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Groundwater Exploration using Geoelectric Technique in Oru-Ijebu, South-West Nigeria

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ABSTRACT

Forty Vertical Electrical Soundings (VES) were carried out using Allied Ohmega resistivity meter with schlumberger configuration in parts of Oru-Ijebu to determine the necessary geoelectrical parameters for delineating the aquiferous zones. Four to five distinct geoelectric layers were delineated from the survey area except for VESORU21 which exhibited six geoelectric layers namely the top soil, clayey sand/laterite, clay and granite gneiss. The first layer serves as the topsoil with high variable resistivity ranging from 11.2Ωm (VESORU7) to 153.8Ωm (VESORU25) with their corresponding thickness of 0.9m to 3.8m respectively. The thickness of the entire top soil of the investigated area ranges from 0.4m to 3.8m. The second layer is composed of sand, clay sand, laterite and partly sandy clay. The resistivity of clay/clayey sand overburden varying from 16.2Ωm with a thickness of 8.7m in VESORU17 and 484.3Ωm with a thickness of 3m VESORU6. The highest resistivity exhibited by the second layer is 974 Ωm in VESORU30 while its lowest resistivity is 21.9Ωm in VESORU34. The resistivity of the third layer which stands as a weathered lithology ranges from 17.2Ωm with a thickness of 10.3m at VESORU7 to 233.2Ωm at VESORU23 whose thickness is indeterminate due to current termination in the field to 196 Ωm; typically diagnostic of clay/clayey sand horizon except beneath VESORU1, VESORU2, VESORU11, VESORU30, VESORU32, VESORU34, and VESORU36 where the inferred lithology is sandstone, fresh basement and partly sandy-clay. The fourth and fifth layers are composed of fresh basement formation notably granite-gneiss rocks with resistivity values ranging from 88.5Ωm VESORU20 to 384Ωm in VESORU15. The maximum aquifer thickness is encountered beneath VESORU25. The weathered layer for the study area is thick enough for groundwater accumulation making it a very prolific one. VESORU1, VESORU2 and VESORU23 are marked by a low groundwater yield due to the dip and the thickness.

Keywords:
Aquifer,
Geoelectrical Section,
Vertical Electrical Sounding (VES),
Oru.

INTRODUCTION

Oru is a community whose population is continuously on the rise by the daily influx of biological population mostly students due to its proximity to Olabisi Onabanjo main and mini campus. The progressive population growth has led to severe shortage of potable water for the area which poses a great challenge to both the inhabitants and the government. To meet the needs of this aforementioned growing population, it is quite necessary to source for further and alternative water supply sources. The electrical resistivity method involving vertical electrical sounding (VES) technique was adopted for this survey. It involves the measurement of apparent resistivity of subsurface as a function of depth or position by changing the electrode spacing interval while maintaining a fixed location for the center of the electrode spread (Atakpo, 2009). The theory of resistivity and its application to ground water studies have been much discussed (Telford, 1990; Sharma, 1997). The objective of the investigation is aimed at producing data which could serve as a basis for more detailed groundwater exploration activities in the area.

Groundwater is referred to as water that fills the porosity of soil or rock found as reserves in the subsurface. Groundwater is water that has percolated downward from the surface, passed through numerous natural filtration processes and it fills the void or pore spaces in different types of accommodating rock formations, (Osborn *et al*., 1998). Groundwater is found in aquifers. An aquifer is defined as any geological formation that is capable of storing water at a rate that is available for economic exploitation. Generally, they are classified into two types which are; confined aquifer and unconfined aquifer and are both differentiated only based on appearance of impermeable layer above the aquifer.

The quantification of groundwater resources depends on accurate hydrogeological information that can be collected through a wide range of approaches. Reliable knowledge of subsurface geologic characteristics is essential in designing effective and sustainable groundwater management strategies because groundwater flow is controlled by the geological framework of the aquifer Proper evaluation of the storage and transmission properties of the different geological materials is necessary to measure the groundwater potential of an aquifer system. This includes characterizing the source and flows of water in aquifers estimating groundwater productivity and predicting groundwater sustainability (Haile *et al.,* 2019).

A variety of geophysical techniques have been used in groundwater research to find good locations for productive boreholes. Vertical Electrical Sounding (VES) and Horizontal Profiling (HP) are two of the many approaches used because they are straightforward and dependable. The depth sounding galvanic method, or VES method, has shown to be particularly helpful in groundwater research. Both the lithology and the fluid contents of the rock affect its electrical resistivity. In a given locality, the number and thicknesses of the geoelectric units as identified by VES measurements might not match those of the geological units. A real resistivity log that resembles the induction log of a given locale is the ultimate goal of VES (Olawuyi and Abolarin, 2013). Often, geophysical surveys especially geoelectrical surveys are used to locate groundwater resources. The geo-electric method known as Vertical Electrical Sounding is one example. A vertical section's one-dimensional resistivity distribution is produced using this method. This method is commonly employed to locate subsurface resistivity anomalies, which are helpful in investigating water-saturated formation (Adi-Suryadi *et al.,* 2018). Groundwater despite being the main source of portable water supply for domestic, industrial and agricultural uses and has been under intense pressure of degradation due to urbanization, industrial and agricultural related activities. The impact of this trio on soil and groundwater is alarming with years of devastating effects on humans and the ecosystem (Ehirim and Nwankwo, 2010). Oru-Ijebu is originally characterized by numbers of significant aquifers meeting the domestic needs of the local dwellers but needs higher renewal capacity based on the influx of biological population mostly the teeming resident students due to its proximity to their institution; Olabisi Onabanjo University main and mini campuses. This research work was consequently undertaken within the framework of the emergency program which aims at supplying the community with drinking water.

MATERIALS AND METHODS

Study area

Location and Accessibility

The study area lies within Oru-Ijebu. It is located between latitude 6°57′19″ and longitude 3°56′31″ The area is accessible through major roads and minor roads, linking Oru-Ijebu with several towns and localities including Ago-Iwoye, Awa, Ilaporu, Imope and Ijebu Igbo and it lies within the basement complex of South western Nigeria and the transportation network consists of minor rods, major roads and footpaths. The relief is moderately low forming ridges in some places an undulated plain dotted with small isolated hills or hills rocks are noticed generally within Ago Iwoye. The general level of surface rises Northwards from about 0-500ft above the coast northward to the area of the crystalline rocks. Drainage pattern is predominantly dendritic. The mapped area falls within the equatorial belt giving the area two major seasons namely, the wet and dry season. The climate is characterized by annual average minimum and maximum temperatures of 220 and 350 respectively, it experiences double maximal rainfall of which the peak being between June and September (Onakomaiya *et al.,* 1992). The month of December and January seasons are relatively dry in Oru community. Before the first rain in Late March or Early April, the weather is humid; the humidity is about 50% all year round. The dry season is rather short with very hot days. In a year, maximum rain is recorded between June and October in this area. The vegetation of the mapped area shows that it lies within the tropical rainforest of Nigeria with many light forest, scattered cultivations and scrubs.

Geological Setting and Hydrogeology

The study area, Oru and its environs, lies within the Basement Complex of south western Nigeria. It forms part of the Pan African mobile belt which lies to the east of West African Craton. Hence, several authors have worked on and classified the basement rocks based on their association and geochronology. Some of the classifications were carried out by Jones and Hockey (1964), Oyawoye (1972) and Oyinloye, 2007. Rahaman (1976) classified the basement complex rock units into 5 different groups viz: the migmatite – gneiss – quartzite complex, the newer metasediments, Chanockite, diorite and gabbro, older granite, Unmetamorphosed acid and basic intrusive and hyperbyssal rocks. The major rock types in the area of study include granite gneiss, granite, banded gneiss, pegmatite and undifferentiated migmatite and these have been intruded by quartz veins and pegmatite veins. (Fig.1). Granite gneiss is the major rock that dominated the study area. It belongs to the Gneiss group. There is a considerable variation in the amount of mafic and felsic minerals. They are typically medium grained in texture and the minerals present include quartz, biotite, plagioclase, orthoclase and other mineral accessories. Granite gneiss stretches from the eastern part to the north west of the area. Generally, it is grey in colour and texturally medium grained. Mineralogically, it consists of quartz, plagioclase, feldspar, biotite and hornblende. Granite is the second abundant rock type in the area covering the entire eastern and northwestern region. The colour is grey and texturally medium grained. Banded Gneiss are foliated and the rocks consist of alternating bands of light and dark minerals. The light band is composed of felsic mineral mainly quartz and feldspar while the dark band consists of mafic minerals. Mineralogically, banded gneiss contains both felsic and mafic minerals. Pegmatite is located at the western part of area of study. The entire Oru Township is underlain by pink pegmatite. Pegmatite is a very coarse grained minor igneous rock; they are formed from the residual magma that is rich in volatile and fugitive elements. They occur as massive intrusion in Oru. Texturally, it ranges from medium to coarse grained. Mineralogically, feldspar, mica (muscovite dominating over biotite) and quartz are the most abundant minerals while muscovite and tourmaline occurs as accessory mineral. Muscovite flakes from the weathered pegmatite liter the immediate (Figure 1). These types of aquifers are superimposed or isolated. In a crystalline medium, capacitive and conductive functions both exist within each aquifer. Potentialities of these aquifers depend into hydrological balance parameters and their configuration. Water bearing fissures and fractures; tectonics is the major factor governing the water flow in the study area. Figure 1 below shows the Geological Map of Study Area (Adekoya *et al.*, 2017); Figure 2 shows the Location and accessibility map of the study area, Figure 3a shows the superimposed investigated VES locations on the google satellite imagery map and Figure 3b displays VES investigated points superimposed on google street map.

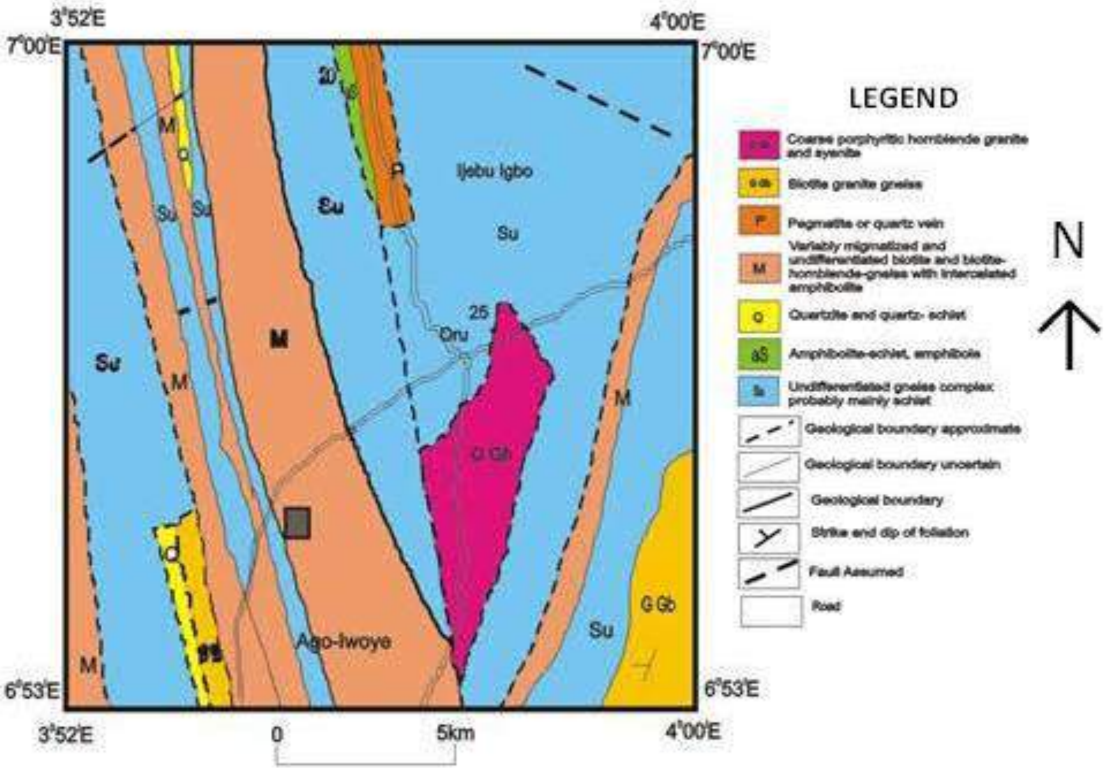


Figure 1: Geological Map of Study Area. (Adekoya *et al.,* 2017)

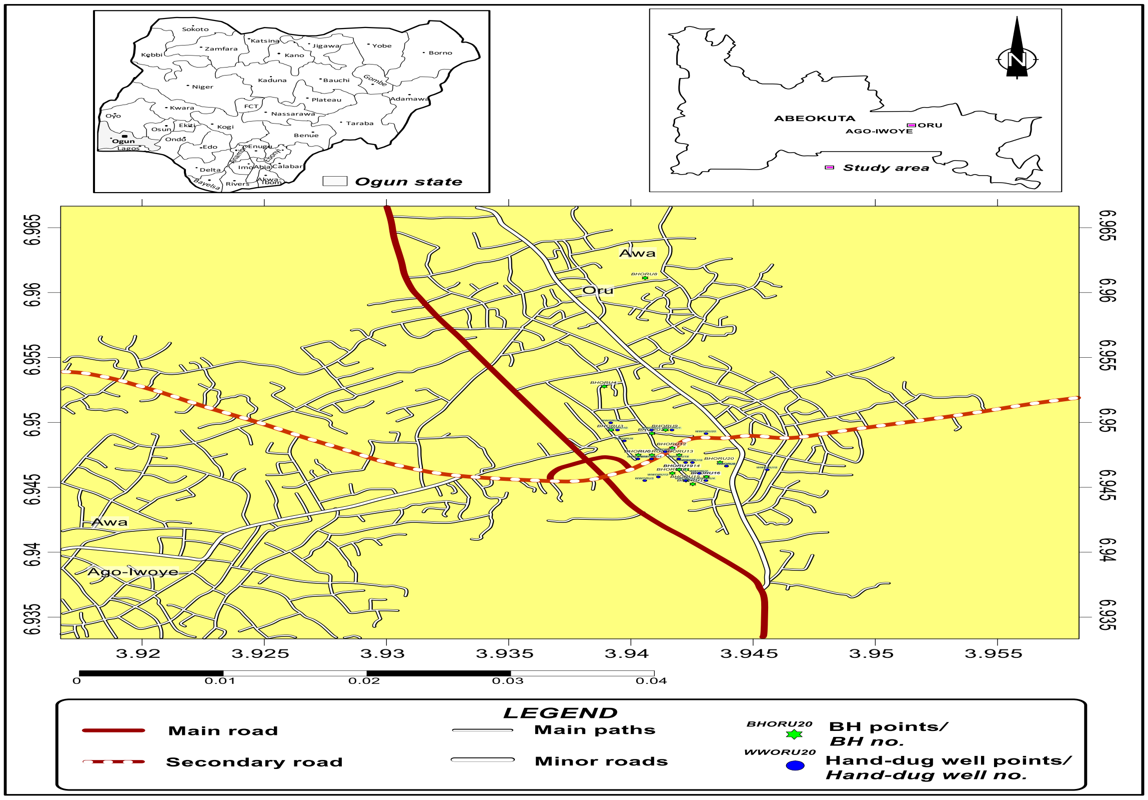


Figure 2: Location and accessibility map of the study area

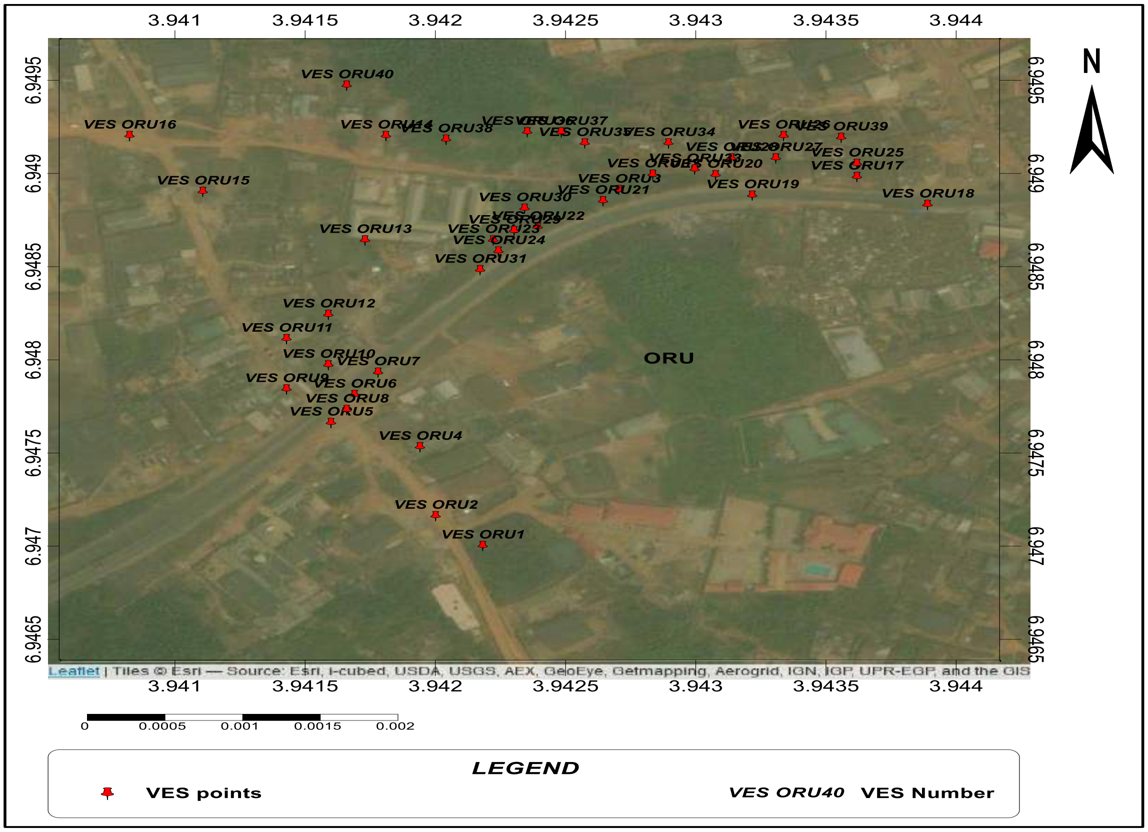


Figure 3a: superimposed VES points on google satellite imagery map

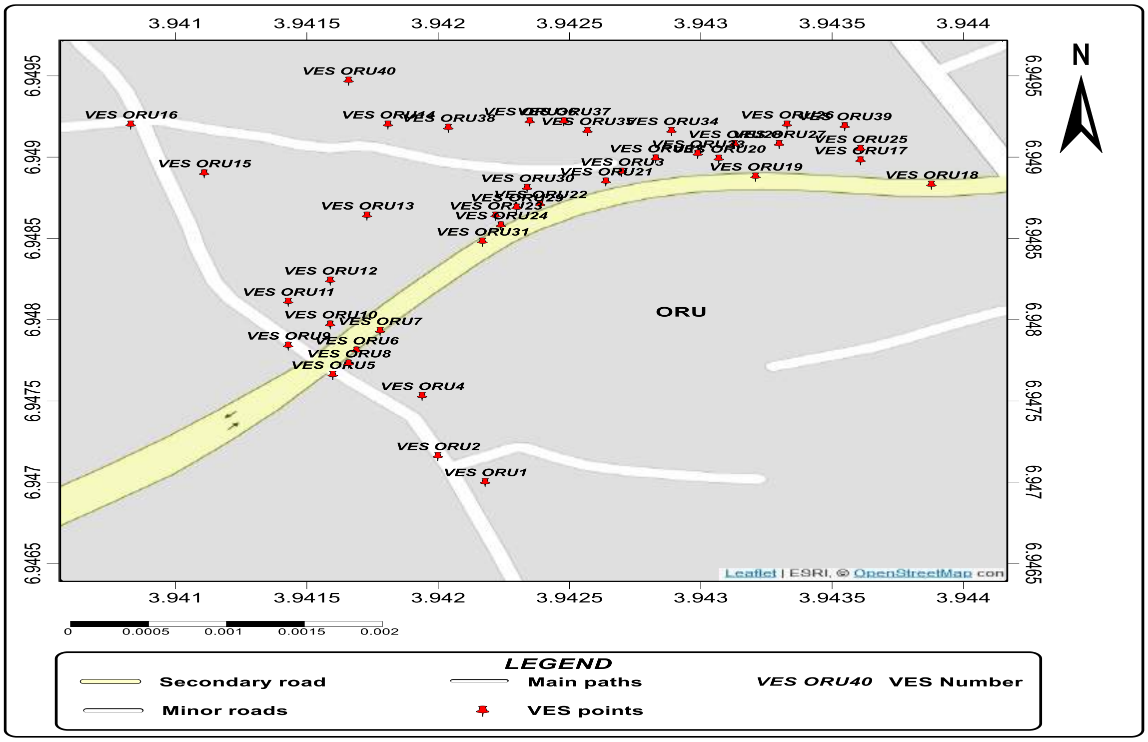


Figure 3b: VES investigated points superimposed on google street map

MATERIALS AND METHODS

Theoretical Background

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface (Ishola *et al*., 2016). From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, density, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. Electrical imaging technique has been widely used in developed countries to study the sub-surface system. New inversion algorithms produce electrical images, which can represent a realistic 2D or 3D sub-surface system. As field data have become more reliable with deployment of refined techniques, electrical imaging has become very effective in delineating fracture and contaminated zones. Electrical tomography (imaging) involves measuring a series of constant separation traverses with the electrode spacing being increased with each successive traverse. Since increasing separation leads to information from greater depths, the measured apparent resistivity values may be used to construct a vertical contoured section displaying the variation of resistivity, both laterally and vertically over the section. The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2). Generally, there are two approaches for the resistivity surveying as displayed in Fig. 4 (Ishola *et al*., 2016).

i. The vertical electrical sounding (VES) that measures the variation of resistivity with depth
ii. The horizontal profiling that measures the lateral variation in the electrical properties of rocks.

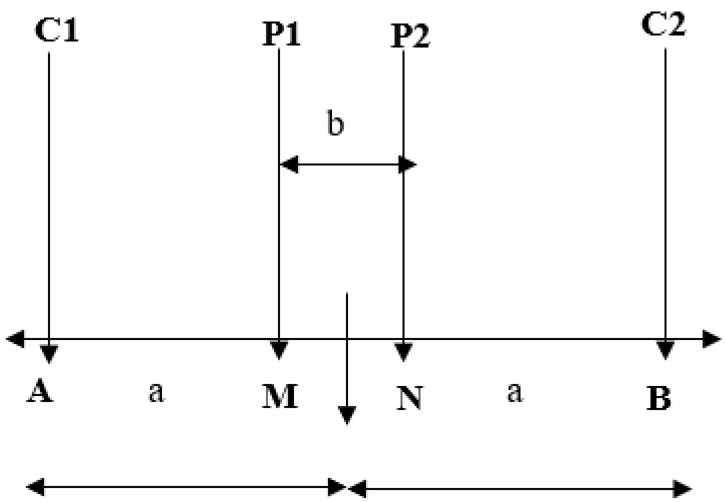


Figure 4: Field illustration showing Schlumberger arrays (Ishola *et al.*, 2016)

In a heterogeneous ground in which there exists a vertical variation in resistivity with depth, the apparent resistivity rather than the true resistivity is measured. The current flow in such a medium is influenced by its density, porosity and salinity of the fluid contents. The apparent resistivity ρ can be expressed as:

$$\rho = \frac{2\pi\Delta V}{I}\left(\frac{1}{AM}-\frac{1}{MB}-\frac{1}{AN}+\frac{1}{BN}\right)^{-1} \quad (1)$$

Where R corresponds to the resistivity of the space between potential electrodes and G is the geometric factor which depends on the electrode configuration. The schlumberger configuration are given by r = AN− AM = BM+ BN and

$$G = \left[\left(\frac{\pi}{2r}\right)\frac{L}{R}\right]^{-1} \quad (2)$$

It is significant to examine the electric current ground flow under the influence of external potential because it enables to understand a major characteristic of direct current methods that is depth of investigation. We have by the ohm's law (Ishola *et al.*, 2016; Telford et al., 1990).

$$J = -\frac{1}{\rho}\nabla V \quad (3)$$

Where I and V are the current density and potential difference respectively; for two grounded electrodes (Fig. 4). We have

$$V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1}-\frac{1}{r_2}\right) \quad (4)$$

(Telford et al., 1990; Ishola *et al.*, 2016)

Thus, the horizontal component J_x for the two electrode system is

$$J_x = \frac{-1}{\rho}\frac{I\rho}{2\pi}\left(\frac{\partial}{\partial r}\right)\left(\frac{1}{r_1}-\frac{1}{r_2}\right) \quad (5)$$

$J_x = \frac{I}{2\pi}\left(\frac{x}{r_1}-\frac{x-L}{r_2}\right)$ Furthermore $r^2 = x^2+y^2+z^2$

$$J_x = \frac{I}{2\pi}\left(\frac{x}{r_1^3}-\frac{x-L}{r_2^3}\right) \quad (6)$$

Assuming to be in the median plane, then $r_1 = r_2 = r$ and $x = \frac{L}{2}$, what allows us to write

$$J_x = \frac{I}{2\pi}\left(\frac{x}{r_1^2}-\frac{x-L}{r_2^2}\right) \quad (7)$$

This equation highlights the fact that current density at vertical x position depends on the depth z and the spacing electrode injection. The phenomenon can be seen considering the current J (and not J). Integrating elementary current, δI_x would yield to the expression of the current function flowing by one part of the plane given by Telford et al., 1990.

$$\delta I_x = I_x\partial_y\partial_z = \frac{I}{2\pi}\frac{L}{[(\frac{L}{2})^2+y^2+z^2]^{\frac{3}{2}}}\partial_y\partial_z \quad (8)$$

$$\text{So, } \frac{I_x}{I} = \frac{L}{2\pi}\int_{Z_1}^{Z_2}\partial_z\int_{-\infty}^{+\infty}\frac{\partial_y}{[(\frac{L}{2})^2+y^2+z^2]}\}$$

$$= \frac{2}{\pi}\left\{\tan^{-1}\frac{2Z_1}{L} - \tan^{-1}\frac{2Z_1}{L}\right\}$$

When $L = 2z_1$ and $z_2 = \infty$

$$\frac{I_x}{I} = 1-\frac{2}{\pi}\tan^{-1}1$$

$$= 1-\frac{2\pi}{\pi 4} = 0.5 \quad (9)$$

The relationship shows that almost half of the injected current propagating in the direction x (I_x/I ≈ 0.5) investigates a depth lower than half of electrodes separation. The true resistivity and thickness of the subsurface layers were interpreted by partial curve matching with the two layer model master curves and the corresponding auxiliary curves. The thickness and resistivity values obtained from the partial curve matching were then used for a quantitative computer iteration using Resist Software [Pirttijärvi, 2009]. The results obtained from the computer modeling are presented in Table 1.

Data Acquisition and interpretation

The Terrameter model SAS 300B was used to acquire seventeen (40) VES soundings using the Schlumberger configuration, and maximum electrode separation (AB/2) is restricted to 100 m. The Schlumberger configuration consists of a linear electrodes array

(AMNB) as shown in Figure 4. Potential electrodes M and N are kept fixed at the centre of the array while current electrodes A and B are moved outward symmetrically [Telford, 1990]. The operational principle lay on the fact that ground injection of current through current electrodes A and B enables the measurement of the potential drop between potential probes M and N. The current penetrates deeply into the ground as the electrode A and B spacing increases**.** The interpretation of result was carried out both qualitatively and quantitatively the qualitative interpretation was achieved by plotting the obtain Resistivity data on the log-log paper which relate the resistivity data to the geology of the study area while quantitative interpretation is referring to a curve matching and computer assisted program called iteration The 1-D forward modeling adopted for the VES interpretation is called WinRESIST version 1. 0 program. I-D forward modeling (1DF) is a computer program that provides a way for the user to interactively model vertical electrical sounding data by changing the geologic conditions and parameter that control earth resistivity responses (Pirttijärvi, 2009). This provides a comparison of real resistivity data to synthetic data in other to make geologic interference from the features observed in the real data. The user iteratively changes the model to facilitate a sufficient match with the real data so that the model is a possible representation of the geologic condition that produced the real resistivity data. The computer program (RESIST VERSION 1. 0) involves a shorter computer code in layering model, running more iterating and thereby improving the screen graphic by eliminating the generation of anomalous layers caused by noise in the field data.

The interpretation of Forty (40) Schlumberger sounding conducted in the study area indicated that the lithological layers vary from 2-4 layers. The subsurface layers within this study area include Topsoil, Clayey sand, Clay, Sandy clay and Fresh Basement based on their corresponding resistivity values obtained during the interpretation. The summary of the lithological parameter which includes thickness, depth, resistivity, and curve type were obtained from the screen graphic by eliminating the generation of anomalous layers caused by noise in the field data.

RESULTS AND DISCUSSION

Interpretation and Curve Types

The main objective of the quantitative interpretation of VES curve is to obtain the geoelectrical parameters and geoelectric section. Geoelectrical parameters are true resistivity and layer thickness. Interpretation of sounding curves shows the following curves types: KH, HK, HKH (Figure 3). The apparent resistivity curves reveal a dominant curves type KH over the entire area. This dominant curve type shows that a homogenous subsurface succession is encountered; in most sounding curves the same layer were found (Figure 5).

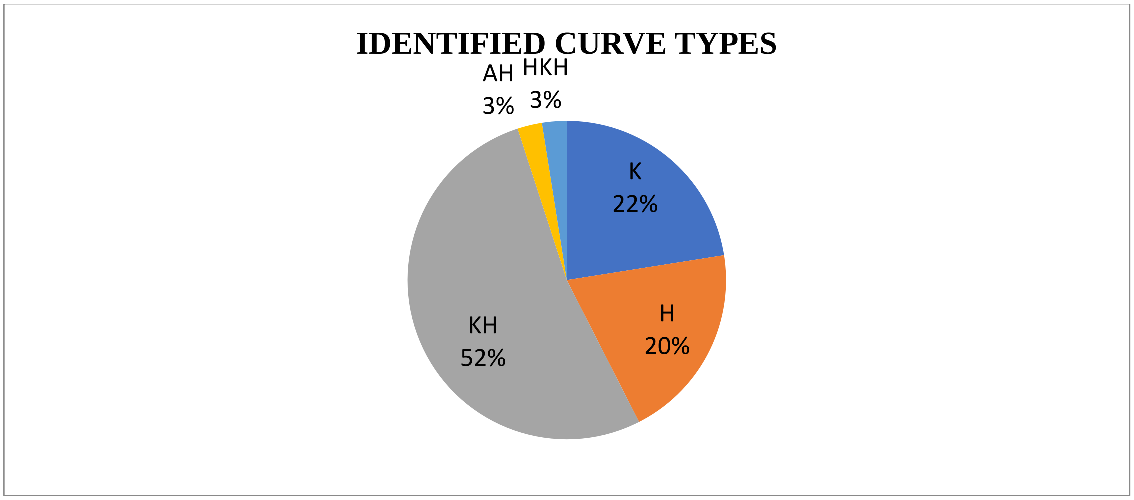
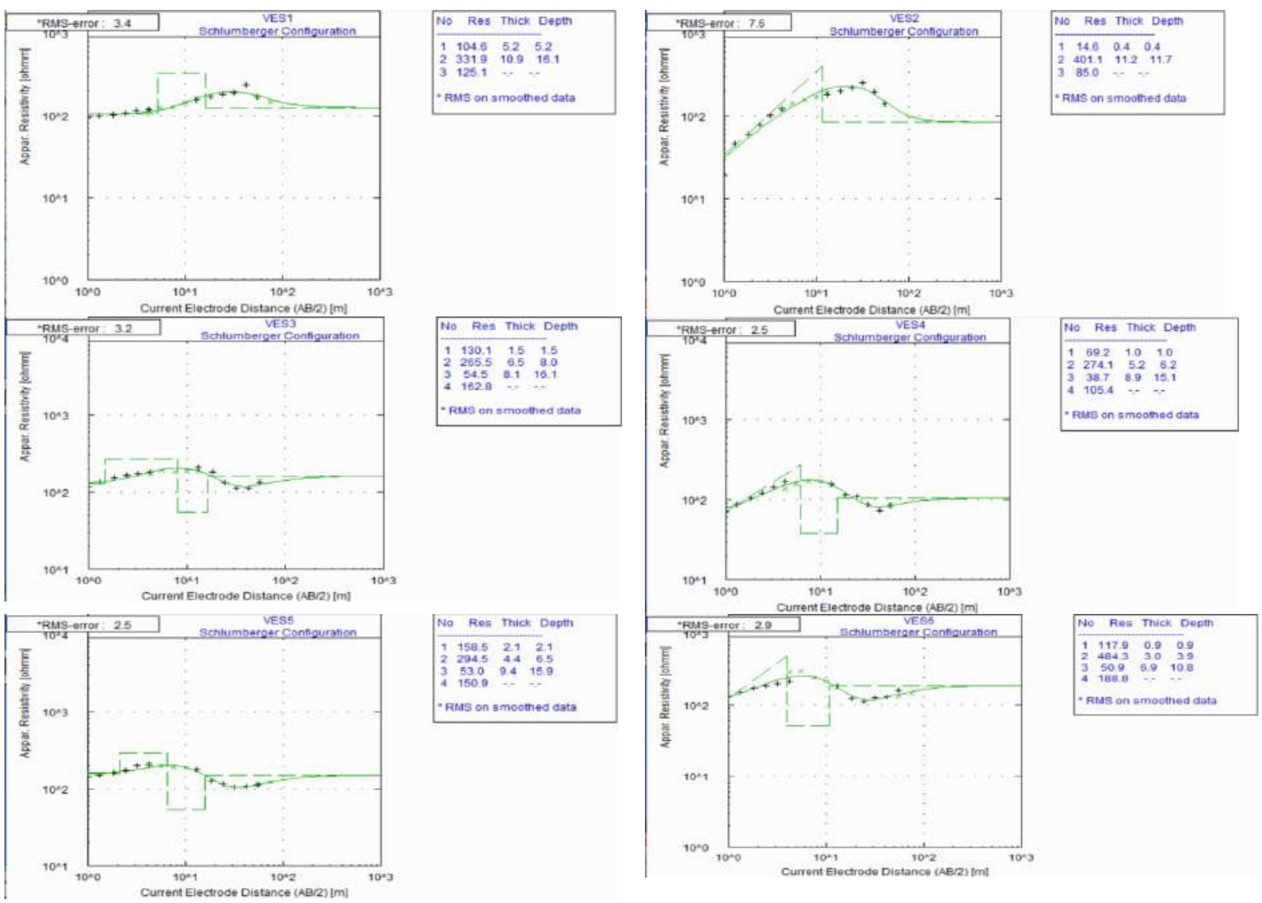


Figure 5: Percentage Representation of the Identified Curve Types in the Study Area

The geoelectric section is a diagrammatic model of the subsurface lithological layer present in the established points within the study location, The approach was employed to have a pictorial view of how the subsurface lithology is either correlating or showing lateral discountinuity and this image also considered the depth, and thickness of the established vertical electrical point in the study area. In the case study, the variation in geoelectric section of the study area displayed in Table 1 (and pictorially represented in Figure 6a- Figure 6d) reveals four to six distinct layers namely the top soil, clayey sand/laterite, clay and granite gneiss. The near-surface layer that had highly variable resistivity ranging from 11.2 VESORU7 to 153.8Ωm in VESORU25 with their corresponding thickness of 0.9m to 3.8m respectively. The thickness of the entire top soil of the investigated area ranges from 0.4m to 3.8m. These values reflect the state of variable composition and moisture content of the topsoil. The second layer is composed of sand, clay sand, laterite and partly sandy clay. The resistivity of clay/clayey sand overburden varying from 16.2Ωm with a thickness of 8.7m in VESORU17 and 484.3Ωm with a thickness of 3m VESORU6. The highest resistivity exhibited by the second layer is 974 Ωm in VESORU30 while its lowest resistivity is 21.9Ωm in VESORU34. The third and fourth geoelectrical layers represent an aquifer unit. The resistivity of the third layer which stands as a weathered lithology ranges from 17.2Ωm with a thickness of 10.3m at VESORU7 to 233.2Ωm at VESORU23 whose thickness is indeterminate due to current termination in the field to 196 Ωm; typically diagnostic of clay/clayey sand except beneath VESORU1, VESORU2, VESORU11, VESORU30, VESORU32, VESORU34, and VESORU36 where the inferred lithology is sandstone, fresh basement and partly sandy-clay. The fourth and fifth layers are composed of fresh basement formation notably granite-gneiss rocks with resistivity values ranging from 88.5Ωm VESORU20 to 384Ωm in VESORU15. The exact thickness of the four layers could not be determined as the electrode current terminated within this layer except for VESORU21 whose fourth layer exhibited resistivity value of 178.4Ωm with a thickness 5.6m inferred to be sandy clay while its fifth layer counterpart displayed a resistivity value of 49.2Ωm with an accompanied thickness of 8.7m inferred to be clay (Table 1). These layers were interpreted to be bedrock with lower resistivity ranges. In most parts of the area, the resistivity values were less than 1000Ωm corresponding probably to clay and intercalations of sand-clay formation; where the resistivity value is less than 700Ωm in the study area could correspond to a shaly show in the layer. The determinants of rock resistivity are attributable to several factors such as the pore fluids contents, weathering, and fracturation among others (Teikeu, 2012). The variation of depth to the aquifer in the study area is displayed in Figure 7 where the maximum depth to the aquifer is encountered in VESORU21.



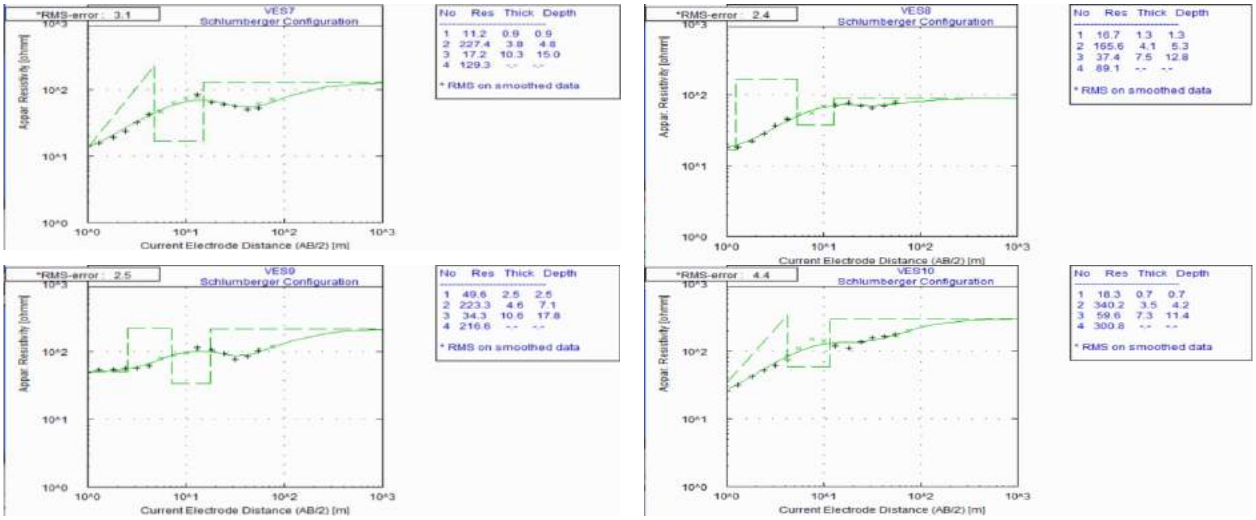
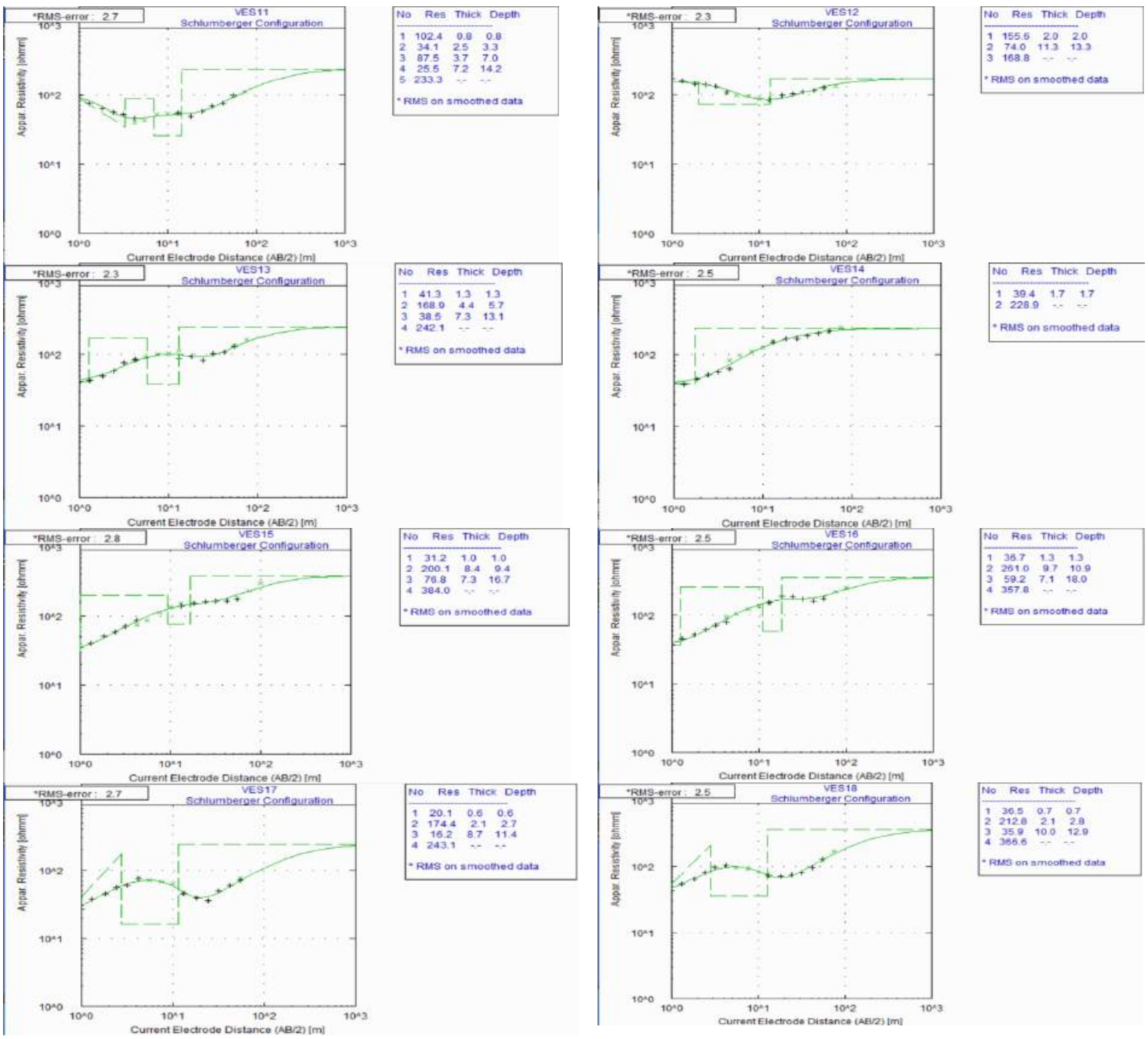


Figure 6a: Typical type curves of the study area (VESORU1-VESORU10)



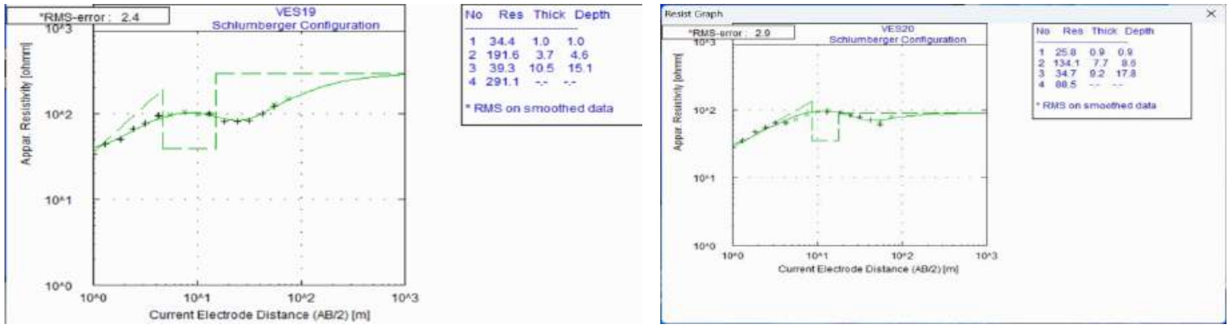
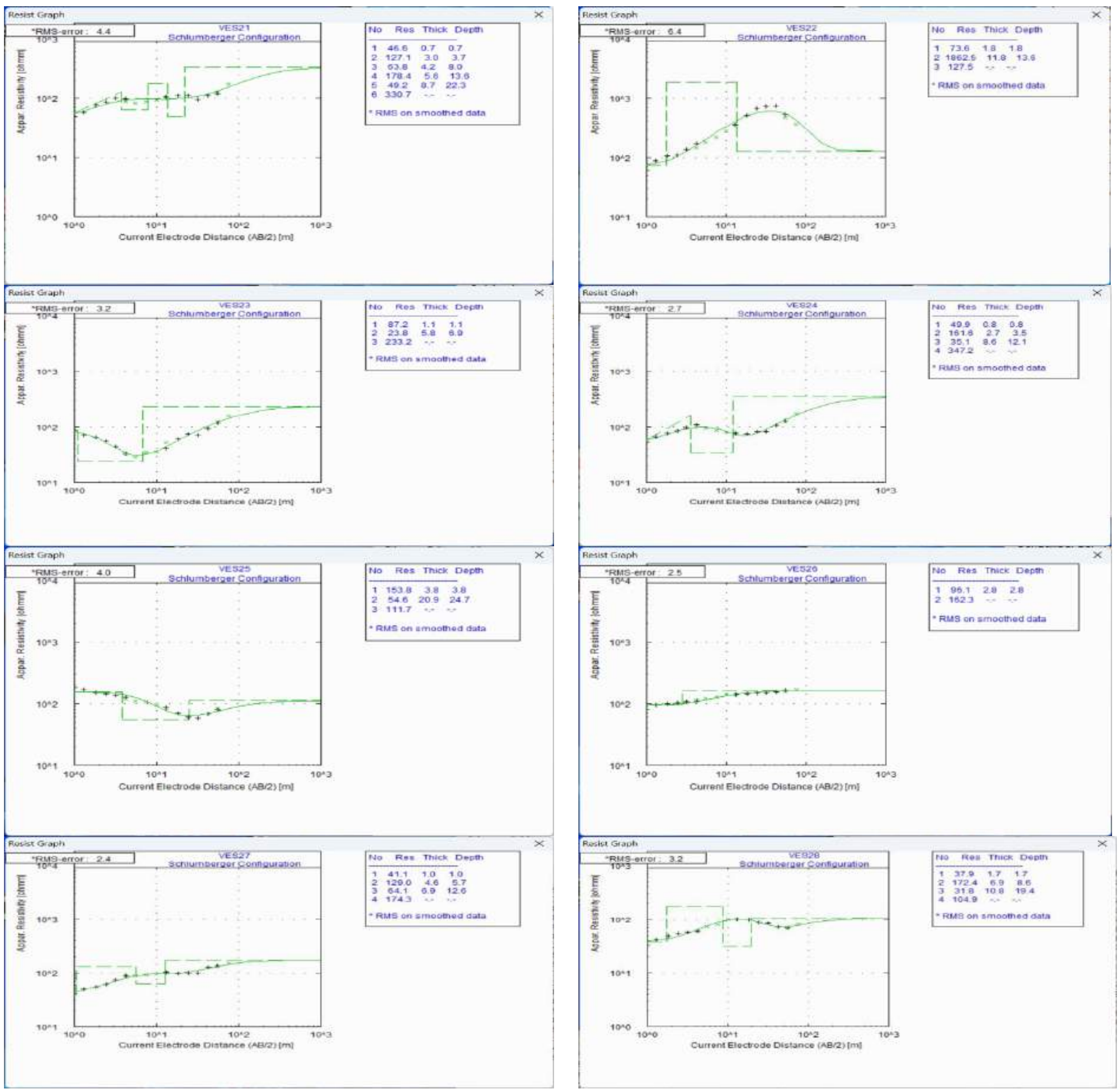


Figure 6b: Typical type curves of the study area (VESORU11-VESORU20)



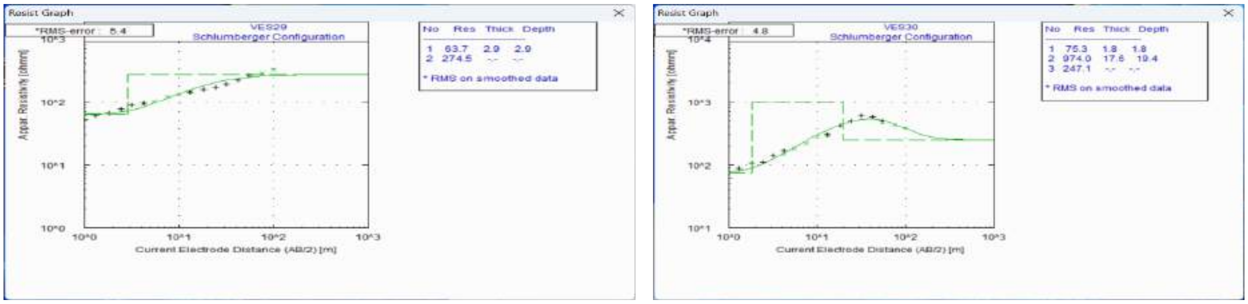
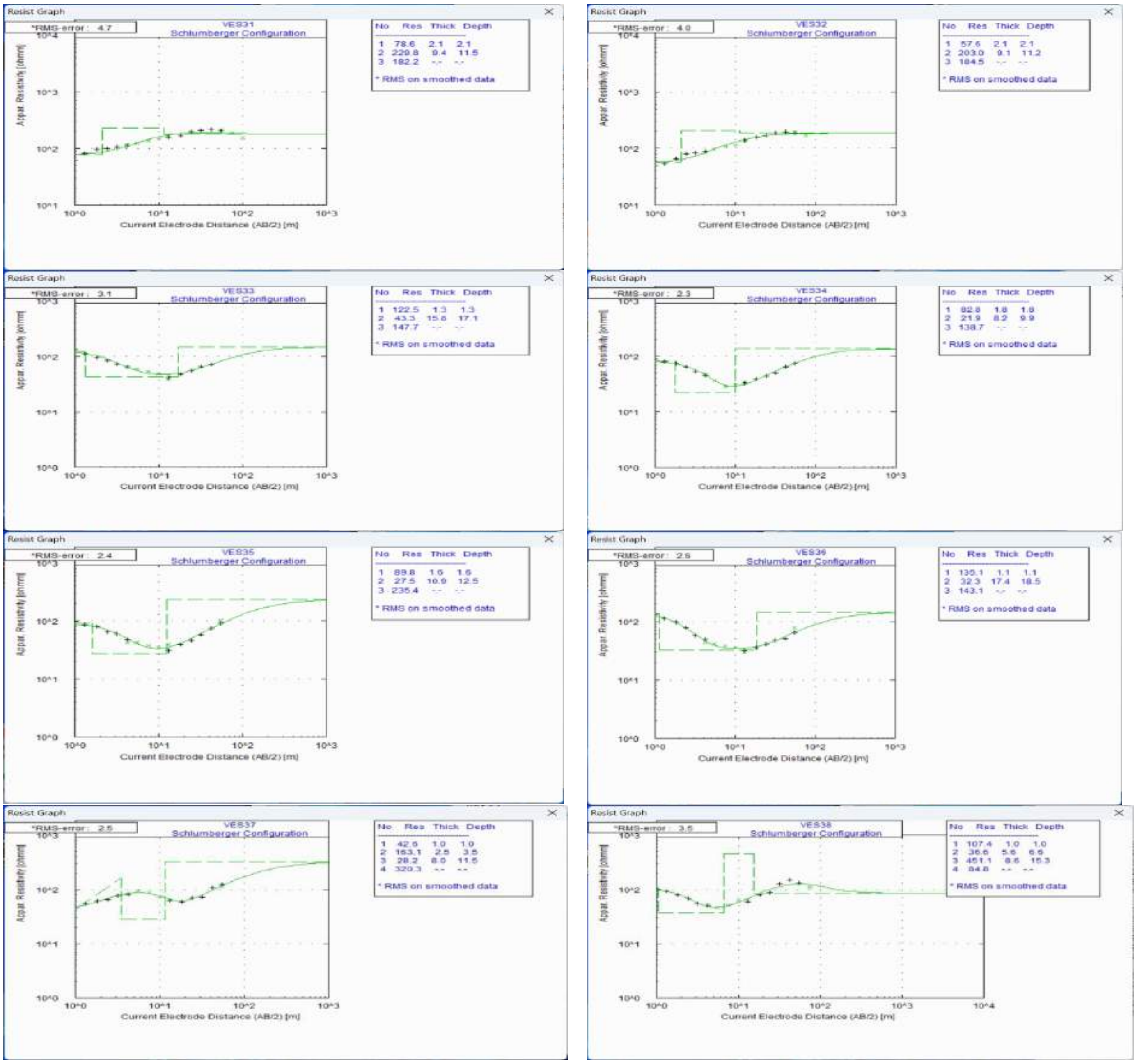


Figure 6c: typical type curves of the study area (VESORU21-VESORU30)



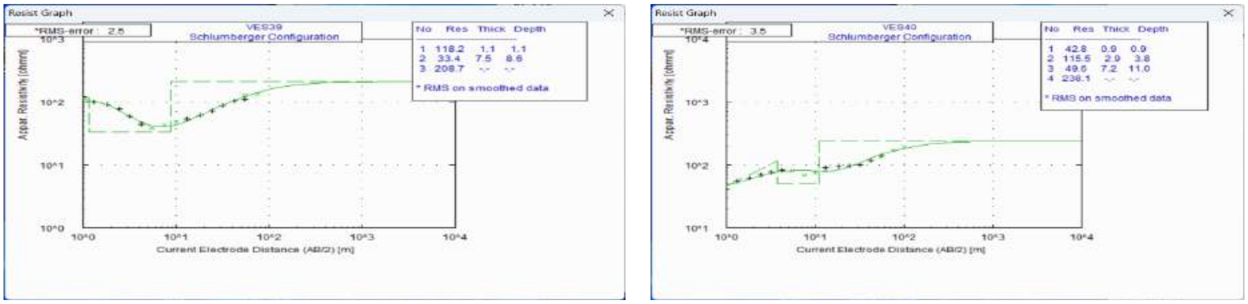


Figure 6d: typical type curves of the study area (VESORU31-VESORU40)

Table 1: Geoelectric Parameters of Investigated Locations in Oru

VES NO	Resistivity	Thickness (m)	Depth (m)	Lithology	Curve type
VESORU 1	104.6	5.2	5.2	Topsoil	K
	331.9	10.9	16.1	Clayey sand	
	125.1	-	-	Fresh basement	
VESORU 2	14.6	0.4	0.4	Topsoil	K
	401.1	11.2	11.7	Sand	
	85.0	-	-	Fresh basement	
VESORU 3	130.1	1.5	1.5	Topsoil	KH
	265.5	6.5	8.0	Sand	
	54.5	8.1	16.1	Clay	
	162.8	-	-	Fresh basement	
VESORU 4	69.2	1.0	1.0	Topsoil	KH
	274.1	5.2	6.2	Clayey sand	
	38.7	8.9	15.1	Clay	
	105.4	-	-	Fresh basement	
VESORU 5	158.5	2.1	2.1	Topsoil	KH
	294.5	4.4	6.5	Clayey sand	
	53.0	9.4	15.9	Clay	
	150.9	-	-	Fresh basement	
VESORU 6	117.9	0.9	0.9	Topsoil	KH
	484.3	3.0	3.9	Clayey sand	
	50.9	6.9	10.8	Clay	
	188.8	-	-	Fresh basement	
VESORU 7	11.2	0.9	0.9	Topsoil	KH
	227.4	3.8	4.8	Clayey sand	
	17.2	10.3	15.0	Clay	
	129.3	-	-	Fresh basement	
VESORU 8	16.7	1.3	1.3	Topsoil	KH
	165.6	4.1	5.3	Clayey sand	
	37.4	7.5	12.8	Clay	
	89.1	-	-	Sandy clay	
VESORU 9	49.6	2.5	2.5	Topsoil	KH
	223.3	4.6	7.1	Clayey sand	
	34.3	10.6	17.8	Clay	
	216.6	-	-	Fresh basement	
VESORU 10	18.3	0.7	0.7	Topsoil	KH
	340.2	3.5	4.2	Clayey sand	
	59.6	7.3	11.4	Clay	
	300.8	-	-	Fresh basement	

VES NO	Resistivity	Thickness (m)	Depth (m)	Lithology	Curve type
VESORU 11	102.4	0.8	0.8	Topsoil	AH
	34.1	2.5	3.3	Clay	
	87.5	3.7	7.0	Sandstone	
	25.5	7.2	14.2	Clay	
	233.3	-	-	Fresh basement	
VESORU 12	155.6	2.0	2.0	Topsoil	H
	74.0	11.3	13.3	Clay	
	168.8	-	-	Fresh basement	
VESORU 13	41.3	1.3	1.3	Topsoil	KH
	168.9	4.4	5.7	Sandy clay	
	38.5	7.3	13.1	Clay	
	242.1	-	-	Fresh basement	
VESORU 14	39.4	1.7	1.7	Topsoil	K
	228.9	-	-	Fresh basement	
VESORU 15	31.2	1.0	1.0	Topsoil	KH
	200.1	8.4	9.4	Clayey sand	
	76.8	7.3	16.7	Clay	
	384.0	-	-	Fresh basement	
VESORU16	36.7	1.3	1.3	Topsoil	KH
	261.0	9.7	10.9	Clayey sand	
	59.2	7.1	18.0	Clay	
	357.8	-	-	Fresh basement	
VESORU 17	20.1	0.6	0.6	Topsoil	KH
	174.4	2.1	2.7	Sandy clay	
	16.2	8.7	11.4	Clay	
	243.1	-	-	Fresh basement	
VESORU 18	36.5	0.7	0.7	Topsoil	KH
	212.8	2.1	2.8	Clayey sand	
	35.9	10.0	12.9	Clay	
	366.6	-	-	Fresh basement	
VESORU 19	34.4	1.0	1.0	Topsoil	KH
	191.6	3.7	4.6	Sandy clay	
	39.3	10.5	15.1	Clay	
	291.1	-	-	Fresh basement	
VESORU 20	25.8	0.9	0.9	Topsoil	KH
	134.1	7.7	8.6	Sandy Clay	
	34.7	9.2	17.8	Clay	
	88.5	-	-	Fresh basement	
VESORU 21	46.6	0.7	0.7	Topsoil	HKH
	127.1	3.0	3.7	Sandy clay	
	63.8	4.2	8.0	Clay	
	178.4	5.6	13.6	Sandy clay	
	49.2	8.7	22.3	Clay	
	330.7	-	-	Fresh bedrock	
VESORU 22	73.6	1.8	1.8	Topsoil	K
	1862.5	11.8	13.6	Compacted sandstone	
	127.5			Fresh bedrock	

VES NO	Resistivity	Thickness (m)	Depth (m)	Lithology	Curve type
VESORU 23	87.2	1.1	1.1	Topsoil	H
	23.8	5.8	6.9	Clay	
	233.2	-	-	Fresh bedrock	
VESORU 24	49.9	0.8	0.8	Topsoil	KH
	161.6	2.7	3.5	Sandy Clay	
	35.1	8.6	12.1	Clay	
	347.2	-	-	Fresh bedrock	
VESORU 25	153.8	3.8	3.8	Topsoil	H
	54.6	20.9	24.7	Clay	
	111.7	-	-	Sandy Clay	
VESORU 26	96.1	2.8	2.8	Topsoil	K
	162.3	-	-	Sandy clay	
VESORU 27	41.1	1.0	1.0	Topsoil	KH
	129.0	4.6	5.7	Sandy clay	
	64.1	6.9	12.6	Clay	
	174.3	-	-	Fresh bedrock	
VESORU 28	37.9	1.7	1.7	Topsoil	KH
	172.4	6.9	8.6	Sandy clay	
	31.8	10.8	19.4	Clay	
	104.9	-	-	Fresh bedrock	
VESORU 29	63.7	2.9	2.9	Topsoil	K
	274.5	-	-	Clayey sand	
VESORU 30	75.3	1.8	1.8	Topsoil	K
	974.0	17.6	19.4	Sand	
	247.1	-	-	Clayey sand	
VESORU 31	78.6	2.1	2.1	Topsoil	K
	229.8	9.4	11.5	Clayey sand	
	182.2	-	-	Sandy clay	
VESORU 32	57.6	2.1	2.1	Topsoil	K
	203.0	9.1	11.2	Clayey sand	
	184.5	-	-	Sandy clay	
VESORU 33	122.5	1.3	1.3	Topsoil	H
	43.3	15.8	17.1	Clay	
	147.7	-	-	Sandy clay	
VESORU 34	82.8	1.8	1.8	Topsoil	H
	21.9	8.2	9.9	Clay	
	138.7	-	-	Sandy clay	
VESORU 35	89.8	1.6	1.6	Topsoil	H
	27.5	10.9	12.5	Clay	
	235.4	-	-	Clayey sand	
VESORU 36	135.1	1.1	1.1	Topsoil	H
	32.3	17.4	18.5	Clay	
	143.1	-	-	Sandy clay	
VESORU 37	42.6	1.0	1.0	Topsoil	KH
	163.1	2.5	3.5	Sandy clay	
	28.2	8.0	11.5	Clay	
	320.3	-	-	Clayey sand	

VES NO	Resistivity	Thickness (m)	Depth (m)	Lithology	Curve type
VESORU 38	107.4	1.0	1.0	Topsoil	HK
	36.6	5.6	6.6	Clay	
	451.1	8.6	15.3	Sand	
	84.8	-	-	Sandy clay	
VESORU 39	118.2	1.1	1.1	Topsoil	H
	33.4	7.5	8.6	Clay	
	208.7			Clayey sand	
VESORU 40	42.8	0.9	0.9	Topsoil	KH
	115.5	2.9	3.8	Sand	
	49.6	7.2	11.0	Clay	
	238.1	-	-	Clayey sand	

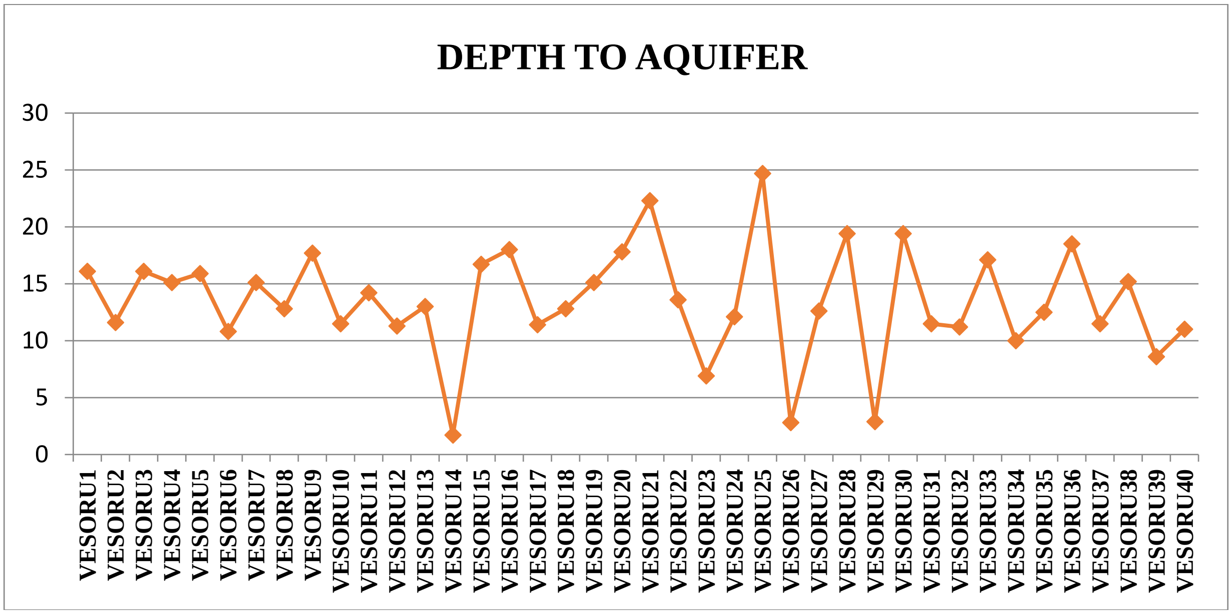


Figure. 7: Variation of Depth to Aquifer in Oru

Lithological Variation and Aquifer Characterization

Traverse A

This traverse cuts across VES 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 Topsoil resistivity ranges between 11.2 and 158.5Ωm and thickness value of between 0.2 and 5.2m. The second layer which is the clayey sand has resistivity value ranging between 17.2Ωm and 484.3Ωm and thickness value ranging between 2.5 and 11.2m, and the last layer which is that fresh bedrock has a resistivity of 85 and 300.8Ωm and a depth value between 6.9 and 10.6m (Fig. 8a).

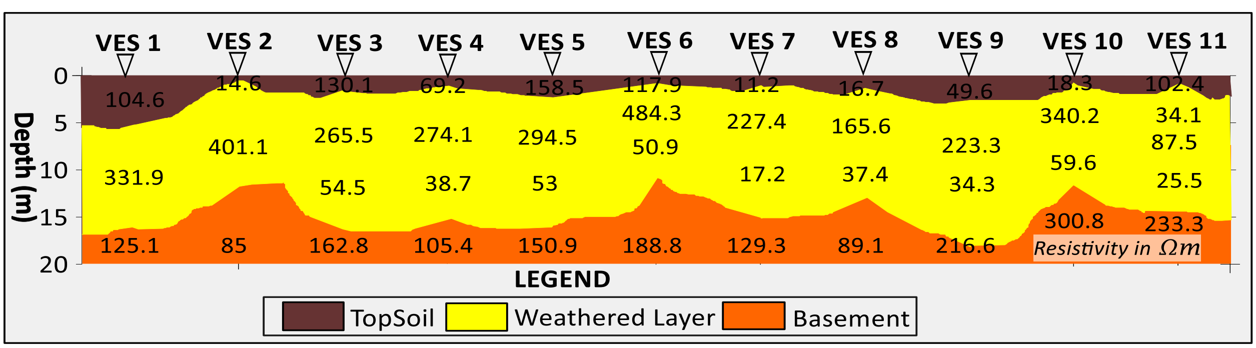


Figure 8a: Geoelectric section of traverse A

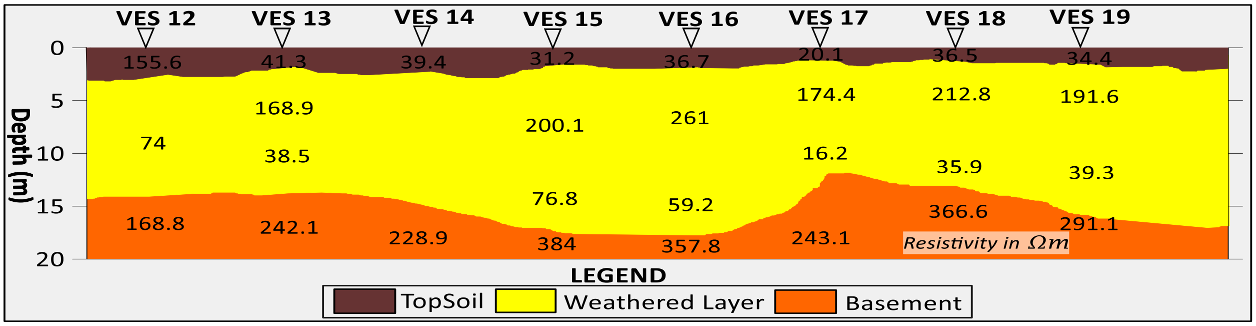


Figure 8b: Geoelectric section of traverse B

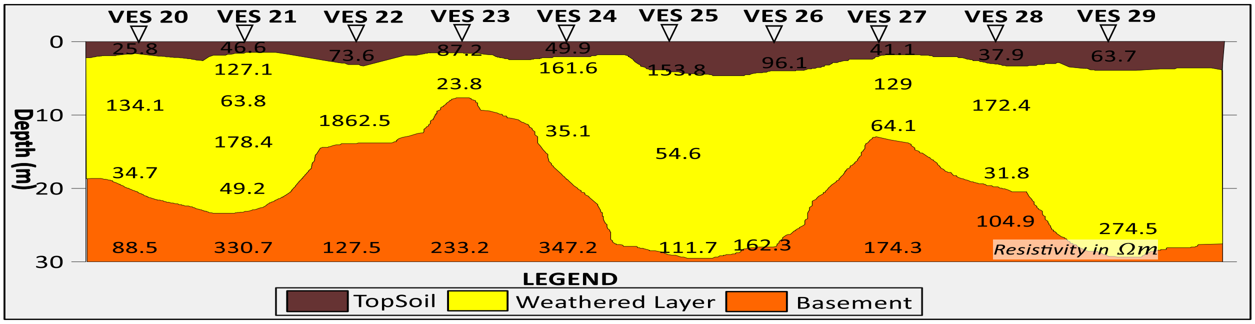


Figure 8c: Geoelectric section of traverse C

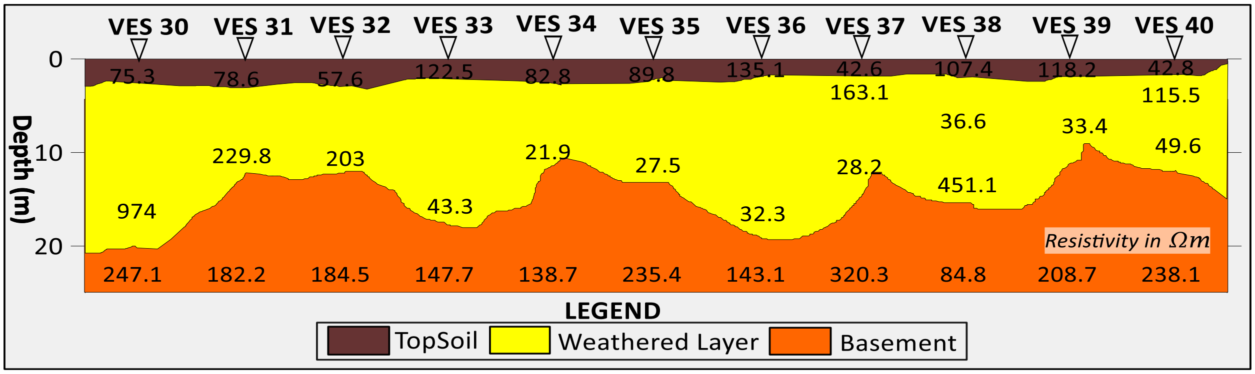


Figure 8d: Geoelectric section of traverse D

Traverse B

This traverse cuts across VES 12, 13, 14, 15, 16, 17, 18, and 19 Topsoil resistivity ranges between 20.1 and 155.6 Ωm and thickness value of between 0.6 and 2.0m. The second layer which is the clayey sand has resistivity value ranging between 38.5Ωm and 261Ωm and thickness value ranging between 2.1 and 11.3m, and the last layer which is that fresh bedrock has a resistivity of 168.8 and 384Ωm and a depth value between 7.1 and 11.3m (Fig. 8b).

Traverse C

This traverse cuts across VES 20, 21, 22, 23, 24, 25, 26, 27, 28 and 29 Topsoil resistivity ranges between 25.8 and 153.8 Ωm and thickness value of between 0.7 and 3.8m. The second layer which is the clayey sand has resistivity value ranging between 23.8Ωm and 1862.5Ωm and thickness value ranging between 2.7 and 20.9m, and the last layer which is that fresh bedrock has a resistivity of 88.5 and 347.2Ωm and a depth value between 6.9 and 10.8m (Fig. 8c).

Traverse D

This traverse cuts across VES 30, 31, 32, 33, 34, 35, 36, 37, 38, 39 and 40 Topsoil resistivity ranges between 42.6 and 135.1 Ωm and thickness value of between 0.9 and 2.1m. The second layer which is the clayey sand has resistivity value ranging between 21.9Ωm and 974Ωm and thickness value ranging between 2.5 and 17.6m, and the last layer which is that fresh bedrock has a resistivity of 84.8 and 320.3Ωm and a depth value between 7.2 and 8.6m Fig. 8d).

Groundwater Potentials in Oru-Ijebu

The results of the study show that an aquifer is encountered at varying depth ranging from about 1.7m in VESORU14 to 24.7m in VESORU25 in Oru-Ijebu as shown in (Fig. 7). The resistivity of the third layer which stands as a weathered lithology ranges from 17.2Ωm with a thickness of 10.3m at VESORU7 to 233.2Ωm at VESORU23 whose thickness is indeterminate due to current termination in the field to 196 Ωm; typically diagnostic of clay/clayey sand except beneath VESORU11, VESORU30, VESORU32, VESORU34, and VESORU36 where the inferred lithology is sandstone, fresh basement and partly sandy-clay. The thickness of the overburden is an important hydrogeologic consideration for groundwater development in the basement terrain, because water gets into the saturated zone through the overburden [Takounjou-Fouépé, 1986]. The maximum aquifer thickness is encountered beneath VESORU25 (Figure 8c). The weathered layer for the study area is thick enough to enable ground water accumulation making it a very prolific one. In terms of the thickness of the weathered layer VESORU25 is a very good aquifer, VESORU15, VESORU16, VESORU19, VESORU20, VESORU21, VESORU28, VESORU30, VESORU36 and VESORU38 good aquifer and VESORU1, VESORU3, VESORU4, VESORU5, VESORU7, VESORU8, VESORU30, VESORU9, VESORU10, VESORU11, VESORU12, VESORU13, VESORU14 and VESORU17 are god to moderate aquifer suitable for groundwater exploitation, because they exhibit weathered and fractured formations with significant thickness. In VESORU1, VESORU2, and VESORU23 are marked by a low groundwater yield due to the dip and the thickness of the weathered zone. This area may be good prospects for drinking boreholes with high expectations.

CONCLUSION

The application of electrical resistivity method of geophysical prospecting utilizing VES technique has provided detailed information on the thickness and hydrogeoelectrical characteristics of the aquifer in the investigated area. The presence of thick and highly prolific aquifer constitutes an adequate water resistivity values for different encountered formations has been established using the interpreted VES results which can help to understand the subsurface lithological variation prevailing in the area. The groundwater occurs basically under unconfined condition at depths of about 1.7m in VESORU14 to 24.7m in VESORU25. The shallow aquifer may be vulnerable to contamination seepages emanating from the surface and migrating and circulating to the subsurface with unprecedented impacts on the groundwater system of the study area because of its characterized thin overburden. The presence of Clay lenses at different depths may form confining layers. The thickness of the underlain granite-gneissic layer could not be completely evaluated as the investigation ended within this layer. This study has revealed the general subsurface information and has provided an insight into the subsurface shallow aquifer systems as well as delineated appropriate locations for groundwater development program in the area.

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