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Archives of Applied Science Research, 2010, 2 (2): 24-34
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Mapping of unconfined aquifer using vertical electrical sounding (VES) at Lagos State University (Lasu), Ojo

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Abstract

Geophysical investigation involving the use of electrical resistivity was carried out at LASU, Ojo with a view to mapping out its unconfined aquiferous zone. A total of eight vertical electrical soundings (VES) were taken and the H and K curves were used in matching the graphs. The results acquired from the survey were subjected to iteration software (win Resist) which delineated four geo-electric layers namely: topsoil, sand, sandy clay and clay. The results observed in VES1-4(AA) and VES 5-8(AA`) establish that unconfined aquifer is between the thickness of 0.5m-2.9m with resistivity ranging from 102.1-322.9 (Ωm) *in both geo-electric sections.*

Keywords: Unconfined Aquifer, groundwater, water table, artesian well.

INTRODUCTION

An aquifer is an underground layer of water bearing permeable rock or unconsolidated materials from which groundwater can be usefully extracted using a water-well [3]. There are two end members in spectrum of types of aquifers; confined and unconfined (with semi confined aquifer being in between them). Ground water below a layer of solid rock or clay is said to be a confined aquifer [7,5], the rock or clay being the confining layer. An unconfined aquifer is the one that is open to receive water from the surface, and whose water table surface is free to fluctuate up and down, depending on the recharge/discharge rate**.** There are no overlying "confining beds" of low permeability to physically isolate the ground water system. The water table in such an aquifer represents the top of the zone of saturation, below which all of the pores and open spaces in between grains of sand and gravel are entirely filled with water. This type of aquifer is recharged across its entire surface by infiltrating rain water and by lakes and streams leaking into the subterranean system. During the rainy season, the water table will typically rise since there is usually abundant water on the surface. During the dryer months of the year, the water table will slowly drop as there is less recharge, and the groundwater slowly moves to other parts of the aquifer. Also, use of the ground water by pumping wells will also lead to a decline in the water table surface. An aquifer in an unconfined state has entirely different storage properties than an aquifer in the confined or artesian state.

Groundwater comes from rain that seeps into the ground. Gravity pulls the other water down through the spaces between the particles of soil or through cracks in rocks, and eventually the water reaches a depth where all openings in soil or rock are filled with water. This is called the saturated zone**.** The water in this zone is called groundwater.

The groundwater in confined aquifer is usually under pressure and causes water in an artesian well to rise above the aquifer level; the well overflows and is called a flowing artesian well. Aquifers that are not below a confining layer are called unconfined aquifer. Because the top of these aquifers is the water table, they are also called water table aquifers. In a water table aquifer, the water level in a well is the same as the water table level outside the well.

For a groundwater reservoir to be classified as unconfined, it must be shown that it is not confined by impermeable material. Horizontal permeability in sedimentary rocks and sediments is commonly greater than the permeability at right angles to the bedding planes in these materials. Thus, it is common to have a reduction in vertical permeability above an aquifer creating a degree of confinement, which in most areas varies widely from place to place above the water table of the groundwater reservoir. Water in unconfined aquifers is subject to losses due to plant uptake and evaporation.

Location and Geology of the study area

Lagos State University, Ojo is located along Lagos- Badagry Expressway in Ojo local government area. It is easily accessible with network of roads. Its geographical coordinates are 6^{o}45'N and 2^{o}49'E.

Lagos State is situated at the southwest of Nigeria and therefore falls within the sediments terrain of the country. The City of Lagos forms part of a sedimentary basin, made up of a sequence of clay and sand, with shale and limestone intercalations. With an estimated population of over 15 million inhabitants, the City of Lagos is the most populous and most commercially vibrant urban centre in Africa. The soil is composed of bedrock that is sedimentary and mainly of alluvial deposits while the soils are largely loose.

The main relief of the area is the low lying nature of its terrain, more than half of the entire area has the elevation of between 3 and 6 metres high above the sea level [6,7]. Their exist reddish and brown loamy soil in the upland and light gray sand mixed variously with varying proportion of vegetation matters on the lowland.

MATERIALS AND METHODS

Methodology

Resistivity soundings and mappings are geophysical methods to provide an image of the underground resistivity by non-distractive means [8,9]. Since the electric resistivity of the underground depends on properties such as water content, electric resistivity methods help to get information about groundwater level, moisture distribution near the surface and artificial buildings like dams etc.

Theory of electrical resistivity method

The resistance of a resistive object determines the amount of current through the object for a given potential difference across the object, in accordance with Ohm's law [9],

$$I = \frac{V}{R} \cdots\cdots\cdots (1)$$

From Ohm's law,

$$R = \frac{\Delta V}{I} \cdots\cdots\cdots (2)$$

The resistance R of a conductor of uniform cross section can be computed as

$$R = \rho \frac{L}{A} \cdots\cdots\cdots (3)$$

Where,
L is the length of the conductor, measured in metres (m),
A is the cross sectional area, measured in square metres (m^2),
ρ is the electrical resistivity (also called specific electrical resistance) of the material, measured in Ohm meter (Ωm) resistivity is a measure of the materials ability to oppose electric current.

Comparing equations (2 and (3) we have

$$\frac{\Delta V}{I} = \rho L \big/ A$$

$$\rho = \Delta V A \big/ IL \cdots\cdots (4)$$

Equation (4) can be used to determine the resistivity of any homogenous and isotopic medium provided the geometry is simple. For semi-infinite medium, however, the resistivity at every point must be defined. If we allow parameters (A) and (L) to infinitesimal size then:

$$\rho = \frac{L \rightarrow 0 \frac{\Delta V}{L}}{A \xrightarrow{Lim} 0 \frac{I}{L}} = \frac{E}{J} \cdots\cdots\cdots (5)$$

Where E = Electric field and J = Current density

$$\therefore J = \frac{E}{\rho} = \sigma E \cdots\cdots\cdots (6)$$

But E is the gradient of a scalar potential

i.e. $E = -\nabla V$

$$j = -\sigma \nabla V$$

Current crossing the spherical body of surface area A is

$$I = JA = 4\pi r^2 J \cdots\cdots\cdots (7)$$

$$I = 4\pi^2 P \frac{\partial v}{\partial r}$$

$$\therefore \ \partial v = \frac{\partial}{\partial r}$$

$$\therefore v = -\int \frac{IP}{4\pi r^2} \partial r$$

$$v = \frac{IP}{4\pi r^2} \partial r$$

In practice, the earth structure is an approximate of hemisphere than the current density

$$J = \frac{I}{A} = \frac{I}{2\pi r^2}$$

$$E = \frac{IP}{2\pi r^2}$$

$$\partial v = \frac{IP}{2\pi r^2} \partial r$$

$$V = -\int \frac{IP}{2\pi r^2}$$

$$V = \frac{IP}{2\pi r}$$

This is the potential of P due to a current at C, the surface of the earth.

Field procedure

A geophysical survey was carried out at Lagos State University (Ojo Campus) using vertical electrical sounding (VES). At each VES station, electrodes were placed in a straight line and the inter-electrode spreads were gradually increased about a fixed centre. The current was sent into the ground and the potential difference (V) due to this current was measured and recorded against the electrode spacing. These values of current (I) and potential of the electrode configuration adopted, to get the apparent resistivities (Pa).

Data Acquisition and Presentation

A maximum electrode spacing of 120m was employed during data acquisition. VES 1-4(AA) were sounded in the same place as VES 5-8(AA) but at different time intervals. The profile of VES 1-4 (AA) and VES 5-8 (AA`) were each 120m long.

The apparent resistivities values were plotted against the current electrode spacing $\left(AB/2\right)$ to form sounding curves. The field curves obtained are then matched with theoretical curves. Matching starts from the left hand side of the profile to the right hand side. The profile is adjusted to the left, right, up and down until a good fit is obtained between the theoretical curve and the field curve. In acquiring the second layer resistivity value, the field curve is superimposed on the appreciate auxiliary point charge allowing already marked point or origin to coincide with the origin of the auxiliary point chart thus tracing out the curve which corresponds to the K value on the log-log sheet. The field curve is again superimposed on the appropriate axis and the already derived auxiliary curve is made to pass through the master curve origin until the best point is obtained. The second part of the origin of the K_2 value is then cross matched. The above process is repeated for each number of layers until the whole curve is exhausted.

RESULTS AND DISCUSSION

Geo electric sections of VES 1-4 (AA)
The geo-electric section (figure 9) consists of VES 1, 2, 3 to 4.
Only 5 layers were observed in VES 1, 2 and 4 while 6 layers were observed in VES 3.
For VES 1, 2, 3 and 4, the first layer is the top soil with resistivity ranging from 152.8 (Ωm) to 254.3 (Ωm) and thickness ranges from 0.6m to 0.9m. Their second layer is sand with resistivity ranging from 170.0 (Ωm) to 322.9 (Ωm) and thickness ranges from 0.5m to 2.9m.

For VES 1, 2 and 4, their third layer which is sandy clay was inferred with resistivity ranging from 581.0 (Ωm) to 885.7 (Ωm) and thickness ranging from 5.3m to 9.3m while in the third layer for VES 3, sand was inferred with resistivity of 104.9 (Ωm) and thickness of 1.9m.

In the forth layer clay was inferred with resistivity ranging from 86.5 (Ωm) to 94.2 (Ωm) and thickness ranging from 22.4m to 31.6mfor VES 1,2 and 4 while sandy clay was inferred with resistivity 937.9 (Ωm) and thickness of 1.5m for VES 3.

In the fifth layer sandy clay was inferred with resistivity ranging from 915.3 (Ωm) to 3445.1 (Ωm) for VES 1,2 and 4. Their is no thickness because the curve was terminated at this layer while in the fifth layer for VES 3 clay was inferred with resistivity of 50.4 (Ωm) and thickness of 11.6m.

In the sixth layer, sandy clay was inferred for VES 3 with resistivity of 2606.7 (Ωm); have no thickness because the curve terminated at this layer.

Geo electric sections of VES 5-8 (AA`)
This geo-electric section (figure 10) consists of VES 5, 6, 7 and 8.
Only 5 layers were observed in VES 5, 7 8 while VES 6 has 6 layers.

For VES 5, 6, 7 and 8, their first layer which is the top soil has resistivity ranging from 149.7 (Ωm) to 209.7 (Ωm) and thickness ranging from 0.5m to 1.0m. Their second layer which is sand was inferred with resistivity ranging from 113.6 (Ωm) to 276.4 (Ωm) and thickness ranging from 0.5m to 1.6m.

For VES 5, 7 and 8, their third layer is sandy clay with resistivity ranging from 407.4 (Ωm) to 639.8 (Ωm) and thickness ranging from 5.4m to 7.4m while in the third layer for VES 6, sand was inferred with resistivity 102.1 (Ωm) and thickness of 1.8m. Their fourth layer which is clay was inferred with resistivity ranging from 59.6 (Ωm) to 116.0 (Ωm) and thickness ranging from 15.0m to 36.1m while in the fourth layer for VES 6, sandy clay was inferred with resistivity 927.6 (Ωm) and thickness of 1.6m.

Table 1: Summary of interpreted results of VES 1-4 (AA)

Ves no	Geo-electric layers	Resistivity $P\ (\Omega m)$	Thickness (m)	Depth (m)	Sediment inferred	Rms error
1	1	254.3	0.8	0.8	Top soil	3.9
	2	170.0	2.5	3.4	Sand	
	3	790.0	9.3	12.7	Sandy clay	
	4	91.7	22.4	35.7	Clay	
	5	915.3	-	-	Sandy clay	
2	1	178.6	0.9	0.9	Top soil	2.7
	2	192.6	1.2	2.1	Sand	
	3	581.0	5.3	7.4	Sandy clay	
	4	86.5	31.6	39.0	Clay	
	5	1265.6	-	-	Sandy clay	
3	1	152.8	0.6	0.6	Top soil	4.5
	2	322.9	0.5	1.0	Sand	
	3	104.9	1.9	2.9	Sand	
	4	937.9	1.5	4.4	Sandy clay	
	5	50.4	11.6	16.1	Clay	
	6	2606.7	-	-	Sandy clay	
4	1	248.3	0.7	0.7	Top soil	4.0
	2	170.6	2.9	3.6	Sand	
	3	885.7	8.2	11.8	Sandy clay	
	4	94.2	30.4	42.2	Clay	
	5	3445.1	-	-	Sandy clay	

Table 2: Summary of interpreted results of VES 5-8 (AA)

Ves no	Geo-electric layers	Resistivity $P\ (\Omega m)$	Thickness (m)	Depth (m)	Sediment inferred	Rms error
5	1	176.4	0.9	0.9	Top soil	2.9
	2	113.6	0.5	1.4	Sand	
	3	459.0	7.4	8.7	Sandy clay	
	4	72.3	26.2	35.0	Clay	
	5	1024.9	-	-	Sandy clay	
6	1	149.7	0.5	0.5	Top soil	4.7
	2	276.4	0.5	1.1	Sand	
	3	102.1	1.8	2.9	Sand	
	4	927.6	1.6	4.5	Sandy clay	
	5	37.0	8.7	13.2	Clay	
	6	2464.5	-	-	Sandy clay	
7	1	209.7	1.0	1.0	Top soil	2.6
	2	151.2	1.5	2.5	Sand	
	3	639.8	6.8	9.3	Sandy clay	
	4	116.0	36.1	45.4	Clay	
	5	1080.2	-	-	Sandy clay	
8	1	168.0	0.8	0.8	Top soil	2.5
	2	184.2	1.6	2.5	Sand	
	3	407.4	5.4	7.9	Sandy clay	
	4	59.6	15.0	22.9	Clay	
	5	1086.9	-	-	Sandy clay	

In their fifth layer sandy clay was inferred with resistivity ranging from $1024.9(\Omega m)$ to $1086.9(\Omega m)$ and has no thickness because the curve was terminated at this layer while in the fifth layer for VES 6, clay was inferred with resistivity of $37.0(\Omega m)$ and thickness of 8.7m.

For VES 6, sandy clay was inferred with resistivity of $2464.5(\Omega m)$ in the fifth layer; has no thickness because the curve terminated at this layer.

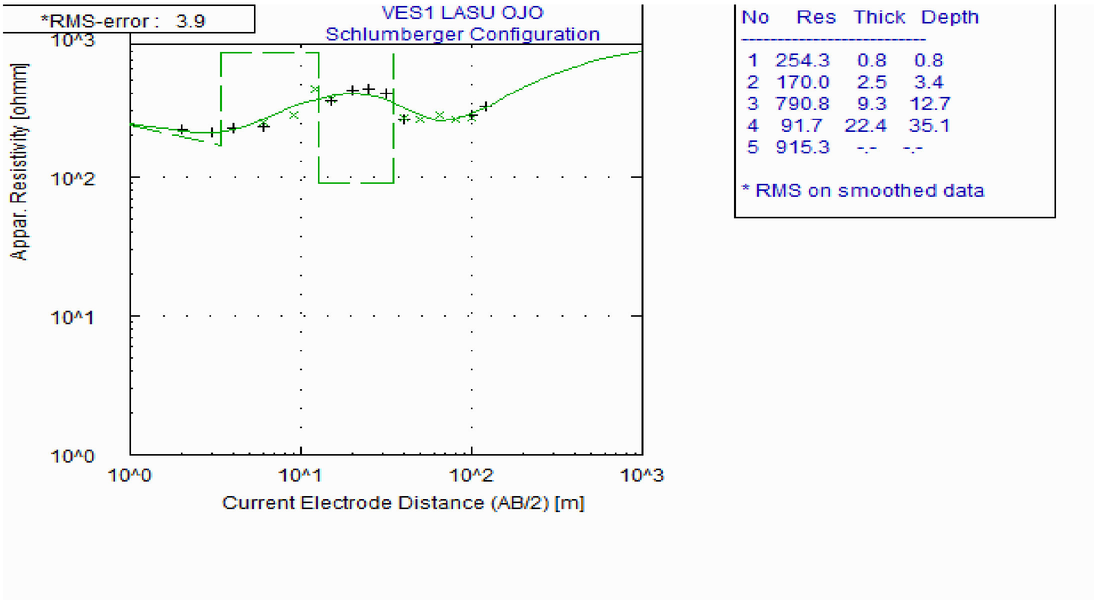


Figure 1.1

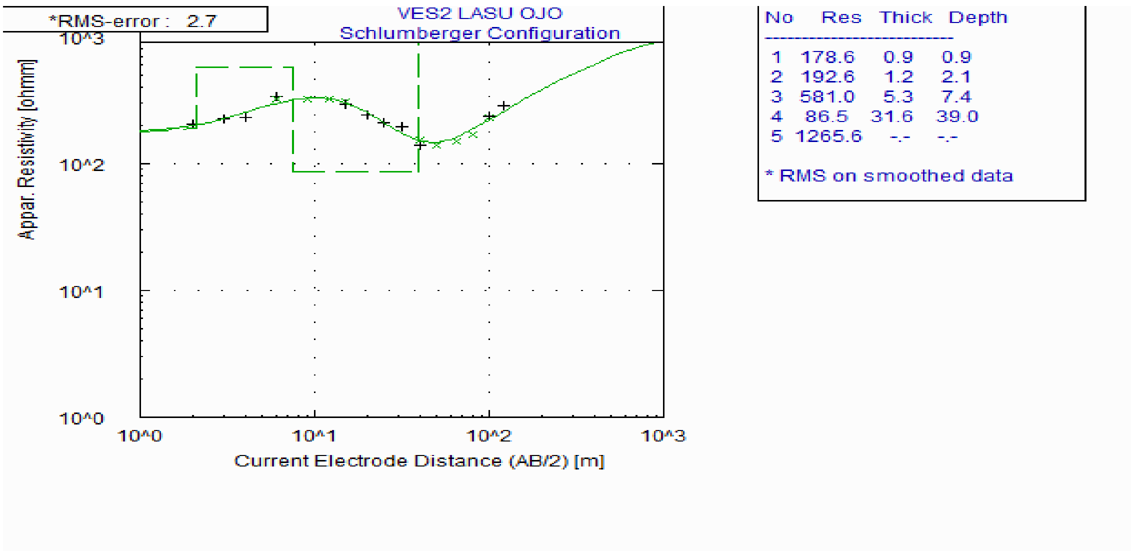
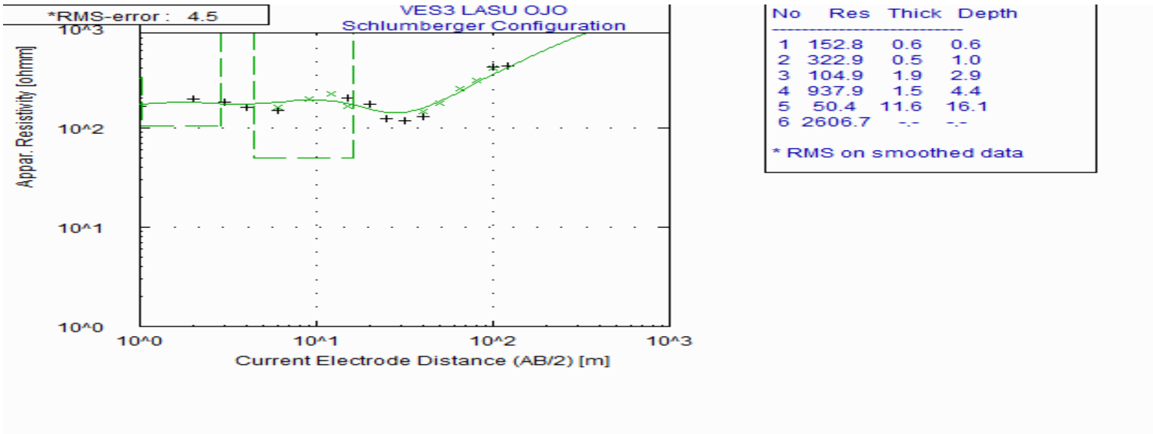


Figure 1.2



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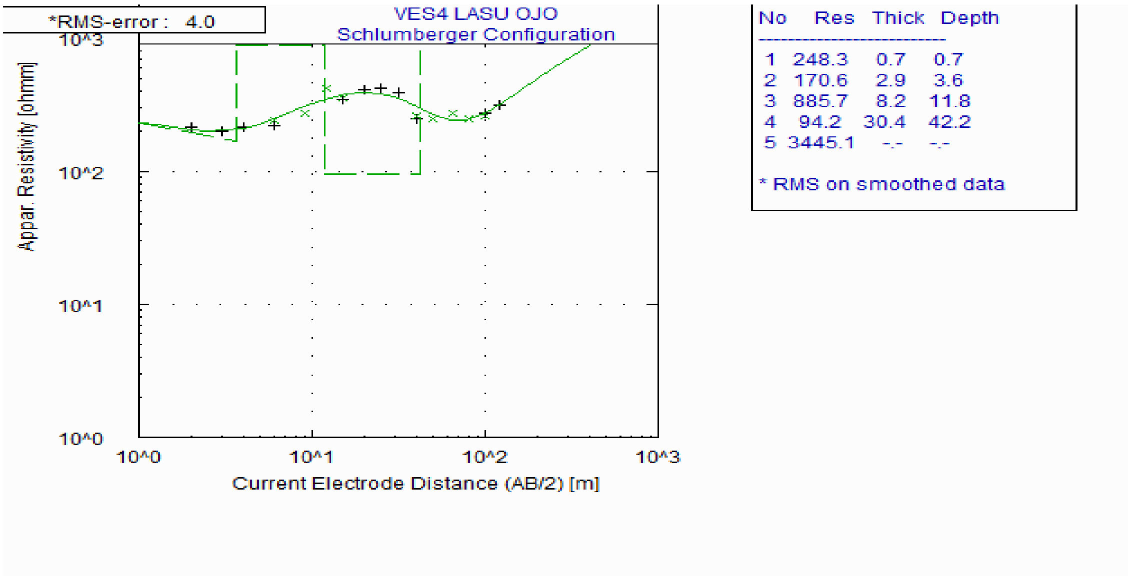

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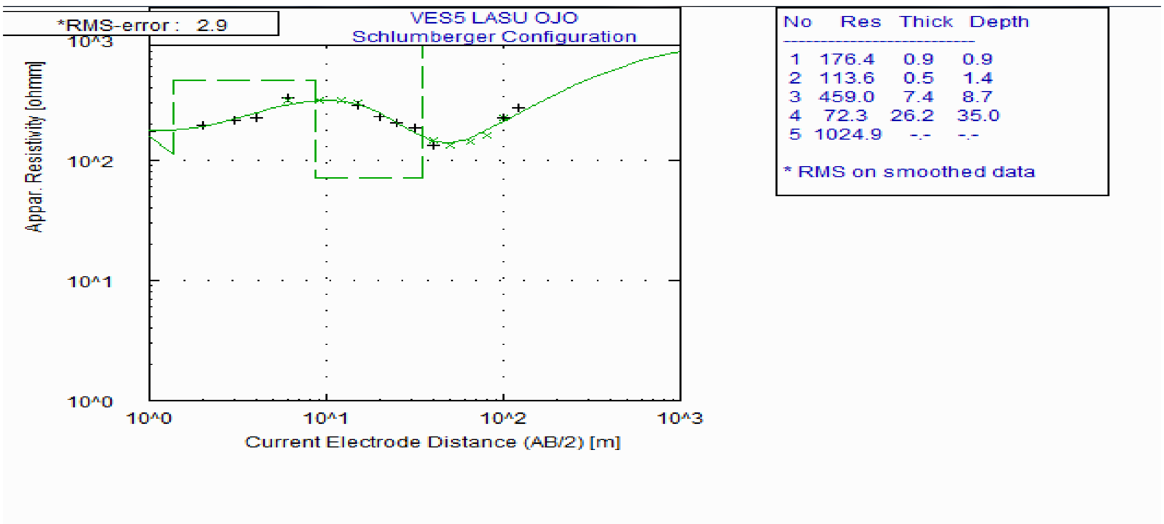
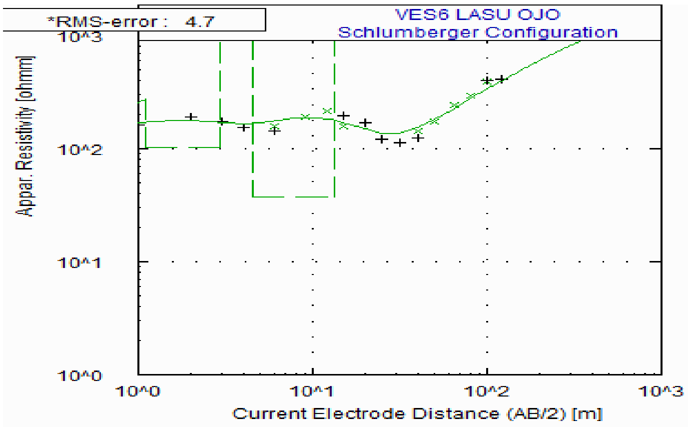


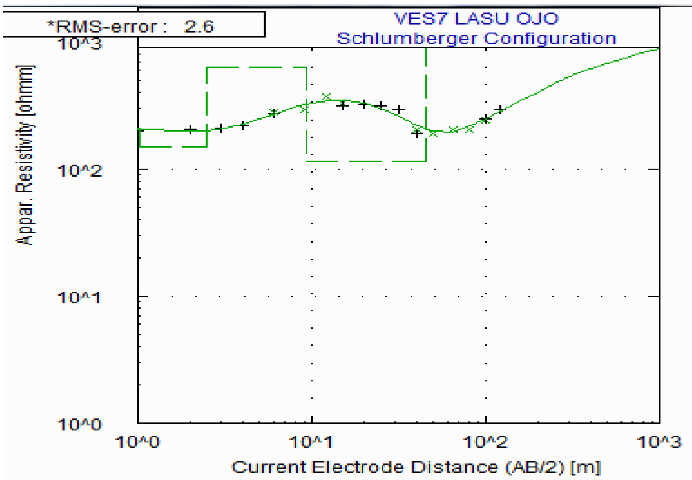
Figure 1.5



No	Res	Thick	Depth
1	149.7	0.5	0.5
2	276.4	0.5	1.1
3	102.1	1.8	2.9
4	927.6	1.6	4.5
5	37.0	8.7	13.2
6	2464.5	-.-	-.-

* RMS on smoothed data

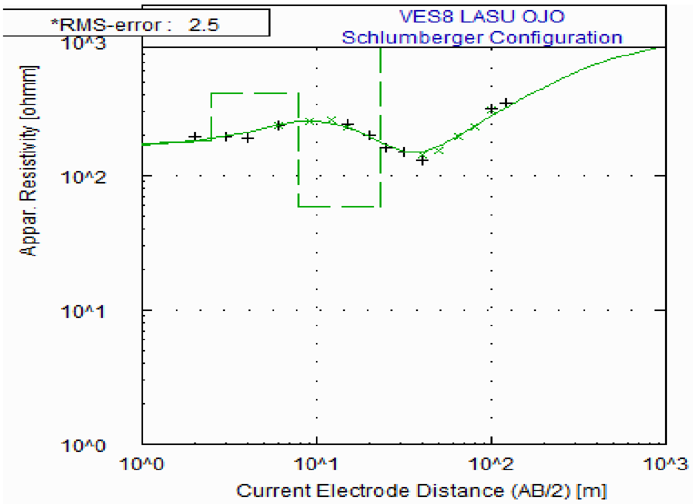
Figure 1.6



No	Res	Thick	Depth
1	209.7	1.0	1.0
2	151.2	1.5	2.5
3	639.8	6.8	9.3
4	116.0	36.1	45.4
5	1080.2	-.-	-.-

* RMS on smoothed data

Figure 1.7



No	Res	Thick	Depth
1	168.0	0.8	0.8
2	184.2	1.6	2.5
3	409.4	5.4	7.9
4	59.6	15.0	22.9
5	1086.9	-.-	-.-

* RMS on smoothed data

Figure 1.8

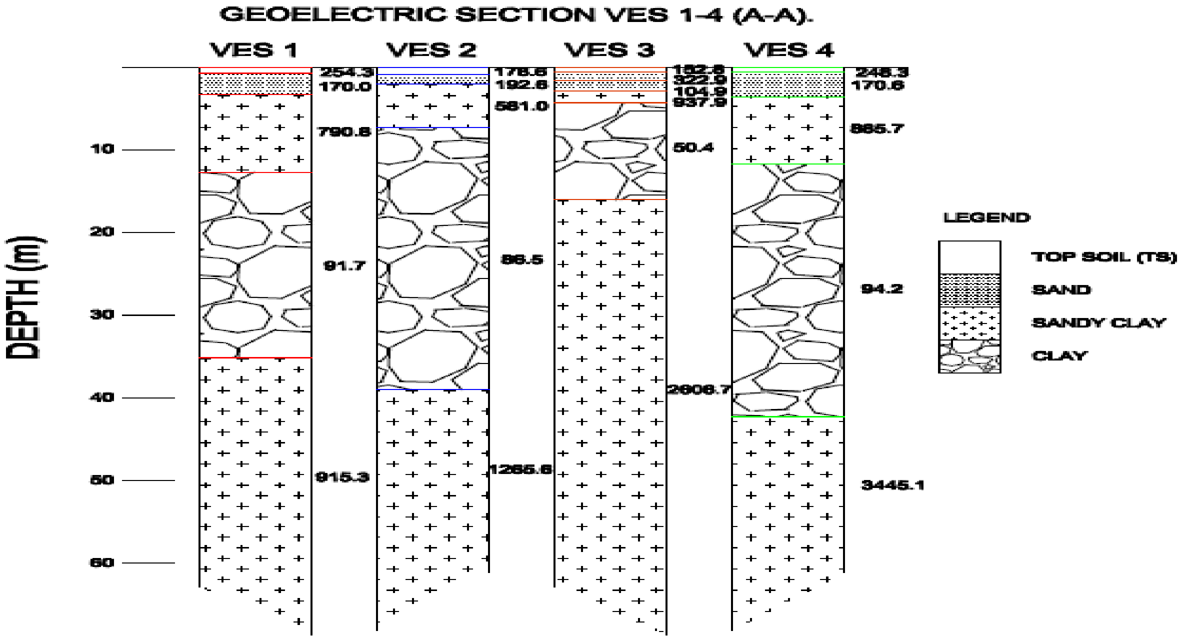


Figure 2

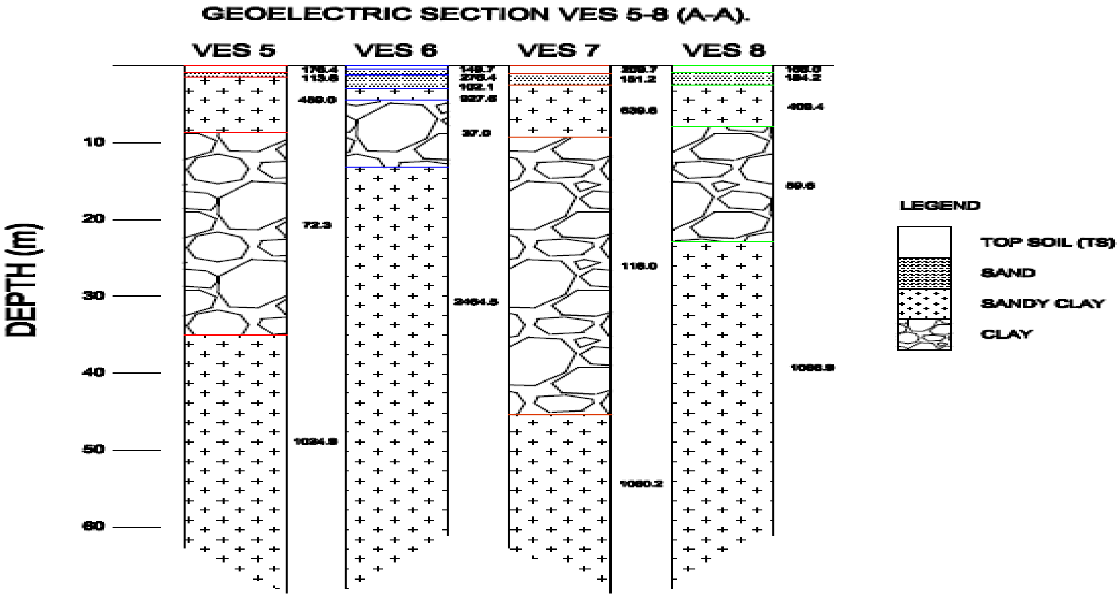


Figure 3

CONCLUSION

The results from geo-electric section of VES 1-4(AA) and VES 5-8(AA`) delineated 4 geo-electric layers namely topsoil, sand, sandy clay, and clay.

In conclusion, it has shown that there is similarity in the soil formation or structure of the geo-electric section of VES 1-4(AA) and VES 5-8(AA`) but with difference in depth and resistivity for each layer. The map of the unconfined aquifer is seen in each layer as follows.

In VES 1, the second layer signifies the sand formation which has a thickness of 2.5m with resistivity of 170 (Ωm), in VES 2; the second layer has sand formation which has a thickness of 1.2m with resistivity of 192.6 (Ωm). In VES 3, sand formation was also observed in the second and third layers which have a thickness of 2.4m with resistivity of 322.9-104.9 (Ωm); in VES 4, sand formation was present in the second layer which has a thickness of 2.9m with resistivity of 170.6 (Ωm). In VES 5, the second layer signifies sand formation with a thickness of 0.5m and resistivity of 113.6 (Ωm); VES 6 has sand formation in the second and third layer with thickness of 2.3m and resistivity of 276.4-102.1 (Ωm). In VES 7, sand formation was observed in the second layer which has thickness of 1.5m with resistivity of 151.2 (Ωm) and finally in VES 8, the second layer signifies sand formation which has a thickness of 1.6m with resistivity of 184.2 (Ωm).

It was observed that water can be gotten from the thickness of 1.2m to 2.9m with resistivity ranging from 104.9 (Ωm) to 322.9 (Ωm) in geo-electric section of VES 1-4(AA) but it is not suitable for drinking because it is unprotected(unconfined) that is, very close to the topsoil.

It was also observed that water can be gotten from the thickness of 1.1m to 2.9m and resistivity ranging from 102.1 (Ωm) to 276.4 (Ωm) in geo-electric section of VES 5-8(AA`) but it is not suitable for drinking because it is unconfined, that is, very close to the topsoil.

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