



Applications of Vertical Electrical Sounding (VES) and Two-Dimensional (2-D) Imaging Methods for Groundwater Exploration and Basement Configuration at GOFAMINT Church Camp, Ibadan, Southwestern Nigeria.

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ABSTRACT

Groundwater exploration has been a critical problem in the basement complex terrain underlain by hard rocks which have low porosity and permeability. This low yielding terrain has created problem of water scarcity within the region. The study area falls within this region and has been affected by this problem. The occurrence of groundwater in this terrain is localized and concentrated within weathered zone and network of fractures. A total of thirty Vertical Soundings (VES) were taken with some of the VES point on the 2-D profiles mainly to probe further the conductive anomalies. Apparent resistivity values were plotted against AB/2 on bilogarithmic paper and was later curve matched to obtain the layer parameters. This serves as an input to the computer iterative algorithm to create the model of the subsurface. A total of two 2-D imaging profile were taken to visualize the subsurface in two dimensions. An inter-electrode spacing of 10 meters was employed with six levels. From the study, the results of the VES reveals that some of the fractures might be dry with exception of few which are promising hydrogeologically. Also, the VES results revealed the following geoelectric layers ranging from top soil, clay, lateritic pan, weathered zone, fractured basement/fresh basement. The top soil has thickness ranging from 0.2 to 3.0 meters with mean of 1.9 meters and resistivity ranging from 63 to 836 Ω m with mean of 301 Ω m. The lateritic clay has thickness ranging from 3.1 to 5.7 meters with average of 4.4 meters and resistivity between 60 to 351 Ω m with mean of 154 Ω m. The hard lateritic pan has thickness of 0.6 to 3.9 meters with mean of 2.2 and resistivity of 1369 to 2568 Ω m with mean of 1936 Ω m. The weathered layer has thickness ranging from 1.1 to 36.4 meters with mean of 9.0 meters and resistivity ranging from 11 to 380 Ω m with mean of 87 Ω m. The fresh rock (rock boulder) has thickness of 4.4 meters and resistivity of 2094 Ω m. Fractured / fresh basement has an infinite thickness and resistivity ranging 377 to 5564 Ω m with mean of 1921 Ω m. Depths to basement top were determined at each VES points and were used to model the basement topography. The 2-D pseudosection of profile 01 present nearly horizontal layers indicating uniformity in resistivity at each layer while the profile 02 shows few structural heterogeneities mainly at western and central part of the site with characteristic dome. The low resistivity value, thick overburden and fractured bedrock constitute the aquifer unit. Also, series of basement depression could also serve as water collection center and hence prominent area of groundwater abstraction. There is also no evidence of mineralization from the result obtained.

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INTRODUCTION

Generally, Electrical prospecting involves detection at surface, effects produced by electrical current in the ground. The large contrast in resistivity between ore bodies and their host rocks is exploited in electrical prospecting. This method is also an important geophysical technique in the exploration for groundwater in a basement complex terrain.

The electrical methods which involve Vertical Electrical Sounding (VES) and Two – Dimensional (2 – D) Imaging are the most popular in groundwater and mineral exploration owing to their inherent ability to detect changes related to variations in fluid content, chemical composition and temperature in the subsurface, and the minimum capital and labour required to use them in small-scale surveys.

Therefore, integrated geophysical techniques which involve the use of VES and 2 – D Imaging were employed to investigate the study area (GOFAMINT Church Camp in Ibadan) for the purpose of detecting structure favourable for groundwater accumulation and zone of high conductive mineralization potential.

Some Electrical Resistivity works had been conducted in the Southwestern Nigeria where the study area fall into. But no successful survey had been ever recorded in this area of study (GOFAMINT Church Camp in Ibadan). The area suffers from acute water shortage due to non-productive borehole and well. This is one of the reasons to carry out the research in order to unravel the geology and structure

below the area and to give accurate explanation for the problem.

Artificially generated electric current was introduced into the ground and the variation in apparent resistivity (both laterally and vertically) was measured. The electrical techniques require the measurement of potential differences in the ground between suitably implanted electrodes.

PREVIOUS WORK

The purpose of electrical survey is to determine the subsurface resistivity distribution by making measurement on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated (Loke, 1999).

The resistivity of groundwater varies from 10 – 100-ohm meter depending on the concentration of dissolved salt. The low resistivity (about 0.2ohm meter) of sea water is due to relatively high salt content. This makes the resistivity method an ideal technique for mapping the saline and fresh water interface in coastal areas (source: Loke Note 2000).

The technique of groundwater exploration by the vertical electrical resistivity method has been explained by Kollert (1969). It has been successfully utilized in assessing water supply potentials in basement aquifers (Chilton and Foster, 1995; Okwueze, 1996; and Olorunfemi et al, 1999). It has also been used in investigating shallow groundwater occurrence in Ibadan, southwestern Nigeria (Olayinka et al. 1999), and also in exploring aquifer

boundaries in plains of Yemen (Van Overmeeren, 1989).

Oduanya and Amadi (1999) used empirical resistivity model of predicting shallow groundwater occurrence in the basement complex. They explained that the electrical resistivity of weathered layer are controlled by the degree of water saturation.

Also, one of the new development is the use of 2-D electrical imaging / tomography surveys to map areas with moderately complex geology (Griffiths and Barker 1993). Griffiths and Turnbull (1985) produced details of a multiple electrode array for use with constant separation traversing.

Olayinka (1990) discussed the various methods of interpreting Wenner Resistivity pseudosection data and its application in crystalline basement rocks. A contoured pseudo-section conveys an immediate qualitative two-dimensional (2-D) variation of resistivity within the subsurface (Olayinka 1991b).

In order to remove geometric effects from the pseudo-section and produce an image of true depth and true formation resistivity, the observed data must undergo a form of processing known as INVERSION. The inversion technique recently described by Loke and Barker (1996) appears to be powerful and effective means of processing pseudo-section data to provide a contoured image of true depth and true formation resistivity. It uses a sensitivity matrix of coefficient based on the signal of contribution (Barker, 1990) to form the first model. Then using a finite difference

forward modeling algorithm modified from Dey and Morrison (1979), an iterative least squares optimization technique is applied. An acceptable model is normally arrived at within five iterations and the whole process can be carried out on a modern colour computer in less than a couple of minutes.

Abdulbariu et al., 2023 applied very low frequency electromagnetic in the study of basement structure such as fracture which serves as conduit for groundwater passage and hence pinpointed their locations and orientations and suggested them for groundwater abstraction. Ibrahim, et al., 2016 described and utilized geomagnetic signatures and estimated the depth of basement rocks and fracture around Iseyin area for groundwater and mineral exploration,

MATERIALS, METHODS AND BASIC ELECTRICAL THEORIES AND PRINCIPLES

Electrical resistivity survey requires ground contact and hence the need for some accessories to carry out the survey is necessary. The instruments used include.

RESISTIVITY METER (CAMPUS OMEGA)

It is a very sensitive and high-quality resistance meter (Plate 1) that measures resistance over a wide range of conditions. It is also capable of taking series of readings depending on the number of cycles and averages it automatically. The power source is a 12.0 V rechargeable battery.

Other materials used include, Electrodes, Clips, Cables, Hammer, Field note / Recording sheets etc. Also softwares such as Winresist, DiproFwin, Surfer, Corel Draw, Microsoft Office were used.



Plate 1: Field Setup for Electrical Resistivity Survey.

FIELD PROCEDURE

Schlumberger configuration was adopted for the Vertical Electrical Sounding method while the Werner configuration was used for the 2 – D Electrical imaging survey in the study area.

A maximum current electrode spacing of $(AB/2)$ of 240 meter and the minimum 100 meter was employed where there were space constraints.

Two pairs of stainless steel are used as electrodes. A pair serve as the current

electrode that carry current from resistivity meter to the ground while the other pair serve as the potential electrode that measures the potential difference generated on the surface as a result of current injection. At least two – third of the length of the electrode is driven into the ground to create effective contact.

The potential electrodes remain fixed for some time while the current electrodes were increased progressively to have a deeper current penetration into the ground. However, with the very large values of distance between the current electrodes about the centre, we then increase the potential electrode in order to maintain a measurable potential difference. Most of the VES point were located on 2 – D Imaging profile (Fig. 20 and 21) mainly to probe anomalous zone identified from their profile.

Two profiles of 2 – D Imaging were carried out with Werner array of equal inter electrode spacing of 10 meters. The number of Levels (n) for each of the profile was equal to six (6). The length of the profile 01 was 260 meter while that of the profile 02 was 240 meters.

Serious precautions were taken to avoid current leakages which usually result in cusp in the sounding curve.

The VES Field data were plotted on bi-logarithmic graph and a preliminary interpretation was carried out using partial curve matching involving two-layer master curves and the appropriate auxiliary charts. This is term as quantitative interpretation. The layered model thus obtained served as input for an inversion algorithm using the software called WINRESIST (Zohdy 1989).

ELECTRICAL RESISTIVITY METHODS

This method uses an artificially generated current from a power source. It involves sending a direct current into the ground through electrodes. This current will flow within the subsurface and cause a potential difference to develop. The amount of potential difference generated depends on conductivity (inverse of resistivity) of the subsurface materials, temperature, density of fractures and the nature of fluid filling the pores. The potential difference is measured and converted to resistivity to provide an insight about the underground materials.

ELECTRICAL PRINCIPLES AND BASIC THEORIES

The force of attraction or repulsion between two charged spheres is proportional to the product of the individual electric charges and inversely proportional to the square of the distance between the centres of the spheres. This is Coloumb`s law of electric charges. This law can be written in the form of equation below:

$$F = K \frac{Q_1 Q_2}{r^2} \quad (1)$$

Where Q_1 and Q_2 are the electric charges, r is their separation and K is a constant.

The unit of charge is the coulomb (C), defined as the amount of charge that passes a point in an electrical circuit when an electric current of one ampere (A) flows for one second (i.e., $1C=1A\ s$). The ampere is defined as the current that produces a force of 2×10^{-7} N per meter of length between infinitely long thin conductors that are one meter apart in

vacuum. In System International (SI) units K is written as $(4\pi \epsilon_0)^{-1}$, so that:

$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2} \quad (2)$$

Where the constant ϵ_0 is called the permittivity constant. It is approximately equal to $8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$

ELECTRIC FIELD INTENSITY AND POTENTIAL

Electric field intensity is the force exerted on a unit electric charge Q_2 by another charge Q_1 . While electric field potential is the work done in carrying a unit charge from infinity to that point.

Therefore, the electric field intensity,

$$E = F/Q_2$$

Let $Q_1 = Q_2 = Q$ in Eq.(ii), equation for the electric field E at a distance r from a charge Q is obtained

$$E = \frac{Q}{4\pi\epsilon_0 r^2} \quad (3)$$

According to this definition E has the dimensions of newton/coulomb (N C^{-1}).

At an infinite distance from a positive charge Q the repulsive force on a unit positive charge is zero, but at a distance r it is given by Eq. (iii).

Therefore, at distance r from a unit charge, the potential energy is denoted U and its unit is energy per unit charge i.e., Joule / Coulomb. If we move a distance dr against the E , which is $(-E\ dr)$.

i.e., $dU = -E\ dr$, so that

$$E = -\frac{dU}{dr} \quad (4)$$

We can readily compute the electric potential U at r by integration:

$$U = -\int_{\infty}^r E\ dr = -\int_{\infty}^r \frac{Q}{4\pi\epsilon_0 r^2} dr \quad (5)$$

From which

$$U = \frac{Q}{4\pi\epsilon_0 r} \quad (6)$$

The energy needed to move a unit charge from one point to another in the electric field of Q is the potential difference between the two points. The unit of potential difference is the same as that of U (i.e. joules/coulomb) and is called a *volt*. From Eq. (iv) more common alternative units for the electric field E is volt/meter ($V\ m^{-1}$).

Electric charge flows from a point with higher potential to a point with lower potential. The situation is analogous to the flow of water through a pipe from one level to a lower level. The rate of flow of water through the pipe is determined by the difference in gravitational potential between the two levels. Likewise, the electric current in a circuit depends on the potential difference in the circuit.

Ohm's Law

The current flow I through a conductor or within a circuit is directly proportional to the potential difference V applied across the ends of the conductor or the circuit.

$$V = IR \quad (i)$$

Again, the resistance R of a wire is directly proportional to length L of the wire and inversely proportional to the cross section area A of the wire and the constant of proportionality ρ is the resistivity.

$$R = \rho L/A \quad (ii)$$

Rearranging and combining equations (i) and (ii) gives

$$\rho = (V \cdot A) / (L \cdot I) \quad (iii)$$

But $V / L = E = dv/dr$ (potential gradient) and

$I / A = C$ (Current density)

$$\text{Div } \underline{C} = 0 \quad (iv)$$

Therefore,

$$\rho = \underline{E} / \underline{C} \quad (v)$$

But conductivity $\sigma =$ inverse of resistivity i.e $\sigma = 1 / \rho$

Therefore,

$$\underline{C} = \sigma \underline{E} \quad (vi)$$

Equation (vi) is known as Ohm's Law

The electric field can be derived from the potential thus given us the equation below

$$\underline{E} = -\text{gradient } V \quad (vii)$$

From equations (vi) and (vii)

$$\underline{C} = -\sigma \text{ grad } V \quad (viii)$$

The high current density will have a stiff potential gradient associated with it.

Combining equation (iv) and (viii)

$$\text{div } \underline{C} = -\sigma \text{ div grad } V = 0 \quad (ix)$$

$$\text{div } \underline{C} = \nabla^2 = 0 \text{ LAPLACE'S EQUATION}$$

We have the following expression in rectangular coordinates.

Rectangular Coordinates:

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0 \quad (x)$$

Laplace's Equation in terms of a Single Point Electrode buried inside Ground

The lines of a current will radiate uniformly outward and the equipotential surface will be a sphere.

The electric field lines are parallel to the current flow and normal to the equipotential surface as shown in figure 1.

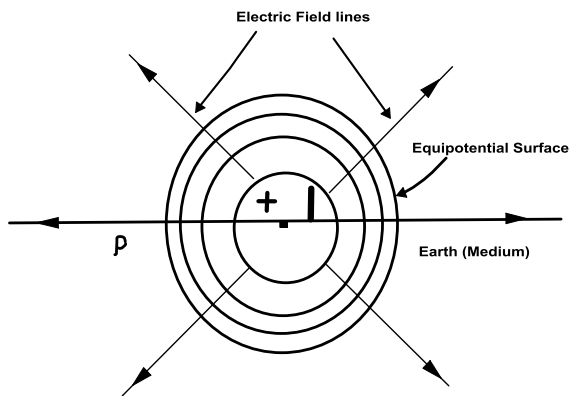


Fig 1: A single point Electrode Buried inside the Ground

ρ = resistivity of the medium which is assumed to be uniform.

$$\frac{\partial^2 V}{\partial r^2} + \frac{2}{r} \frac{dV}{dr} = 0 \text{ Laplace's equation in spherical coordinates} \quad (xi)$$

$$V = A + B / r \quad (xii)$$

Where A and B are constants.

At very large distances from source the potential will be zero such that

$$V = B / r \quad (xiii)$$

i.e A = 0

Differentiating equation (xiii) gives

$$dv/dr = - B/r^2 = E \quad (xiv)$$

From equation (viii)

$$\underline{C} = \frac{-1}{\rho} \frac{dv}{dr} \quad (xv)$$

Substituting equation (xiv) into (xv) gives

$$\underline{C} = \frac{1}{\rho} \frac{B}{r^2} \quad (xvi)$$

By rearranging

$$B = \rho r^2 \underline{C} \quad (xvii)$$

The current density \underline{C} along the spherical surface will be the current divided by the surface area. That is

$$\underline{C} = I / 4\pi r^2 \quad (xviii)$$

Substituting Equation (xviii) into (xvii) and the resulting equation into equation (xiii) will give

$$B = \frac{\rho I}{4\pi} \quad (xix)$$

$$V = \frac{\rho I}{4\pi r} \quad (xx)$$

This is solution to Laplace's equation about a point electrode buried inside the ground.

A SINGLE POINT ELECTRODE SYSTEM

At the surface of the semi- infinite medium, the equipotential surface is a hemispherical surface with surface area $2\pi r^2$. The line of current flow is perpendicular to equipotential surface (Fig. 2).

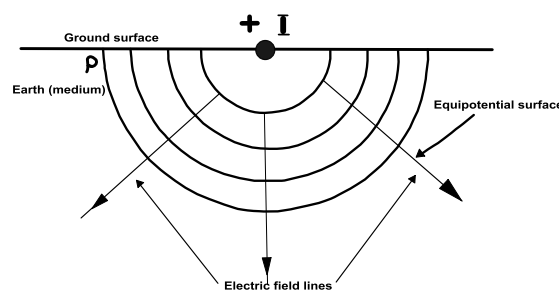


Fig 2: A single point Electrode at the surface of the semi-infinite medium

The current density \underline{C} along the hemispherical surface will be the current divided by the surface area. That is

$$\underline{C} = I / 2\pi r^2$$

Again, substituting this equation into equation (xvii) and the resulting equation into equation (xiii) gives rise to the following equations

$$B = \underline{\rho} I / 2\pi \quad (xxi)$$

$$V = \underline{\rho} I / 2\pi r \quad (xxii)$$

V = potential which is scalar quantity, ρ = resistivity of the medium and r = distance from the point source.

At any point in the earth, the potentials acting could be added algebraically (Fig. 3) since it is a scalar quantity, that is, it has only magnitude and no direction.

Let us consider the potential produce at a single potential electrode by two current electrode system (Fig. 3)

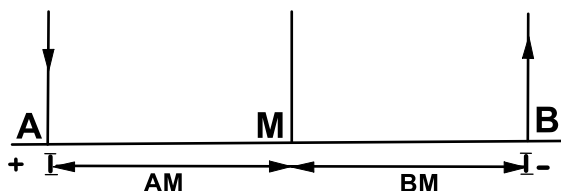


Fig. 3: Schematic Diagram of single Potential Electrode within Two Current Electrodes System

At the point of observation M,

The potential due to current at A is given as

$$V_A = \frac{\rho I}{2\pi AM}$$

The potential due to current at B is given as

$$V_B = \frac{\rho I}{2\pi BM}$$

The total potential acting at point M due to current at point A and B

$$V_A + V_B = \frac{\rho I}{2\pi AM} + \frac{-\rho I}{2\pi BM}$$

$$V_A + V_B = \frac{\rho I}{2\pi} \left[\frac{1}{AM} - \frac{1}{BM} \right] \tag{xxiii}$$

This relationship can be extended to practical electrode arrangement.

This arrangement consist of two pairs of electrode with a pair serving as current source electrode (A, B) and the other pair serves as the potential electrode (M, N) as shown in fig 4.

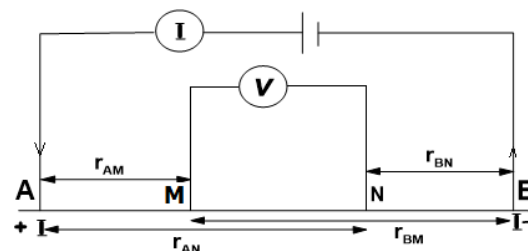


Fig. 4: The Generalized Four-Electrode System.

Potential at M due to current (+I) at A is $\rho I / 2\pi AM$

Potential at M due to current (-I) at B is $-\rho I / 2\pi BM$

Therefore the combined potential at M due to current at A and B

$$U_M = \frac{\rho I}{2\pi} \left[\frac{1}{AM} - \frac{1}{BM} \right] \tag{xxiv}$$

Also, the combined potential at N due to current A and B

$$U_N = \frac{\rho I}{2\pi} \left[\frac{1}{AN} - \frac{1}{BN} \right] \tag{xxv}$$

The potential difference (ΔU) between M and N due to current at A and B

$$\Delta U = \frac{\rho I}{2\pi} \left[\left[\frac{1}{AM} - \frac{1}{BM} \right] - \left[\frac{1}{AN} - \frac{1}{BN} \right] \right] \tag{xxvi}$$

Therefore, apparent resistivity,

$$\rho_a = \frac{\Delta U}{I} \frac{2\pi}{\left[\frac{1}{AM} - \frac{1}{BM} \right] - \left[\frac{1}{AN} - \frac{1}{BN} \right]} \tag{xxvii}$$

$$R = \Delta U / I \text{ and } K = \frac{2\pi}{\left[\frac{1}{AM} - \frac{1}{BM} \right] - \left[\frac{1}{AN} - \frac{1}{BN} \right]}$$

$$\text{Hence, } \rho_a = R * K \tag{xxviii}$$

Where $R = \Delta U / I$, Electrical Resistance while K represents the terms in bracket and is called the geometric factor.

Electrode Configurations

The geometries and form of electrode system used in resistivity surveying. There are various

arrays with different geometric factor. The most commonly used arrays are

- The Wenner Array
- The Schlumberger Array and

Wenner Configuration

In this array adjacent electrodes are equally spaced and collinear (Fig. 5a), therefore

$$r_{AM} = r_{BN} = a, \text{ and } r_{AN} = r_{BM} = 2a$$

Substituting this into equation (xxvii) gives

$$\rho_a = 2\pi a \frac{V}{I} \tag{xix}$$

$K = 2\pi a$ is the geometric factor for Wenner configuration.

Schlumberger Array

In this type of array, the inter-electrode spacing are not equal but the arrangement is collinear (Fig. 5b).

$$\text{In this case } r_{AM} = r_{BN} = a - b/2 \text{ and } r_{AN} = r_{BM} = a + b/2$$

Again, substituting this into (xxvii) gives

$$\rho_a = \pi (a^2/b - b/4) * V/I \tag{xxx}$$

$K = \pi(a^2/b - b/4)$ which is the geometric factor for schlumberger configuration.

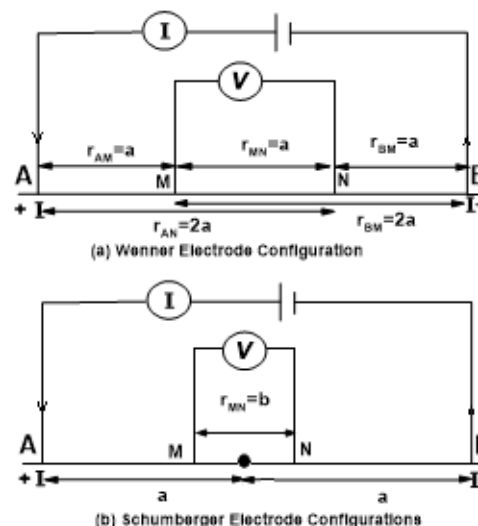


Fig.5: Schematic Diagram of Electrode Configuration (a) Wenner (b) Schlumberger

RESULTS INTERPRETATION AND DATA ANALYSIS

Geological Investigation Result

The geology in the study area around the VES points is magmatite-gneiss. They are hard basement rock with some minor faults. The outcrop is also characterised by few structural elements such as joints, fractures, quartz and quartzo-feldspathic vein, banding and gneissic layering. Some of the outcrop show slight alteration.

Geophysical Investigation Results

The results of the geophysical investigation is presented below

4.2.2 Vertical Electrical Sounding Results

It is noted that for a productive well, the VES curve must have a well-defined minimum resistivity and appreciable depth. Therefore, among various curve types, H-type is the most appropriate for water and even conductive mineral. The H-type curve shows high resistive top layer; falls to a minimum due to an intermediate layer that is a better conductor

than the top layer then increases because of a resistive bottom layer.

Plot of apparent resistivity against distance provide the layer parameters (resistivity and thickness). They exhibited various characteristic curve types/shapes such as curve type A (Fig. 6), curve type KH (Fig. 7), curve type H (Fig. 8), curve type QH (Fig. 9), curve type K (Fig. 10), and curve type HA (Fig. 11). Other characteristic VES curve types (Graph 1) are found in appendix. The geology around the VES points are presented in Table 1. They are interpreted from the result of the VES data and curves following computer iterated and algorithmic process.

Also, for ease of interpretation, the VES were grouped into VES TRAVERSE and 2-D geoelectric section for all the VES traverse and are presented below in Figures 12 – 19. The value of respective layer resistivity and thickness are also presented (see table 1).

VES TRAVERSE 01: This comprises VES 1 to 3 and VES 1 and 3 has three layers while VES 2 has four layers. The top soil has thickness range between 1.7 and 2.8 meters and resistivity range between 63- and 171-ohm meter. For VES 2, the second layer is lateritic clay with thickness of 5.7 meters and electrical resistivity of 351-ohm meter. The weathered zone has thickness ranging from 9.9 to 36.4 meters and resistivity ranging from 75 to 380-ohm meters. This layer is quite thick and likely to contain water. VES 1 and 3 can be drilled for borehole with medium yield and VES 2 which has relatively low resistivity (79-ohm meter) can be

developed into hand dug well as this point contain good quantity of water. The fresh basement has an infinite thickness with electrical resistivity exceeding 1869-ohm meter. Figures 12 shows the geoelectric section.

VES TRAVERSE 02: This comprises VES 4-7. VES 4, 5 and 6 show three layers with the top soil having thickness ranging from 0.6 to 3.0 meters and apparent resistivity ranging from 173 to 1450-ohm meters. The weathered layer thickness ranges from 4.5 to 17.0 meters and the resistivity ranges from 26 to 94-ohm meters. This may be water filled clayed sand. This layer is finally underlain by fresh basement having an infinite thickness and resistivity of between 664- and 1473-ohm meter. VES 6 is a potential point for drilling while VES 4 and 5 can be developed into hand dug wells. VES 7 have four layers with thin top soil of 0.2 meters and electrical resistivity of 434 ohm meters. This is underlain by layer of lateritic clay 3.1 meters with resistivity of 107 ohm meters. The weathered layer has thickness 2.0 meters with resistivity 12 ohm meter. This may contain water but cannot be drilled for borehole because of the shallow thickness. But it may be probably developed into well. It is finally underlain by unaltered fresh basement of infinite thickness having resistivity of 1215 ohm meter. The geoelectric sections across the VES points are shown in figure 13 while the layer parameters are presented in table 1.

VES TRAVERSE 03: This comprises VES 8-11.

They are all characterized by a three-layer curve of H type (Table 1). The top soil is relatively thin with thickness of 0.5 to 1.6 meters and resistivity of 154 to 450 ohm meters (Fig. 14), the weathered layer has thickness ranging between 1.1 and 15.8 meters and resistivity ranging between 14 and 77 ohm meter. This may be water saturated units. Therefore, VES 8 and 9 may be drilled for boreholes (Table 1). They are underlain by an infinite basement rock with electrical resistivity ranging between 755 and 2715 ohm meter.

VES TRAVERSE 04: This comprises VES 13 and

14. They are three layers with H-type curve. The top soil is thin and is about 0.8 to 1.8 meters. The resistivity range is 440 to 451 ohm meter (Fig. 15). They are underlain by a weathered layer of thickness ranging from 4.4 to 20.3 meters and resistivity ranging from 17 to 128 ohm meter. The fresh basement has infinite thickness with the resistivity exceeding 1442 ohm meter. VES 14 can be developed into drill hole while VES 13 can be dug for well (Table 1).

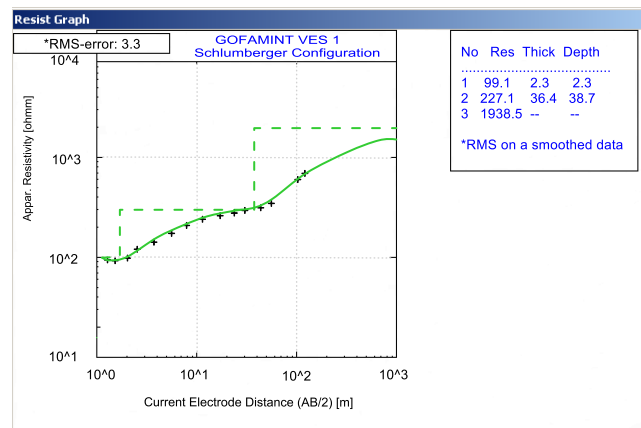


Figure 6: Characteristics Shapes of VES Curve Type A

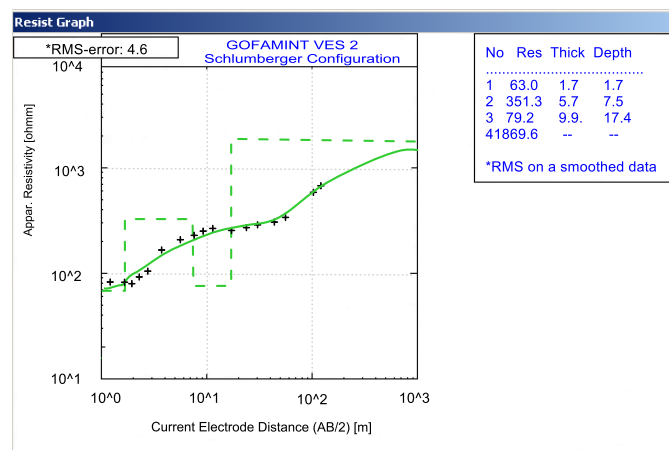


Fig. 7: Characteristics Shapes of VES Curve Type KH

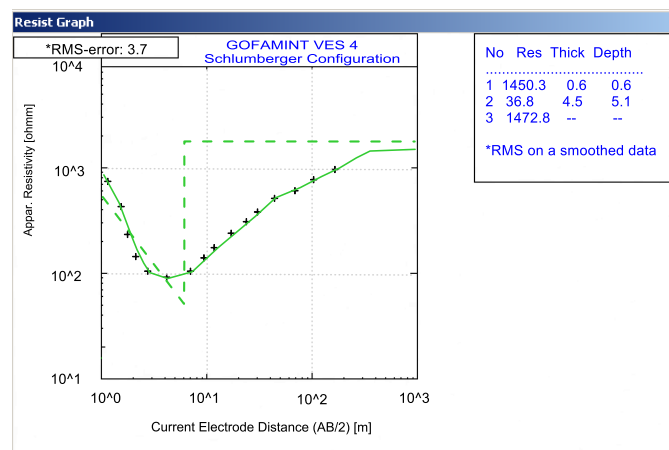


Figure 8: Characteristics Shapes of VES Curve Type H

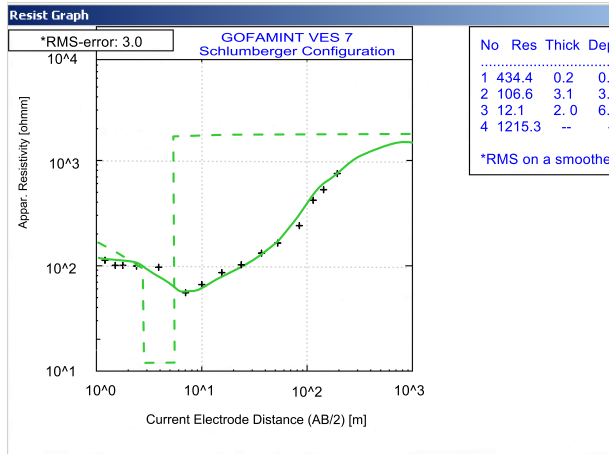


Figure 11: Characteristics Shapes of VES Curve Type HA

Figure 9: Characteristics Shapes of VES Curve Type QH

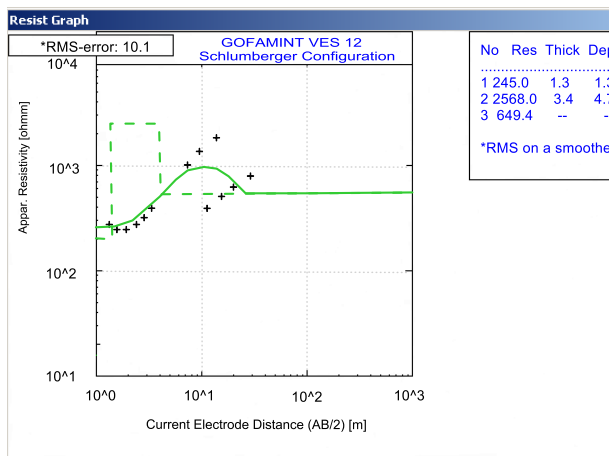


Figure 10: Characteristics Shapes of VES Curve Type K

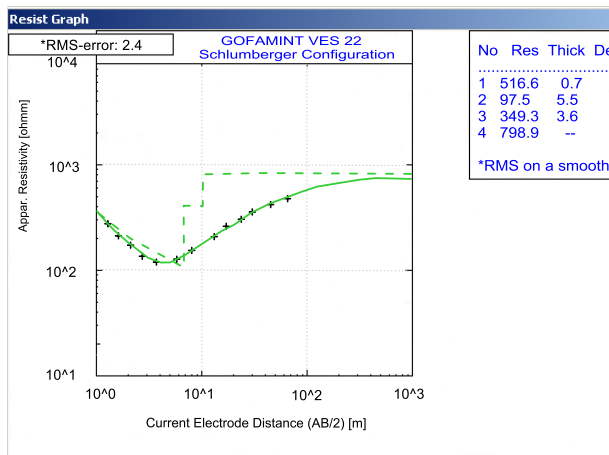


Figure 11: Characteristics Shapes of VES Curve Type HA

Table 1: Layer parameters interpreted from VES results

VES POINTS	LAYER RESISTIVITY (Ωm)	LAYER THICKNESS (m)	CURVE TYPE	COMMENT
1	99	2.3	A	Top Soil
	227	36.4		Weathered Layer
	1939			Fresh Basement
2	63	1.7	KH	Top Soil
	351	5.7		Lateritic Clay
	79	9.9		Weathered Layer
	1870			Fresh Basement
3	171	2.8	A	Top Soil
	380	25.9		Weathered Layer
	5564			Fresh Basement
4	1450	0.6	H	Lateritic Pan
	37	4.5		Weathered Layer
	1428			Fresh Basement
5	173	3	H	Top Soil
	26	5.2		Weathered Layer
	1399			Fresh Basement
6	301	1.3	H	Top Soil
	94.4	17		Weathered Layer
	664			Fractured Basement
7	434	0.2	QH	Top Soil
	107	3.1		Lateritic Clay
	12	2		Weathered Layer
	1215			Fresh Basement
8	403	1	H	Top Soil
	77	15.8		Weathered Layer
	2650			Fresh Basement
9	265	1.6	H	Top Soil
	72	10.6		Weathered layer
	2715			Fresh Basement
10	450	1.5	H	Top Soil
	14	3.2		Weathered Layer
	1687			Fresh Basement
11	154	0.5	H	Top Soil
	27	1.1		Weathered Layer
	755			Fractured Basement
12	245	1.3	K	Top Soil
	2568	3.4		Lateritic pan
	649			Fractured Basement
13	451	1.8	K	Top Soil
	17	4.4		Weathered Layer
	1448			Fresh Basement
14	404	0.8	H	Top Soil
	128	20.3		Weathered Layer
	1442			Fresh Basement
15	109	0.9	K	Top Soil
	2357	3.9		Lateritic pan

	468			Fractured Basement
16	667	1.1	H	Top Soil
	88	6.3		Weathered Layer
	1434			Fresh Basement
17	429	1.4	H	Top Soil
	54	7.5		Weathered Layer
	2402			Fresh Basement
18	1369	0.9	H	Lateritic pan
	39	1.7		Weathered Layer
	489	9.9		Fractured Basement
19	192	0.5	HA	Top Soil
	60	3.1		Lateritic Clay
	185	6.1		Weathered Layer
	1858			Fresh Basement
20	358	1.6	H	Top Soil
	48	6.8		Weathered Layer
	2741			Fresh Basement
21	188	1.5	H	Top Soil
	11	3.5		Weathered Layer
	1144			Fresh Basement
22	517	0.7	HA	Top Soil
	98	5.5		Lateritic Clay
	349	3.6		Weathered Layer
	799			Fractured Basement
23	181	1.6		Top Soil
	18	6		Weathered Layer
	2506			Fresh Basement
24	836	1.1	H	Top Soil
	24	4.3		Weathered Layer
	377			Fractured Basement
25	303	1.4	H	Top Soil
	34	5.6		Weathered Layer
	2541			Fresh Basement
26	343	1.3	H	Top Soil
	60	4.2		Weathered Layer
	873			Fractured Basement
27	79	0.5	H	Top Soil
	22	1.7		Weathered Layer
	5286			Fresh Basement
28	306	0.3	KH	Top Soil
	2094	4.4		Fresh Rock
	148	6.8		Weathered Layer
	2431			Fresh Basement
29	161	1.3	H	Top Soil
	74	5.2		Weathered Layer
	1765			Fresh Basement
30	158	0.8	H	Top Soil
	92	27.1		Weathered Layer
	3173			Fresh Basement

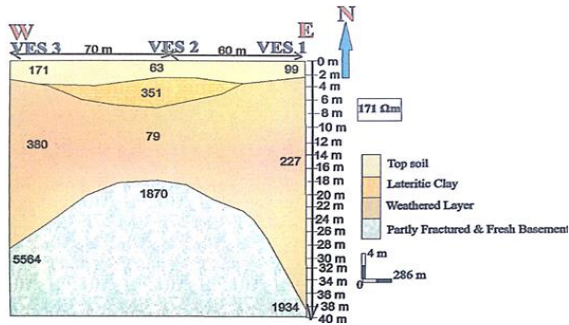


Figure 12: Geoelectric section across VES TRAVERSE 01.

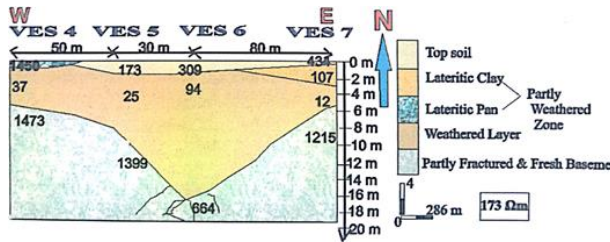


Figure 13 Geoelectric section across VES TRAVERSE 02.

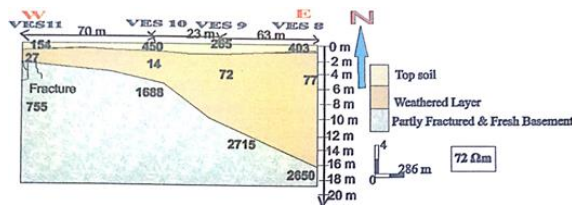


Figure 14: Geoelectric section across VES TRAVERSE 03.

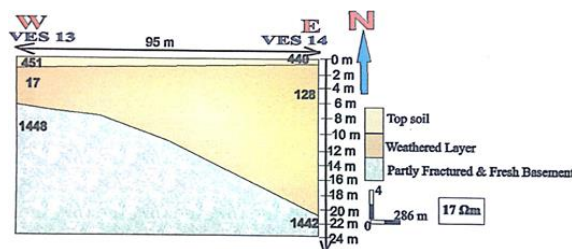


Figure 15: Geoelectric section across VES TRAVERSE 04.

VES TRAVERSE 05: It consists of VES numbers 12, 15, 16, 17, and 18. They are located on the GOFAMINT 2-D PROFILE 2. In all, the top soil has thickness range of 0.9 to 1.4 meters with resistivity range between 109 to 1369 ohm meter (Fig. 16). In VES 16, 17 and 18, the weathered layer

directly underlies the top soil and has thickness ranging between 1.7 to 7.5 meters with resistivity ranging from 39 to 88 ohm meter. VES 12 and 15 have no weathered zone but they are characterize by hard consolidated lateritic pan with thickness ranging from 3.4 to 3.9 meters and resistivity ranging from 2357 to 2568 ohm meter. The basement has infinite thickness with resistivity between the ranges of 468 to 2402 ohm meter. The low value of resistivity for the basement in some of the VES points is an indication of fractured basement containing water (Table 4.1). VES 16 and 17 can be developed into hand dug wells.

VES TRAVERSE 06: It consist of VES 19, 20, 21, and 22 but VES 22 was slightly moved northward away from the traverse which was aimed at investigating a point which seems to be hydrogeologically promising. The top soil has thickness of 0.5 to 1.6 meter and resistivity of 188 to 517 ohm meter (Fig. 17). VES 19 and 22 reveal lateritic clay of thickness ranging from 3.1 to 5.5 meters and resistivity ranging from 60 to 98 ohm meter. The weathered layer has thickness ranging from 3.5 to 6.8 meters with resistivity ranging from 11 to 349 ohm meter. The infinitely thick basement exist at a depth range of 5.0 to 9.8 meters and resistivity range of 799 to 2741 ohm meter. VES 20 and 21 can be dug for well (table 1)

VES TRAVERSE 07: It constitute VES 23, 24, and 25 and are all located on GOFAMINT 2-D PROFILE 1. They are all three layers with H curve type (Table 1). The top soil has thickness of 1.4 to 1.9 meters with resistivity of 181 to 836 ohm meter (Fig. 18). The weathered layer has thickness of 4.3 to 6.0 meters and resistivity of 18 to 34 ohm meter. The infinitely thick basement is at the depth of 6.2 to 7.5 meters with electrical resistivity of 377 to 2541 ohm meter. No borehole can be sited here but hand dug wells can be dug at all the VES points on this profile.

VES TRAVERSE 08: This is made up of VES 27, 28, and 29. The curve has different shape. The top soil has thickness of 0.3 to 1.3 meters with resistivity of 79 to 306 ohm meter (Fig. 19). VES 28 reveals four geoelectric layers. The VES point was located a few meters away from relatively low lying outcrop of migmatite-gneiss. Therefore, the second layer represents the portion of the outcrop buried at a very shallow depth of 0.3 meter. It has thickness of 4.4 meter with resistivity of 2094 ohm meter. The three VES points shows weathered layer whose thickness range from 1.7 to 6.8 meters with electrical resistivity of 22 to 148 ohm meter. Fresh basement rock of infinite thickness with resistivity ranging from 1765 to 5286 ohm meter underlies the whole units. Existing

hand dug well close to VES 27 (22 ohm meter) contain water.

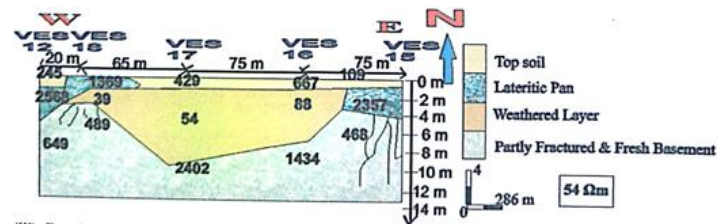


Figure 16: Geoelectric section across VES TRAVERSE 05

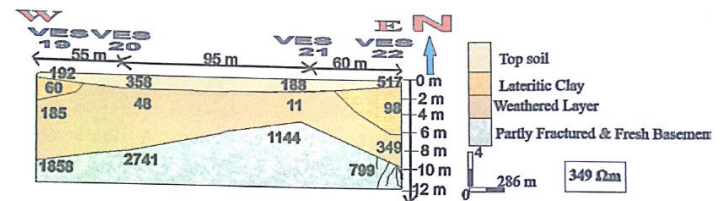


Figure 17: Geoelectric section across VES TRAVERSE 06

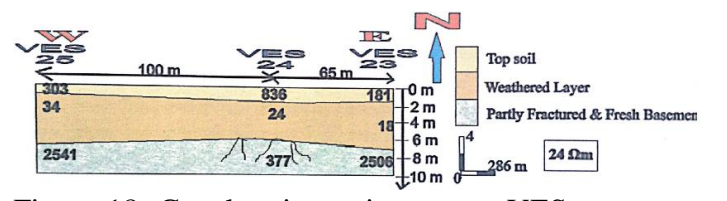


Figure 18: Geoelectric section across VES TRAVERSE 07

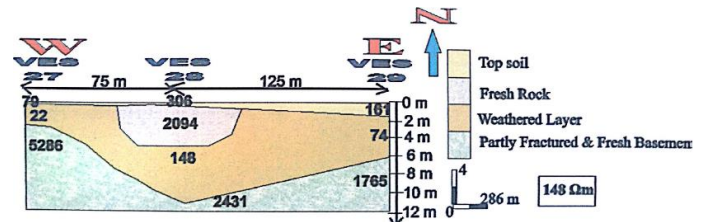


Figure 19: Geoelectric section across VES TRAVERSE 08

VES 26: This is a single VES point because of space constraint. The top soil has thickness of 1.3 meter with resistivity of 343 ohm meter. The weathered layer is 4.2 meters thick with resistivity of 60 ohm meter. The geological units are underlain by basement of infinite thickness with resistivity of 873 ohm meter.

VES 30: This is also the only VES point. It was located close to an existing borehole with usable quantity of water. This was aimed at investigating the geologic section in the vicinity of the borehole and also to serve as a control. The top soil has thickness of 0.8 meter with resistivity of 158 ohm meter. The weathered zone thickness of 27.1 meter with resistivity of 92 ohm meter. The basement unit has infinite thickness with resistivity of 3173 ohm meter.

Two – Dimensional (2-D) Electrical Imaging Results

A more accurate model of the subsurface is a two- dimensional (2-D) model where resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line. In this case, it is assumed that resistivity does not change in the direction that is perpendicular to the survey line. In many situations, particularly for surveys over elongated geological bodies, this is a reasonable assumption. Two 2-D Electrical Imaging were taken and the inverted pseudosections are presented in Figures 20 and 21.

GOFAMINT 2-D PROFILE 01: The inverted section reveals a homogeneous geology along each successive layer, that is, there is parallel series of layers lying almost parallel to one another (Fig. 20). Close to the surface is an occurrence of low resistivity zone that has a resistivity ranging from 40 to 83 ohm meter with thickness

ranging from 5 to 7 meters. This is interpreted to be near surface clayey material or a material or water bearing horizon which can be developed into hand dug well. This interpretation is supported by the occurrence of small pool of water in this region in the field. The VES points (VES 23, 24 and 25) were located on this profile also confirms this interpretation. This zone is underlain by a layer with resistivity ranging from 83 to 366 ohm meter and thickness of approximately 8 to 12 meters. This is also underlain by a more resistive unit having a resistivity ranging from 366 to 736 ohm meter with thickness also ranging from 7 to 9 meters. The contour lines appear to be horizontal and this is an indication of uniform weathering of the basement rock.

GOFAMINT 2-D PROFILE 02: On the contrary, this profile shows a section that is quite different from the first profile. This is characterized by inhomogeneity in the surface (Fig. 21). Again, a low resistive zones close to the surface at western and eastern end and towards the central part of inverted section. The resistivity ranges between 22 to 82 ohm meter with thickness ranging from 3 to 12 meters. Also, close to the surface, is a more resistive layer with resistivity 800 ohm meter. It is interpreted to be lateritic layer. They are underlain by an undulating layer having resistivity ranging from 7 to 699 ohm meter with

thickness range of 10 to 40 meters i.e. thin at the top and thick at both flank of a basement dome underlying the whole overburden units. VES 12, 15, 16, 17 and 18 were located on this profile.

The geoelectric section agrees closely with the result of the 2-D imaging. Only shallow hand dug well can be sited on these profiles because of lack of appropriate depth as revealed by VES.

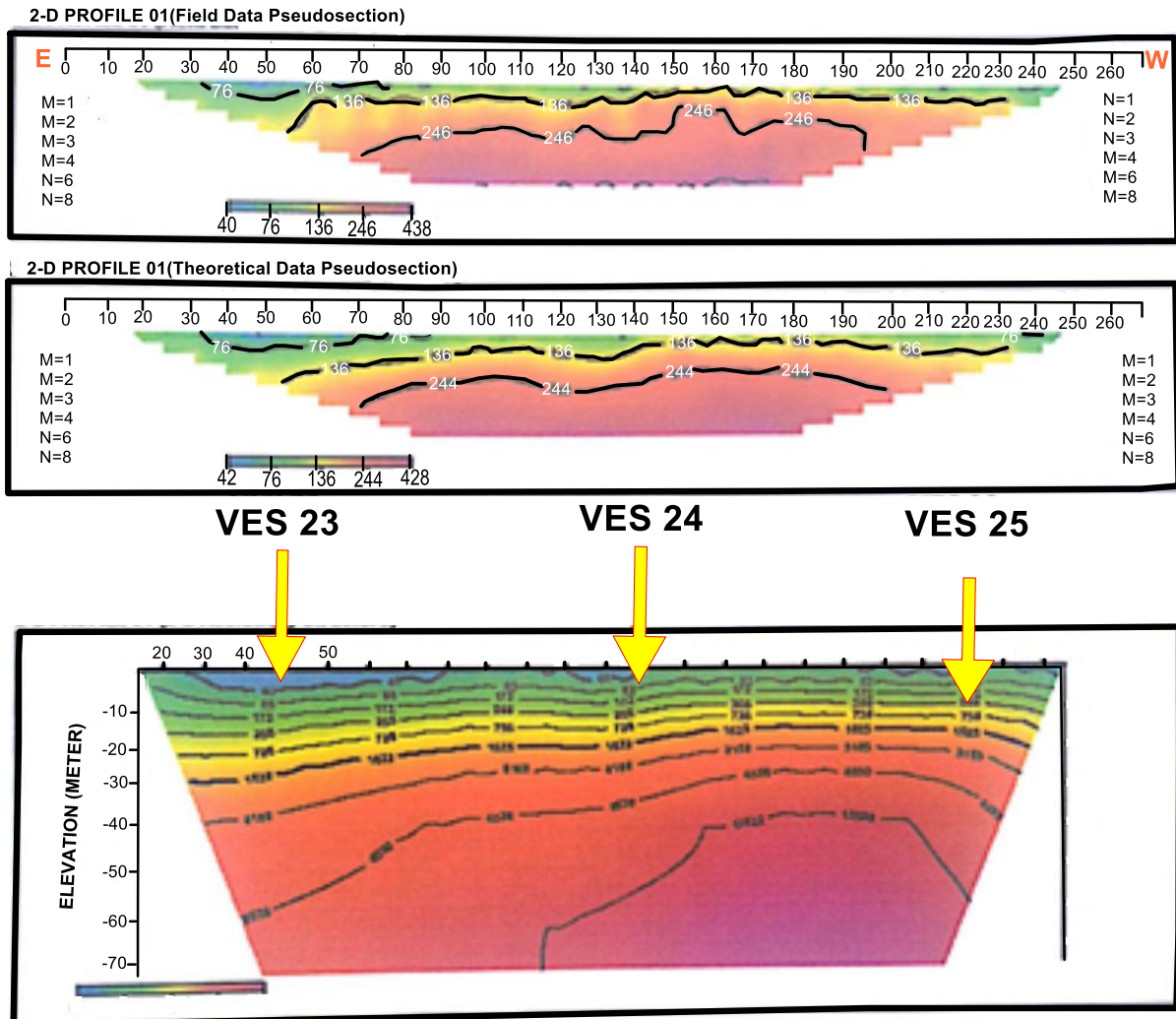


Fig. 20: Electrical imaging or Tomography (i) measured apparent Resistivity Field Data Pseudosection (ii) Calculated / Theoretical Data Pseudosection (iii) 2-D Resistivity Structure. (Blue colour represents the lowest resistivity while the purple colour denote the highest resistivity).

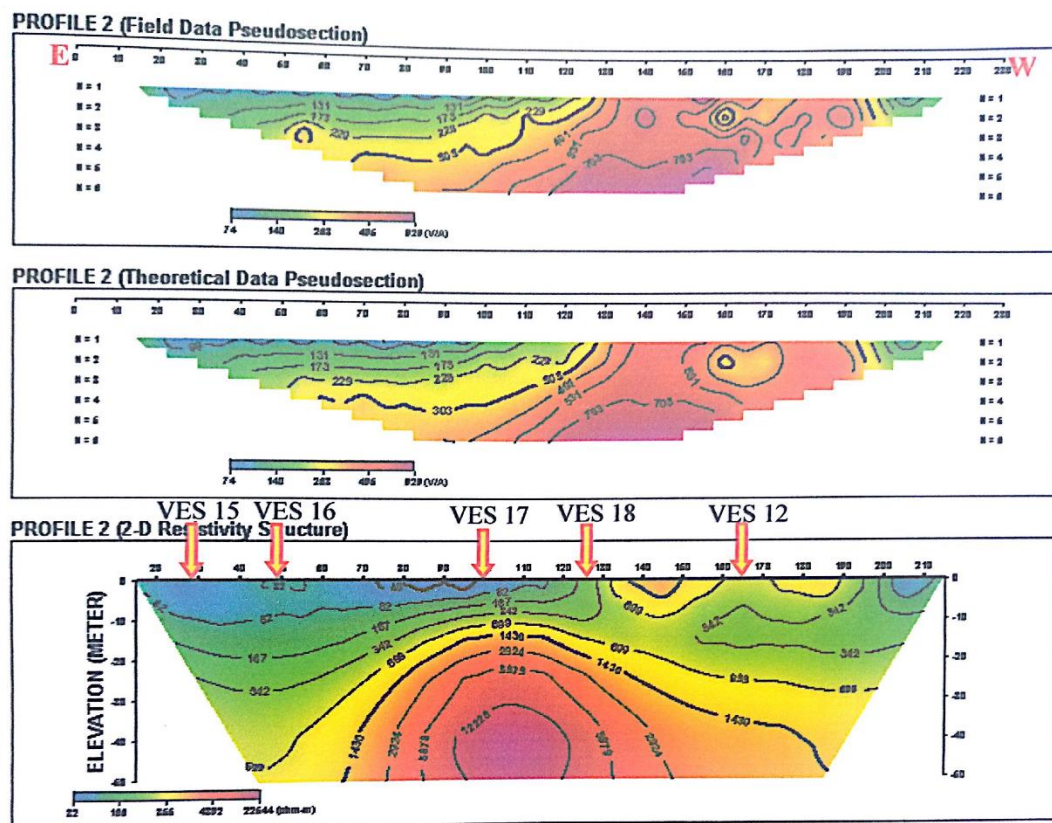


Fig. 21: Electrical imaging or Tomography (i) measured apparent Resistivity Field Data Pseudosection (ii) Calculated / Theoretical Data Pseudosection (iii) 2-D Resistivity Structure. (Blue colour represents the lowest resistivity while the purple colour denote the highest resistivity)

Modeling of Basement/Bedrock Topography

The surface basement topography plays an important role in occurrence and distribution of groundwater and also in engineering construction. Groundwater flows from region of higher elevation to that of lower elevation. Therefore, depth to basement at each VES point was determined. The basement modeling presents the configuration and geometry of the basement surface. The series of depression within the basement serve as a water collecting center while the subsurface basement high can withstand large engineering load or structures. Therefore,

decision can be made on where to site borehole and heavy building (to prevent structural failure).

CONCLUSION

The study area was investigated using integrated geophysical techniques to reveal the subsurface geology and characterize the basement aquiferous zones and suitable point for large engineering structures.

Vertical Electrical soundings (VES) analysis reveals that the geoelectrical layers ranging from top soil, lateritic clay, consolidated lateritic pan, clayey sand (weathered layer), rock boulder, fractured and fresh basement. The VES results are

presented as tables and maps (model of subsurface basement topography produce from depth to basement top at each VES point) and were used to delineate zone of groundwater accumulation and probable area of heavy load / building.

The result of the 2-D Electrical Imaging shows shallow occurrence of water. It also reveals that some portion of the site are underlain by nearly horizontal geoelectric layers with homogeneous lithology in each successive layers (GOFAMINT 2-D PROFILE 01, figure 20) while other portion are characterized by lithological inhomogeneities and domal underground structure (GOFAMINT 2-D PROFILE 02, figure 21). They are able to show the underground structure in two dimensions.

The resistivity values for weathered zones at different VES points in collaboration with the results of 2-D Electrical Imaging serve as the basis for the characterization of the basement aquifer. Region that shows low resistivity, thick overburden and fractured basement (from VES and 2-D Imaging) are delineated as the basement aquifer and vice versa. Also, the series of basement depression identified from the geoelectric sections and model of the subsurface basement topography may serve as water collecting center. This is because the survey site is a low water yielding basement terrain.

There are no observable major faults in the site. These indicate large engineering

structure can be supported without problem of differential displacement and settlement (which may ultimately lead to structural failure). This interpretation is subject to detail geotechnical investigation.

Finally, it is evident that integrated geophysical technique can be used effectively for groundwater exploration and modeling the basement topography.

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