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Application of Electrical Resistivity Method in Delineating Brine Contaminated Aquifer in Abakpa Area, Lower Benue Trough, Nigeria

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Abstract:- Electrical resistivity prospecting using Vertical Electrical Sounding (VES) technique was conducted in Abakpa Area of Cross River State. The study was meant to delineate fresh water aquifer and brine (saline water) contaminated zones, identify locations not infiltrated by brine, estimate aquifer thickness and determine the depths to fresh water producing aquifer in the area. Fifteen soundings were carried out using Schlumberger electrode configuration with a maximum current electrode spread of 500m. A Syscal resistivity meter model SS-MP-ATS was used to measure the ground resistance in order to compute the apparent resistivity of the subsurface. Lithology log data of some boreholes in the area and resistivity software was used to enhance interpretation. The study revealed three to seven geoelectric layers. The saline water and brackish water saturated layers have resistivity ranging from 0.3Ωm to 12.4Ωm while fresh water saturated aquifer has resistivity from 12.5Ωm and above. Both saline and fresh water aquifer occur in shale, siltstone and sandstone formation. The depth to aquifer in the location ranges from 7.8m to 56.9m while the thickness of aquifer ranges from 6.8m to 41.3m. The study area is characterized by multi aquifer system with some locations producing both saline and fresh water aquifer. The study has revealed locations significantly infiltrated by brine (saline water) to include: Lacristo Hotel, Cross River University of Technology, Basin road and River road while Santa Maria, Hillary palms, Obi-odu estate, Holy Trinity Catholic Church, Orokoro road, Federal Science School road, Michael Ugoma Street and Jovonne lane have sufficient volume of untapped fresh water aquifer. It has also been established from this research that drilling boreholes to specification will help to reduce the degree of abandonments due to brine infiltration and poor water quality since the vulnerable zones have been delineated.

Keywords:- *Brine, Contaminated Zones, Electrical Resistivity, Vulnerable Zones, Delineated Geoelectric Layers.*

I. INTRODUCTION

Brine intrusion is the gradual infiltration of salt water into fresh water aquifer. Studies have shown that the intrusion is occasioned by the induced flow of sea water into fresh water aquifer. The induced gradients usually result in migration of salt water from the sea towards a borehole where ground water is being pumped from aquifers that are in hydraulic connection with the sea (Abdalla *et al.,* 2010). Brine intrusion into coastal aquifer has long been identified as a serious problem around the world because it constitutes the commonest of all forms of groundwater pollution (Adepelumi *et al.,* 2009). Although there are no known related publications on the study area, various geophysical researches have been carried out in the world to delineate saline water contaminated zone and also demarcate the interface between saline and fresh water. Over exploitation of coastal aquifers, tidal influences and shallow wells in the coastal part of Nigeria have been identified as contributing factors to salt water intrusion into fresh water aquifer (Bear *et al.,* 1999; Yakirevich *et al.,* 1998; Edet & Worden 2009). Lee and Song (2007), studied the salt water intrusion problem in coastal area of South Korea. They discovered that the infiltration of salt water into fresh water aquifer is due to high groundwater withdrawals. Excessive withdrawals have led to cases where wells, springs and wetland have gone dry. Lake levels have dropped; streams have been reduced with great harm to wildlife and human beings. Frohlich *et al.,* (2002), revealed that the deterioration of fresh water quality due to natural sea water infiltration affects the balanced life of the narrow coastal strip of Rhodes Island, United State of America. The large resistivity contrast between salt water saturated formation has been used to study salt water intrusion in coastal areas (Bates and Robinson, 2000; Hwang *et al.,* 2004). According to British Geological Survey (BGS) (2003), shallow aquifers are vulnerable to pollution from domestic, agricultural and industrial wastes. It has been reported that at lower precipitation and warmer temperatures, the (aquifer) recharge rate will be less due to lack of groundwater present in the subsurface and the increased evaporation rate will however increase the level of salinity (Ranjan, 2007). Coastal aquifers in Nigeria straddling from Lagos state in the west to Cross River in the east have been reported to be affected by sea water intrusion (Edet and Okereke, 2001; Edet, 2008; Edet and Worden, 2009). Excessive pumping of coastal aquifer

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causes a fluctuation in the amount of fresh water moving towards the coastal discharge areas thereby allowing the ocean water to move inland into the aquifer system. This causes an increase in chlorine concentrations in the water and less available storage spaces for the fresh water in the aquifer. In other words, it will result in a decrease in the level of underground water table and also reduce the abundance pressure and storage capacity for fresh water in the aquifer. However, a combinations of these factors will make the zone of dispersion to move inland and drastically reduce the fresh water that is available for the well (Ranjan, 2007). Electrical resistivity method has been used to solve such environmental related problems, especially relating to contamination of subsurface soil, groundwater and aquifer vulnerability (Loke, 2004; Sorensen *et al.*, 2005; Atakpo and Ayolabi, 2009). Barret *et al.*, (2002) effectively used direct current resistivity method to investigate perched water tables containing saline water and fresh water lenses in Southern Australia. Since virtually all human and industrial activities on earth require the use of water particularly groundwater, therefore there is need to preserve this resource. In doing this, a good knowledge of its origin and the environment where it accumulates is necessary to understand the manner in which it can be exploited (Nwankwoala, 2011). Vertical Electrical Sounding (VES) was adopted as choice of electrode because Ushie and Nwankwoala, (2011), showed that it is essential in the deduction of number of geo-electric layers, estimation of depth to bedrock, depth to water table and aquifer thickness. Numerous measurements and studies have established Correlation between resistivity values and ground water salinities. The general assessment of the result showed that the portions of aquifers saturated with sea water present resistivity values that are below 3Ωm, portions saturated with brackish water exhibit resistivity values between 3Ωm and 10Ωm (Zarroca *et al.,* 2011, Goldman and Kafri 2004).

A. Description of Study Area

The study area, Abakpa lies between latitudes $06^0 35'$N and $06^0 37'$N and longitudes $08^0 47'$E and $08^0 46'$E in Ogoja Local Government Area of Cross River State (Figure 1). Accessibility to the study area is aided by major tarred roads, minor untarred roads and footpaths (Figure 2). It is part of Cross River Plain and contributes to the Southern edge of the Lower Benue Trough, Nigeria. The area experiences the tropical type of climate with wet and dry season between April to October and November to March respectively. The average rainfall is about 165.77mm. Precipitation is lowest in December with an average of 12mm and highest in September averaging 295mm (Edet and Ekpo, 2008). Available data for temperature from the Ogoja Meteorological Station (1989 - 2002) showed that the maximum temperature for the dry months ranges from 33.1^0C to 35.8^0C compared to the wet months with temperature in the range of 30.2^0C to 34.1^0C.

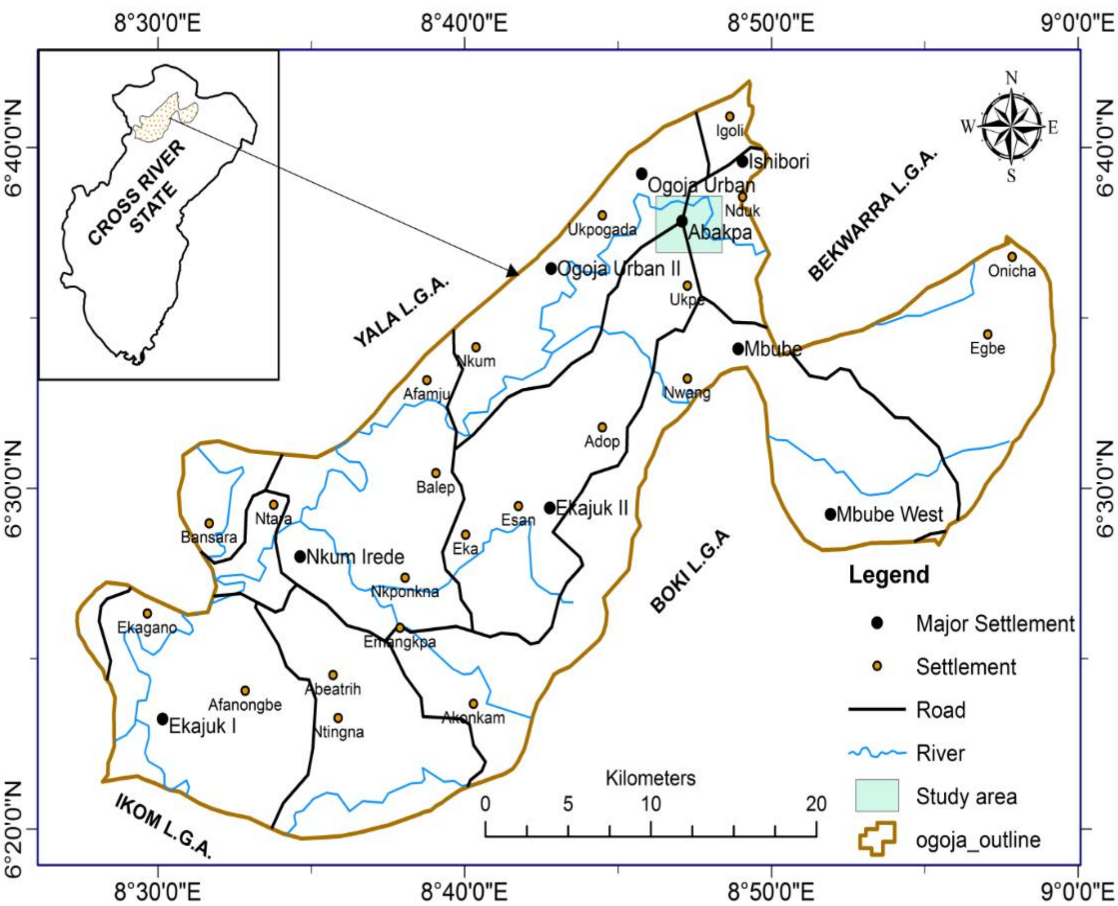

Fig 1:- Map of Ogoja Local Government Area Showing the Study Area (Abakpa) (Modified from Nigerian Geological Survey Agency 2010)

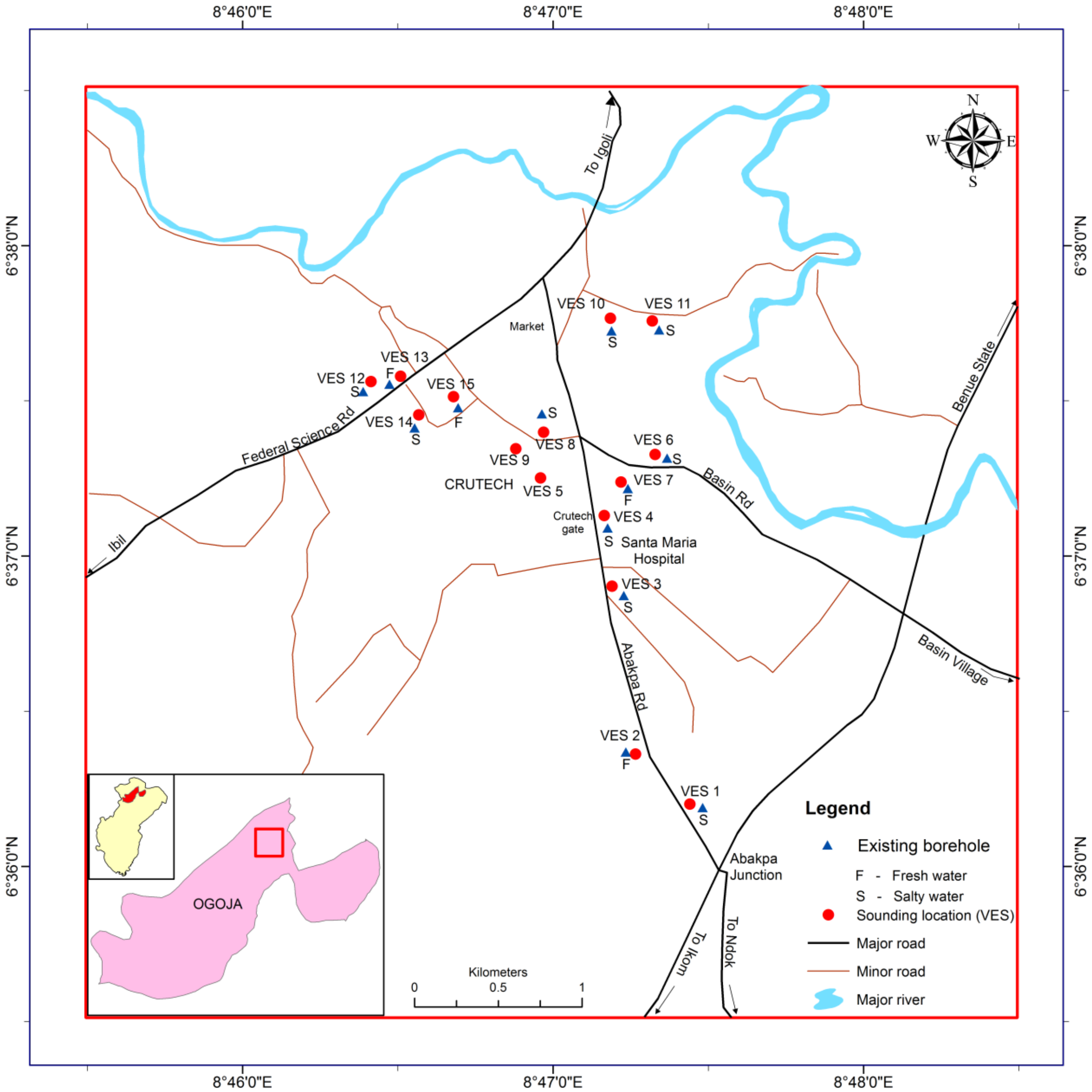

Fig 2:- Map of Abakpa showing VES and sampled borehole locations

B. Geology of the Study Area

The study area is part of the Asu River Group. The Asu River Group is interpreted as sediment of the first transgressive cycle into the Lower Benue Trough. It consists of arkosic sandstones (of Aptian age) and middle marine shale (Abakiliki shale) which become gradually more shally in its uppermost part (Reyment, 1965). The arkosic sediment was formed from the extensive weathering of basement rocks which was invaded by alkaline basaltic rocks prior to the initial marine flooding of the middle Albian times. The study area (Abakpa) is characterized by Cretaceous sediments resting on the Obudu Basement complex (Nigerian Geological Survey Agency 2010) (Figure 3). Its rocks consist of predominantly dark grey fractured shale and sandstones with localized siltstone and limestone units with minor lenses of clay materials (NGSA 2010). (The aquifer system is often exploited by hand dug wells, shallow and deep boreholes

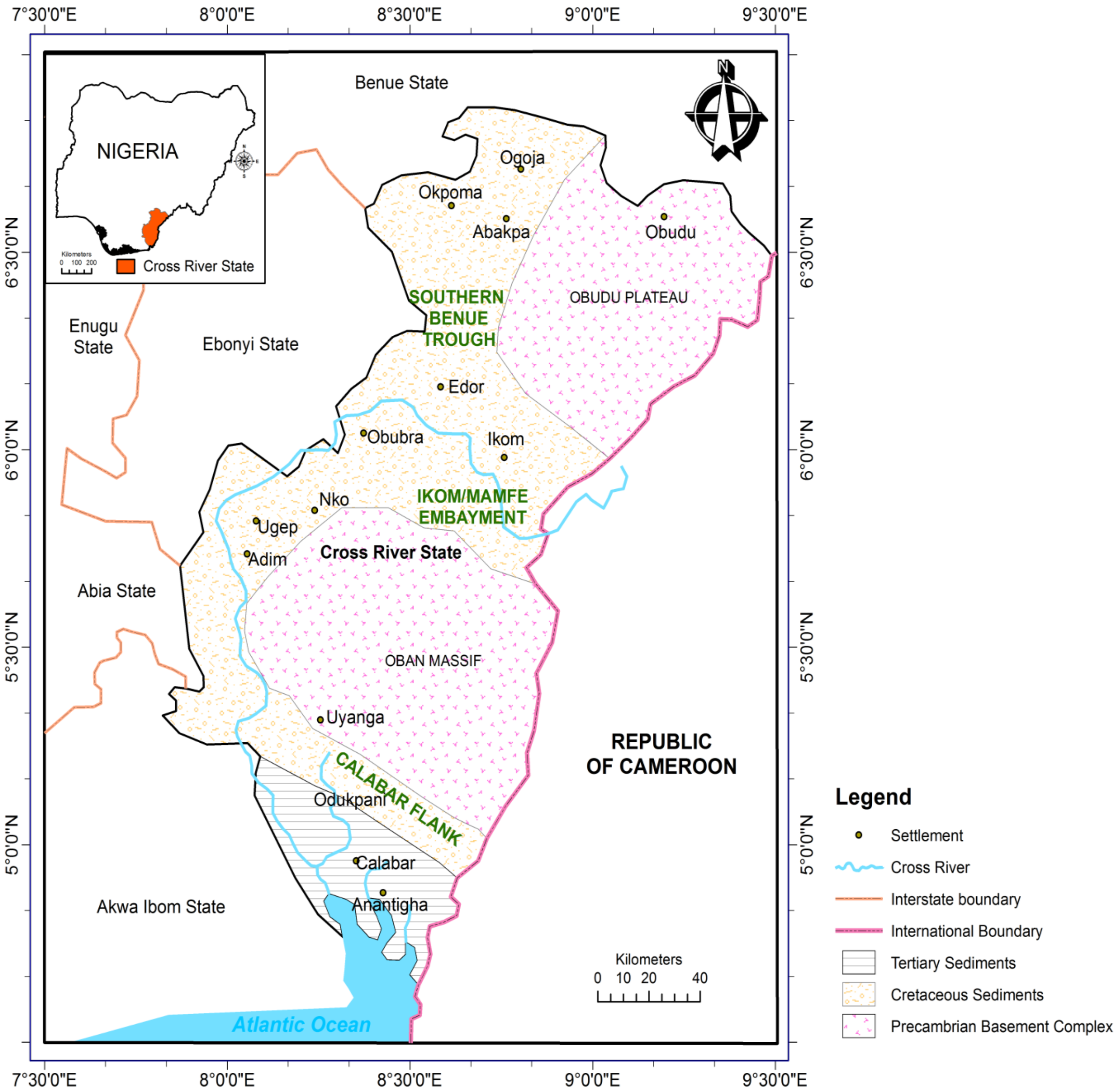

Fig 3:- Geologic Map of Cross River State (Modified from Nigerian Geological Survey Agency 2010)

II. METHOD

A reconnaissance survey was conducted to the area in order to access the road network in the study location, determine the borehole distribution in the area, carry out in-situ test of water samples collected from boreholes in the area to verify the presence (or otherwise) of salt. The Syscal resistivity meter (Model SSR-MP-ATS) designed and manufactured by Iris instrument was used to measure the resistance that the ground offer to the flow of current. Fifteen (15) Vertical Electrical Soundings (VES) were carried out. The Schlumberger electrode configuration was used in the investigation with a maximum current electrode separation (AB) of 500m. The measurement of the resistance was made by injecting current into the ground through two current electrodes (A and B) and measuring the resulting potential difference at two potential electrodes (M and N). The current electrodes spacing (A and B) was kept at a greater distance than the potential electrode separation (M and N) though all the electrodes were maintained at equal distance from the center of the sounding. The half current electrode spacing (AB/2) was maintained at a distance of 1, 1.5, 2, 3, 3, 4, 4, 5, 6, 8, 8, 10, 10, 15, 20, 30, 40, 40, 50, 60, 80, 80, 100, 100, 125, 150, 200, 250 (m) while that of potential electrode (MN/2) was maintained at 0.25, 0.5, 1, 2.5 and 10 (m) respectively. The apparent resistivity value was calculated by multiplying the resistance by the appropriate geometric factor for Schlumberger array.

$$\rho_a = k\frac{\Delta v}{I}$$

(1)

Where: K = geometric factor, V = potential drop across the electrodes, the ratio $\frac{\Delta v}{I}$ = the resistance.

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Equation (1) is the generalized electric resistivity model for calculating the apparent resistivity. For Schlumberger electrode spread, the apparent resistivity model is calculated from:

$$\rho_a = \frac{\pi v}{4I}\left(\frac{Y^2 - a^2}{a}\right)$$

(2)

Letters y and a in equation (2) are distances between current and potential electrodes. The apparent resistivity values were plotted against half electrode spacing (AB/2) for each of the geoelectric sounding using computer software. Resistivity curves and models were generated showing the number of layers, depth of penetration and thicknesses of the various strata. The modeling was done iteratively until the least percentage of root mean square (RMS) error was achieved. Lithology logs of some boreholes in the area produced by Ananan Groundwater Engineering Ltd (Unicef Project) was used together with the local geology of the study area to aid data analysis and interpretation.

III. RESULTS AND DISCUSSION

The field data acquired from fifteen locations were interpreted qualitatively by inspection with standard curves (A, K, H, Q curve type). Field curves were generated and KH, KHK, and HKH were the major dominant curves in the area (Table 1).

VES No.	Location	Curve type	No of Layers
1	Lacristo Hotel	H	3
2	Noble Suite	KH	4
3	Santa Maria	KH	4
4	Crutech	KH	4
5	Hillary Palms	KHK	5
6	Basin Road	QHKH	6
7	Obi Odu Estate	KQHK	6
8	Holy Trinity Catholic Church	KHKHK	7
9	Orokoro Road	HK	4
10	Njerman lane	KHKHA	7
11	River Road	QH	5
12	Federal Science School Road	KHK	5
13	Federal Science School	KHK	5
14	Michael Ugoma Street	QQ	4
15	Jovonne lane	Q	3

Table 1:- Qualitative interpretation of sounding points

Quantitative interpretation was done using inter-pex (version 3) sounding inversion software while Surfer 16 was used to produce 2-Dimensional distribution maps of aquifer depths and resistivity. The interpretation of the sounding points is summarized as follows: VES1 is a three layer model with three distinct features. Its inferred lithological units are topsoil, shale and sandstones. It has saline water aquifer (obtained at layer 3) sitting on fresh water aquifer (layer 4). Its saline water aquifer has resistivity 2.7 Ωm occurring at 22.8m with a thickness of about 20.5m. Drilling beyond 22.8m will penetrate fresh water aquifer. The sounding curve is shown in figure 4.VES 2 is a four layer earth model. Its lithological units are topsoil, silty-sand, shale and sandstone. Its fresh water aquifer is encountered at layer three and has a thickness 34.3m while the resistivity value is 31.4Ωm. The resistivity of the aquiferous layer suggests a fresh water potential zone (Figure 5). VES 3 is dominated by weathered shale, silty sand and sandstone. It has a fresh water aquifer predicted at layer three. Its thickness is about 15.1m and a resistivity value of 35.9 Ωm; exploiting for ground water here at a depth between 15.0m (water table) to about 30.1m can produce fresh water whereas drilling beyond 30.1m may result in penetrating the fourth layer which is saturated with saline water.

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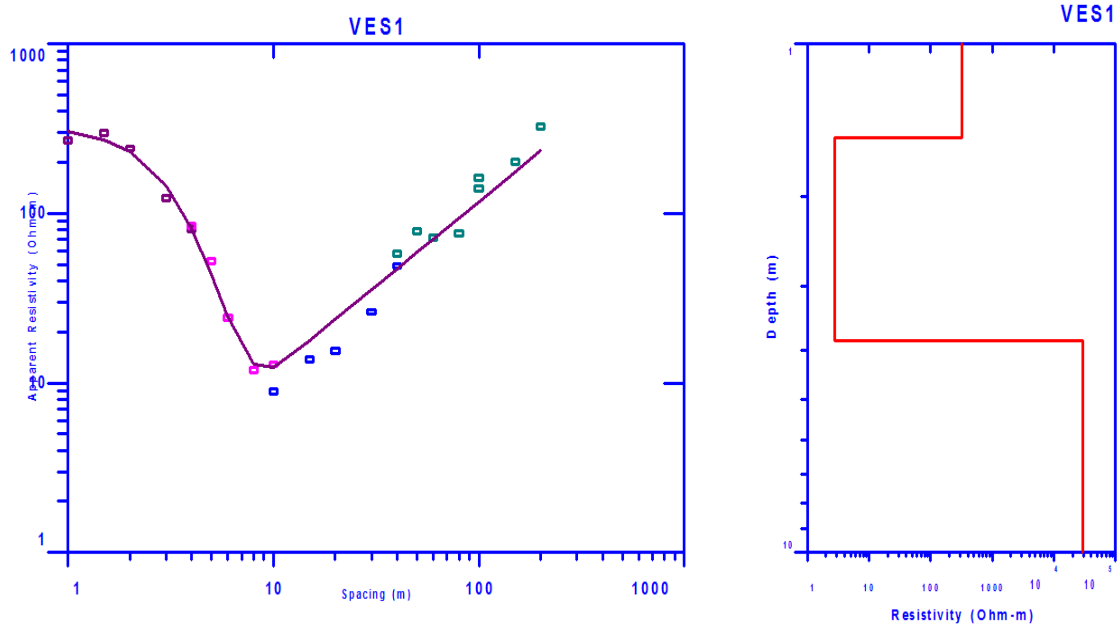

Fig 4:- Sounding Curve and model for VES1 (Lacristo hotel)

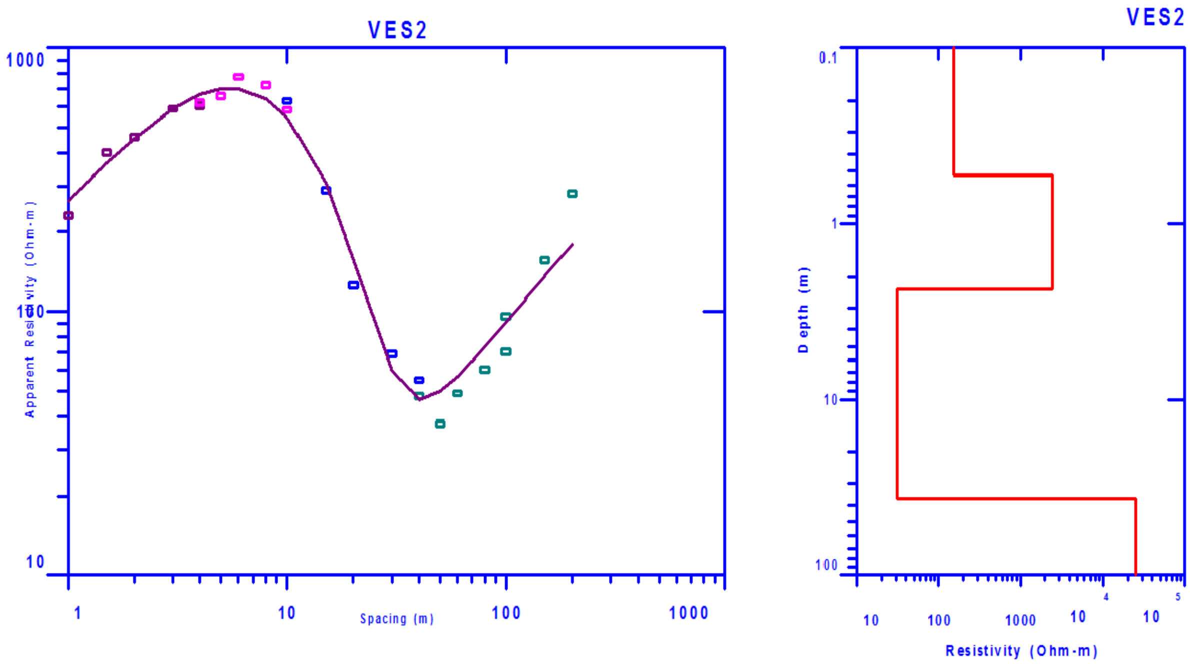

Fig 5:- Sounding curve and model for VES 2 (Noble suits)

At VES 4, the saline water aquifer is predicted at layer three at a depth of 47.9m; its lithology is shale. This layer is underlain by fresh water aquifer whose resistivity is about 128.4 Ωm. drilling beyond 47.9m in this location will produce fresh water. The sounding curve and model is presented in figure 6. VES 5 is characterized by five layers. It has a shallow water table of about 18.7m. The fourth layer whose resistivity is 239.1Ωm is the fresh water producing aquifer. It is being overlain by a layer of brackish water whose resistivity is about 5.8 Ωm. The fresh water aquifer for VES 6 (Basin road) occurs at layer six with a resistivity of 9479.6 Ωm. Overlying this layer is a brackish water contaminated layer whose resistivity and depth are 12.4 Ωm and 56.9m respectively. The saline–freshwater interface for this sounding is obtained at 56.9m. The sounding curve and model are shown in figure 7.

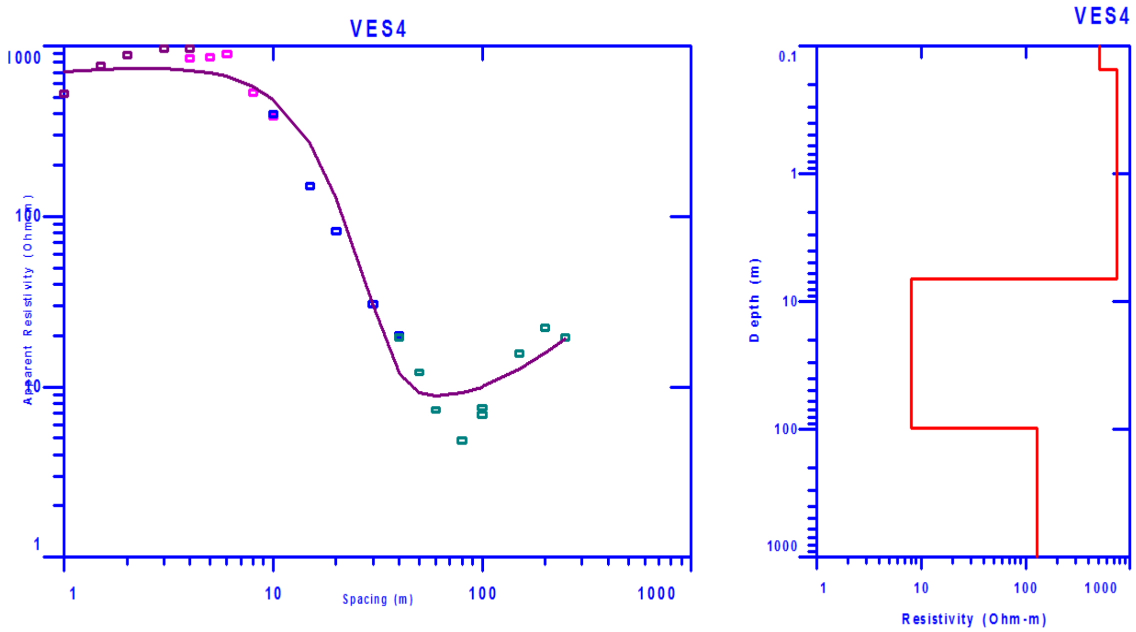

Fig 6:- Sounding curve and model for VES 4 (CRUTECH)

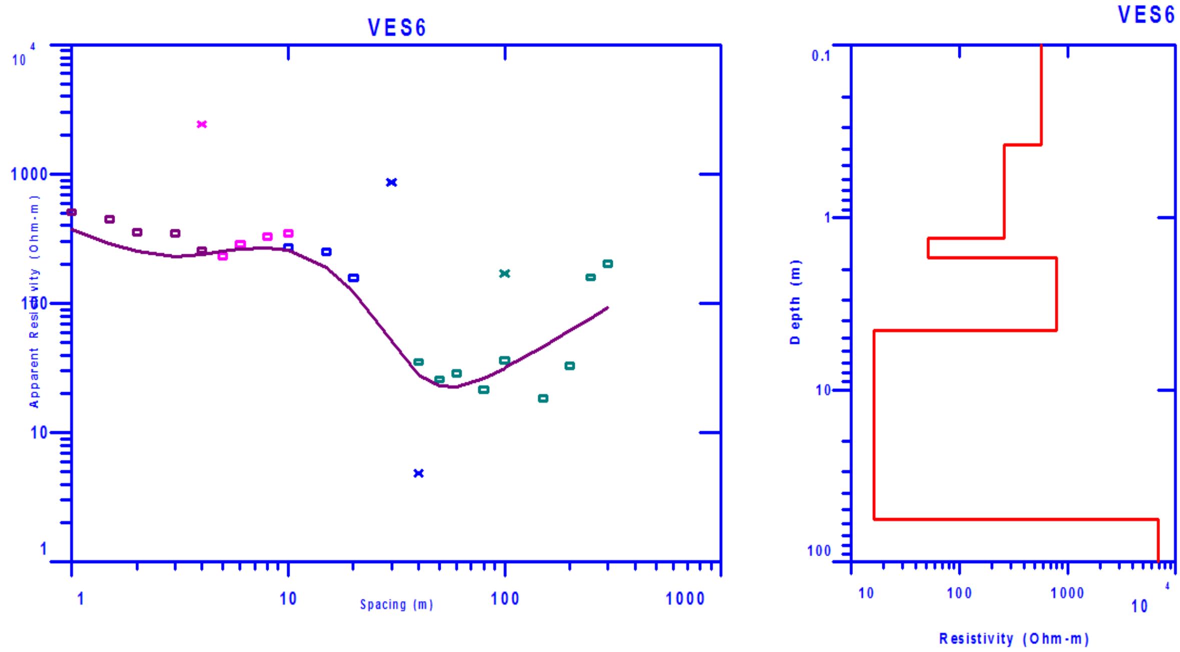

Fig 7:- Sounding curve and model for VES 4 (CRUTECH)

VES 7 has six layers. This sounding point has a fresh water producing aquifer whose thickness is about 19.8m. It occurs at a depth of 34.2m and has a resistivity of 1354.6 Ωm. This layer is being underlain by saline water aquifer whose resistivity is 2.7 Ωm. The fresh/saline water interface of this sounding is obtained at 34.2m. Besides, VES 8 is characterized by seven layers showing multi aquifer system. The freshwater saturated aquifer (layer six) is obtained at 39m. Its resistivity and thickness are 462.4 Ωm and 12.8m respectively. VES 9 has only four layers with the third layer as its fresh water producing zone. The lithological units of this sounding point are topsoil, shale and sandstone. The aquifer occurs at 37.0m with a thickness of 18.6m. The fresh and saline water interface occurs at 37m. At VES 10, a total of seven layers were encountered. Its freshwater aquifer occurs at sandstone unit of layer six and has a depth of 36.0m. The resistivity and thickness of this location are 16.7 Ωm and 10.8m respectively. The curve and model are shown in figure 8. At VES11, five layers were encountered. Layer five (sandstone unit) whose resistivity of 85.6 Ωm is identified as the fresh water producing zone. It is being overlain by zone saturated with saline water (layer four). The resistivity of the layer four which occur at 38.0m is 2.2 Ωm. The sounding curve and model are given in figure 9.

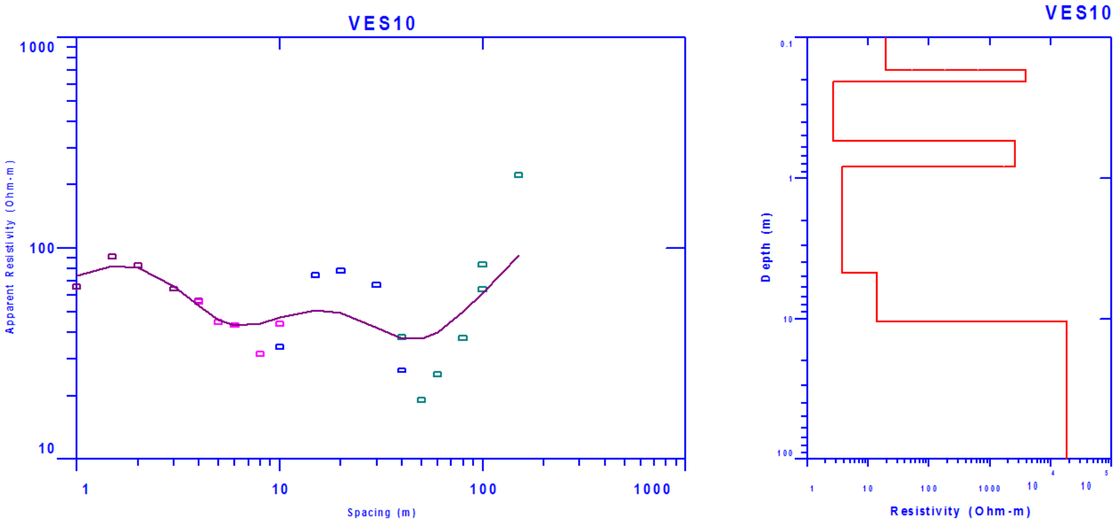

Fig 8:- Sounding curve and model for VES 10 (Njerman lane)

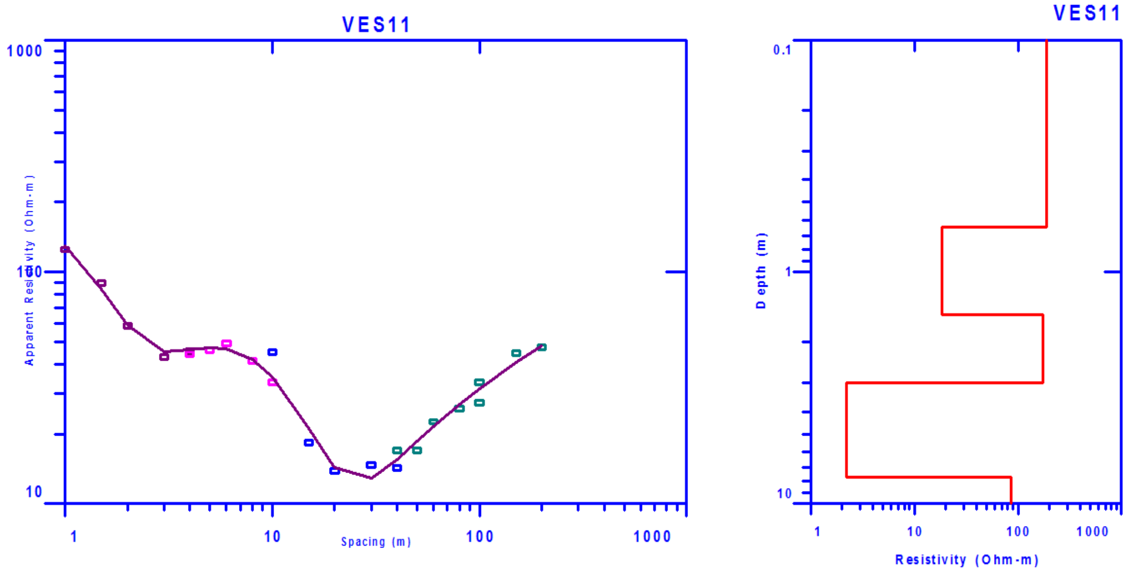

Fig 9:- Sounding curve and model for VES 11 (River road)

VES 12 has five layers. Its fresh water aquifer occurs at layer three with a thickness of 15.2m while the resistivity and depth are 156.3 Ωm and 34.1m respectively. The lithological units are topsoil, shale and sandstone. VES 13 is characterized by five layers (topsoil, sand, shale and sandstone). This sounding point would produce a large volume of fresh water and is one of the locations not infiltrated by brine in the area being investigated. Its fresh water producing aquifer is obtained at 50.0m. The curve and model are given in figure 10. VES 14 has four layers (topsoil, sand and sandstone). Its fresh water aquifer occurs at layer three and has a thickness of 38.8m. Underlying this layer is a highly saline water zone whose resistivity is 0.4Ωm. The last sounding VES 15 has only three layers. The first layer is the topsoil followed by sand which is the second layer. The third layer is dominated by sandstone. The resistivity of this layer is 142.1Ωm and suggestive of fresh water. On average, both brine and fresh water saturated formations occur at shale and sandstone layers across the sounding points. Areas with resistivity values of 0.3Ωm to 12.4Ωm; Lacristo Hotel (VES1), Crutech (VES 4), Basin road (VES 6), River road (VES11) and Federal Science School road (VES 12) are locations predominantly saturated with aquifer infiltrated by brine (saline water) while areas with resistivity of 12.5Ωm and above; Noble suite (VES 2), Santa Maria (VES 3), Hillary Palms (VES 5), Obi Odu estate (VES 7), Holy Trinity Catholic Church (8), Orokoro road (VES 9), Njerman lane (VES 10), Federal Science School (VES 13), Michael Ugoma street (VES 14) and Jovonne lane (VES 15) have reasonable volume of untapped fresh water as shown in aquifer resistivity map (Figure 11). The shallowest aquifer in the area is obtained at 22.8m (VES 1) while the deepest aquifer occurs at 56.9m (VES 6) as presented in aquifer depth map (Figure 12). The dominant formation producing fresh water in the area is sandstone while shale produces more of the saline water. Further analysis from data reveal the presence of three to seven geo-electric units (Figure 13). The generation and correlation of the geoelectric layers across the fifteen sounding points in the area was done using strata version five (5) software. The aquifer parameters for the various sounding points are presented in table 2.

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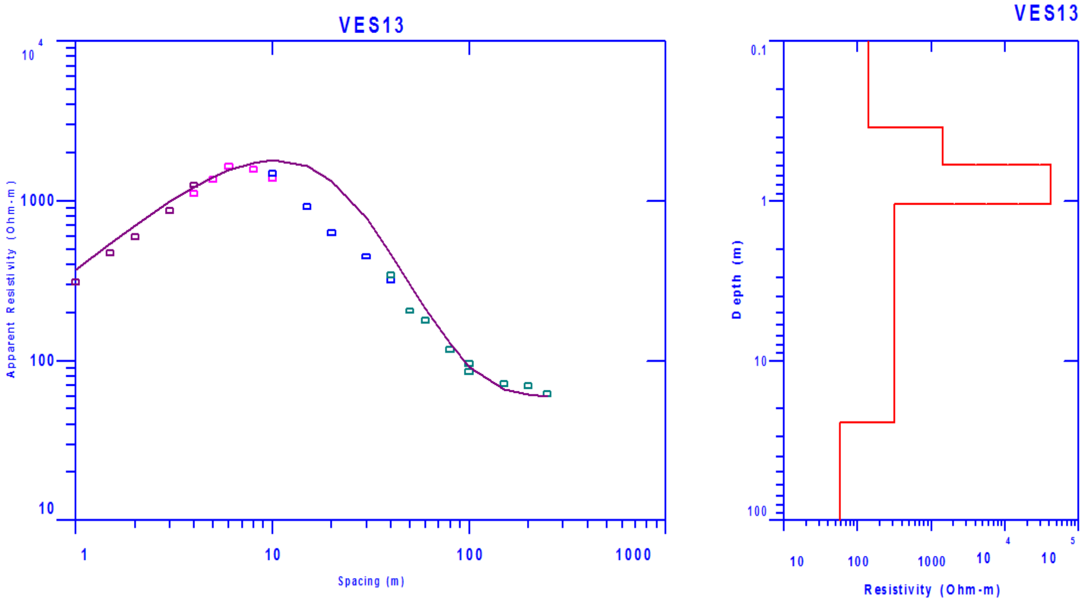

Fig 10:- Sounding curve and model for VES 13 (Jovonne lane)

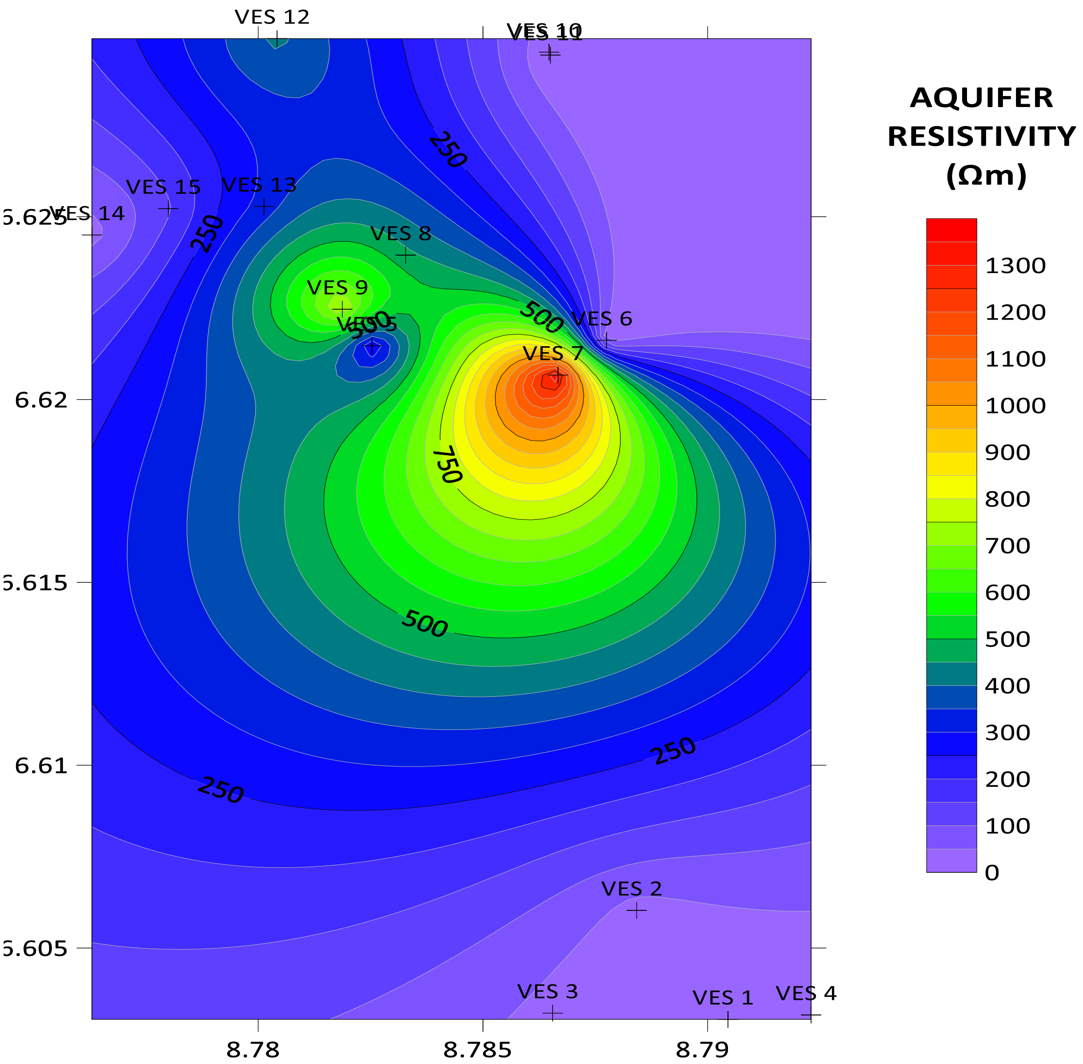

Fig 11:- aquifer resistivity map of the study area

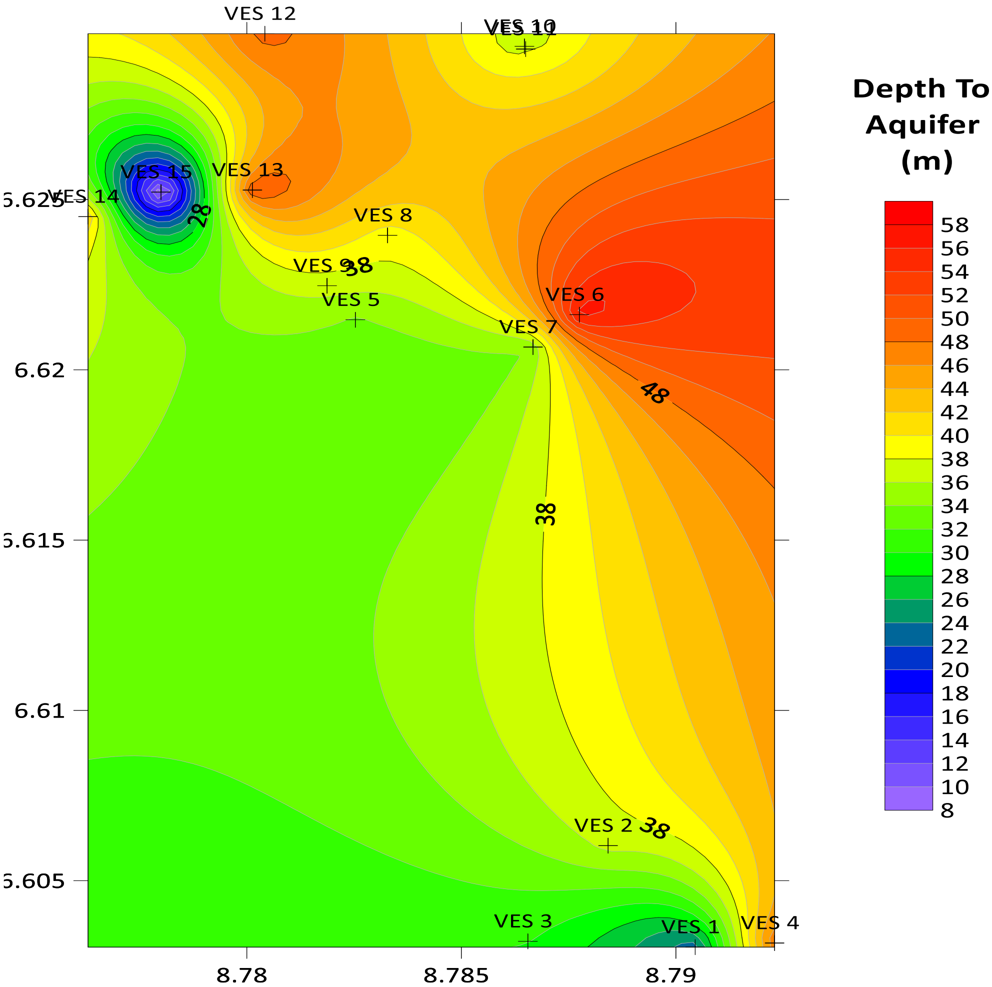

Fig 12:- aquifer depth map of the study area

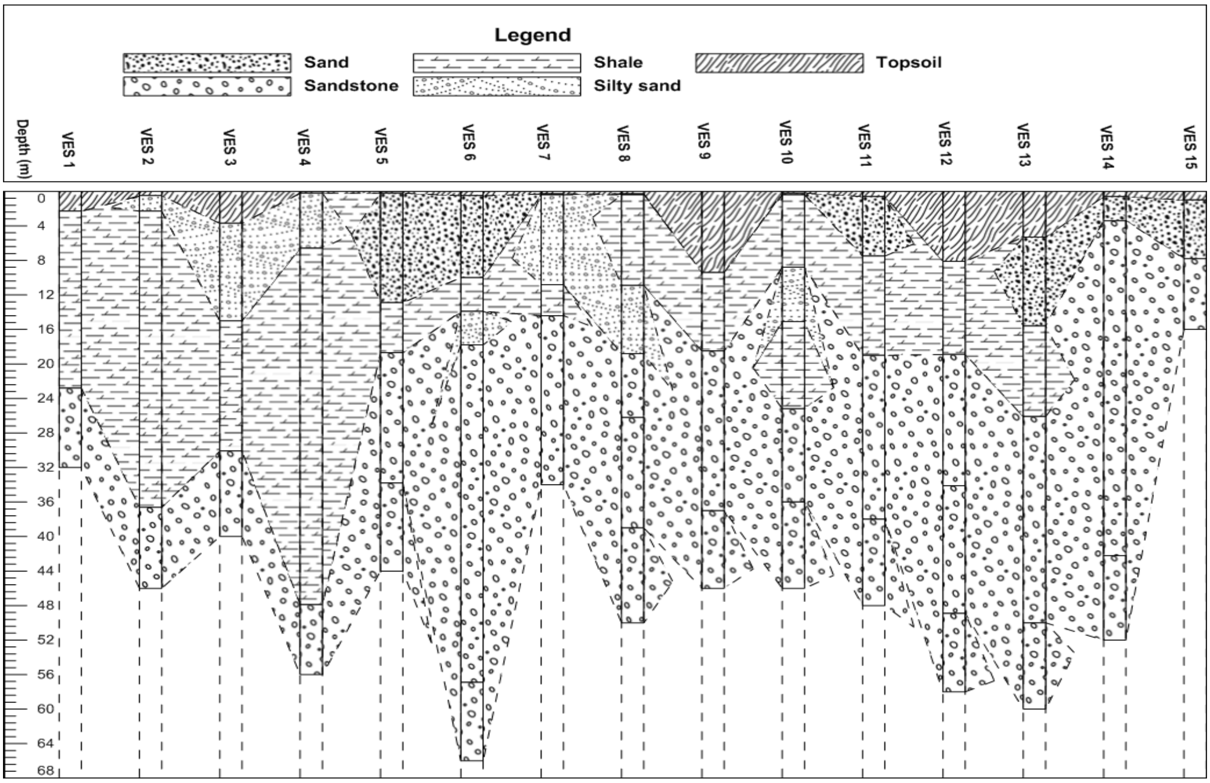

Fig 13:- correlation of geoelectric units across the sounding points

Location	Thickness (m)	Depth (m)	Resistivity (Ωm)
Lacristo hotel	20.5	22.8	2.7
Noble suite	34.3	36.6	31.4
Santa Maria	15.1	30.1	35.9
Crutech	41.3	47.9	8.0
Hillary Palms	15.1	33.8	239.1
Basin road	39.1	56.9	12.4
Obi Odu estate	19.8	34.2	1354.6
Holy Trinity Catholic Church	12.8	39.0	462.4
Orokoro road	18.6	37.0	770.6
Njerman lane	10.8	36.0	16.7
River road	18.7	38.0	2.2
Fed. Sci. Sch. Road (FSSR)	14.8	48.9	3.9
Federal science school (FSS)	23.9	50.0	320.9
Michael Ugoma street	38.8	42.2	31.3
Jovonne lane	6.8	7.8	142.1

Table 2:- Aquifer parameters of the study area

IV. CONCLUSION

This result has further demonstrated the reliability of electrical method of geophysical prospecting in aquifer contamination and vulnerability studies. The results clearly established that the freshwater aquifer of Lacristo Hotel (VES 1), Cross River University of Technology (VES 4), Basin road (VES 6), River road (VES 11), have all been largely infiltrated by brine while Noble suite (VES 2), Santa Maria (VES 3), Hillary Palms (VES 5), Obi Odu estate (VES 7), Holy Trinity Catholic Church (8), Orokoro road (VES 9), Njerman lane (VES 10), Federal Science School (VES 13), Michael Ugoma street (VES 14) and Jovonne lane (VES 15) have sufficient volume of fresh water producing aquifer. However, even with the high level of salinization of groundwater in the area, fresh water aquifer is still found across different locations at varying depths. There is still a high possibility of extracting fresh water without penetrating saline infiltrated layers in locations where fresh water aquifer overlies brine contaminated zone (Federal Science School road; VES 12). In locations where brackish or saline infiltrated aquifer is underlain by fresh water aquifer (Lacristo Hotel; VES 1, Cross River University of Technology; VES 4, Basin Road; VES 6 and Federal Science School Road; VES 12), the borehole should be drilled to deeper depths (beyond saline water layers) and the vulnerable zones cased in other to prevent saline water flowing into fresh water layers. The reason why many boreholes in the study area are abandoned is attributed to lack of proper survey undertaken to ascertain zones contaminated by saline water. However, this investigation has clearly demarcated the vulnerable zones and provide a hydrogeological guide for subsequent ground water exploration studies in the area.

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