THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Application of Hydro-geophysical Methods for Subsurface Stratigraphy and Aquifer Characterization in Sedimentary Terrian: A Case Study of Sabongida-Ora, Edo State, Nigeria

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Abstract:
Understanding subsurface geology is a premise to aquifer characterization. Five (5) Vertical Electrical Sounding (VES) and a 2D Wenner Electrical Resistivity Tomography (ERT) were carried out to image the subsurface for geologic (stratigraphic) characterization of the study area, in bid to delineating zone(s) characterized with high porosity and permeability as well as saturated with sufficient groundwater for exploitation. The field equipment used was ABEM SAS1000 resistivity meter and accessories. The maximum spread obtained for half current separation distance (AB/2) for the VES (with six stations per decay) was 450.00m. The profile length of the ERT was 300m, with unit electrode spacing of 5m. Conventional field and computer assisted data interpretation techniques were observed with final interpreted model relative to altimeter elevation presented after data were subjected to processing to reduce noise effect. The interpreted models were corroborated with borehole data for parametric sampling. Findings showed existence of a perched water (aquifer) within a window depth of 15m to 35m (50ft - 120ft) followed by a claystone (clay unit) of about 100m to 130m (320ft to 400ft) and finally, deep seated confined aquiferous unit at depth of investigation beyond 240m (845ft) was captured.

Keywords: *Stratigraphy; Hydrogeology; Delineation; VES;Wenner ERT; Characterization; Aquifer.*

1. Introduction

It is an established fact that a quick, non-invasive, cost effective means of subsurface characterization is the geoelectrical or electrical resistivity method. These combined hydro-geophysical methods which employs vertical electrical sounding in conjunction with 2D wenner electrical resistivity tomography (ERT), is majorly the geophysical application methods used for hydro-geological investigation which is directed towards aquifer characterization and ground water quality studies (Olayinka and Mbachi, 1992; Ismail Mohamaden, 2005; Astahani, 2006; Bello and Mankinde, 2007 in Mogagi et al, 2011). These methods image the subsurface geologic stratigraphy for characterization of the subsurface in a bid to delineate zones characterized with high porosity, permeability as well as saturation for sufficient ground water exploitation and determination of depth, thickness and boundary between saline and potable fresh water aquifer zones (Khalil, 2006; El-waheidi et al, 1992; Bello and Mankinde, 2007; Astahani, 2006; Ismail Mohamaden, 2005). Ground water exploration involves the use of numbers of Geophysical techniques available in the location of water bearing rocks called Aquifer (Ariyo and Adeyemi, 2012; Emenike, 2001). Mogaji, et al, (2011) defined aquifer as any mass of permeable rock material from which significant amount of water can be recovered from. Sabongida- Ora Edo State is characterized with limited boreholes and ephemeral stream, thus water is a priceless commodity. The need for water in adequate supply and quantity is a necessity for every life that is for domestic and industrial uses (Ariyo and Adeyemi, 2012). This study aimed at shielding light on the subsurface geology for the determination of geo-electrical and hydro-geophysical characteristics of potable aquifer for optimal groundwater exploration. Both Schlumberger and Wenner array configurations were used in this study. The schlumberger method has a greater penetration than the Wenner therefore, it is suitable for depth and thickness investigation whereas Wenner configuration discriminates between resistivities of different geoelecric lateral layers (Olowofela et al, 2005 cited in Adegbola et al, 2010). Consequently, the application of hydro-geophysical method proffer the existence of a perched water aquifer within a window depth of 15m to 35m and a deep seated confined aquiferous unit at depth of investigation beyond 240m with good characteristic for potable water exploration and its supply in the study area.

2. Location of Study Area

The surveyed area lies within the co-ordinate Latitude $06^0\ 53^I$ and $06^0\ 54^I\ 00^0$N and Longitude $05^0\ 52^I$ and $05^0\ 55^I$ E as shown in Fig 1.The elevation ranges between 75-65m above mean sea level with relatively flat and gentle geomorphology. Sabongida- Ora is Owan West LGA headquarters in Edo State (Chinyem, 2011). This area is found within the tropical equatorial climate dominated by two major climatic seasons known as dry and wet season that is from November to March and April to October respectively. Within the area, verage annual rainfall has been reported to be about 1500mm and this serves as the major source of ground water recharge in the area (Chinyem, 2011).

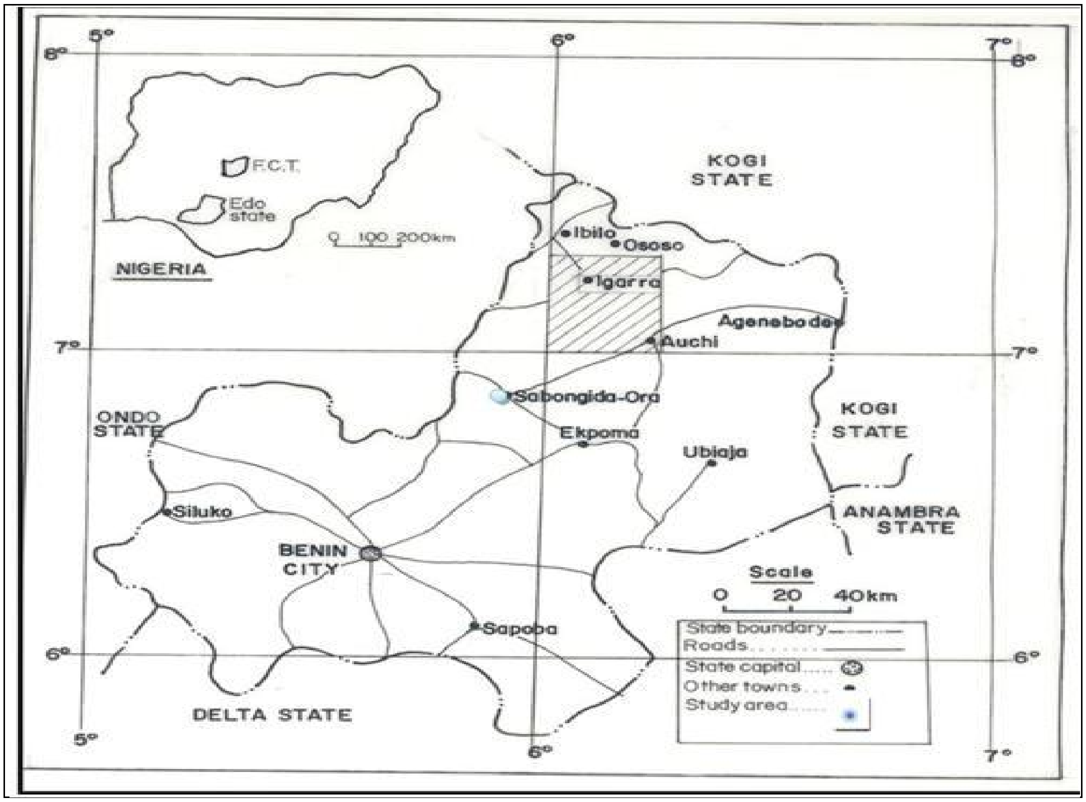

Figure 1: Map of Edo state showing study area (after Chinyem, 2011)

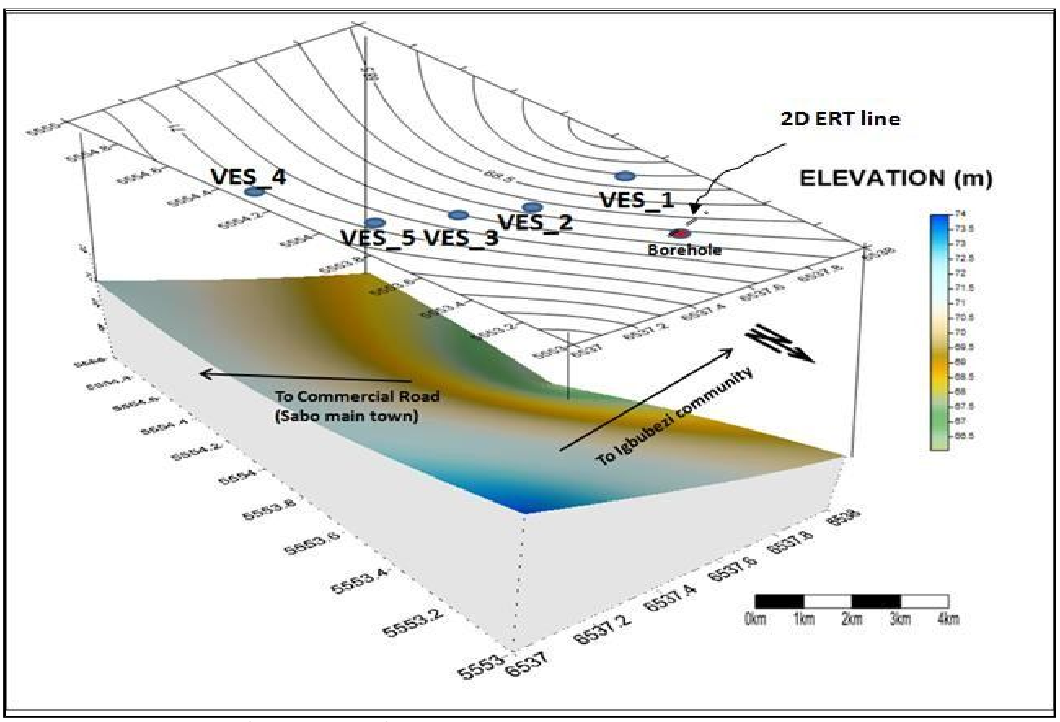

Figure 2: 3D surface model of the study area capturing data points and geomorphology

3. Local Geology

The study area and environs fall within the zones where the lithofacies of the Niger Delta basin grade into the litho-facies of the Anambra basin (Fig 2,3 and 4).The area is underlain by sediments of Cretaceous, Tertiary and Quartenary. The Cretaceous sediments occur in the area as lenses and boulders of brown to reddish brown ferruginized gritty and highly indurated sandstone, mudstone, claystones. Fresh exposures are found in Sabongida-Ora and Eme at the Southern part of the study area and also, the northern part of the study area is composed of the dark grey, often shale/clay and mudstones with occasional thin beds of sandy shale and sandstone units (Chinyem, 2011).

3.1. Regional Hydrogeology

Three main rivers drain the study area; the River Owan, Onuan and Ule and the drainage pattern is generally dendritic. Hydrological data obtained from **Edo State urban water board (**ESUWB, 2015**)** indicates that the "Static water levels" (SWL) of the first and second aquifers lie averagely between 53.1m – 93.8m and 100m – 118.8m respectively in Oke and about 63m – 103m and 106 – 123m respectively in Sabongida-Ora town. Nevertheless, there is a high degree of variability of static water levels from one locality to another (Chinyem, 2011).

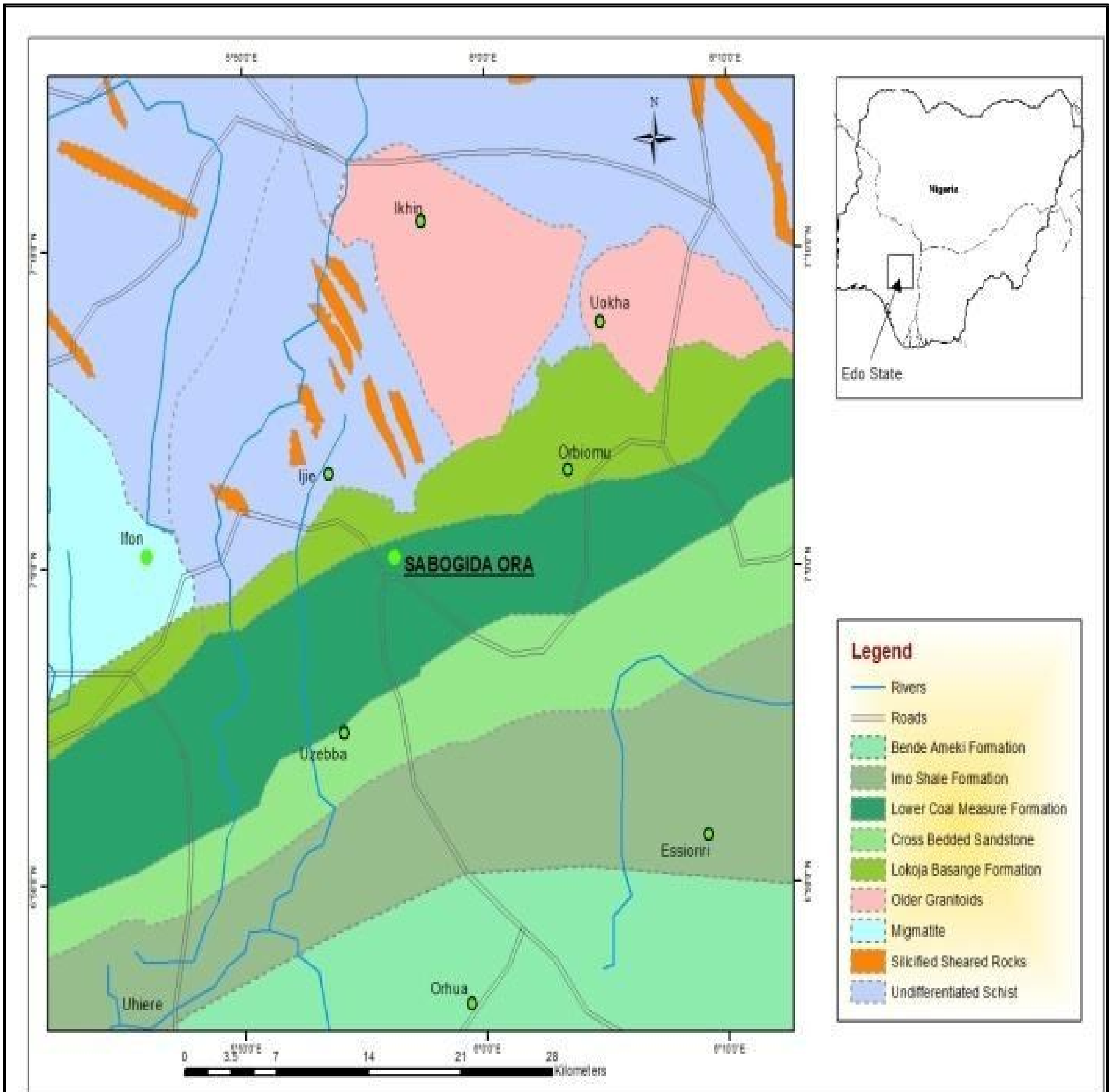

Figure 3: Geologic map of study area, after NGSA (2008)

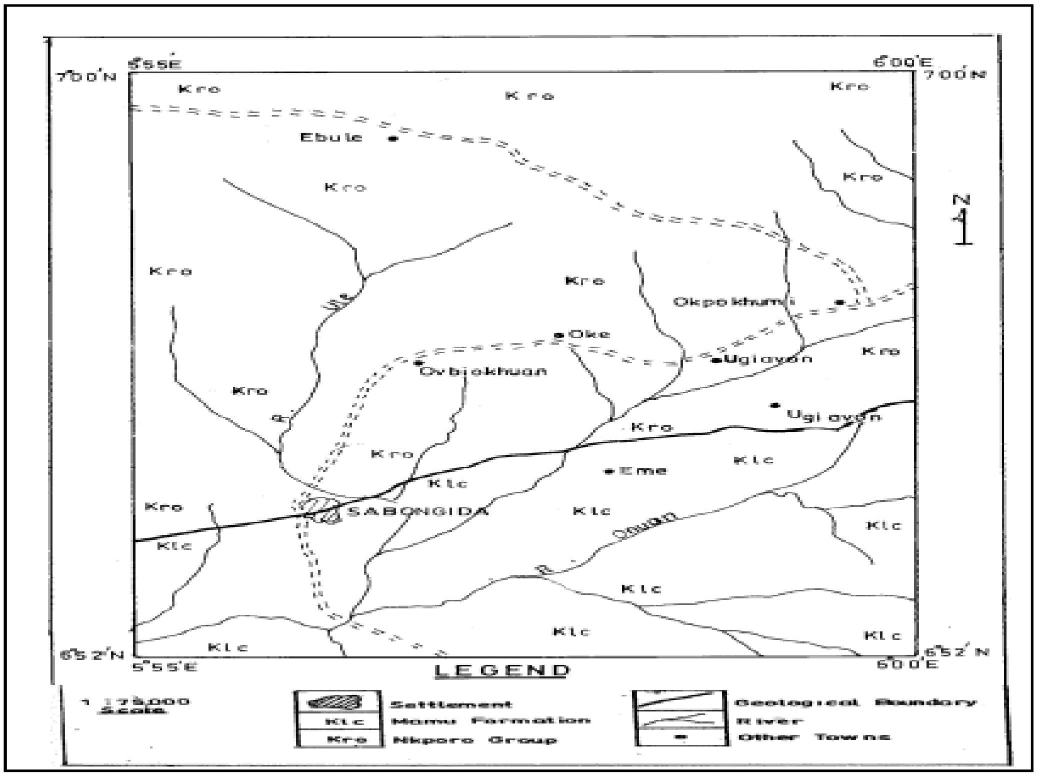

Figure 4: Regional hydrogeology of the study area (after Chinyem, 2011)

4. Materials and Methodology

Electrical resistivity method corroborated with hydro-geologic information (with resistivity meter and its accessories as major materials) was employed in this study.

4.1. Basic Principles

For a homogeneous isotropic ground, the resistivity measured in the field should be constant for any circuit and electrode arrangement. But this is not true for a heterogeneous anisotropic ground (where the resistivity) depends on the direction of current flow) because with varied electrode spacing or constant spacing when the array is moved from place to place, the ratio generally changes. Different values of resistivity are measured but the magnitude depends on the electrode arrangement used. This measured quality is called *apparent resistivity*. To illustrate, consider an infinite formation with the uniform resistivity (ρ). Assume that the current (I) is introduced into the formation through electrodes at position A and B on the surface (see the sketch, Figure 5), assume also that the potential gradient (V) associated with the current is measured across two other electrodes M and N, on the same surface.

Potential difference (ΔV) at M and N is given by

$$V_M^{AB} - V_N^{AB} = AV = \frac{I_\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right] \ldots\ldots\ldots (1)$$

$$\rho = 2\pi \frac{AV}{I}\left[\frac{1}{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}}\right] \ldots\ldots\ldots (2)$$

$$\rho = 2\pi R\left[\frac{1}{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}}\right] \ldots\ldots\ldots (3)$$

$$\rho_a = R \times K \ldots\ldots\ldots (4)$$

$$\text{Where, } K = \left[\frac{2\pi}{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} - \frac{1}{r_4}}\right] \ldots\ldots\ldots (5)$$

K is the geometric factor which is the contribution due to geometric arrangement of electrodes.

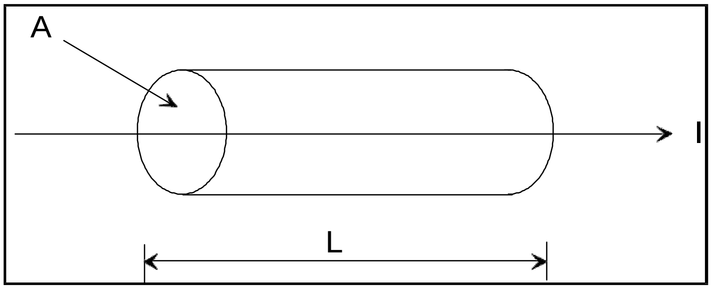

Figure 5: cylindrical conductor illustrating Ohmic conductivity principle.

4.2. Array Configuration Employed

The electrode arrangements applied in this field work include: Schlumberger and Wenner arrays

The Schlumberger configuration was employed to image greater depth of geophysical characterisation in bid to delineating aquiferous framework in deep seated condition. While the Wenner counterpart aided in high resolution 2D electrical resistivity tomographic characterisation of the shallow [perched] aquiferous condition. Both techniques employed conventional four (4) electrode configuration. The sets of data were subjected to interpretation after a careful geophysical processing involving smoothening (reduction) of the raw field employing both manual and computer aided approach to eliminate noise which could lead to spurious anomaly.

5. Results Presentation

Results of the findings within the study area, after careful processing and noise reduction are presented below in fig 6 and7, while Fig 8, 9, 10, 11 and 12 showed graphical representation of VES data with layer model (Using IPI2WIN).

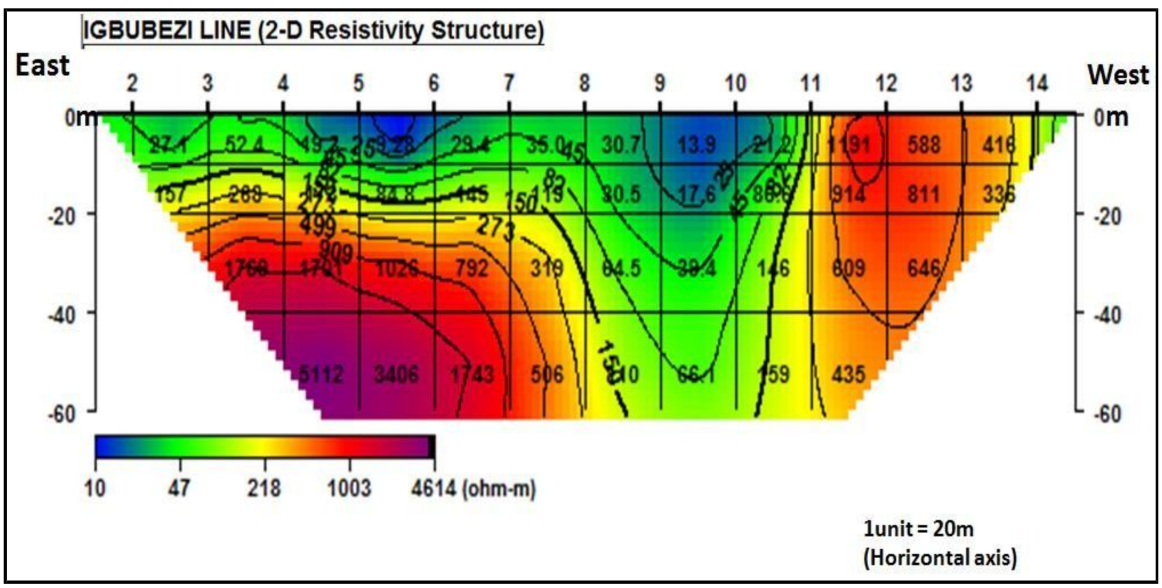

Figure 6: 2D Wenner ERT Model

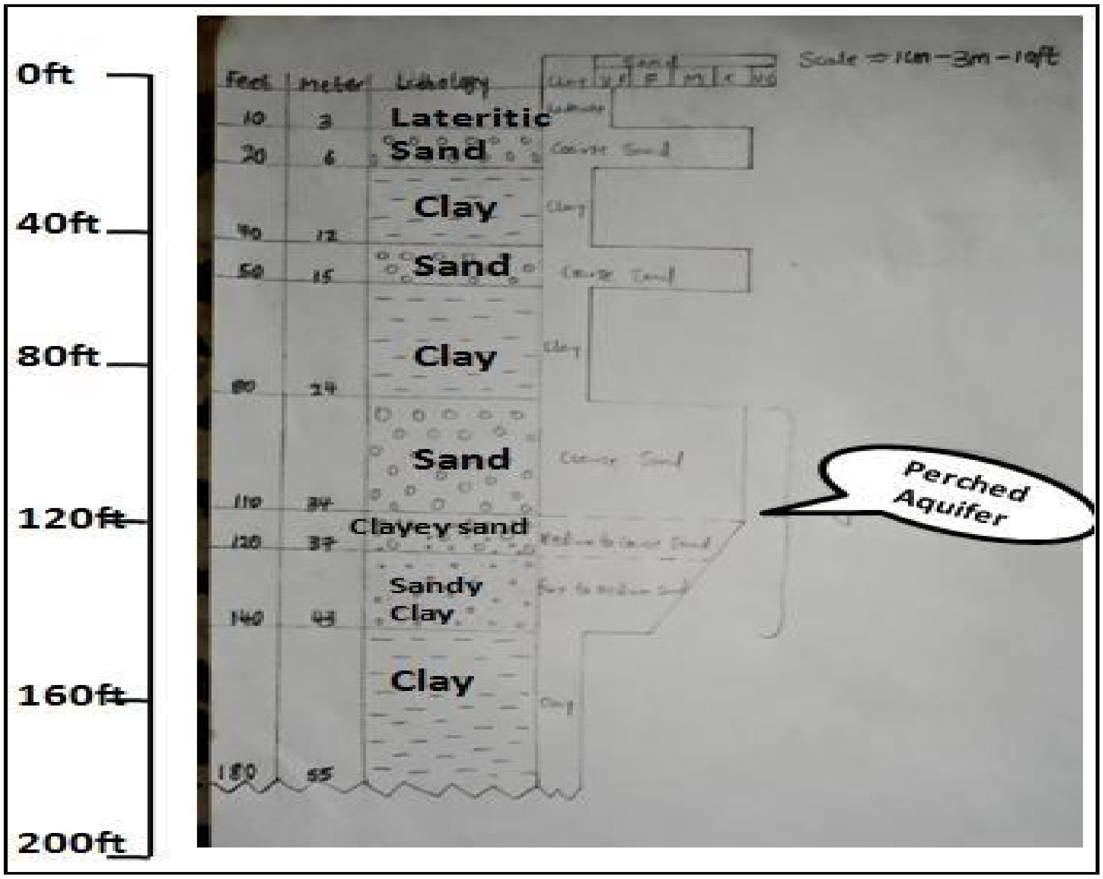

Figure 7: Borehole data capturing the shallow part (0-180ft) of the study area

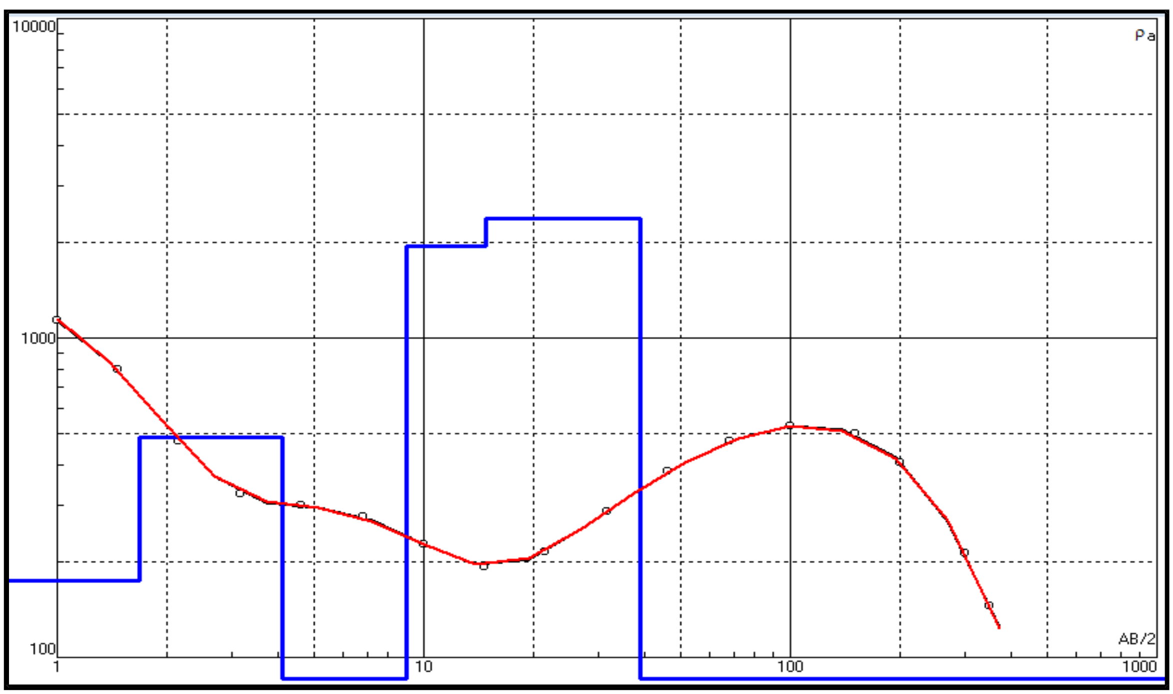

Figure 8: A graphical representation of VES 4 Data with layer model (Using IPI2WIN)

VES 1 MODEL	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION (ref to 0m)	GEOLOGIC INFERENCE
	122.2	0.8	0.8	-0.8	Top soil
	62.5	3.01	3.81	-3.81	Sandy clayey layer (Laterite)
	76.3	5.32	9.13	-9.13	clay
	134.5	6.12	15.25	-15.25	Sandy/silty layer
	900.2	17.21	32.46	-32.46	
	214	15.9	48.36	-48.36	sandy Clay layer
	17.4	82.5	130.86	-130.86	Clay layer
	14.9	∞	∞	∞	Clay layer
	∞ : Infinite layer				

Table 1: Layer model of 4 parameters with geologic inference

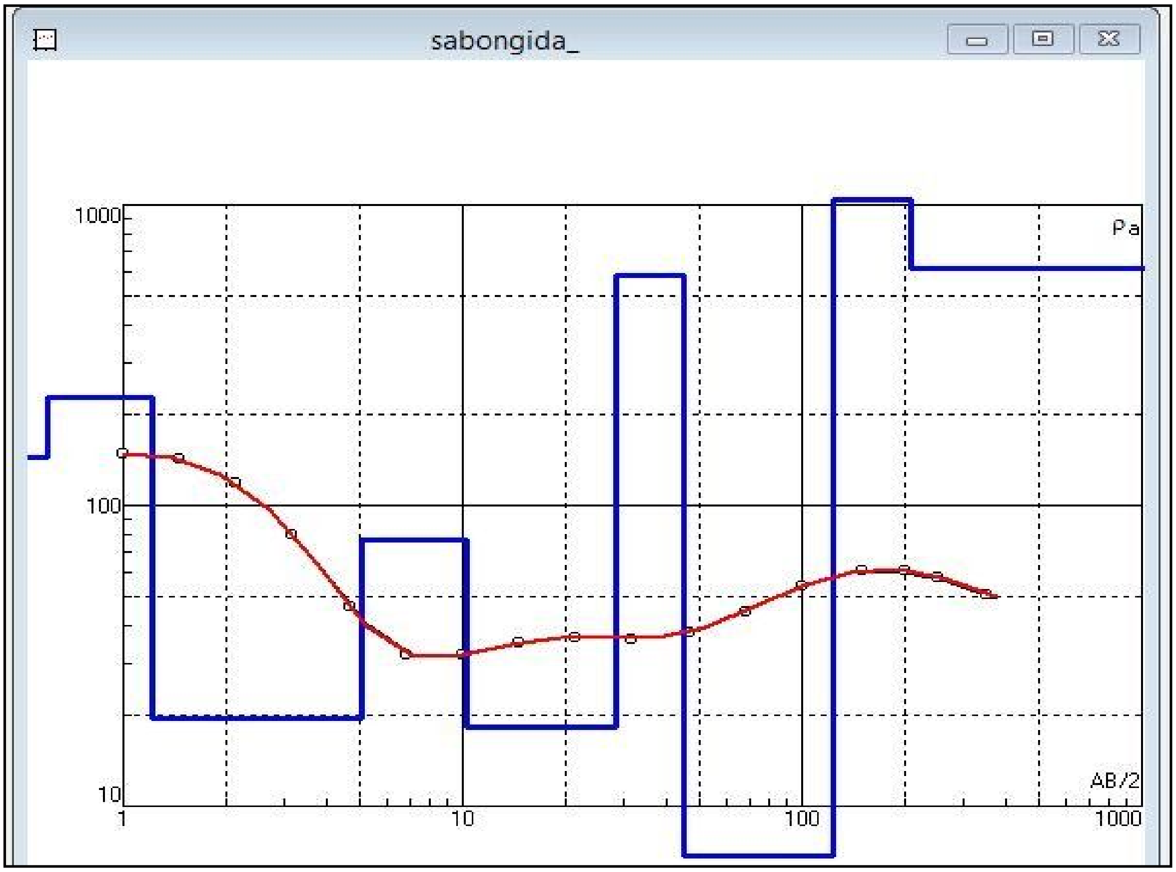

Figure 9: A graphical representation of VES data with layer model (Using IPI2WIN)

VES 2 MODEL	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION wrt 0 m	GEOLOGIC INFERENCE
	143.8	0.585	0.585	-0.585	Top soil
	162.7	0.699	1.284	-1.284	Clayey/silty clayey unit (lateritic)
	12.98	1.362	2.646	-2.646	sandy clayey/clayey sandy/clay unit
	80.49	8.679	11.325	-11.325	
	15.24	11.48	22.805	-22.805	Clay unit
	414.1	24.43	47.235	-47.235	Sandstone (Perched aquiferous unit)
	23.52	94.3	141.535	-141.535	claystone/silty clay unit (Heterogeneous unit)
	1202	∞	∞	∞	Saturated sandstone (Targeted Aquiferous unit)
	∞ : Infinite layer				

Table 2: Layer model of 4 parameters with geologic inference

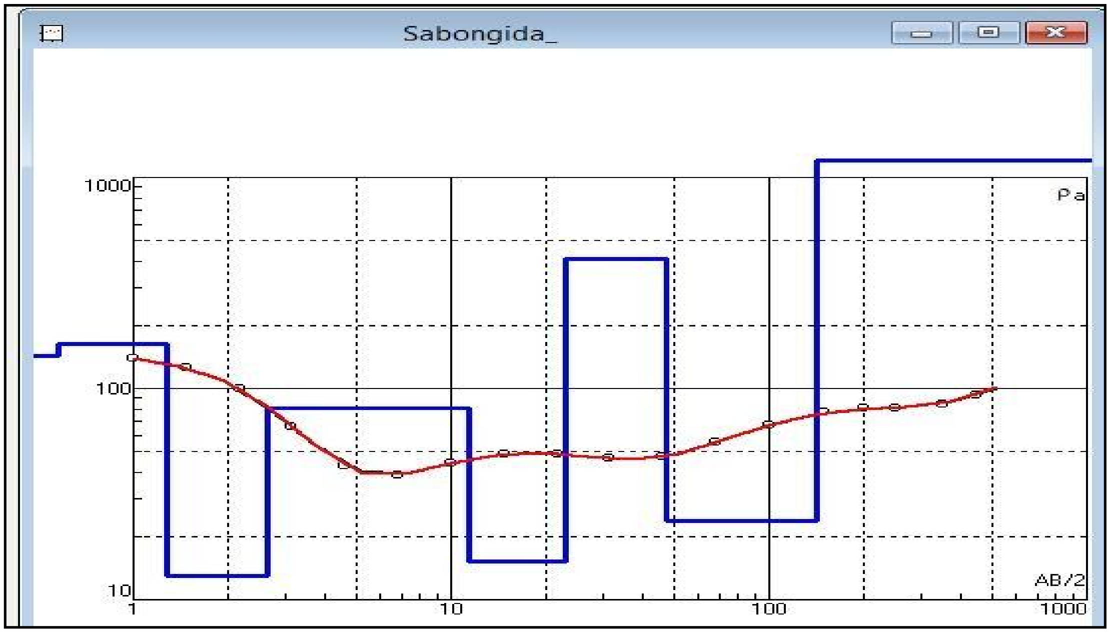

Figure 10: A graphical representation of VES Data with Layer Model (using IPI2WIN)

	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION wrt 0 m	GEOLOGIC INFERENCE
VES 3 MODEL	144.60	0.60	0.6	-0.6	Top soil
	229.10	0.62	1.22	-1.22	Clayey/silty clayey unit (lateritic)
	19.56	3.82	5.04	-5.04	sandy clayey/clayey sandy/clay unit
	76.86	5.23	10.265	-10.265	
	18.32	18.01	28.275	-28.275	
	583.10	16.54	44.815	-44.815	Sandstone (Perched aquiferous unit)
	6.83	78.62	123.435	-123.435	Clay stone
	1040.00	85.50	208.935	-208.935	Saturated sandstone (Targeted Aquiferous unit)
	614.60	∞	∞	∞	
	∞ : **Infinite layer**				

Table 3: Layer model of 4 parameters with geologic inference

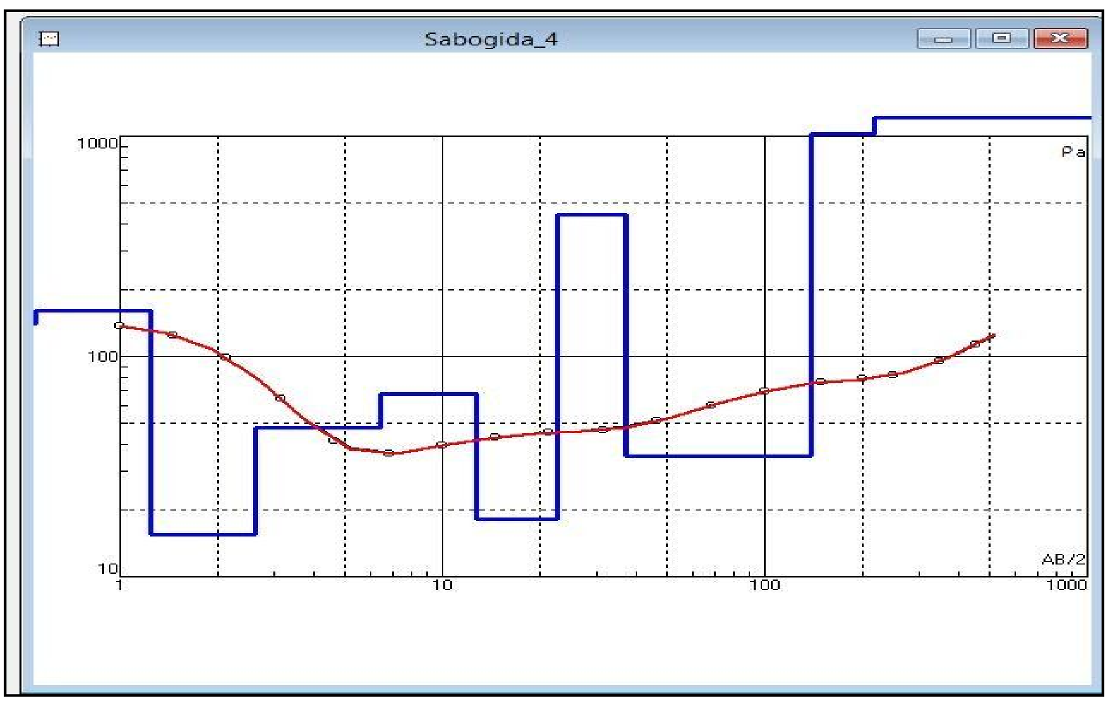

Figure 11: A graphical representation of VES data with layer model (Using IPI2WIN)

	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION wrt 0 m	GEOLOGIC INFERENCE
VES 4 MODEL	141.00	0.43	0.432	-0.432	Top soil
	162.30	0.81	1.24	-1.24	Clayey/silty clayey unit (lateritic)
	15.60	1.42	2.66	-2.66	sandy clayey/clayey sandy/clay unit
	47.80	5.43	8.09	-8.09	
	67.90	7.22	15.31	-15.31	
	440.10	18.40	33.71	-33.71	Sandstone (Perched aquiferous unit)
	35.30	84.30	118.01	-118.01	Clay stone
	1025.00	93.60	211.61	-211.61	Saturated sandstone (Targeted Aquiferous uni
	1217.00	∞	∞	∞	
	∞ : Infinite layer				

Table 4: Layer model of 4 parameters with geologic inference

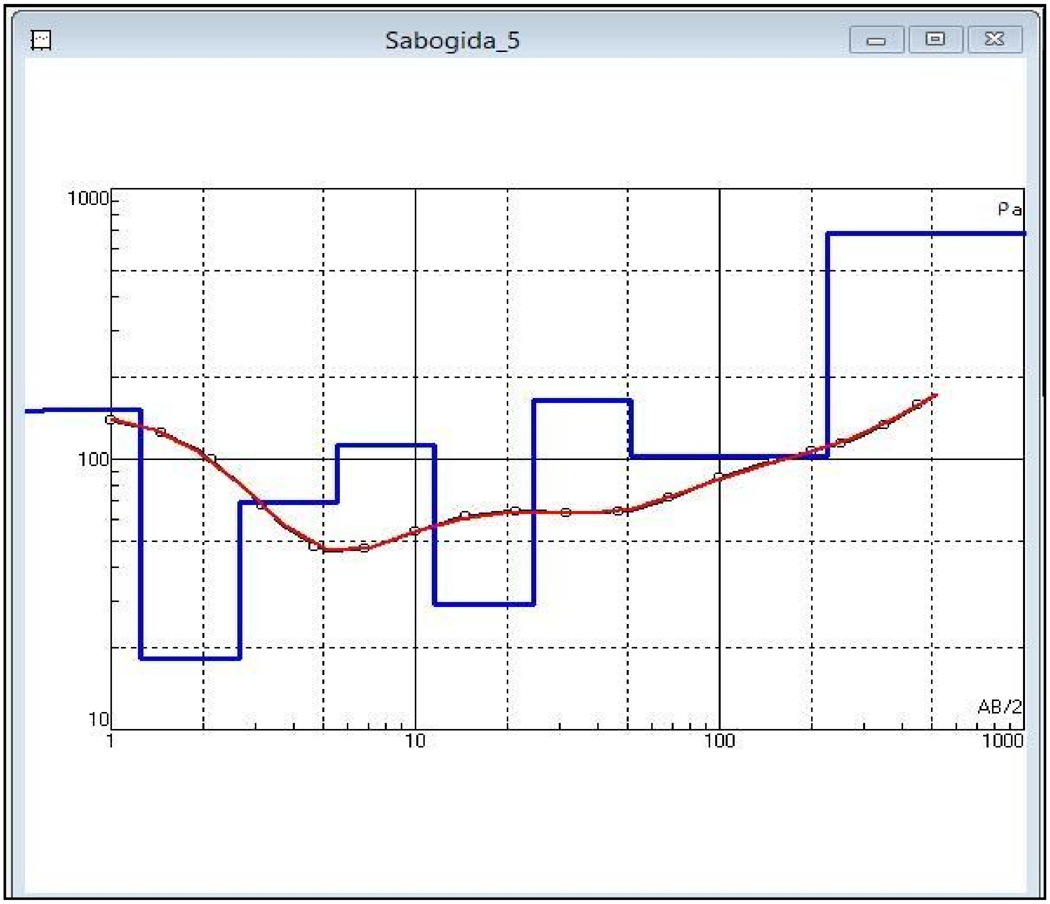

Figure 12: A graphical representation of VES Data with Layer Model (Using IPI2WIN)

	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	ELEVATION wrt 0 m	GEOLOGIC INFERENCE
VES 5 MODEL	141.00	0.43	0.432	-0.432	Top soil
	145.30	0.81	1.24	-1.24	Clayey/silty clayey unit (lateritic)
	19.86	1.42	2.66	-2.66	sandy clayey/clayey sandy/clay unit
	101.20	5.43	8.09	-8.09	
	58.30	7.22	15.31	-15.31	
	605.20	15.40	30.71	-30.71	Sandstone (Perched aquiferous unit)
	57.40	102.30	133.01	-133.01	Clay stone
	1144.00	87.23	220.24	-220.24	Saturated sandstone (Targeted Aquiferous uni
	1240.00	∞	∞	∞	
	∞ : Infinite layer				

Table 5: Layer model of 4 parameters with geologic inference

6. Analysis and Discussion

2D Wenner Electrical Resistivity Tomography (ERT) Profile model provides Igbubezi line (2D Resistivity structure in the direction from East to West as shown in Fig 6 where as borehole data captured the shallow part ranging from (0-180ft) in the study area.

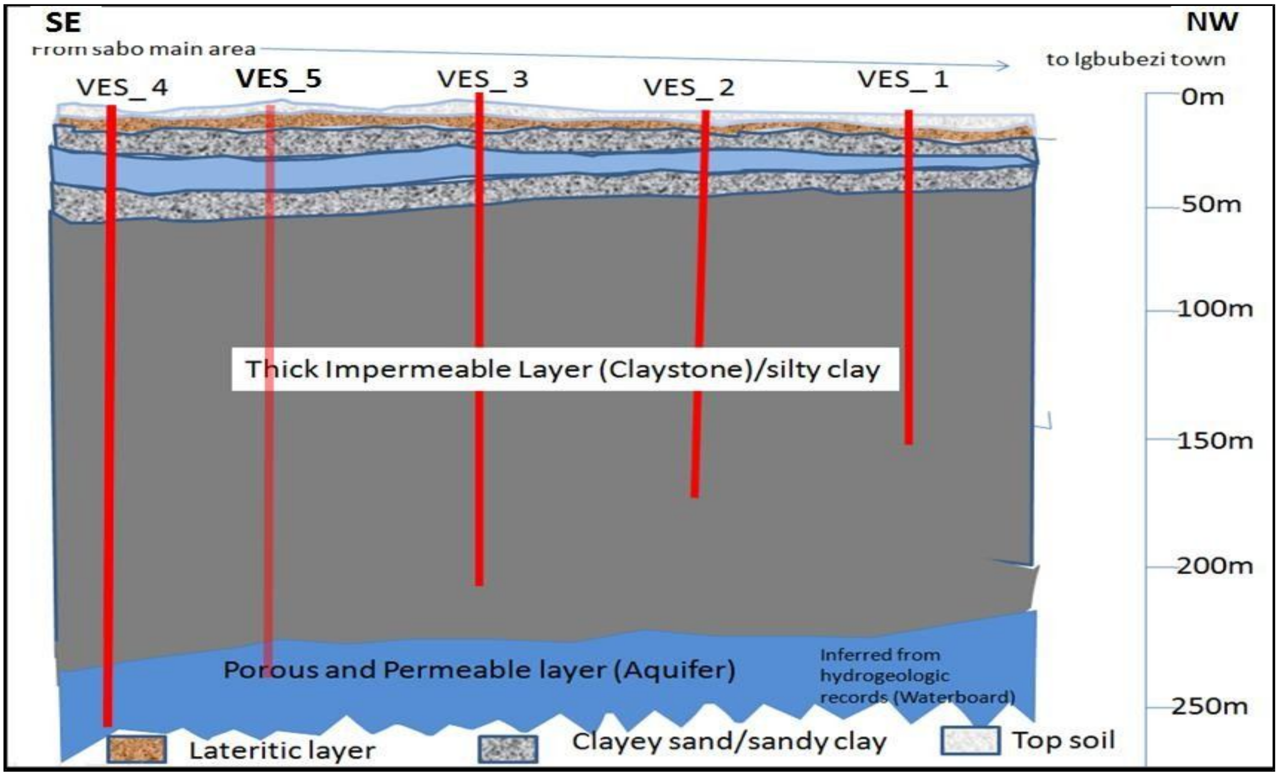

Figure 13: lithology and VES model

Directly above this deep-seated aquifer lies Claystone (clay unit) of about 100m to 130m (320ft to 400ft). This was not fully resolved due to the limitation of resistivity method (suppression and equivalent principles), owing to the variable thickness heterolithic materials sandwiched within it (Figure 13).

- Hydrogeologically, this unit poses threat to drilling, due to its elastic, "swelling" nature; hence pipe stockade may occur if not guided against.
- Before the thick clay unit exists a perched water (aquifer) within a window depth of 20m to 45m (60ft - 140ft). This targeted window exhibits a variable window thickness (Figures 13 and 14).
- The justification of the characterization is seen from the comparison of Lithology log (shallow end), with 2D Electrical resistivity tomography (confirming consistency of both geological/hydrogeological and geophysical models).

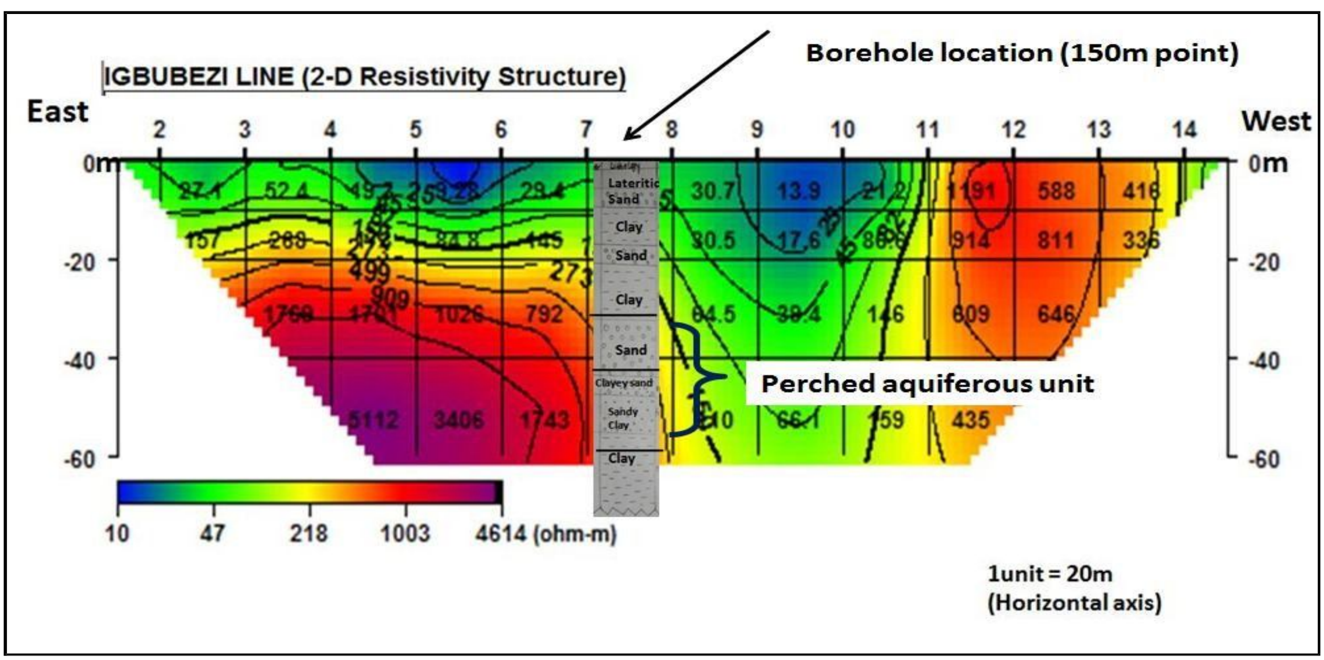

Figure 14: 2D resistivity data interpreted

7. Conclusion

In bid to share light on the subsurface stratigraphy of Sabongida-Ora area and environs, we have demonstrated that, the application of electrical resistivity method (both Wenner and Schlumberger array configurations combined with geological/hydro-geological method is efficacious in characterising subsurface stratigraphy, and there by delineating prolific aquiferous zones.

From, geophysical-electrical resistivity domain, 2D Electrical resistivity (Wenner) tomography and five (5) VES data were respectively used to image both the shallow and deep parts of the study area. The simulated results were corroborated with geological/hydro-geological information.

Findings revealed the existence of shallow, perched aquifer within depth range of 25-40m and deep seated confined aquiferous unit beyond 240m (to account for transmissivity).

8. Acknowledgement

The authors wish to acknowledge Edo state urban water board (water resource department), Ligaliz Geophysical and Reapwell Nigeria Ltd for their immense contributions (in the area of data gathering). Special thanks also goes to Aghaegbunem Peter, Kelvin Ibie Osawe and Ebuka Daniel for their active roles during data acquisition.

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