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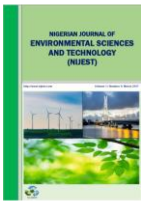

Hydrogeophysical Survey of Groundwater Development at Okada Community Ovia North - East L.G.A. Edo State

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ABSTRACT

Geophysical investigation was conducted at Okada community in ovia North Local Govertment area of Edo state to determine the prospect of aquifer zone. The Petrozenith PZ-02 Terrameter, one of the Electrical Resistivity Equipment was used to conduct a Vertical Electrical Sounding (VES) in the study area. The Garmin Etrex 10 Global Navigation satellite systems (GNSS) was used to acquire Geodetic coordinates of point where VES observations were made. This research was carried out as a pre-drilling Hydro-geophysical survey conducted for the purpose of surveying and studying the proposed water borehole site at Okada Community that has suffered acute water problems for a very long time. There have been series of boreholes drilled in the studied area but all are dry wells. This survey was conducted to investigate the subsurface complexity of the sites in respect of lithology and to recommend the total drill depth based on the prospective aquifer unit so identified. Result of interpretation suggests that the area is underlain with substantive aquiferous formation but at a depth not exceeding 121.60 m (398.95 ft), which is the lower aquifer unit. The value of elevation at point of observation referenced to mean sea level is 94 m.

Keywords: Aquiferous, Shale, Geoelectric, Groundwater, Subsurface, Sandstone

1.0. Introduction

Groundwater is characterised by certain number of parameters which are determined by geophysical methods, resistivity methods, seismic methods and gravity methods (Alile and Ehigiator, 2011). This research was carried out as a pre-drilling Hydro-geophysical survey conducted for the purpose of surveying and studying the proposed water borehole site at Okada Community. There have been series of boreholes drilled in the studied area but all are dry wells. This survey was conducted to investigate the subsurface complexity of the sites in respect of lithology and to recommend the total drill depth based on the prospective aquifer unit so identified.

2.0. Materials and Methods

2.1. Study area

Okada Community (Figure 1) is located on a latitude 6° 44' 0" and longitude 5° 23' 00" in Ovia North-East L.G.A. of Edo State. The subsurface of this area consists of lignite, clay, claystone, shale, mudstone, coal, sandstone with limestone intercalations belonging to the Imo shale group. Vegetation is made of shrubs and few scattered trees within the rain forest belt of Nigeria.

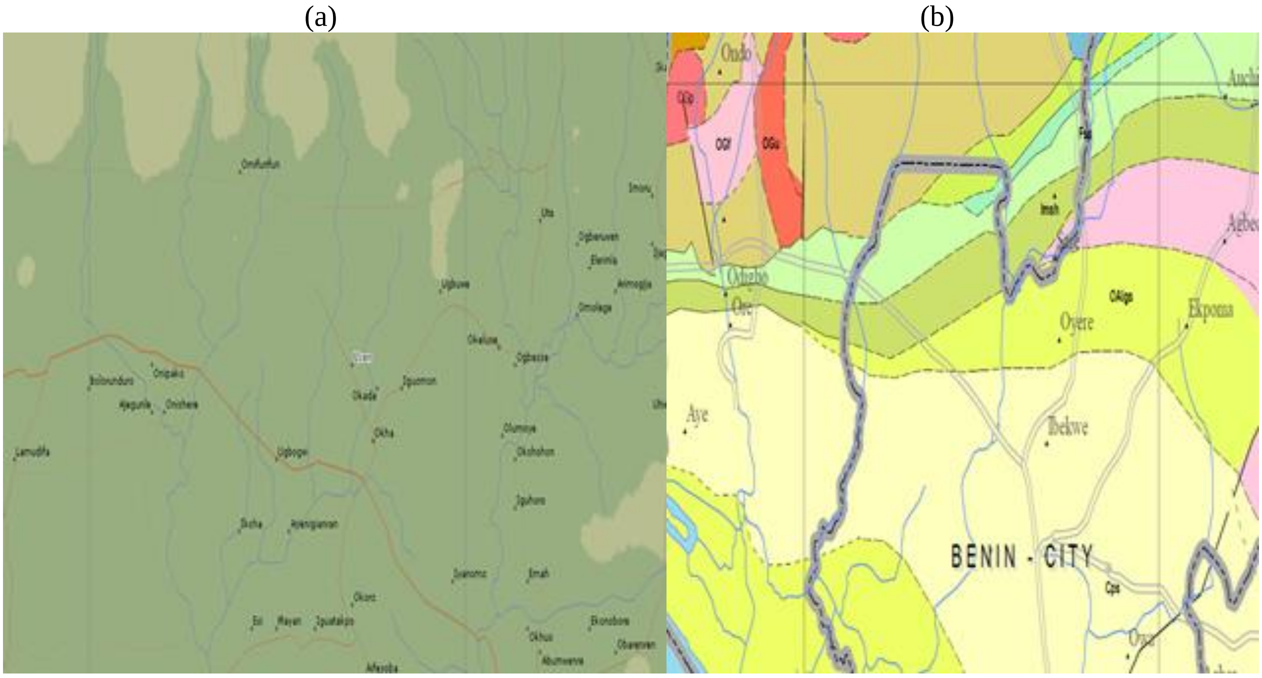

Figure 1: Map of study area (Okada)

2.2. Data acquisition

To compliment surface geological mapping, the Schlumberger configuration was used for a total spread (L) of 500 m. A VES station was located in front of the proposed water borehole site. A spread of 250 m (L/2) was covered on the right running towards Okada, and another 250 m (L/2) was run on the left towards Utese Community. Necessary precautions required in geo-electric measurement were duly considered and maintained. The survey lasted between 09.15 hrs to 18.25 hrs under favourable weather condition.

Precautions are taken during the course of electrode spacing. When electrode spacing is small compared to the layer thickness, nearly all current will flow through the upper layer. The resistivities of the lower layers have negligible effect. This is due to the fact that the measured apparent resistivity is the resistivity of the upper layer (Schlumberger, 2011).

2.3. Data processing

All field data have been subjected to manual computation and finally to computer processing techniques, applying the IPI2WIN Resistivity Sounding Interpretation software. IPI2WIN is software that is designed to analyze geo-electric measurements on a single piece automatically or semi-automatically to get the smallest error. Results of data processing by the software package are integrated in order to arrive at the realistic composition and layering of the subsurface (William, 2012).

For the VES, the Schlumberger electrode configuration was adopted. A Petrozenith PZ-02 Terrameter was used to take field measurements of resistance (R) from which apparent resistivity (ρ_a) was calculated by the relation:

$$\rho_a = K * R \tag{1}$$

where:

R Resistance in ohms

$$K = \frac{\left({}^{AB}/_{2}\right)^2 - \left({}^{MN}/_{2}\right)^2 \times \pi}{2MN} \tag{2}$$

where:

AB	Current electrode spacing in meters
MN	Potential electrode spacing in metres

3.0. Results and Discussion

3.1. Vertical sounding for two horizontal beds

The images developed are useful in dealing with sounding on two horizontal layers, as well as profiling over elementary 2D structures (Telford *et al.*, 2012). Its application to the former also provides some simple illustrations of limiting cases of the bed parameters (Schlumberger, 2011).

The potential of a single electrode to the resistivity of the upper layer in terms of the electrode spacing, the depth to the interface, and the resistivity contrast between the two beds can be expressed in Equation (3) below (Koefoed, 1979). Writing this expression in the form of an apparent resistivity, which would be measured by a four-electrode system and considering the measured potential difference between ρ1 and ρ2, we have (SPDC, 2010):

$$V = \frac{I\rho_1}{2\pi r}\left[\frac{1}{r} + 2\sum_{m=1}^{\infty}\frac{k^m}{\sqrt{\{1+(2mz/r)^2\}}}\right] \tag{3}$$

$$\rho_a \approx -\frac{\pi r^3}{(\Delta r)^2}\left(\frac{\Delta V}{I}\right) \approx -\frac{\pi r^3}{I}\left(\frac{\partial^2 V}{\partial r^2}\right) \tag{4}$$

where:

ρ_a	Resistivity
r	Distance from first electrode
V	Voltage
ΔV	Change in voltage
I	Current

$$\begin{aligned}\Delta V = V_1 - V_2 = \frac{I\rho_1}{2\pi}\Bigg\{&\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right] \\ &+ 2\sum_{m-1}^{\infty}k^m\left(\frac{1}{(r_1^2+4m^2z^2)^{1/2}}-\frac{1}{(r_2^2+4m^2z^2)^{1/2}}-\frac{1}{(r_3^2+4m^2z^2)^{1/2}}\right. \\ &\left.+\frac{1}{(r_4^2+4m^2z^2)^{1/2}}\right)\Bigg\}\end{aligned} \tag{5}$$

Applying Wenner spread; because $r_1 = r_4 = a$, $r_2 = r_3 = 2a$, Equation (5) is simplified as follows:

$$\Delta V = \frac{I\rho_1}{2\pi}\left[1 + \sum_{m-1}^{\infty}\frac{4k^m}{\{1+(2mz/a)^2\}^{1/2}} - \sum_{m-1}^{\infty}\frac{4k^m}{\{4+(2mz/a)^2\}^{1/2}}\right] = \frac{I\rho_1}{2\pi}(1+4D_w) \tag{6}$$

where:

$$D_w = \sum_{m-1}^{\infty}k^m\left[\frac{1}{\{1+(2mz/a)^2\}^{1/2}} - \frac{1}{\{4+(2mz/a)^2\}^{1/2}}\right] \tag{7}$$

But,

$$\rho_a = 2\pi\Delta Vp/I = 2\pi\Delta Vp/I\,(1/a - 1/2a - 1/2a + 1/a) = 2\pi a\Delta V/I \tag{8}$$

So that the apparent resistivity is:

$$\rho_a = \rho_1\left[1 + \sum_{m-1}^{\infty}\frac{4k^m}{\{1+(2mz/a)^2\}^{1/2}} - \sum_{m-1}^{\infty}\frac{4k^m}{\{4+(2mz/a)^2\}^{1/2}}\right] = \rho_1(1+4D_w) \tag{9}$$

Applying Schlumberger spread; when $x = 0$, $r_1 = r_4 = L - l$, $r_2 = r_3 = L + l$, and the potential difference is written by modifying Equation (3) as:

$$V = \frac{I\rho_1 2l}{\pi L^2}\left[1 + 2\sum_{m-1}^{\infty}\frac{k^m}{\{4+(2mz/r)^2\}}\right] \approx \frac{I\rho_1 2l}{\pi L^2}(1+2D_s') \tag{10}$$

where:

$$D_s' = \sum_{m=1}^{\infty}\frac{k^m}{\{1+(2mz/L)^2/\}^{3/2}}$$

The exact expression for apparent resistivity becomes:

$$\begin{aligned}\rho_a = \rho_1\left[1 + \left(\frac{L+l}{l}\right)\times\sum_{m=1}^{\infty}\frac{k^m}{\{1+(2mz)^2/L^2\}^{1/2}} - \left(\frac{L-l}{l}\right)\times\sum_{m=1}^{\infty}\frac{k^m}{\{1+(2mz)^2/L^2\}^{1/2}}\right] \\ = \rho_1(1+D_s)\end{aligned} \tag{11}$$

where:

$$D_s = \left(\frac{L+l}{l}\right)\sum_{m=1}^{\infty}\frac{k^m}{\{1+(2mz)^2/(L-l^2)\}^{1/2}} - \left(\frac{L+l}{l}\right)\sum_{m=1}^{\infty}\frac{k^m}{\{1+(2mz)^2/(L-l^2)\}^{1/2}}$$

Approximately, we have:

$$\rho_a = \rho_1\left[1 + 2\sum_{m=1}^{\infty}\frac{k^m}{\{1+(2mz/L)^2\}^{3/2}}\right] = \rho_1(1+D_s) \tag{12}$$

This result can also be obtained by differentiating Equation (3) with respect to r, multiplying the result by 2 (because there were two current electrodes), and applying Equation (12) to get ρ_a:

$$\rho_a = \frac{\pi L^2}{I}\left(\frac{\Delta V}{\Delta r}\right) \tag{13}$$

Applying double-dipole spread; because $r_1 = r_4 = 2nl$, $r_2 = 2(n-1)l$, $r_3 = 2(n+1)l$, the exact expression for the potential difference is:

$$\begin{aligned}\Delta V = -\frac{I\rho_1}{2\pi(n-1)n(n+1)l} \\ \times\left[1 + n(n+1)\times\sum_{m-1}^{\infty}\frac{k^m}{\left[1+\frac{(2mz)^2}{\{2(n-1)l\}^2}\right]^{1/2}} + n(n-1)\right. \\ \left.\times\sum_{m-1}^{\infty}\frac{k^m}{\left[1+\frac{(2mz)^2}{\{2(n-1)l\}^2}\right]^{1/2}} - 2(n-1)(n+1)\times\sum_{m-1}^{\infty}\frac{k^m}{\left[1+\left(\frac{2mz}{znl}\right)^2\right]^{1/2}}\right]\end{aligned} \tag{14}$$

The apparent resistivity is given by:

$$\rho_a = \rho_1(1+D_d)$$

where $(1 + D_d)$ is the expression inside the large square brackets in Equation (14) above.

If we make n > 1, the preceding result is simplified and we can make use of Equation (10) differentiating twice,

$$\frac{\partial^2 V}{\partial r^2} = \frac{I\rho_1}{\pi r^3}\left[1 - \sum_{m-1}^{\infty} \frac{k^m}{\left[1+\left(\frac{2mz}{r}\right)^2\right]^{3/2}} + 3\sum_{m-1}^{\infty} \frac{k^m}{\left[1+\left(\frac{2mz}{r}\right)^2\right]^{5/2}}\right] \tag{15}$$

And using Equation (9),

$$\rho_a = \rho_1\left[1 - \sum_{m-1}^{\infty} \frac{k^m}{\left[1+\left(\frac{2mz}{r}\right)^2\right]^{3/2}} + 3\sum_{m-1}^{\infty} \frac{k^m}{\left[1+\left(\frac{2mz}{r}\right)^2\right]^{5/2}}\right] = \rho_1(1+D_d) \tag{16}$$

Quantitatively, we can see how the apparent resistivity varies for different electrode spreads. When the electrode spacing is very small, that is *r* << *z*, the cases tend to zero, so that we measure the resistivity in the upper formation, this is the surface resistivity (Schlumberger, 2011).

Figure 2a represent the layer resistivity model which is the plot of resistivity with length as obtained from the processed geophysical data using IPI2WIN software. The Resistivity and the cross sessional area is presented in Figure 2b.

Half the current electrode spacing *(AB/2)*, the potential electrode spacing *(MN*), the derived constant *(K)* and the Resistivity *(Ωm)* of the study area are presented in Table 1.

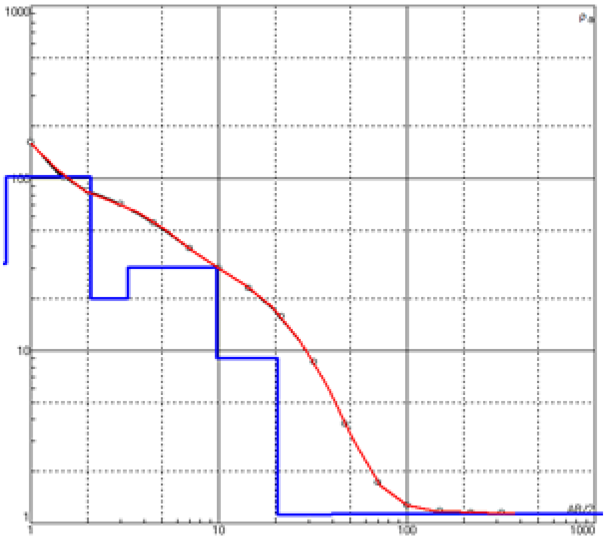

Figure 2a: Layered resistivity model

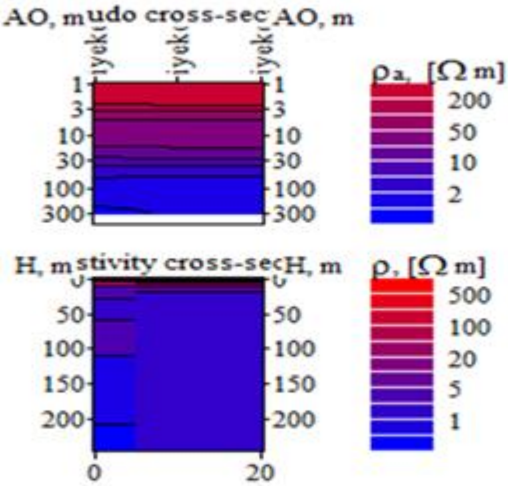

Figure 2b: Measured and modelled

3.2. Discussion

Table 2 below is the results obtained using IPI2WIN software revealing seven sublayers at different depths. At depth 0.5 m of thickness 0.5 m, the resistivity was found to be 368 Ωm, while the lithology indicated sandy topsoil. At a depth of 1.21 m of sand thickness 0.706 m, the resistivity was 482 Ωm with clayey subsoil lithology. The third layer is at a depth of 2.91 m of thickness 1.7 m had resistivity of 323 Ωm and of sandy clayey formation. The fourth formation at depth 7.02 m had a thickness of 4.11 m and resistivity of 551 Ωm. The lithologic formation was found to be sandy. The fifth formation at depth 16.9 m had a thickness of 9.92 m, resistivity of 1620 Ωm and shale sandy lithology. The sixth sand at depth 40.9 m has a thickness of 23.9 m and resistivity of 2133 Ωm reflects the shaly lithology. The seventh sand whose is 116 m has a thickness of 75.8 m, resistivity of 1958 Ωm lithology of prospective sandstone. The eighth sand at depth 255.6 m has a thickness of 139 m, 2038 Ωm resistivity and lithology of shale. The ninth sand which is undefined with an undefined sand thickness has a resistivity of 2053 Ωm and a sandy shale lithology. The resistivity values as reflected from the table increase with depth but with the exception of the third sand layer. The prospective water formation (aquiferous zone) is at a depth of 166.6 m with resistivity of 1958 Ωm. Hydrogeologists (Akinlabi and Oladunjoye, 2008), conducted VES in the study area, the results of their analysis indicate a remarkably inhomogeneity in geological composition. This conclusion agrees with our analysis as presented in Table 2.

Table 1: Resistivity data

SP, V, and I =0			
Current Electrode spacing (AB/2)	Potential electrode spacing (MN)	Constant (K)	Resistivity (Ωm)
1	0.5	5.8905	19.8370
1.5	0.5	13.744	18.3740
2	0.5	24.74	127.5800
3	0.5	56.156	1.3709
4.5	0.5	126.84	4.2790
7	0.5	307.48	2.2799
10	0.5	627.93	1.2740
14.5	0.5	1321	0.48097
14.5	1	659.73	1.1913
21.5	1	1451	0.70151
21.5	2	724.53	1.8449
32	2	1607	1.0053
47	2	3468	0.38686
47	5	1384	1.6591
70	5	3075	1.1028
100	5	6279	0.61832
100	10	3134	1.2309
150	10	7061	0.68225
150	20	3519	1.357
220	20	7587	0.51213
220	50	3002	1.2323
300	50	6395	0.42139
350	50	7658	0.3513

Table 2: Geological formation

Layer	Depth (m)	Thickness (m)	Resistivity (Ωm)	Lithology
1	0.50	0.500	368	Sandy topsoil
2	1.21	0.706	482	Clayey sub soil
3	2.91	1.700	323	Sandy clay formation
4	7.02	4.110	551	Sandy formation
5	16.90	9.920	1620	Shale (Sandy)
6	40.90	23.900	2133	Shale
7	121.60	75.800	1958	Sandstone (Prospective aquifer layer)
8	255.60	139	2038	Shale
9	Undefined	Undefined	2053	Sandy shale

4.0. Conclusion/ Recommendations

Result of interpretation suggests that the area is underlain with substantive aquiferous formation but at a depth not exceeding 121.6 m, which is the lower aquifer unit. The depth is obtained by adding (94 m), the value of the elevation obtained at point of observation with GNSS to the formation depth of 116.6 m. From the above results, the following are hereby recommended.

i. Drilling should be done to a depth not exceeding 121.6 m (398.95 ft) to allow for large reservoirs within the lower aquifers unit to be tapped.
ii. There should be adequate borehole logging of the samples to enable the proper screening of the aquifer zones which are captured; this should be done by an experienced hydrogeologist.
iii. The borehole drilling should be done with a competent drilling rig specifically built for the sedimentary terrain in order to attain this recommended Total Drilled Depth (TDD).
iv. Proper water analysis should be done in a credible analytical laboratory to determine the quality of the water so produced from the borehole.

5.0. Acknowledgement

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References

Alile, M.O. and Ehigiator M.O. (2011). Determination of aquifer layer by the application of electrical method of exploration at Ubiaja in Edo Central of Nigeria. *Scientific research and Essays,* 6(2), 493 – 498.

Akinlabi, I.A and Oladunjoye, M.A. (2008). Geophysical investigation of dam site in a sedimentary terrain. *Research Journal of Applied Sciences,* 3(7), 484 – 489.

Koefoed, O. (1979). *Geosounding principles*. Elsevier Publications. Co., Amsterdam, Oxford, New York, Pp. 46 – 54.

Schlumberger (2011). Lecture notes on resistivity methods, SPDC, Warri. Available at: http://www.nigerianoil-gas.com/industry profile

Shell Petroleum Development Company (SPDC) (2010). Lecture note on resistivity methods. Available at: http://www.nigerianoil-gas.com/industry profile

Telford, W.M., Geldart, L.P., Sheriff, R. E. and Keys, D.A. (2012). *Applied geophysics*. Cambridge University Press, London.

William, L. (2012). *Fundamentals of geophysics*, Cambridge University Press, London. Available at: https://www.textbooks.com.MHG>Geophysics

Zohdy, A. (1989). A new method for the interpretation of Schlumberger and Wenner sounding curves. *Geophysics*, 54(2), 245-253.