

# Vertical Electrical Sounding Investigation of Aquifer Composition and Its Potential to Yield Groundwater in Some Selected Towns in Bida Basin of North Central Nigeria

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## Abstract

Groundwater resource is found beneath the earth crust within the pore spaces or voids between soil particles. Successful groundwater exploration either for domestic, agricultural or industrial uses, pre-drilling information is necessary to determine the depth and yield of groundwater location. Detailed knowledge of the aquifer layer as well as the lithology composition in any successful borehole drilling project is paramount and essential that cannot be ignored. Different geological formations have different groundwater yield potential; therefore, understanding these formations in groundwater exploration becomes imperative. This study adopts Vertical Electrical sounding in sixteen locations group into four stations using geotron G41 earth resistivity meter; with Wenner configuration and maximum electrode spacing at 400m. The resistivity results were processed using the res1d.exe inversion software. Sounding curves were plotted as apparent resistivity against electrode spacing in Wenner electrode array. Representative resistivity sounding curves types obtained after inversion was used to delineate the aquifer and 1D geoelectric sections. The results show five geoelectric layers in the study area namely: top layer, Clay/sand, Clay, Sand Stone and Sand Clay layer. The groundwater bearing layer varies between 37–70 meters across the study Area.

**Keywords:** vertical electrical sounding, groundwater, aquifer, resistivity and groundwater potential

## 1. Introduction

It has been reported that at least 1.1 billion people across the world lack access to safe, clean drinking water. Nigeria with a population of over 160 million people have invested heavily in borehole Projects throughout the Country to satisfy the fast growing demand for safe water and to improve the socio-economic development of its populace (Eduvie, 2006).

Water is an important liquid necessary for human consumption agriculture and industrial purposes. Most of the world surface water is found to be polluted either from anthropogenic activities by man or nature such as salinity among others factors. These factors have necessitated the purification of surface water before consumption or other uses incurring for cost for exploration and hence giving rise to exploration groundwater as alternative source of water supply.

The world groundwater is estimated to be about 0.06% of the available water resources out of which 98% of groundwater is found to be fresh water. Groundwater is found within the pore spaces of soil or rock called the aquifer. The nature of the aquifer is functions of subsurface geological composition that play an important role in determining the circulation of water from the surface (infiltration) to subsurface water through recharge processes. More so; composition of aquifer varies between locations, as each location have a unique geological lithology given rise to variation in groundwater depth among different places. Detail knowledge of the aquifer as well as understanding of aquifer composition is important for optimum groundwater exploration.

Successful groundwater exploration largely depends on the pre- drilling information (survey). Most of the groundwater explorations have failed due to inadequate pre-drilling information. (Gomes, 2006). Different geophysical techniques have been developed to solve exploration problem in petroleum industry. However, as successful as these techniques are in petroleum industry, the economy cost of groundwater explorations are such that the most sophisticated tools are unaffordable in most studies (Schwatz & Zhang, 2003).

Electrical resistivity survey has been adopted in groundwater exploration and has help in reviling the geology of the subsurface layer. The resistivity method becomes a versatile geophysical techniques, based on variation of rock and soils resistivity between less than 2 and seismic velocities which usually do not change by more than a factor of 10 (Olasehinde & Bayewu, 2011). The objective of vertical electrical sounding is to deduce the variation of resistivity's with depth below a given point and correlate it with available geological information to infer groundwater depth while determining layer of promising well or yield.

The electrical resistivity of a surface is a function of the pore-spaces between the particles which allow electric current to flow through it. Therefore, layers with large pore spaces such as sand and sand stones will have a high resistivity value compare to clay layer with a tighter pore space between it particles. The nature of the subsurface resistivity when electric current is injected into it is processed and analysed to give the different lithology and thickness of the layers present. Information about the component of the different layer can infer; present of groundwater in an area. Aquifers are water bearing layers (or formations) that yield water to wells in usable amounts. Typical aquifers are made of sand, gravel or sandstone and clay. These materials have large enough connected pore spaces between grains that water moves freely.

## 2. Background of the Study Area

### 2.1 Physiography and Geomorphology of Bida Basin

Bida basin lies within the Cretaceous-to-Upper Maestrichtian Nupe (Bida or Niger) Basin, Niger trough/Middle Niger Valley South of the River Niger between longitude 5°2'E to 6°78'E and latitudes 8°2'N to 9°46'N (Obaje, 2009). This Basin is a sparsely populated region with an estimated population density of about 34 persons per square kilometer, and is mainly dependent on subsistence agriculture and fishery. The dominant topographic feature is the peneplain of the Niger River Trough which stretches from Jebba to Eggan in such a way that the topography is relatively flat-lying near the River Niger, and rises to the crystalline uplands in the south to an elevation of less than 150 m above mean sea level (msl). Vegetation is of the Guinea Savannah types, with mean annual temperature between 26.5 °C to 27.8 °C and mean annual rainfall of 1000 mm to 1,500 mm (Adefolalu, 1988; Ayoade, 1974).

### 2.2 Geology

Bida is an approximately NW-SE trending trough filled with mainly Santonia to Maestrichtian sediments of sandstones, siltstones and superficial alluvial deposits (Adeleye, 1976). The lithologies of these formations are weathered laterite, sandy clay and clayey sand (Bello & Makinde, 2007). The southern part of the study area is characterized by formations with secondary permeability's with the following lithology: weathered laterite, sandy clay/clayey sand, fractured basement and fresh basement rocks. Generally the rock units in this region are suggested to be highly characterized by intercalations of clay stone, siltstone, silt, clay and weathered bedrock (Braide, 1990; Akande et al., 2005). These geological materials are usually liable to form aquifer and permeable zones to the bedrocks in both the sedimentary terrain and the crystalline basement complex existing in this area. In areas underlain by crystalline rocks, presence of structures like fractures, fissures, veins, joints and such other structural deformations of the basement complex control the flow of groundwater and also influence the rate of recharge and discharge of the main aquiferous (Akande et al., 2005; Bello & Makinde, 2007; Idornighie & Olorunfemi, 1992).

## 3. Methodology

Vertical Electrical Sounding is based on the principle that allows the passage of current into the ground by means of current electrodes and measuring the potential drop between potential electrodes. Current penetrates into the ground with increase in electrodes spacing. In a ground consisting of different lithology with depth, apparent resistivity is measured where the pattern of current flow is influenced by the density, porosity and salinity of the contained fluid in the ground (Mohammed et al., 2007).

Sixteen (16) Vertical Electrical Sounding (VES) stations using Wenner electrode array were established along roads and some open space in the study area. The resistivity measurements were made by using Geotron earth resistivity meter- model G41. The equipment is a fully automated resistivity meter for DC electrical surveys. Measurements were made by injecting current into the ground through two current electrodes  $P_1$  and  $P_2$  and measuring the resulting voltage difference at the potential electrodes  $C_1$  and  $C_2$  respectively (Figure 1). The current and potential electrode separation is spatially increased simultaneously about the mid-point (O) from 0.2 m to 100 m until the length of the array (L) is exhausted and the potential difference is measured. The measured data were processed and interpreted automatically using the res1d.exe inversion software. This software is used to obtain true resistivity and depth from the apparent resistivity data obtained at each VES location. Sounding

curves were plotted as apparent resistivity against electrode spacing in Wenner electrode array. Due to the lithological variation of the study site, near-surface inhomogeneities and topographical variation, which create 2D effects; a 2D modelling was developed using the estimated resistivities and thickness, and its equivalent 2D effect shown across VES stations.

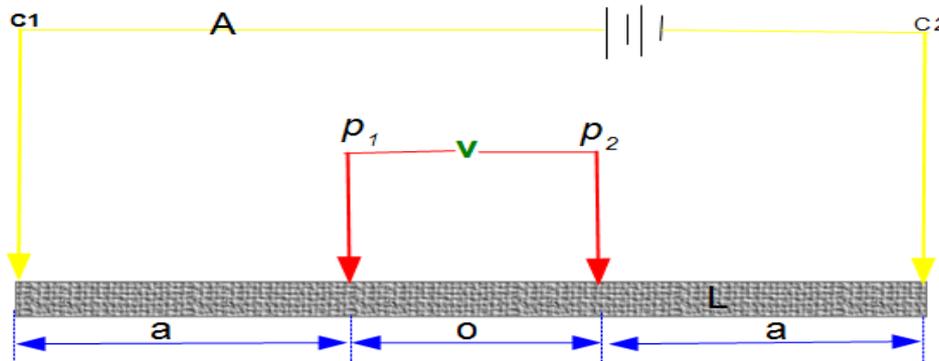


Figure 1. Electrical configuration for the data collection (Wenner)

Wenner configuration protocol with a maximum electrode spacing of 100 meter was used throughout the study because of its advantage of depth penetration over other electrical configuration protocol (El-Difrawy et al., 2006; Giao, 2003). Result obtained were interpreted and inverted using res1d.xe software with initial starting models. Based on inversion results; the different curve types were identify using three layer model curves; A, H, K and Q. The electrical profiling was drawn from the results obtained and a borehole logs within the study area was used as justification for the profiling lithology.

**4. Result**

VES model resistivity values and their Corresponding thicknesses are shown in Table 1. The top layer shows a high resistivity values ranging between 193.85–2637.37  $\Omega/m$  with a thickness of between 0.05–2.17 m. The clay sand layer has resistivity between 35.01–1092.29  $\Omega/m$  and a thickness of 0.7 to 9.09 m. The third layer corresponds to sand stone layer with resistivity ranging from 29.96–1087.02  $\Omega/m$  and a thickness of between 3.99–23.02 m. The fourth layer has resistivity between 34.22–829.08  $\Omega/m$  and a thickness of 8.45–62.44 m respectively. Frequency distribution of the curve types (Figure2) show a predominant of QHA curves while KHA curves is the least occurrence curve in the study area.

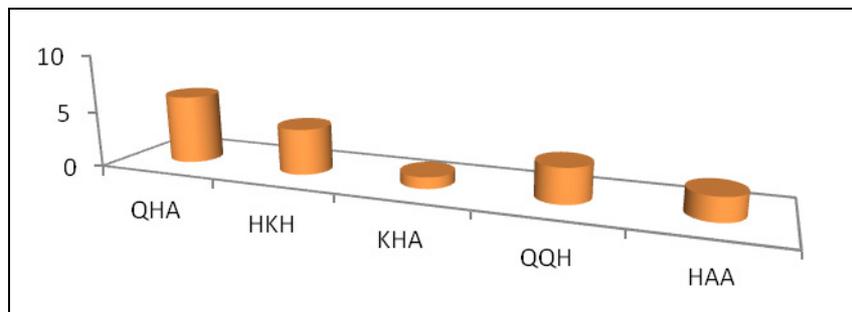


Figure 2. Curves types distribution in the study area

*4.1 Discussion of Results*

The resistivity survey results was analysed and interpreted to enable the delineation of the geoelectric sections of the study area. From the resistivity survey five different layers were delineated at each VES points. The first layer has a resistivity between 193.87  $\Omega/m$  – 2637.372  $\Omega/m$  at VES 14 and 10 and has a thickness of 0.05 m to 2.17 m at VES 4 and 14. The second layer has resistivity between 35.01  $\Omega/m$  – 1092.29  $\Omega/m$  at VES 14 and 4; with a thickness of 0.7 m – 9.09 m. The third layer show resistivity value of 33.18  $\Omega/m$  – 1087.02  $\Omega/m$  at VES 9 and 16; while the thickness is between 3.99 m – 23.02 m at VES 13 and 14 respectively. The fourth layer has a

resistivity values of 34.22 Ω/m–602 Ω/m at VES 3 and 13; while the thickness of the fourth layer is between 13.52 m – 62.44 m at VES point 11 and 7. The under laying layer show a sharp increase in resistivity indicating that it has different geoelectrical properties with the preceding layers and hence can not be estimated.

Table 1. Summary of VES model resistivity values and their corresponding thicknesses

VES Point	Layer 1		Layer 2		Layer 3		Layer 4		Layer 5		Curve Type
	Resistivity (Ωm)	Thickness (m)									
VES1	1091.23	1.00	388.31	9.09	165.31	11.78	829.09	22.03	1138.25	-	QHA
VES2	1832.38	0.50	194.08	1.14	564.32	12.17	209.91	16.72	1251.67	-	HKH
VES3	1140.01	0.08	168.07	1.90	65.10	11.24	34.22	37.23	313.64	-	KHA
VES4	1157.62	0.05	1092.29	2.34	202.54	14.79	565.58	8.45	2450.08	-	QHA
VES5	1731.93	0.36	766.421	2.41	101.66	17.56	408.19	28.35	12464.45	-	QHA
VES6	1369.39	0.40	910.21	1.44	280.63	13.66	75.92	54.73	1410.78	-	QQH
VES7	1169.16	0.81	225.84	2.25	868.44	4.18	94.29	62.44	1210.48	-	HKH
VES8	1369.04	1.00	909.92	2.44	910.21	13.66	75.91	54.73	2533.73	-	HKH
VES 9	1146.92	1.13	590.70	8.59	1087.02	11.862	498.76	27.56	9658.00	-	HKH
VES10	2637.37	0.53	683.86	0.70	646.85	9.84	137.35	19.17	14656.53	-	QQH
VES11	1131.32	0.54	403.90	2.66	54.28	10.76	339.81	13.52	1373.67	-	QHA
VES12	1473.78	0.54	623.44	2.87	146.41	7.71	35.54	16.77	1679.32	-	QQH
VES13	1212.99	2.12	327.07	2.107	347.84	3.99	602.58	20.736	872.00	-	HAA
VES14	193.87	2.17	35.01	6.49	29.96	23.02	157.31	13.30	536.97	-	QHA
VES15	1308.77	1.56	284.03	4.16	502.51	22.17	543.55	20.30	3308.00	-	HAA
VES16	1308.39	0.52	126.50	3.751	33.18	8.69	334.34	16.953	1286.27	-	QHA

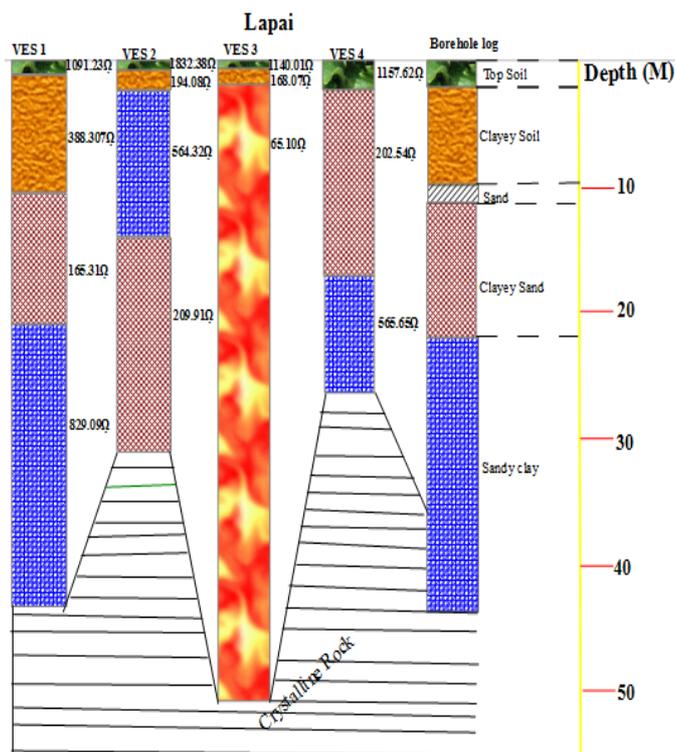


Figure 3. Geoelectric section and BHL of Lapai



The occurrence of uncertainty in 1D interpretations, such that different layer model yield nearly the same response to electric current during resistivity survey is common. These ambiguities can be treated when drawing the geoelectric section by margin such layers with similar or close resistivity value as the same guided by the principle of equivalent and suppression (Yadav & Singh, 2007; Sharma & Kaikkonen, 1999; Nath et al., 2000). Therefore, resistivity contrast of few meters was suppressed as same clay layer in Figure 6 (VES 2) since the difference in their resistivity is almost the same.

#### 4.2 Components of the Aquifer and Groundwater Potentials

From the resistivity survey results and available borehole logging from the study area show a lithology of three (3) to four (4) layers present. Each of these layers having a unique characteristics constituent of the layer. As mentioned earlier from the 1D section, the first layer is the top soil, the second layer is the Sand Clay, and the third layer is Sand Stone; fourth layer as Clay sand while the fifth layer is clay.

The superficial geoelectric layer (top layer) is characterized by relatively high electrical resistivity values (1140.01–1703.76 ohm-m) and thin depth of (0.08 m–2.38 m). It constitutes mainly of littered weathered material, sand, and some bolder rocks particles with the maximum depth occurring at the south east of the study area (Figure 7).

The second layer is made up of sand clay. The layer serve as a fielder bed through which pollutant in infiltrated water is prevented from reaching the confined aquifer or water table. The thin thickness of the sand clay layer in Figure 4 makes it liable to pollution while the layer is thicker at VES 4 Figure 7 hence less vulnerable to pollutions from the surface.

The groundwater bearing zones in the area is mostly located between the clay and the sand clay layer corresponding to fourth layer. The responsible factor for this is attributed to porosity and permeability of aquifer contents. Clay has high porosity; hence, half of its volume store water. The void between clay particles is microscopically small with large surface area favour slow movement and retention of water. Clays do not make good aquifers compared to sand clay with lower porosity for free flow of water as sands clays have more interconnected pores (Singhal & Gupta, 2010).

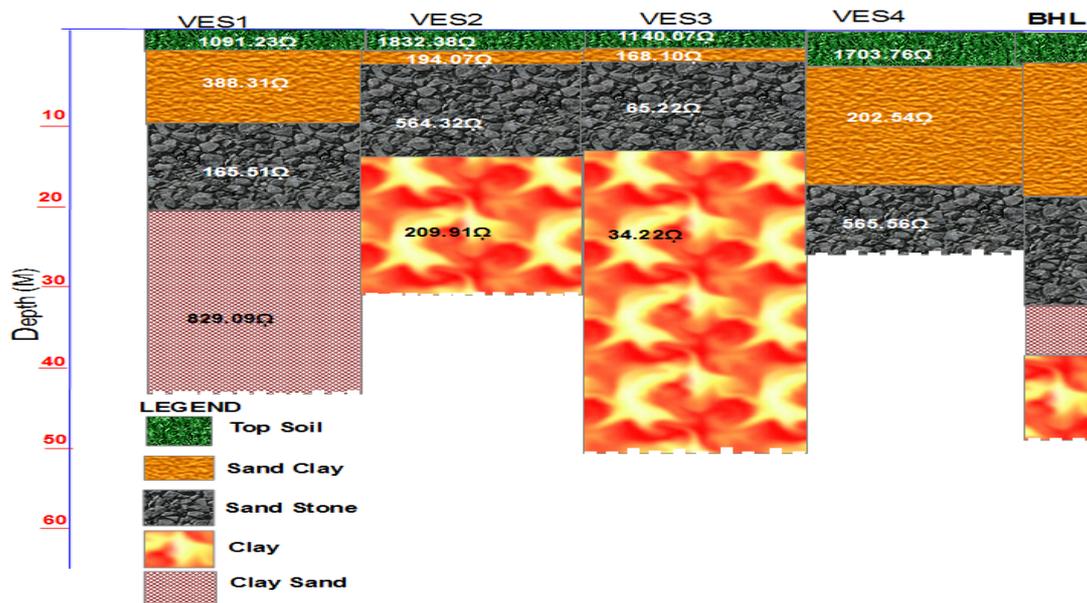


Figure 7. 2D geoelectric section of Lapai

#### 4.3 2D Profiling of the Study Area

The major aquifer (water bearing unit) of the study area is mainly weathered basement due to the good porosity and permeability characteristics of the material medium depending on the amount of clay material present. However, in Figure 5 (Lapai); the available borehole lithology indicates that the northern part is made up of basement formation similar to Figures 2, 3, and 4. The south Western part is made of sedimentary formation.

This is confirmed by the resistivity results; where the composition of the lithology differs between VES 1, 2, 3 and 4 where 4 appeared with a distinct layer indicating that VES 4 is of sedimentary formation. The groundwater yield potential is higher in VES 1, 2 and 3 since sand clay (VES 1) having a large pore for storage of water within its pore spaces while VES 2, and 3 have a fair water yield potential. VES 4 has a poor yield capacity since its constituents are made of sand stone allowing for poor groundwater storage. The sand stone zone is the aquiclude layer while clay and clay sand is the aquifer layer (Chilton & Foster, 1995; Idris-Nda & Nwosu, 2006).

The groundwater yield in basement complex terrain is generally low for clay bearing/low permeability weathered layer aquifer and high for weathered and fractured aquifer with enhanced permeability through secondary porosity (Olorunfemi et al., 2005; Olorunfemi & Fasuyi, 1993).

For a sustainable groundwater exploration, the depth of drilling can be terminated at 36–70 meters. This is capable of yielding the desired groundwater. In the study area based on the results and available boreholes lithology data, VES 1 and 3 (Figure 7), VES 1, 3 and 4 (Figure 8), VES 1 and 3 (Figure 9) and VES 3 (Figure 10) are the promising wells in the study area.

The existence of a fault within the study area to a larger extent determined the depth of groundwater in the area (Adiat et al., 2012). In Lapai (Figure 5) the groundwater depth (i.e. aquifer) is between 34–40 meters in basement area and 40–50 m in the sedimentary complex. Agaie and Mokwa (Figures 2 and 4) have a groundwater depth between 60 to 75 meters respectively with clay sand and clay as the aquifer and sand stone as the aquiclude. Bida (Figure 3) have a groundwater depth between 40 to 50 meters.

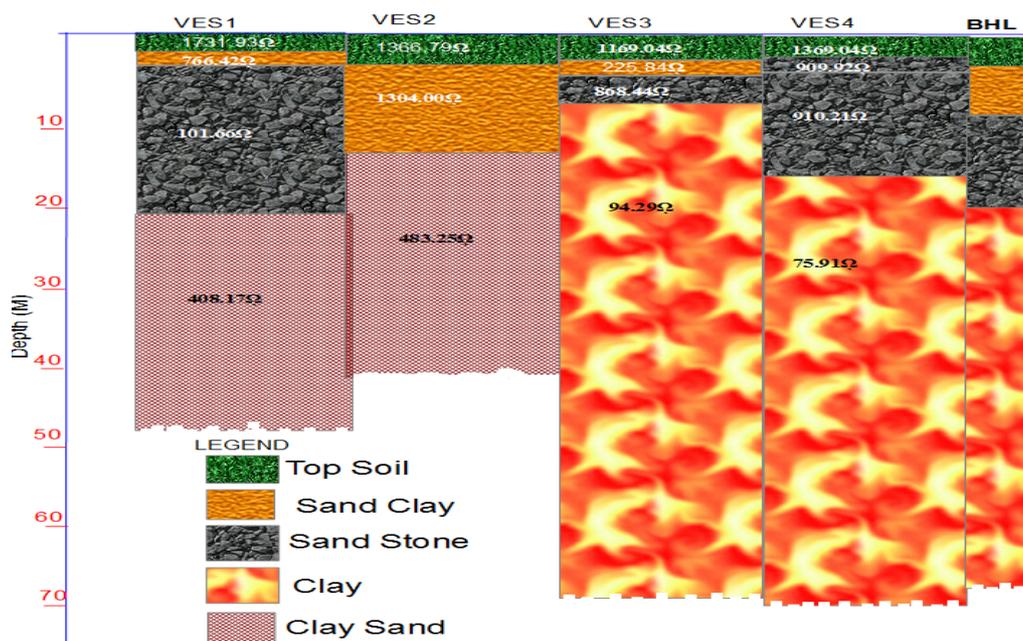


Figure 8. 2D geoelectric profile of Agaie

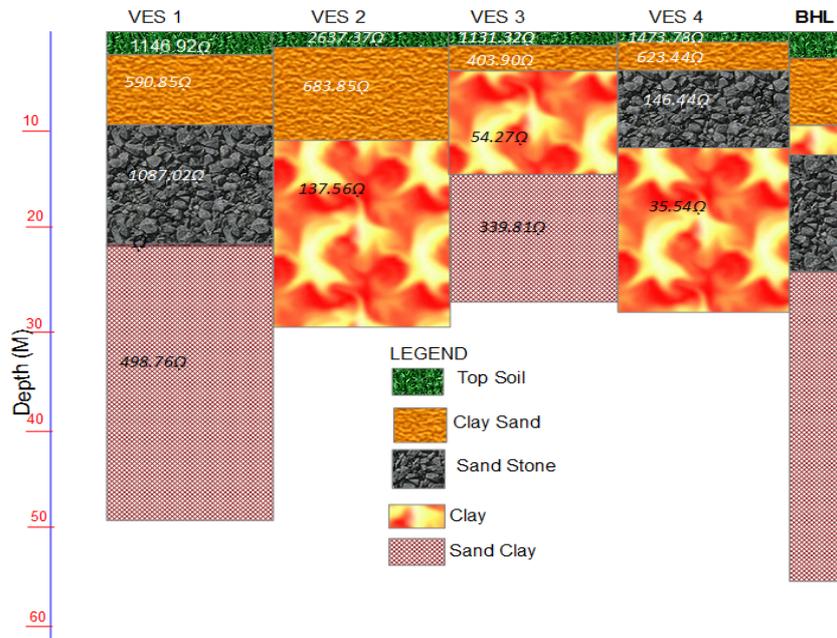


Figure 9. 2D geoelectric profile of Bida

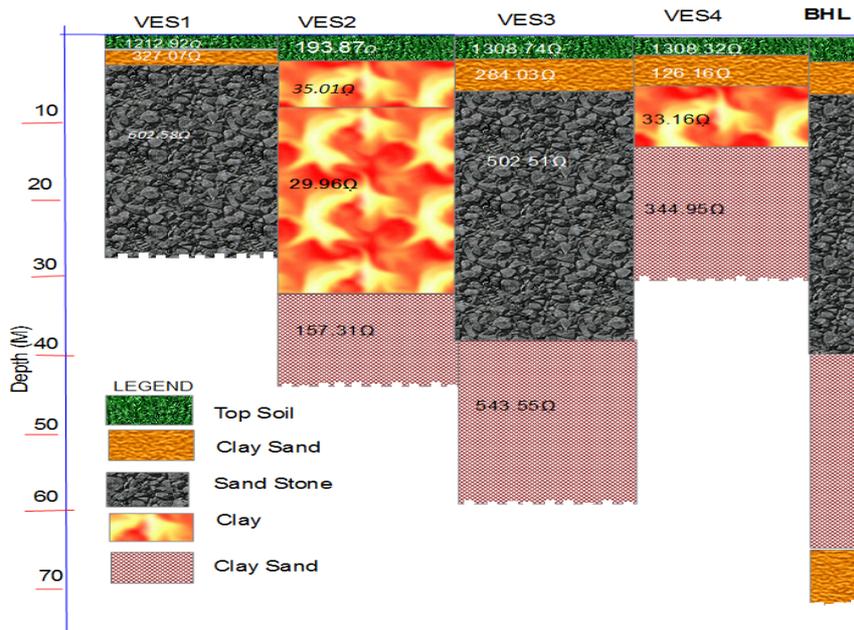


Figure 10. 2D geoelectric profile for Mokwa

**5. Conclusion**

A vertical electrical sounding method has been applied and the results were able to delineate different geoelectric sections which were correlated with available borehole logs; to determine their corresponding geological formations. The promising well were from the resistivity survey were mapped based on the nature and properties that constitutes the aquifer layer and the overburden material and thickness.

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