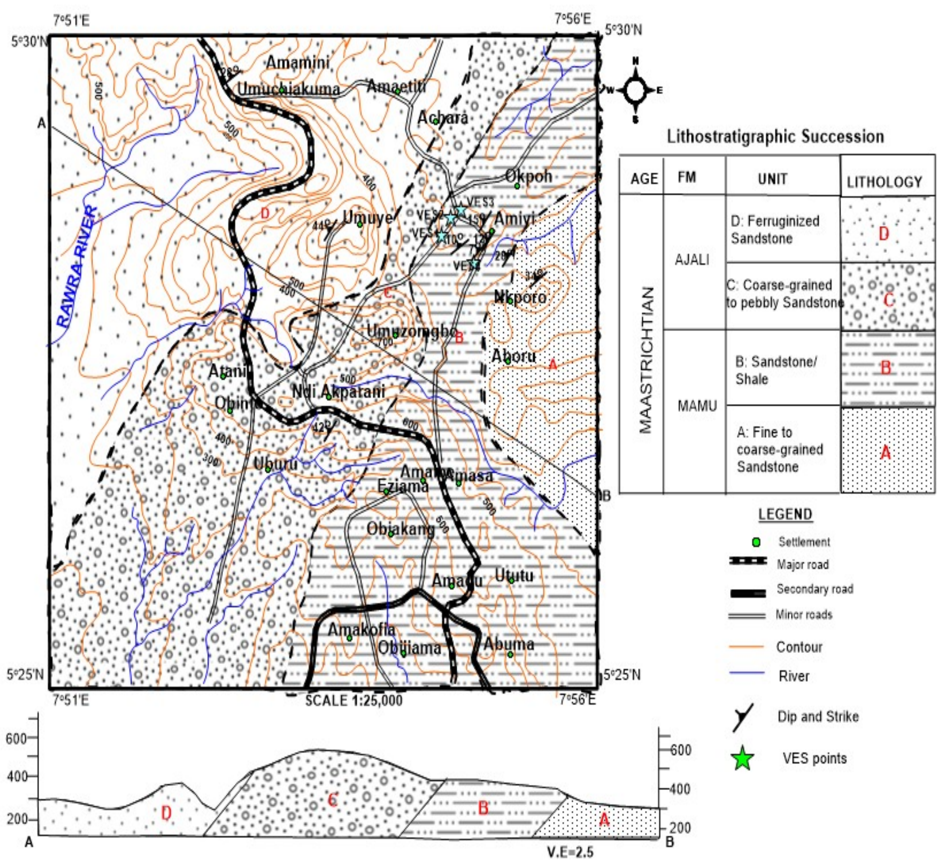

Figure 2. Geologic map of the study area

MATERIALS AND METHODS

A total of four (4) Vertical Electrical Sounding (VES) stations were surveyed (Figure 3) using ABEM SAS 1000 Terrameter and Schlumberger electrode configurations was employed due to its characteristics deep penetrations into the subsurface (Okolie 2011). In this configuration, the electrodes are on a line, where a pair of potential electrodes (usually denoted by M and N) were kept at centre, while a pair of current electrodes (usually denoted as A and B), both are gradually moved away from each other, with an electrode separation of 5 m, 10 m, 15 m, and 20 m at the length of 500m each of the traverse, for the current to probe deeper into the earth. Current is injected into the ground through a pair of electrodes, which produces an electrical field at the surface as seen in Figure 4.

The Versatile Omega resistivity meter (ABEM SAS 1000) was used in acquiring the data. For each sounding, the terrameter computes and displays a mean digital value of the resistivity of the subsurface under investigation using the theory that measured potential difference as given by Lowrie (2002) and Kearey and Brooks (1991). The field data were converted to apparent resistivity in ohm-meter by multiplying the geometric factor (K) given by equation (1), with the layer resistance (R) measured by the terrameter, as defined by Kearey and Brooks (1991). The apparent resistivity data were plotted against the half current electrode spacing (AB/2) on a bi-log graph to obtain sounding curve (Atakpo et al. 2008). The results from the modeling were finally iterated to the lowest Root Mean Square (RMS) percentage error using computer software, "IPI2 WIN" (Okolie et al., 2010) to determine the smoothed reistivities and thicknesses of the layers as seen in Figure 5 and Table 2. Subsequently, the subsurface lithology was obtained and the geoelectric section of the study sites drawn. Digger 5 Golden Software was used to digitize the geologic maps and the geoelectric cross sections.

The VES were interpreted from the observed apparent resistivity curves, which are classified primarily on the basis of the shapes of the curves, but at the same time, related to the geological situation in the subsurface. The shape of a VES curve depends on the number of layers in the subsurface, the apparent resistivity value and the thickness of each layer (Igboekwe et al. 2012).

$$\rho_a = \pi \left\{ \frac{\left[\frac{AB}{2}\right]^2 - \left[\frac{MN}{2}\right]^2}{\frac{MN}{2}} \right\} \frac{v}{I} = k\frac{v}{I} \tag{1}$$

where; ρ_α = Apparent resistivity in Ω-m, $AB/2$ = Half current electrode spacing, $MN/2$ = Half potential electrode spacing, k = Geometric factor, v/I = R = Subsurface resistance (Ω).

RESULTS AND DISCUSSION

The survey was limited to total of four (4) traverses, which cut through the study area as shown in Figure 3. The first surveyed point, VES 1, was done at Ebem Okpo; VES 2, VES 3, and VES4 were respectively run at Amaeri Okpo, Obichie Okpo, and Amiyi Okpo. Table 2 summarizes the smoothed iterated results of the modeling. The geoelectric sections of the true resistivity distribution generated from sounding curve (Figure 5) are shown in Figure 6. Thereafter, aquiferous zones were inferred from the geoelectric layer in relation to the depth and thickness of each layer.

The qualitative results of VES1 showed six [6] distinct geoelectric layers. The first subsurface layer consists of brown-reddish top soil with resistivity values of 243 Ωm and a thickness of 0.81 m. The second and third layers have been inferred as sand with apparent resistivity values ranging from

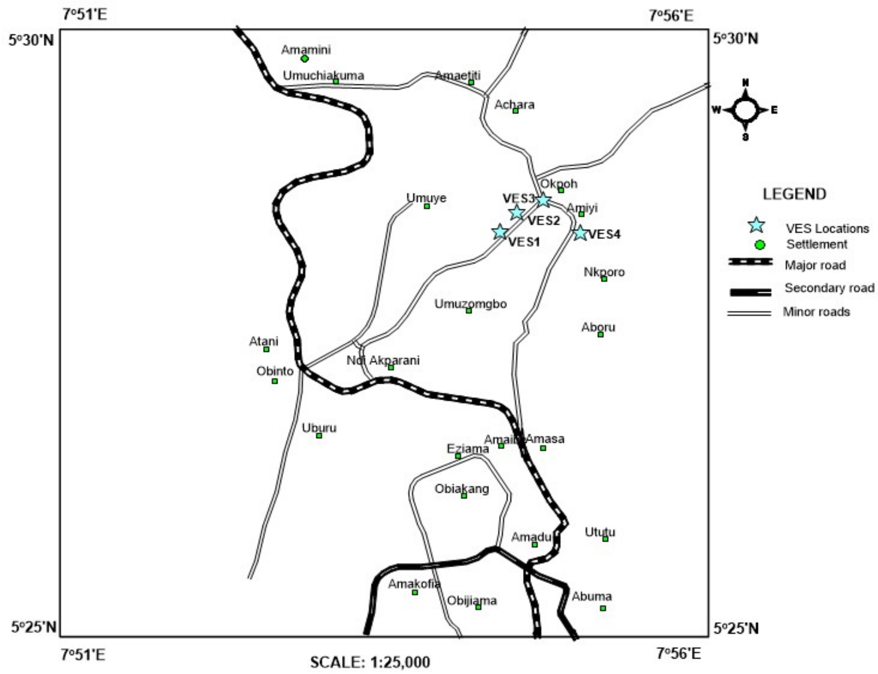

Figure 3. Map of the study area showing the four VES stations

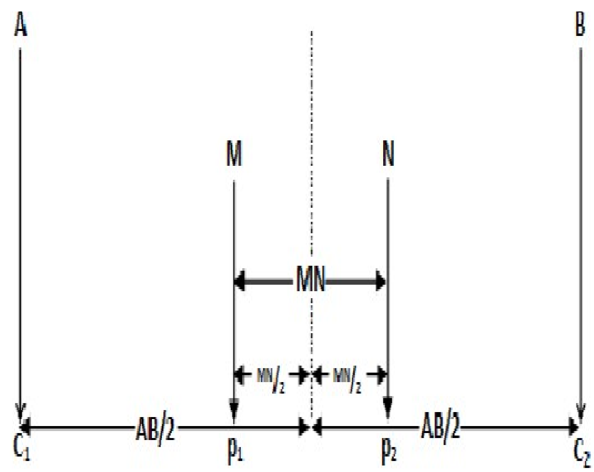

Figure 4. Schematic diagram of Schlumberger array configuration

492-1715.8 Ωm and thickness of 0.95 - 2.4 m. The fourth and fifth subsurface layers consists of shale formation with thickness range of 11.4 - 129.8 m and resistivity values of 40 - 418.3 Ωm as shown in Fig. 5a. The sixth layer showed indeterminate thickness with apparent resistivity of 449 Ωm. This layer is inferred as a sandstone formation, suitable for groundwater development. Therefore, aquifer would be met at about 145 m.

The qualitative and quantitative analyses of VES 2 delineated seven [7] distinct geoelectric layers as shown in Table 2. The first layer corresponds to top soil with apparent resistivity of about 313Ωm and thickness of about 1m. The second and third layers consist of mainly lateritic sand and sand bed with thickness of about 0.69 - 3.09 m with apparent resistivity of 105.3 - 558.5 Ωm. The fourth and fifth subsurface layers are mainly clayey shale and saturated shale with resistivity values of 38.1 - 202Ωm

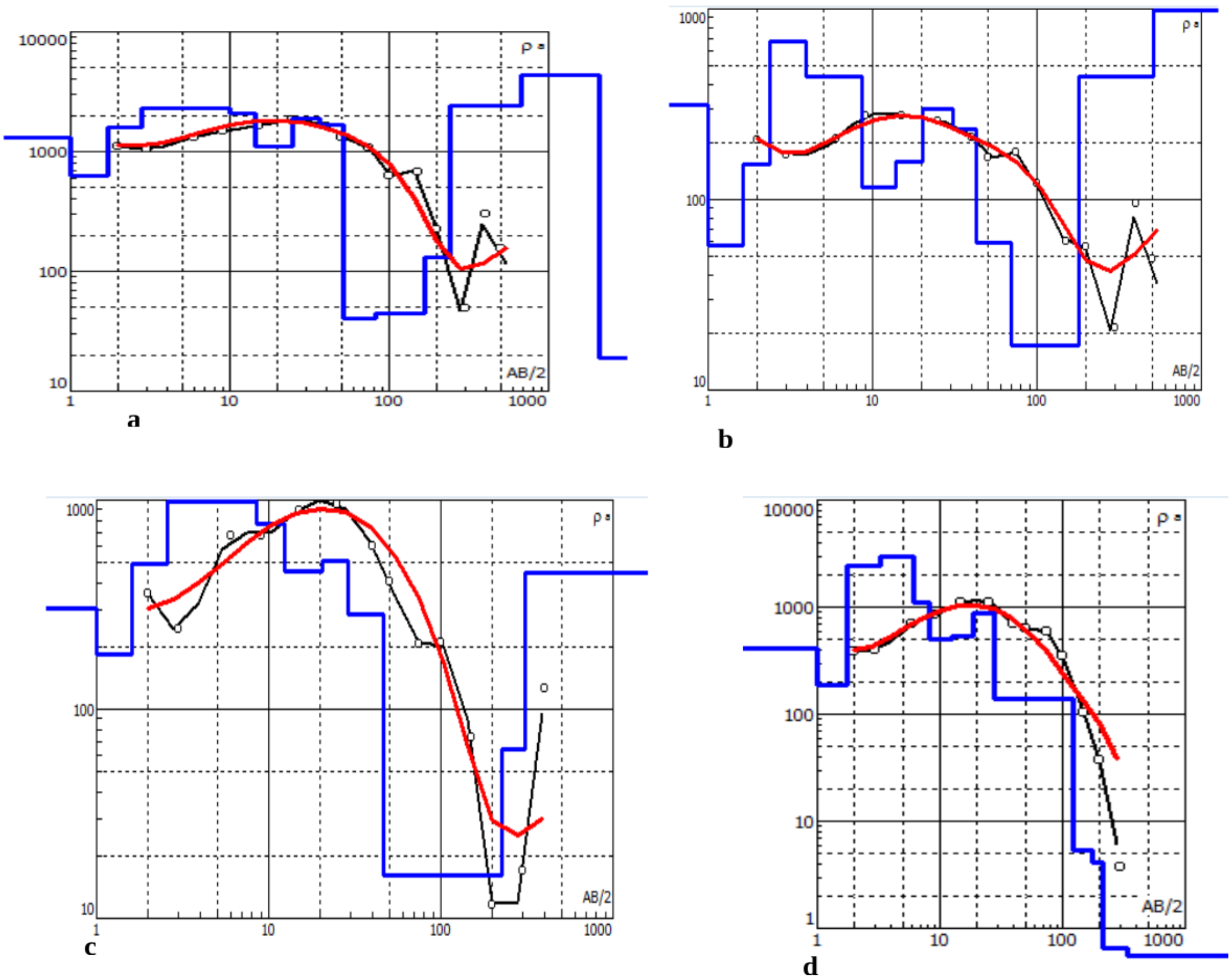

Figure 5. Field sounding curves for VES1 in Ebem Okpo (a), VES2 in Ameri Okpo (b), VES3 in Obichie Okpo (c) and VES4 in Amiyi Okpo (d)

and thickness ranging from 8.62 - 68. 3 m. The layers from the base of layer one to the top of layer six becomes aquitad with an average thickness of about 69.6m terminating at about 417.7m depth. The sixth and seventh geoelectric layer become prolific aquifer which consists of mainly sandstone formation with resistivity values of 442 - 4355Ωm and thickness of 336 m to undefined thickness. These layers contain appreciable quantity of groundwater.

VES 3 show eight [8] distinct lithologic units as seen in Figure 6c. The first and second layers are overburden of top soil and lateritic clay bed of resistivities of 996.5 - 1590 Ωm, respectively and a total thickness of about 1.95m. The third and fourth layers consist of thick layers of silt/clay with resistivity values of 2195Ωm and 1548Ωm, and thickness of 5.7m and 12.27 m respectively. It is underlies by massive saturated shale layer with resistivity values ranging from 42.6 - 132 Ωm and thickness of 57.75 - 73.6 m, which overlies a sandstone layer of 913.5m thick with resistivity of 3352 Ωm, at depth of 913.5 m. This type of thick lithological sequence is capable of supplying economically quantity of water to well. VES is considered as a viable location for development of water borehole for groundwater resources. Hence, confined aquifer structure occurs at a depth of about 151 m in Obichie Okpo.

Table 2. Summary of smoothed iterated results of sounding curve and coordinate of VES stations in the study area

VES No	VES Location	Coordinates & Elevation	No of Layers	Resistivity of Layers (Ωm)	Thickness of Layers (m)	Depth (m)	Curve Type
1	Ebem Okpo	N5°28'30.2" E7°54'40.1" 67.9m	6	ρ_1 = 243 ρ_2 =492 ρ_3 = 1715.5 ρ_4 = 418.3 ρ_5 = 40 ρ_6 = 449	t_1 = 0.81 t_2 = 0.95 t_3 = 2.4 t_4 = 11.4 t_5 = 129.8 t_6 = ?	z_1 = 0.81 z_2 = 1.76 z_3 = 4.16 z_4 = 15.56 z_6 = 145.36 z_7 = ?	KH
2	Amaeri Okpo	N5°28'37.0" E7°54'47.7" 69.8m	7	ρ_1 = 313 ρ_2 = 105.3 ρ_3 = 558.3 ρ_4 = 202 ρ_5 = 38.1 ρ_6 = 442 ρ_7 = 4355	t_1 = 1 t_2 = 0.691 t_3 = 3.09 t_4 = 8.62 t_5 = 68.3 t_6 = 336 t_7 = ?	z_1 = 1 z_2 = 1.691 z_3 = 4.781 z_4 = 13.401 z_5 = 81.701 z_6 = 417.701 z_7 = ?	HKH
3	Obichie Okpo	N5°28'39.4" E7°54'53.9" 64.5m	8	ρ_1 = 966.5 ρ_2 = 1590 ρ_3 = 2195 ρ_4 = 1548 ρ_5 = 42.6 ρ_6 = 132 ρ_7 = 3352 ρ_8 = 19	t_1 = 0.859 t_2 = 1.09 t_3 = 5.755 t_4 = 12.27 t_5 = 57.75 t_6 = 73.6 t_7 = 913.5 t_8 = ?	z_1 = 0.859 z_2 = 1.949 z_3 = 7.724 z_4 = 19.994 z_5 = 77.744 z_6 = 151.344 z_7 = 1064.84 z_8 = ?	KH
4	Amiyi Okpo	N5°28'18.6" E7°54'55.4' 66.5m	7	ρ_1 = 409 ρ_2 = 187 ρ_3 = 2170 ρ_4 = 634.7 ρ_5 = 141 ρ_6 = 3.40 ρ_7 = 0.374	t_1 = 1 t_2 = 0.725 t_3 = 2.18 t_4 = 6.35 t_5 = 94.3 t_6 = 70.43 t_7 = ?	z_1 = 1 z_2 = 1.725 z_3 = 3.905 z_4 = 10.255 z_5 = 104.55 z_6 = 174.985 z_7 = ?	K

VES 4 has seven layers as shown in Figure 5d. The top layer is brown-reddish top soil with apparent resistivity of 409Ωm and a thickness of 1m. The second layer has apparent resistivity of 187Ωm and thickness of 0.725m. It overlies sandstone layers of varying resistivities of 634.7 - 2170 Ωm with an average thickness of 5.355m. This is presumably underlain by massive shale beds with resistivity values ranging from 3.4 - 141 Ωm with an average thickness of 82.365m at the depth of about 104m. The resistivity distribution of the rock layers with depth and thickness show that VES 4 has a shallow surface perched aquifer at depth of 1.7 - 10.2m. The geoelectric section generated from VES 4 curve shown in Fig. 6d indicate that the massive saturated shales underlying the sandstones is thick enough to host water though not too encouraging for prospect for groundwater exploration in the area.

CORRELATION OF THE FOUR GEOELECTRIC SECTIONS

Correlation of geological units and geoelectric sections of the four VES stations as seen in Figure 7 show delineation of six to eight distinct subsurface layers to depth of 1065 m above. The results show that K, KH and HKH curve type predominant (Table 2), implying that Ebem Okpo Ihechiowa area has homogenous subsurface stratification consists of mainly overburden (top soil), thick sandstone units intercalated with thin shale and saturated shale beds. The first layer is a top soil whereas the second

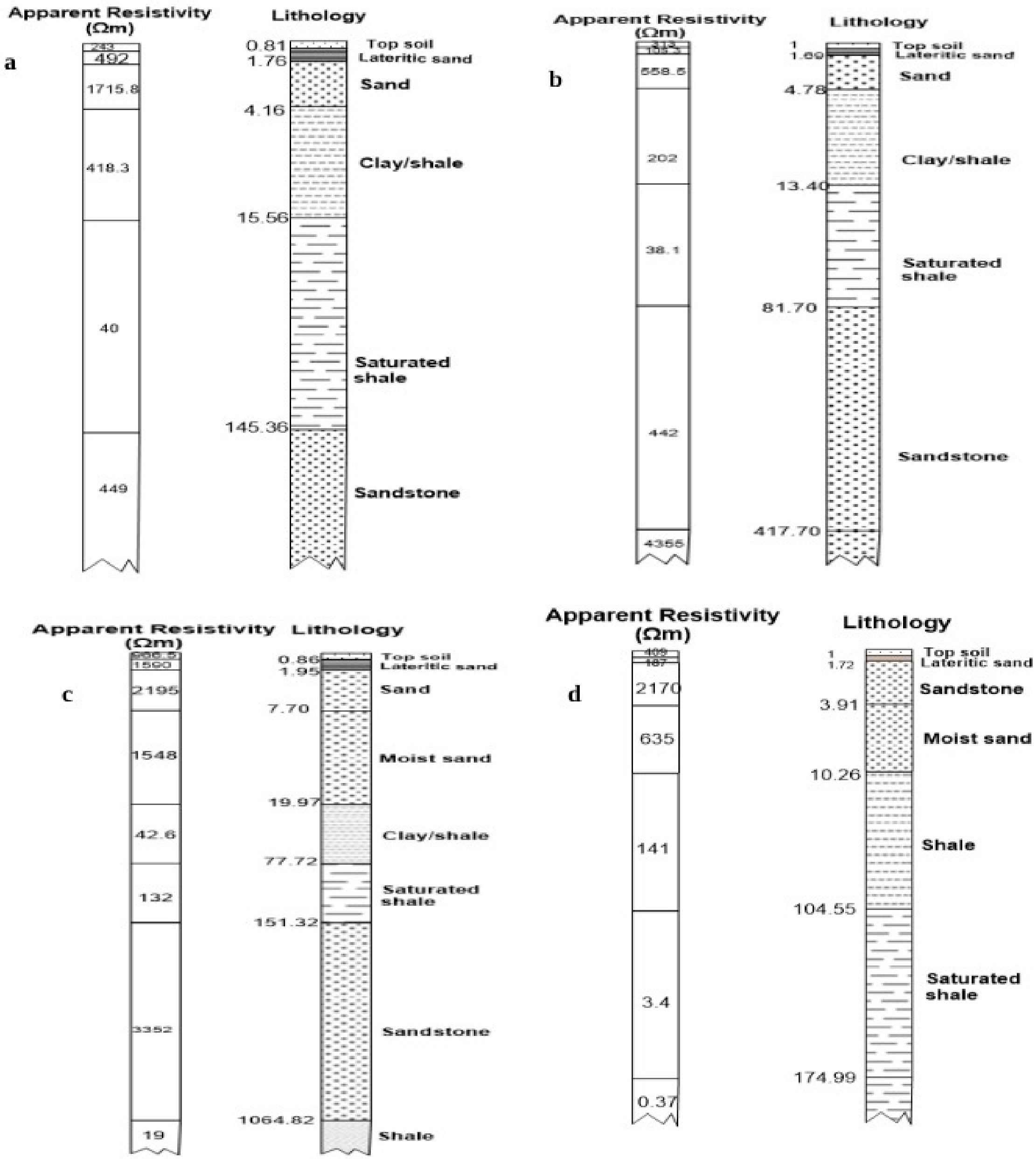

Figure 6: Geoelectric Layers of (a) Ebem Okpo, (b) Ameri Okpo, (c) Obichie Okpo and (d) Amiyi Okpo

layer consists mainly of lateritic sand. The third and fourth layers are made up of moist sandstone. These layers have shallow aquifer met at the depths range of about 4 to 20 m with resistivity values of 558 - 2195 Ωm and thickness of 3 - 12 m across the four wells, although it is well pronounced in VES 3 compare to other three VES stations. The fifth layers composed of shale alternated with saturated shale bed. The six and seven layers in VES 1, VES2 and VES3 are the aquiferous zone of sandstone formation. This is the second prolific aquifer met at the depth of about 145m in VES 1, 81m in VES 2 and 151m in VES 3. However, depth for a prolific aquifer is not met in VES 4 may be the investigation did not reach 500m depth. Therefore, from the base of fifth layer in VES 1 and 2, and base of sixth layer in VES 3 to an undefined thickness becomes aquiferous zone.

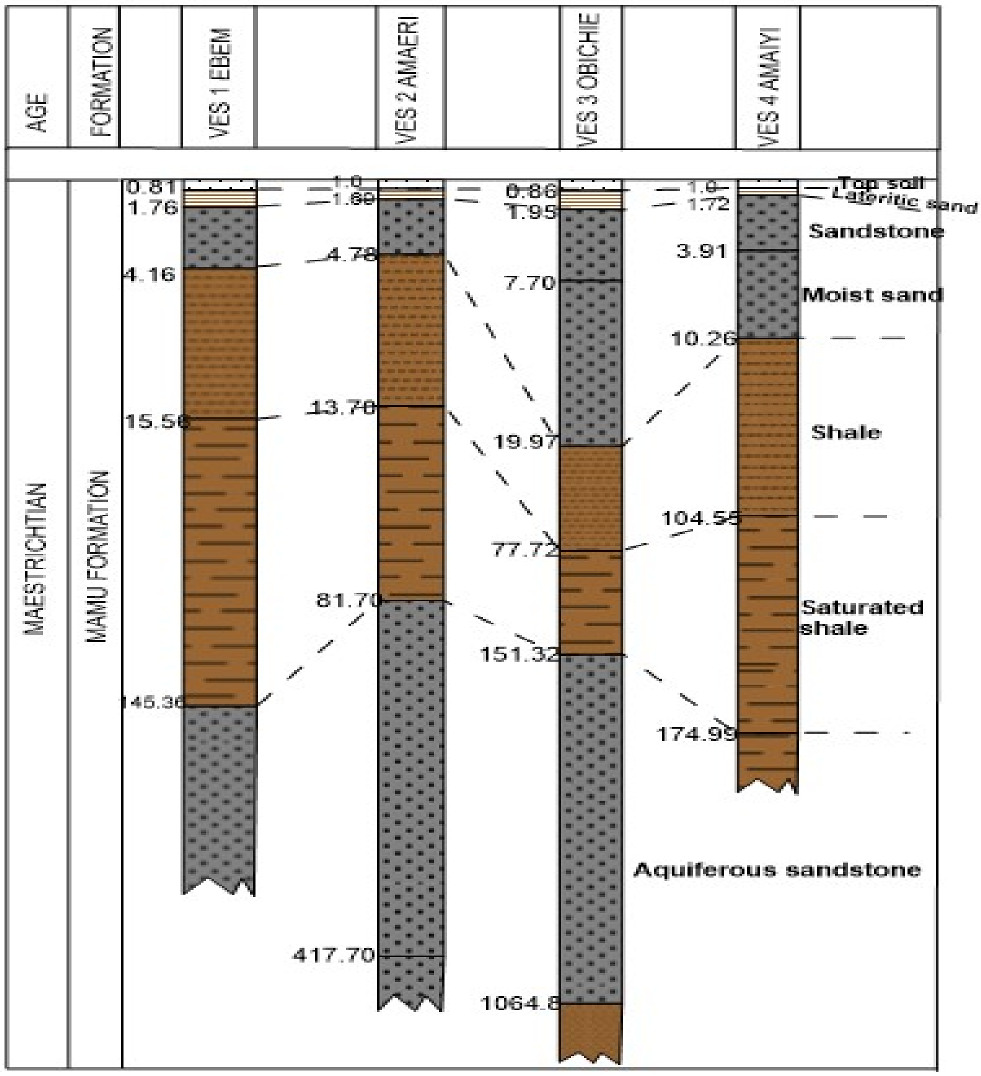

Figure 7. Geoelectric and geologic sections of the four VES Stations

CONCLUSIONS AND RECOMMENDATIONS

The result of the VES investigation revealed that Ebem Okpo Ihechiowa area has six to eight subsurface lithologic units with K, KH and HKH curve types indicating homogenous sedimentary terrain. However, the study delineates geoelectric layers with lithologic sequence of alternating thick sandstone formation and thin shale unit. The first subsurface layer (top soil) consists mainly of loose sand with thickness of 0.8 m to 1.m across the four VES stations. The second layer is mainly lateritic sand to a depth of about 2 m. The third and fourth layer consists of moist sand bed to a depth of 20 m The existence of some shallow aquifers within the study area could be traceable to this delineated thick sand layer although it is not too encouraging for prospect for groundwater exploration. The fifth layer consists of shale and saturated shale to a depth of about 151 m. The sixth to eight subsurface layer consists of thick sandstone formation. This delineated sandstone deposit is large and thick for economically quantity of groundwater development.

From the above findings and analyses of the 4 VES conducted around the study area; boreholes for sustainable water supply should be drilled to the following depths to hit prolific aquifers as recommended below:

Depth of about 145 meters (479ft) is recommended for Ebem Okpo.

Depth of about 81 meters (267ft) is recommended for Amaeri Okpo.

Depth of 151 meters (498ft) is recommended for Obichie Okpo.

Only shallow surface aquifer can be hit at the depth of 1.7 to 10.2m in Amiyi.

It is also recommended that other geophysical exploration methods such as seismic refraction method may be employed for further investigation in order to assure economically feasible quantity of water supply to a well within the study area.

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