© 2015 IJSRST | Volume 1 | Issue 5 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Geo-electrical Evaluation of the Effects of Waste Dump Sites on Groundwater in Eneka, Rivers State, Nigeria

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ABSTRACT

This study aims at investigating the effects of waste dumps on the groundwater in Eneka using resistivity method. Two dump sites and a dump-free site were investigated in the area. The investigation involved seven horizontal resistivity profiling and four vertical electrical soundings. The result of the investigation revealed that the surrounding soil and water in the waste dumpsites have been contaminated to depths below 20 meters which is within the aquifer system of the area. This was evident in the attendant low resistivity values of 0.04 ohm.m - 60.07 ohm.m around the dumpsites relative to the high resistivity values greater than 500 ohm.m in the dump - free areas. The results of the investigation are serious considering the negative implications on public health and the ecosystem of the area if not checked, monitored and managed.

Keywords: Geo-electric, Resistivity, Waste Dumpsites, Groundwater, Boreholes, Aquifers

I. INTRODUCTION

Groundwater is an essential and vital resource in all countries. Innumerable large towns and cities in Nigeria derive major components of their domestic, irrigation and industrial water supply from groundwater. A number of factors can affect the quality of groundwater reservoir, such as contamination from surface pollution or toxic industrial wastes (Barker, 1996). These pollutants pose common environmental problems that have created the need to find suitable methods for monitoring the extent of such environmental damage (Berstone and Dahlin, 1996).

The geo-electrical imaging method has been widely used in environmental and geotechnical investigations for mapping geological structures (Griffiths and Barker, 1993) as it can delineate the resistivity distribution of such structures. It aims to determine the physical properties on the plane delineated by injecting current along different paths and measuring the associated voltage drops. Ugwu and Nwosu (2009) worked on the effect of waste dumps on groundwater in Choba using geophysical method.

This study aims at investigating the effect of waste dumps and evaluation of potential contaminants on the groundwater in a typical open refuse dumpsite in the study area using resistivity sounding method and laboratory water sample analysis. This is because the population of the area depends on groundwater as the source of fresh water. The fresh water is gotten through water boreholes. These boreholes are located in and around the dumpsite. Therefore, assessing the groundwater quality becomes necessary because of the following:

1. Lack of strategies by government and local authorities to protect aquifers from contamination through refuse dumpsites. These assessment and evaluation are necessary for proper planning and designing water resources by the government.
2. Aesthetic problems associated with the open waste dumpsite in the study location such as dust, bad odour, scavenger birds, insects, snakes, etc.
3. Inadequate refuse dumpsite preparation. The waste dumpsite studied comprises of solid municipal wastes which are undergoing decomposition in an open exhumed laterite pit generally referred to as burrow pit, hence the necessity of this study.

The Study Area

The waste two waste dumpsites studied are located in Eneka town, along Eneka-Igwuruta and Eneka - Rukpokwu roads in Obio/Akpor Local Government Area of Rivers State (Fig. 1) covering an area of 1,200 and 2,800.04 square meters. The site is located between latitudes 4^o53^lN and 4^o54^lN and longitudes 7^o0^lE and 7^o2^lE.

Flat topography with a mean elevation of 28 meters above mean sea level characterizes the area. It is also characterized by alternate wet and dry seasons, with a total annual rainfall of about 240cm; relative humidity of over 90% and mean annual temperature of 27°C (Udom and Esu, 2004). The dump site is full to capacity with waste therefore dumping has been suspended. The waste dump is composed of mainly organic and inorganic municipal waste materials which are already degrading.
Eneka town is located in the mangrove belt in eastern Niger Delta in Rivers State, Nigeria. Geologically, the area under study is a typical Niger Delta environment of which sedimentary basin has been subdivided into three stratigraphic units, namely, the Benin, Agbada and Akata Formations in order of increasing age (Short and Stauble, 1967). The Benin Formation is predominantly sandy with little shale which may represent back swamp deposits. The formation has thickness ranging from 0-2100m (Etu Efeotor and Odigi, 1983). The Agbada Formation consists of alternating deltaic (fluvial, intertidal and fluvio marine) sands and shales while the Akata Formation consists of low density high pressure deep marine shales (Etu Efeotor, and Odigi, 1983).

The study area is basically underlain by the Benin Formation, classified as coastal plain sands (Reyment, 1965). It consists of massive, highly porous and permeable freshwater bearing sands with minor clay intercalations (Fig. 1). The formation is generally water-bearing and hence it is the main source of potable groundwater in the area (Etu-Efeotor and Odigi, 1983; Udom, *et al*., 1999). The aquifers are recharged mainly by rainfall and nearby drainages. Aquifer conditions from nearby boreholes around the waste dumpsite exist at depth of 25m to 40m below the water table.

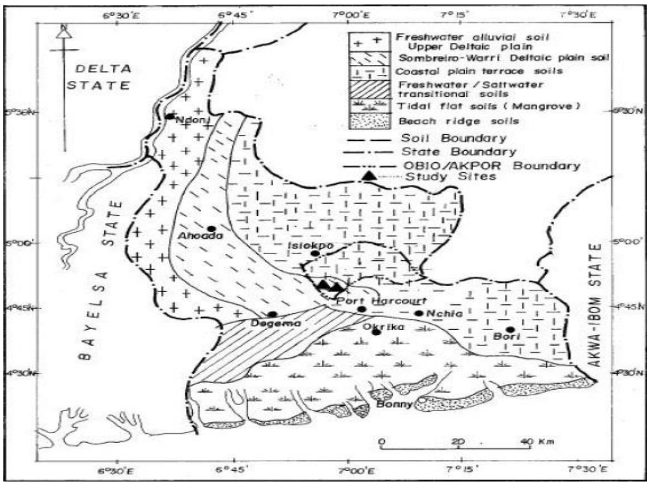

Figure 1 : Geological map of the study area

II. METHODS AND MATERIAL

Resistivity Survey

This study, aimed at using an integrated approach in ground water and soil contamination at the selected two waste dump sites is designed to involve two electrical resistivity field techniques, namely; vertical electrical sounding (VES) and electrical profiling. Vertical electrical sounding would be used to identify lithology of the area, the nature of the subsurface as well as the depth to water table and aquifer depth. Profiling would be used for mapping contaminant plumes and there direction of flow from the waste dump site. A total of four vertical electrical soundings and six 2-D imaging surveys were used. Vertical electrical soundings were carried out in two waste dumpsites, one in dump site1 and two in dump site 2, and one sounding (VES) in an area adjudged to be waste-free which serves as the control.

A maximum electrode spread (AB/2) of 200 metres and MN/2 of 15metres were utilized in the survey, using the Schlumberger electrode array. The measured resistance values (R) were converted into apparent resistivity (ρ_a) by multiplying with the geometric factor (K), such that:

$$\rho_a = \frac{\pi\left[\left(^{AB}/_2\right)^2 - \left(^{MN}/_2\right)^2\right]R}{MN} = KR \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where ℓa=Apparent Resistivity
AB= Distance between current electrodes

MN=Distance between potential Electrodes
R=Measured resistance from the ground

These values were then entered manually in a recording sheet for computer processing using Schlumberger automatic software (Henkel, 1985). The 2-D resistivity imaging uses a multi – electrode system with equal electrode spacing ranging from 10m – 30m for successive measurement (Fig. 2). A 20 – electrode Wenner – alpha configuration was adopted for the survey and successive electrode positions were occupied along the survey path by leap – forging (Loke, 1999).
The Wenner-alpha configuration was adopted because of its good signal strength and continuous coverage. The apparent resistivity values were calculated from the field resistance values using the equation:

$$\rho_a = 2\pi a R \qquad (2)$$

Where a is the electrode spacing and R is the field resistance value. The values of the apparent resistivities, electrode spacing and the x – locations were entered in a text file for processing.

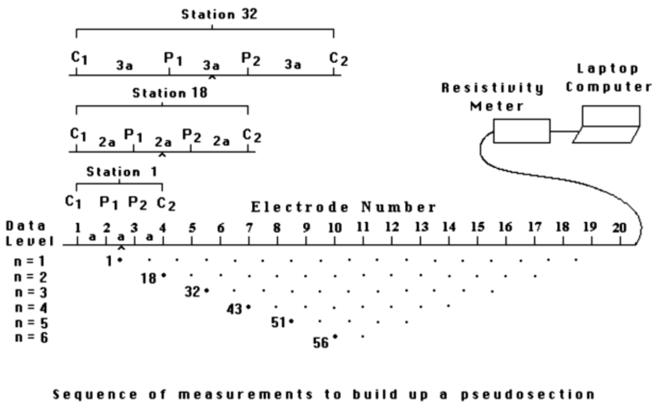

Figure 2 : The arrangement of electrodes for a 2-D electrical survey and the sequence of measurement used to build a pseudo section (Loke, 1999).

Instrumentation

For the geoelectric soundings carried out in this study, an ABEM Terrameter (SAS) 1000C and its accessories such as electrodes, cables on reels, hammer, measuring tapes and battery. It is a process whereby consecutive readings are taken automatically and the results are averaged continuously while the continuous running average is presented automatically in the display. The terrameter comprises of a 12 volts D.C battery powered deep penetration resistivity meter with an output of current electrode separation of up to 2000meters. It uses a power oscillator at very low frequency of 4 Hz to drive current into the ground which produces a current deflection in the galvanometer. The same current that goes into the ground passes through a potentiometer which is now adjusted to produce the same deflection in the galvanometer, the ratio V/I is now directly given by the resistance of the potentiometer. This is read off at the display. The instrument is designed in such a way that it is easily carried from one point to another and also versatile and sensitive. Each electrode is having one pointed end for easy driving with the hammer into the ground at the respective positions during the survey. Two reels of potential and current cables respectively were used in the study. Measuring tapes were used for measuring survey lines, electrode distances and locations.

Field Procedure

The field survey includes a total of three (3) profile lines and four electrical soundings. Field work commenced by delineating sounding stations, for the vertical electrical sounding (VES) as well as electrode positions in the traverses for the profile lines. In the marked positions of the VES sounding points, a series of resistivity measurements were taken with an expanding current electrode separation. The midpoint of the potential electrode configuration remained fixed at the observation stations while the length of the configuration was generally increased. VES 1 and 2 were taken with a maximum current electrode spread AB/2 of 100m, while VES 3, AB/2 of 200 metres was utilized. VES 4 which is the control station is 300 meters from the waste dumpsite.

Electrical current was injected into the ground through the current electrode. The resulting voltage was measured between the potential electrodes, the terrameter then displays the resistance, R, of the earth path through which the current passed by multiplying the displayed resistance, R, with the geometric factor (K) the apparent resistivity is obtained.

There were fifteen electrodes for the resistivity imaging measurement. All the three profile lines are in NW – SE direction and they are all running parallel to each other and to the dumpsite. Each profile line is separated from another at a distance of 25 meters. The electrodes are laid in a straight line with "a" spacing of 10m between two consecutive electrodes, as shown in Figure 2 where C_1 and C_2 are current electrodes, while P_1 and P_2 are potential electrodes. After taking the first reading at station, the cables were moved in a leap – frog manner to the next position being electrodes 2, 3, 4 and 5 which are used for C_1, P_1, P_2, C_2 respectively. This is repeated down the line until electrodes 12, 13, 14 and 15 are used for the last measurement with "1a" spacing. For the 15 electrodes there are 12 possible measurements with 10m spacing for the Wenner array.

After completing the sequence of measurements with 10m spacing, the next is with "2a"= 20m electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for the first measurement. For the second measurement, electrodes 2, 4, 4, 6, 8 are used. This method is repeated down the line until electrodes 9, 11, 13, and 15 for the last measurement of 2 meters. The same process is repeated for measurements of 30 meters.

Data Processing

The VES field data was processed using the Schlumberger automatic analysis software (Henker, 1985). This computer program automatically generates model curves using initial layer parameters (resistivity and thickness) derived from partial curve matching of the field curve with standard curves and calculates the three layer parameters of the geoelectric section. The results are presented in terms of the resistivity and the depth of the geoelectric section for the four VES positions.

The three resistivity profiling data were processed using an iterative constrained least square inversion method to create a model of subsurface resistivity by inverting the apparent resistivity data. The software used is called RES2DINV which is a 2-D resistivity and IP inversion program for interpretation of resistivity data. The computer program will automatically subdivide the subsurface into a number of blocks and it then uses a least-square smoothness constrained inversion scheme to determine the appropriate resistivity value for each block. The location of the electrodes and the apparent resistivity values must be entered into a text file which can be read by the RES2DINV program.

Data Interpretation

There are two methods of interpreting electrical sounding data namely; the quantitative and the qualitative method. The qualitative interpretation of sounding data involves the preparation of apparent resistivity sections. These sections are constructed by plotting the apparent resistivities as observed along vertical lines located beneath the sounding stations on the chosen profile. The second type which is in this thesis is the approximate quantitative interpretation technique (auxiliary point method), using the two-layer apparent resistivity model curves in conjunction with auxiliary graphs. The interpretation includes curve matching and direct interpretation technique could be done manually or by computer programs.

The computer program used for the interpretation of 2-D resistivity data would carry out an inversion of the data and present the result in a contouring format, which reflects qualitatively the spatial variation in resistivity in the vertical. The contoured data can be modeled using a 2- D finite or finite difference algorithm. Alternatively, the data can be inverted automatically with the commercially available computer program, RES2DINV to provide an image of true resistivity (Griffiths and Barker, 1993).

III. RESULT AND DISCUSSION

The data involved in this survey includes five vertical electrical sounding and six 2-D resistivity profiling data. There is strong correlation existing between the VES result and the 2-D resistivity survey result, so comparisons were made between the two results and discussed where necessary.

Interpretation of VES Results

VES 1, the actual resistivity of each of the four geoelectrical layers, as well as their depths are displayed in Figure 3. The first layer with resistivity of 41.70 Ωm and a thickness of 1.24 m is interpreted as the topsoil (with laterites). Relative lower resistivity is due to organic constituents mixed with soil and diffused liquid contaminants from the waste site as was confirmed from physical site condition at the surface.

The second and third layers have resistivities which are 146.4 Ωm and 492.6 Ωm, with thickness of 3.44m and 16m respectively. The layers are probably sand formation; the second layer is basically within the vadose zone. The third layer is water saturated sand formation and they are all contaminated. The fourth layer with resistivity 24.8 Ωm and undetermined thickness and depth is clay. This is the last layer which is impermeable to water therefore making the third layer the aquifer. These five low resistive layers fall within the resistivity less than 80.0 Ωm as delineated in 2-D resistivity imaging of profile line 1.

In VES 2 (Fig. 4), the sounding curve obtained is indicating a five layer case. The first geoelectric layer of resistivity 22.0 Ωm and thickness of 1.83m is considered as topsoil and laterite with low resistivity due to mixture of conductive organic and inorganic compounds from waste materials in the dumpsite.

The second and third layers being 31.1 Ωm with a thickness of 2.12m and 45.8 Ωm with a thickness of 4.71m, respectively. The second and third layers are delineated as laterite, and laterite with sand respectively, and they are contaminated with leachate plume. The fourth and fifth layers are sand layers with resistivities of 66.7 Ωm and thickness 12.0m, and 38.4 Ωm with undetermined thickness. These two zones are water saturated, and from their resistivities which are low, indicate that the layers are contaminated with leachate plume. These five layers fall within the zones delineated with 2-D survey of profile line 2 of resistivity less than 50.0 Ωm in Fig. 4.

For VES 3, the first geoelectric layer of resistivity 34.7 Ωm and thickness of 1.85m is considered as topsoil and laterite with low resistivity due to mixture of conductive organic and inorganic compounds from waste materials in the dumpsite. The second and third layers being 52.7 Ωm with a thickness of 2.31m and 79.9 Ωm with a thickness of 5.19m respectively (Fig.5). The second and third layers are delineated as laterite, and laterite with sand respectively, and they are contaminated. The fourth and fifth layers are sand layers with resistivities of 49.7 Ωm and thickness 12.55m, and 33.9 Ωm with undetermined thickness. These two zones are waste saturated, and from their resistivities which are low, indicate that the layers are contaminated with leachate plume.

In the fourth VES, the first layer has a resistivity of 59.5 Ωm and thickness of 1.86m. This layer is the topsoil and laterites are contaminated. The second and the third layers have resistivities 82.1 Ωm and thickness 2.85m, 141.0 Ωm and thickness 9.69m respectively. The second layer is laterite and the third layer is laterite with sand. The layers are contaminated with which is indicative of their low resistivities. The fourth layer has resistivity and thickness of 261.0 Ωm and 29.70m respectively. The fifth layer has resistivity of 150 Ωm and an undetermined thickness. The fifth and fourth layers are basically sand-saturated with water that has been contaminated (Fig.6).

The Fifth VES serves as the control and located in an area adjudged to be free from waste dump about 2000m from the dumpsites being studied. The first layer which is the topsoil and laterite has a resistivity of of 353 Ωm and thickness of 1.81m (Fig.7). The high resistivity value of 535 Ωm is an indication of pollution-free layer (Ugwu and Nwosu, 2009). The second layer has a resistivity of 643 Ωm and thickness of 2.33m, which is laterite and sand layer and is delineated by unpolluted water. The water table of the area falls within this layer.
The third, fourth and fifth layer are zones saturated with unpolluted water. They are basically sand layers from their resistivities of 929.0 Ωm, 1693 Ωm and 718 Ωm respectively. These layers are suspected to be layers of fresh water. Table 1a & 1b is the data for VES 1 and interpretation while Table 2a & b shows data for VES 2 Survey and interpretation. Table 3a & b is the data for VES 3 Survey and interpretation while Table 4a & b is the data for VES 4 Survey and interpretation. Table 5a & b is the data for VES 5 Survey and interpretation.

Table 1a: Data for VES 1 Survey

AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)
2.0	51.82	50.0	167.93
3.0	67.71	75.0	97.40
6.0	107.42	100.0	58.90
9.0	127.31		
15.0	191.76		
25.0	267.11		
40.0	194.04		

Table 1b: Resistivity, Depth, Thickness and Interpretation

RHO (Ohm.m)	DEPTH (M)	THICKNESS(M)	INTERPRETATION
41.7	1.24	1.24	Top soil
146.4	4.96	3.44	Sand
492.6	20.9	16.05	Contaminated Sand (Ehirim et al, 2011)
24.80			Clay formation(Ehirim et al, 2011)

Table 2a: Data for VES 2 Survey

AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)
1.0	19.3	10.0	126.6	50.0	132.4
2.0	32.1	15.0	171.8	70.0	83.0
3.0	44.6	15.0	173.5		
4.0	55.9	20.0	211.3		
4.0	56.2	25.0	224.1		
6.0	80.5	25.0	224.1		
7.0	91.5	30.0	215.4		
8.0	103.0	40.0	180.5		
8.0	103.0	50.0	132.4		

Table 2b: Resistivity, depth, thickness and interpretation

RHO (Ohm.m)	DEPTH (M)	THICKNESS(M)	INTERPRETATION
22.0	1.83	1.83	Top soil (Ugwu and Nwosu,2009)
31.1	3.95	2.12	Sand (Ugwu and Nwosu,2009)
45.8	8.66	4.71	Sand (Ugwu and Nwosu,2009)
66.3	20.70	12.04	Water saturated Sand formation
38.4			Water saturated sand formation

Table 3a: Data for VES 3 Survey

AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)
1.0	66.7	10.0	459.0	50.0	188.0
2.0	143.0	15.0	516.0	70.0	93.8
3.0	208.0	15.0	517.0		
4.0	256.0	20.0	502.0		
4.0	255.0	25.0	456.0		
6.0	336.0	25.0	459.0		
7.0	371.0	30.0	385.0		
8.0	407.0	40.0	264.0		
8.0	407.0	50.0	188.0		

Table 3b: Resistivity, depth, thickness and interpretation

RHO (Ohm.m)	DEPTH (M)	THICKNESS(M)	INTERPRETATION
34.7	1.85	1.85	Top soil
52.7	4.16	2.31	Sand
79.9	9.35	5.19	Sand
49.7	21.90	12.55	Contaminated sand formation
33.9			Sand formation-saturated zone

Table 4: Data for VES 4 Survey

AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)
1.0	20.6	10.0	574.0	50.0	2377.0
2.0	51.6	15.0	1164.0	70.0	1803.0
3.0	89.6	15.0	1148.0	80.0	1446.0
4.0	128.0	20.0	1946.0	80.0	1472.0
4.0	126.0	25.0	2319.0	100.0	1077.0
6.0	248.0	25.0	2319.0	100.0	1077.0
7.0	332.0	30.0	2571.0	125.0	836.0
8.0	420.0	40.0	2571.0	150.0	626.0
8.0	574.0	50.0	2399.0	150.0	626.0
				200.0	392.0

Table 4b: Resistivity, depth, thickness and interpretation

RHO (Ohm.m)	DEPTH (M)	THICKNESS(M)	INTERPRETATION
59.5	1.86	1.86	Top soil
82.1	4.71	2.85	sand
141.0	14.40	9.69	Contaminated sand formation(Ehirim et al; 2011)
261.0	44.30	29.9	contaminated sand formation(Ehirim et al; 2011)
150.0			Sand formation

Table 5a : Data for VES 5 Survey

AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)	AB/2(M)	RHO (Ohm.m)
1.0	346.0	10.0	727.0	50.0	881.0
2.0	384.0	15.0	832.0	70.0	755.0
3.0	417.0	15.0	834.0	80.0	688.0
4.0	447.0	20.0	911.0	80.0	684.0
4.0	447.0	25.0	941.0	100.0	489.0
6.0	558.0	25.0	941.0	100.0	
7.0	619.0	30.0	957.0		
8.0	665.0	40.0	929.0		
8.0	665.0	50.0	881.0		

Table 5 b: Resistivity, depth, thickness and interpretation

RHO (Ohm.m)	DEPTH (M)	THICKNESS(M)	INTERPRETATION
535.0	1.81	1.81	Top soil
643.0	4.14	2.33	Sand
929.0	10.60	6.46	Pollution free- sand formation (Ehirim et al,2011)
1693.0	28.30	17.7	Saturated sand formation(Ehirim et al,2011)
718.0			Sand formation

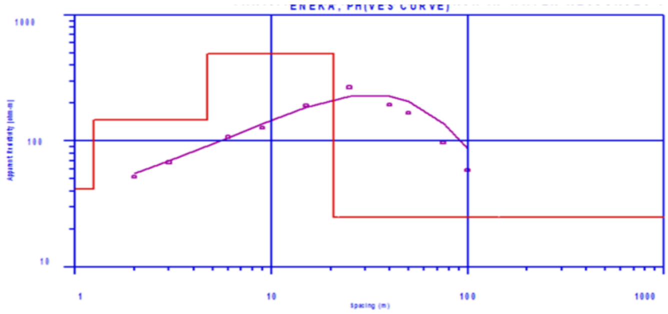

Figure 3 : Result of VES 1 showing the model geoelectric sounding curve, the layer resistivity and their corresponding depths

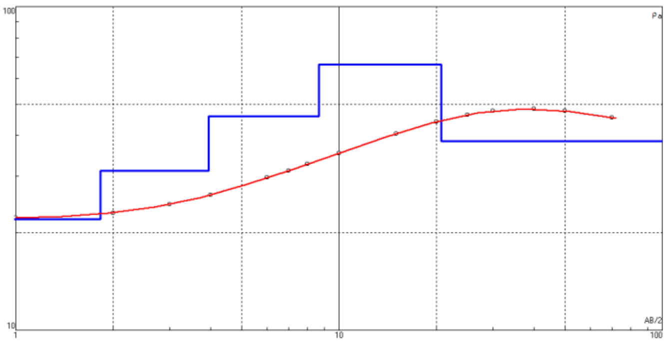

Figure 4 : Result of VES 2 showing the model geoelectric sounding curve, the layer resistivity and their corresponding depths.

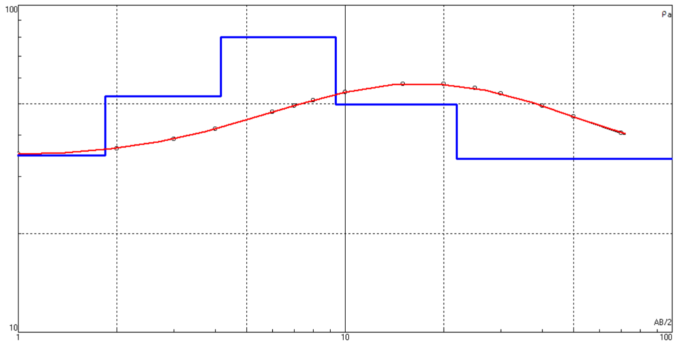

Figure 5 : Result of VES 3 showing the model geoelectric sounding curve, the layer resistivity and their corresponding depths

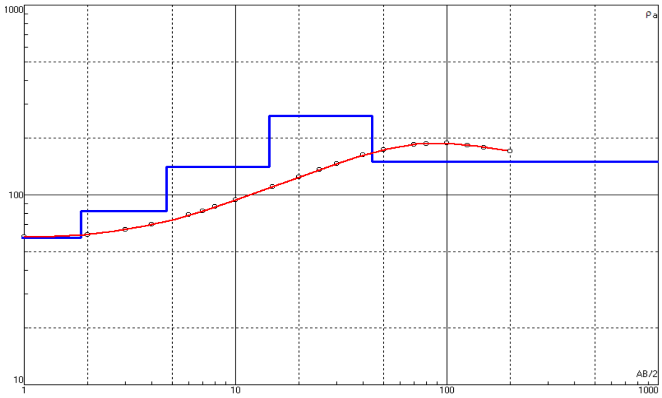

Figure 6: Result of VES 4 showing the model geoelectric sounding curve, the layer resistivity and their corresponding depths

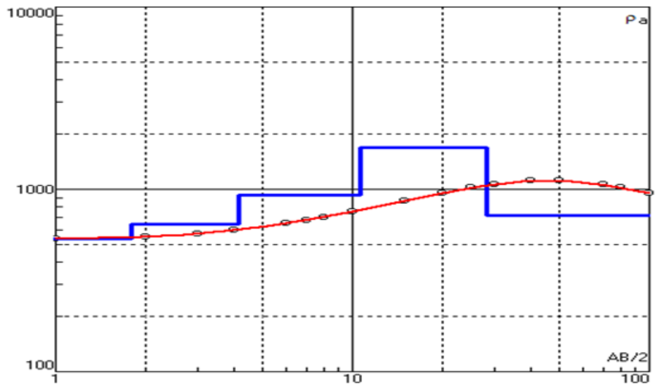

Figure7: Result of VES 5 showing the model geoelectric sounding curve, the layer resistivity and their corresponding depths

IV. CONCLUSION

The results of the vertical electrical sounding data shows that the refuse dumpsite may have been contaminated to depths exceeding 40 m as indicated by VES 3 which is well within the aquifer system of the area. Key challenges elucidated by this study include:

1. Open refuse dumpsite is likely to remain the source of groundwater contamination since it is the cheapest and simplest mode of waste disposal in developing countries like Nigeria.
2. In order to protect the groundwater quality of the area, monitoring program for groundwater quality status around the vicinity of the dumpsite is suggested.
3. Open dumpsite should be located in a geologically impermeable layer like clay. Improvement should also be made by government in ensuring the use of engineered landfill.
4. Borehole drillers should be encouraged to undertake geophysical investigation of an area before sinking wells to ascertain the nature of the groundwater within the environment.
5. Government should legislate on making geophysical investigation/studies mandatory before wells are sunk by anybody.
6. For siting new refuse dumpsites, the potential for pollution of groundwater could be reduced by maintaining a buffer zone between the dumpsite and the property line of the adjacent property. The buffer zone should be in the direction of groundwater flow.
7. Further studies on groundwater quality in and around the refuse dumpsite in all directions will be necessary.

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