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GEOELECTRICAL INVESTIGATION OF THE EARTH SUBSURFACE FOR PRE-FOUNDATION STUDIES AT AIRPORT HOUSING ESTATE, MAIKUNKELE, MINNA, NIGER STATE, NIGERIA

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ABSTRACT
Geoelectrical investigation was carried out using Geosensor Terrameter DDR1 at Airport Housing Estate, North Central Nigeria, Minna. The study area is bounded by latitude $09^{0}.39'$N to $09^{0}.40'$N and longitude$06^{0}.26'$E to $06^{0}.27'$Eandlies within the basement complex region of Northern Nigeria. Vertical Electrical Sounding and Electrical Resistivity Profiling techniques were carried out for the survey. The aim of the survey was to determine the subsurface layer parameters (resistivity, depth and thickness) which shall be employed in delineating sites for building construction. A total of ten profiles with twenty stations along each profile at intervals of 50 m were investigated. The ERP results were used to produce an apparent resistivity contour map from which the high resistivity points were obtained and subjectedto Vertical Electrical Soundings. The VES has a maximum current electrode separation (AB/2) of 100 m. The results obtained from VES plots reveal three distinct geoelectric layers; the top soil, the weathered/fractured layer, the fractured/fresh basement layer. Three distinct curve types were observed for the entire VES plotted curves; H-type, A-type and K-type. The areas suitable for building construction and Civil Engineering works are; The South, East and extremes of North-Western and North-Eastern parts of the study area. The points identified as great threat for high rising buildings and Civil Engineering works are E18, A18, G14, D13, G17 and F9 due to presence of clay content and weathered basement at shallow depth ranging between 0.8m to 5.01m.

Keywords: *Geoelectric, Resistivity, Basement, Vertical Electrical Sounding, Electrical Resistivity Profiling*

INTRODUCTION

Foundation investigation requires the characterization of subsurface soil and determination of soil strength as prerequisites for the foundation design of important civil engineering structures (Folorunso *et al*., 2012)

The significance of subsurface investigations using geophysical techniques is of great importance for assessing the aptness of an area for the building construction, and other civil engineering work. There were several cases of high rising building collapsing and the greatest contributing factor to this is the lack of proper geophysical investigation prior to construction activities which will reveal the nature of the subsurface and provide sound information on the suitability of the terrain for building construction. Most buildings are constructed on soil that has inadequate bearing capacity to support the weight of the structure. The near-surface soils may consist of expansive clays that shrink or enlarge as the moisture content is changed (Andrew *et al.*, 2013).Movement of foundation may occur if the clay moistening and drying is not uniform (Andrew *et al.*, 2013). Subsurface geological features such as fractures, voids, nearness of the depth to bedrock, nearness of the water table to the surface are among the inconveniences that pose constraint to building constructions especially to their foundations. The use of the geoelectrical method as an effective tool for gaining knowledge into the subsurface structure, in particular, for identifying anomalies and defining the complexity of the subsurface geology is fast gaining grounds (Soupois *et al.*, 2007; Colangelo *et al*., 2008; Lapenna *et al.*, 2005).

Geophysical resistivity method was used for this research and is based on the response of the earth to the flow of electrical current passed through the ground by use of electrodes. Geophysical investigation is one of the methods used in probing the soil/subsoil and subsurface for any engineering construction activities. The deduced soil characteristics are used as preliminary information to determine the suitability of the site for the proposed structure. If this crucial step is omitted, concealed geologic features within the subsurface may precipitate excessive total or differential settlement leading to failure
or collapse of civil structures (Fatoba *et al.*, 2013).

Geophysical methods are implemented in a very wide applications ranging from ground investigations in building constructions to inspection of dams (Soupios *et al*., 2007).

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. This development started with the introduction of practical electrical tomography field systems, like the geoelectrical Wenner pseudo-section and was soon followed by effective processing and inversion software. The imaging technique is particularly powerful and useful in the study areas of complex geology, in groundwater problems and in many other shallow subsurface investigations (Dahlin, 1996).

Electrical resistivity surveying is now increasingly being used in detecting fractures and cavities in the subsurface, waste sites characterization, geotechnical investigations of buildings, roads, dams and other construction sites, identifying and locating subsurface utilities, delineating archaeological features and monitoring pollution in the ground.

There are many electrode configurations designed for collection of geoelectrical resistivity data, but the use of a particular configuration depends on the particular geological situation and the research interest. The most commonly used electrode arrays include Wenner, Schlumberger, dipole-dipole, pole-pole and pole-dipole arrays.

The Electrical Resistivity Profiling (ERP) and Vertical Electric Sounding (VES) techniques were intensively employed in this survey because of its significance in pre-foundational studies. Hence, it has been chosen for this work because it has proven to be an economic, quick and effective means of solving most groundwater problems in different parts of the world. The thickness of the overburden can also be determined using VES technique as presented in this work.

Geology of the study area

The study area lies in the Basement Complex of North Western Nigeria. In basement complex, the rocks are of the Precambrian age, they are groups of crystalline rocks generally represented by granites, schist, migmatite, gneiss, quartzite and a host of other rocks (Tsepav*et al*., 2008). These rocks have been subjected to series of tectonic processes which led to the development of various structures within the rocks. These structures are basically fractures trending in various patterns depending on the rock formation and the accompanied tectonic processes.

The target zones for construction development in basements are mainly the shallow basement free from faults and deeply weathered zones where the unstable minerals have been removed by denudation processes. The raining period runs from April to October with the highest amount of rainfall recorded in August while the average annual rainfall is between 1,200–1,300 mm (Niger State Water and Sanitation Board, 2001). The mean annual temperature is between 22 to 25 ºC. The period between November and February are marked with the NE trend wind called the harmattan, which often causes poor visibility during this period. Geology maps of Niger state is given in Figure 1.

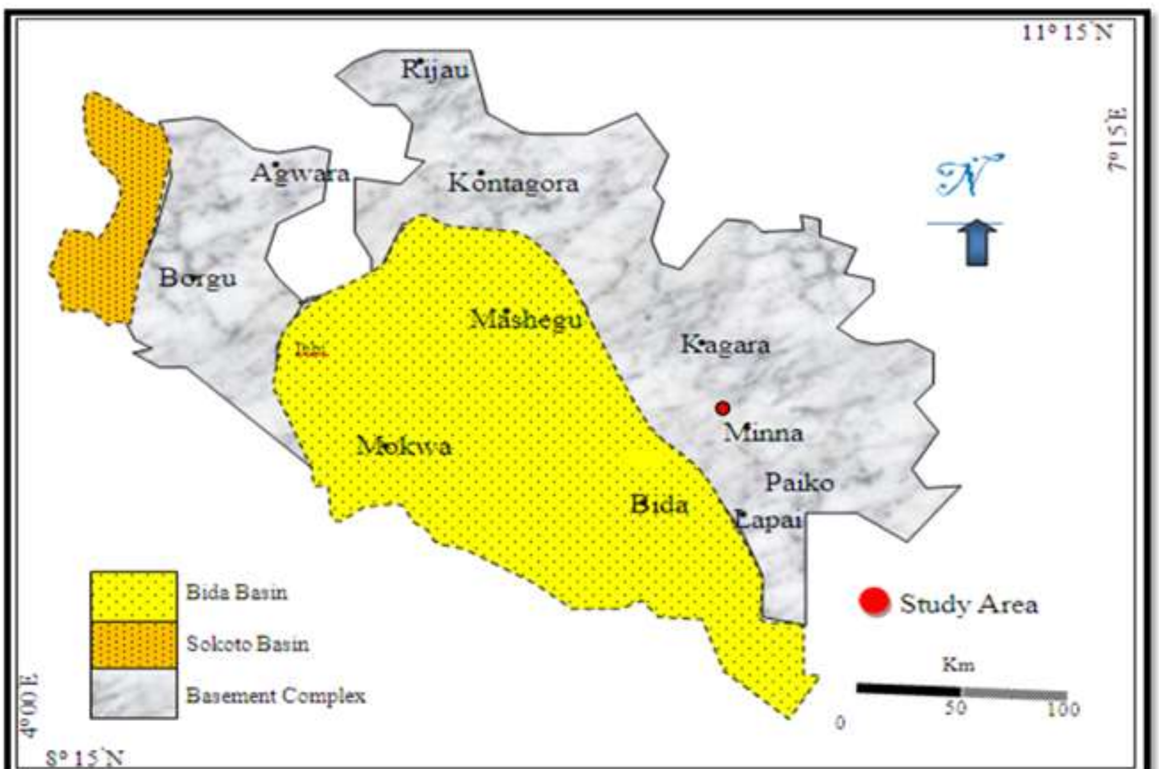

Fig. 1: Geology map of Niger state (Basement Complex and Sedimentary Basin)

Description of the study area
Gidan-Waya is a settlement in Maikunkele, Bosso local government of Niger state about 1 km from Bosso Local Government Secretariat. The study area is about 300 meters from the main road along Minna - Zungeru - Kontagora Highway. The study area extends to the airport housing estate about 500 meters from the main road. The size of the study area is 1km by $\frac{1}{2}$km. The study area is bounded by latitude $09^0.39'$N to $09^0.40'$N and longitude $06^0.26'$E to $06^0.27'$E andlies within the north eastern part of Minna. The area has distinct dry season which usually last from December to March and a rainy season which last from April to October with a typical Guinea savannah climate. The observed rock types in the study area are granite and are mostly exposed at the eastern part of the study area. A stream crosses through the study area from about 180 meters eastward at points D1, D2 and D3 to about 250 meters westward at pointF20. The geological map of the study area is given in Figure 2.

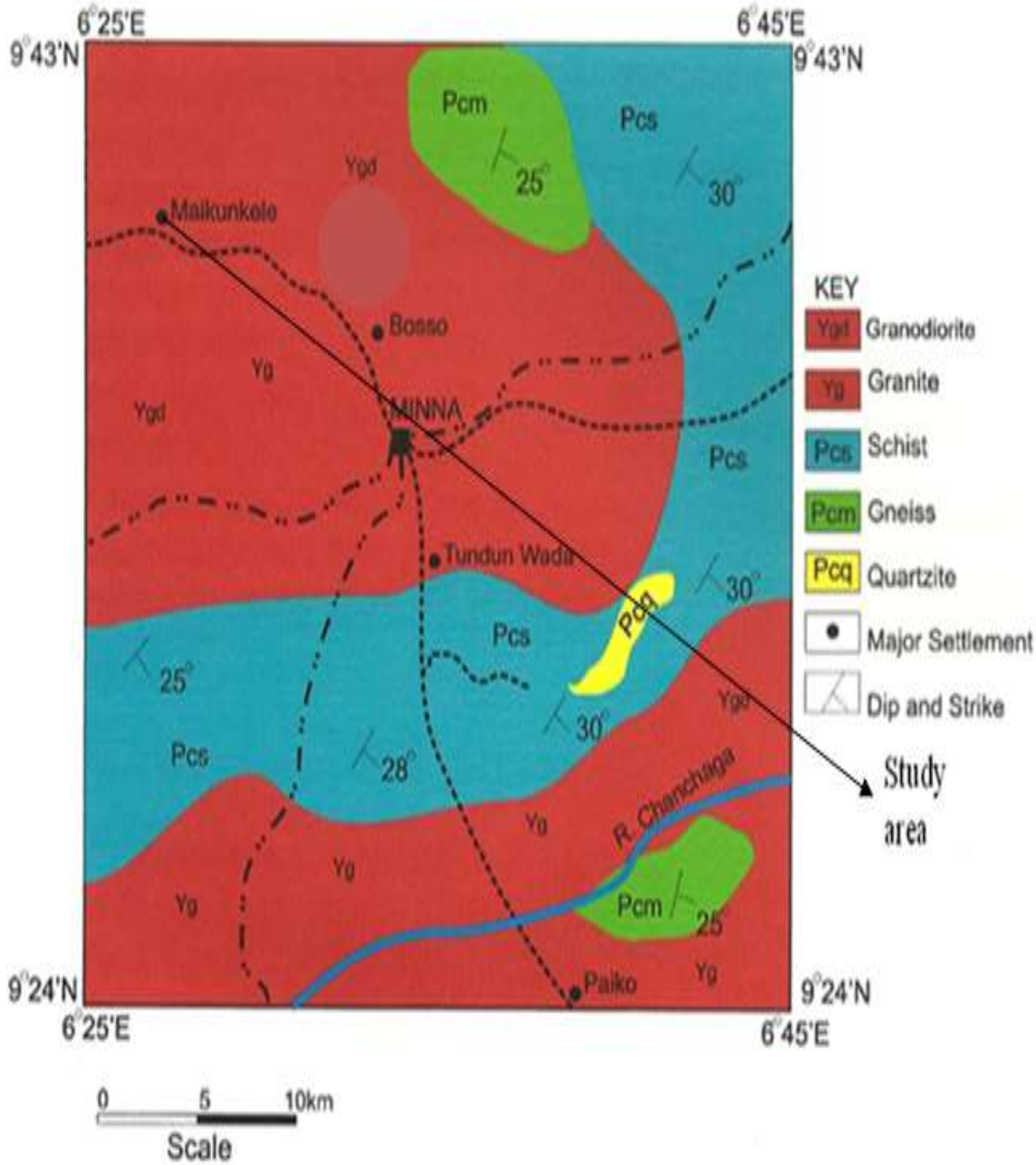

Fig. 2: Geology Map of the Study Area (Alabi, 2011)

MATERIALS AND METHODS

This research utilized Electrical resistivity method to investigate The Earth Subsurface for Building Construction at Airport Housing Estate, Maikunkele, Minna, Niger State. Electrical Resistivity Profiling (ERP) and Vertical Electrical Sounding (VES) techniques were uses to determine the subsurface layer parameters (resistivity, thickness and depth).Electrical resistivity method(s) ware employed for the research due to its ease and flexibility in obtaining sound information of the Earth subsurface. Through these methods, we determined the Earth subsurface resistivity distribution which can be related to the physical conditions of interest such as degree of water saturation, lithology, porosity and presence or absence of faults, cracks or fractures in rocks can be revealed. Resistivity measurements of the ground are normally done by injecting current through two current electrodes and measuring the resulting voltage difference at two potential electrodes.

The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Generally, most rock resistivity is roughly equal to that of pore fluids divided by the fractional porosity.

Archie's law provides a closer approximation in most cases which is given by:

$$\rho_{Rock} = \rho_{Fluid}\, A\, \emptyset^{-m} \quad (1)$$

where; ρ_{Fluid} equals the electrical properties of the fluid in the pores, **F** is the porosity (ratio of void volume/total volume), and **A** and **m** are constants that depend on the geometry of the pores. The equation for Ohm's Law in vector form for current flow in a continuous medium is given by:

$$J = \sigma E \quad (2)$$

where; σ the conductivity of the medium, J isis the current density and **E** is the electric field intensity. In practice, what is measured is the electric field potential. We note that in geophysical surveys, the medium resistivityρ, which is equals to the reciprocal of the conductivity, is more commonly used. The relationship between the electric potential and the field intensity is given by

$$E = -\nabla\Phi \quad (3)$$

Combining equations (2) and (3), we get

$$J = -\sigma\nabla\Phi \quad (4)$$

In almost all surveys, the current sources are in the form of point sources. In this case, over an elemental volume ∇Vsurrounding the a current source *I*, located at $(X_S, Y_S, Z_S,)$ the relationship between the current density and the current is given by

$$\nabla * J = \left(\frac{I}{\Delta V}\right) \delta(x - x_s)\delta(y - y_s)\delta(z - z_s) \quad (5)$$

This is the basic equation that gives the potential distribution in the ground due to a point current source. A large number of techniques have been developed to solve this equation. This is the "forward" modeling problem, i.e. to determine the potential that would be observed over a given subsurface structure. Fully analytical methods have been used for simple cases, such as a sphere in a homogenous medium or a vertical fault with constant resistivity. For an arbitrary resistivity distribution, numerical techniques are more commonly used. For the 1-D case, where the subsurface is restricted to a number of horizontal layers, the linear filter method is commonly used.

For 2-D and 3-Dcases, the finite-difference and finite-element methods are the most versatile. Maxwell's equations for Earth materials are given as:

$$\nabla \times \mathrm{H} = J\, \frac{\partial D}{\partial t} \quad (6)$$

$$\nabla * B = 0 \quad (7)$$

$$\nabla \times \mathrm{E} = -\frac{\partial B}{\partial t} \quad (8)$$

$$\nabla \cdot D = 0 \quad (9)$$

Ten (10) profiles; A - J were established on the area of study each of 1000 meters (1Km) length, the distance between one profile and the other is 50 meters. Twenty points were established on each profile at the interval between of 50 m. Two hundred ERP points were probed at 45 m depth after which twenty two were found to be promising and were subjected to Vertical Electrical Sounding in order to achieve the aim of getting sound and detail information of the subsurface with respect to the pre-foundational studies of the area. The investigation was done using Geosensor Terrameter Model DDR1.

RESULTS AND DISCUSSION

The interpretation was done using a computer program called WinResist version 1.0.This program performs automatic interpretation of the Schlumberger sounding curves. This curve gives the equivalent n-layer model from the apparent resistivity of each sounding.The program plots the VES curves with the corresponding resistivity, depth and thickness of each subsurface layer.Further analysis of the interpreted VES data was done using Surfer11.The profile layout of the study area is given in Figure 3.

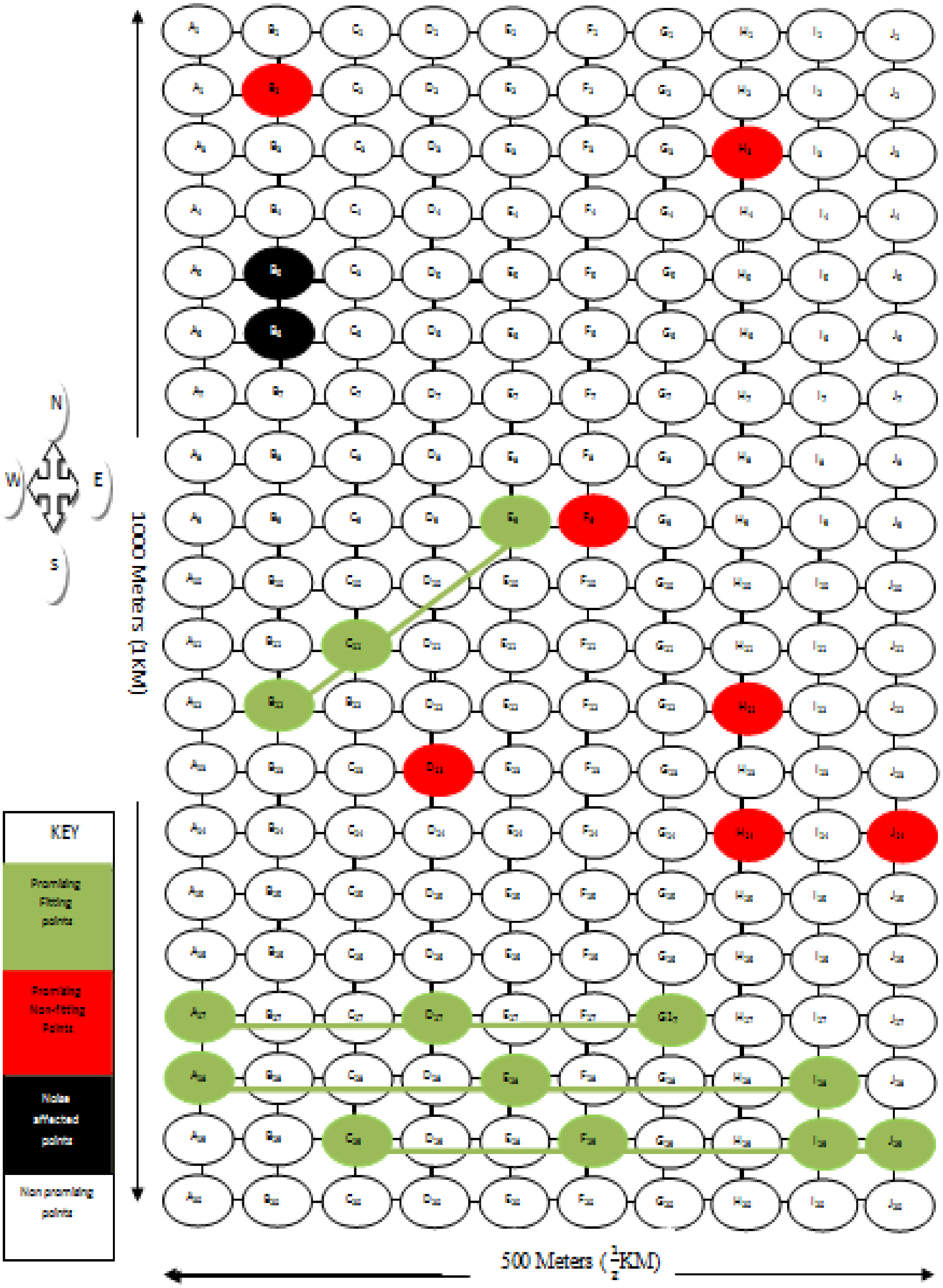

Fig. 3: Profile layouts for the study area

The ERP data collected directly from the field for 200 points were processed to apparent resistivity using the standard conversion factor obtained from the electrode geometry ($\rho a = Rk$ and $K = 2\pi a$).The apparent resistivity data for ERP was used to generate an Iso-resistivity contour map of the study area from which the promising points were obtained on the basis of low resistivity closures and later subjected to Vertical Electrical Sounding (VES). Figure 4 shows the contour map for apparent resistivity of the entire study area (ERP contour map).

ERP data (Table 1) and Iso-resistivity contour map (Figure 4) showed the resistivity values ranging from 1 – 300 Ωm while probing 45 m of the subsurface. The points with low resistivity closures indicate presence of faults/cracks/clay/fracture/weathered zones which is alarming at the depth of 54 m. The general results obtained from the VES values were presented in tables 2, 3 and 4. The depth column indicates the beginning of a layer (initial point). Each VES plot gives the required information i.e. depth, thickness and the corresponding resistivity values for each point for easy interpretation.

VES curves with their corresponding resistivity, depth and thickness are shown in Figure 5a and 5b.

The depth to basement contour map is shown in Figure 6 with contour intervals of 1 m. The map gives the depth to basement from the surface. The data used to generate the map is the depth values corresponding to the last layer for all the VES points. The map shows that the depth varies from 6 m to 26 m. VES points A17, A18, D13, E18 & E13 are relatively deep with depth ranging from 17 m to 26 m while other points are relatively shallow.

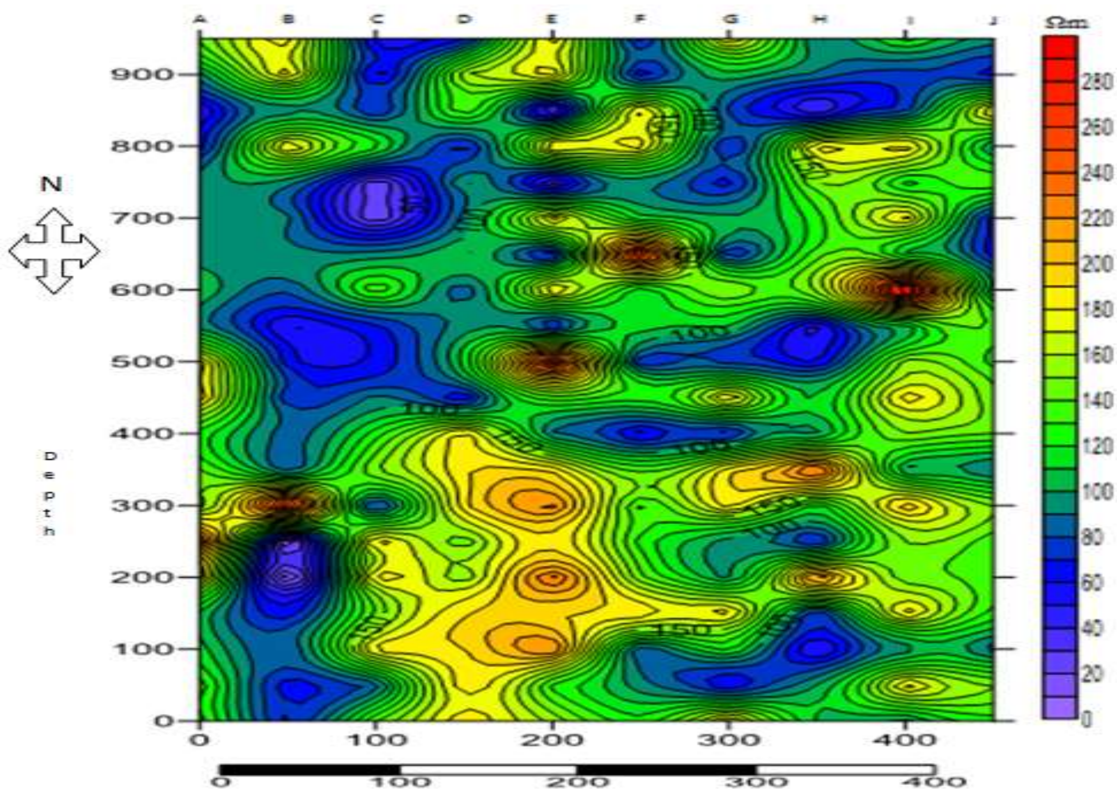

Fig. 4: Electrical Resistivity Profiling (ERP) Contour map

Table 1**: Summary table for general ERP results**

Points	X (m)	Y (m)	Z (Ωm)	Points	X (m)	Y (m)	Z (m)	Points	X (m)	Y (m)	Z (Ωm)
A1	0	0	134.6267	C1	100	0	141.375	E1	200	0	157.0771
A2	0	50	137.0772	C2	100	50	80.77225	E2	200	50	125.6541
A3	0	100	115.1924	C3	100	100	188.5	E3	200	100	226.2
A4	0	150	107.7089	C4	100	150	141.375	E4	200	150	188.5
A5	0	200	188.5	C5	100	200	188.5	E5	200	200	235.625
A6	0	250	242.3545	C6	100	250	188.5	E6	200	250	188.5
A7	0	300	141.375	C7	100	300	65.5603	E7	200	300	226.2
A8	0	350	141.375	C8	100	350	150.8	E8	200	350	188.5
A9	0	400	125.6541	C9	100	400	125.6541	E9	200	400	87.9541
A10	0	450	188.5	C10	100	450	94.25	E10	200	450	135.475
A11	0	500	188.5	C11	100	500	62.82705	E11	200	500	282.75
A12	0	550	94.25	C12	100	550	67.31335	E12	200	550	62.82705
A13	0	600	110.4045	C13	100	600	141.375	E13	200	600	188.5
A14	0	650	94.25	C14	100	650	94.25	E14	200	650	53.85445
A15	0	700	94.25	C15	100	700	18.85	E15	200	700	188.5
A16	0	750	94.25	C16	100	750	18.85	E16	200	750	31.4041
A17	0	800	62.82705	C17	100	800	125.6541	E17	200	800	188.5
A18	0	850	47.125	C18	100	850	67.31335	E18	200	850	23.5625
A19	0	900	94.25	C19	100	900	51.272	E19	200	900	188.5
A20	0	950	141.375	C20	100	950	51.40395	E20	200	950	188.5
B1	50	0	65.975	D1	150	0	188.5	F1	250	0	121.9595
B2	50	50	62.82705	D2	150	50	188.5	F2	250	50	94.25
B3	50	100	80.678	D3	150	100	188.5	F3	250	100	75.4
B4	50	150	62.82705	D4	150	150	188.5	F4	250	150	188.5
B5	50	200	0	D5	150	200	150.8	F5	250	200	141.375
B6	50	250	0	D6	150	250	141.375	F6	250	250	125.6541
B7	50	300	282.75	D7	150	300	188.5	F7	250	300	125.6541
B8	50	350	77.60545	D8	150	350	188.5	F8	250	350	137.0772
B9	50	400	84.825	D9	150	400	188.5	F9	250	400	53.85445
B10	50	450	70.6875	D10	150	450	56.55	F10	250	450	125.6541
B11	50	500	62.82705	D11	150	500	113.1	F11	250	500	67.31335
B12	50	550	47.125	D12	150	550	94.25	F12	250	550	115.9275
B13	50	600	80.1125	D13	150	600	80.77225	F13	250	600	107.7089
B14	50	650	94.25	D14	150	650	113.1	F14	250	650	282.75
B15	50	700	94.25	D15	150	700	94.25	F15	250	700	112.1952
B16	50	750	94.25	D16	150	750	102.8079	F16	250	750	94.25
B17	50	800	188.5	D17	150	800	62.82705	F17	250	800	188.5
B18	50	850	94.25	D18	150	850	141.375	F18	250	850	188.5
B19	50	900	188.5	D19	150	900	161.5634	F19	250	900	60.4
B20	50	950	188.5	D20	150	950	62.82705	F20	250	950	62.82705

Points	X (m)	Y (m)	Z (Ωm)	Points	X (m)	Y (m)	Z (m)
G1	300	0	188.5	I1	400	0	94.25
G2	300	50	56.55	I2	400	50	188.5
G3	300	100	125.6541	I3	400	100	94.25
G4	300	150	188.5	I4	400	150	188.5
G5	300	200	94.25	I5	400	200	141.375
G6	300	250	94.25	I6	400	250	150.8
G7	300	300	188.5	I7	400	300	201.8835
G8	300	350	188.5	I8	400	350	94.25
G9	300	400	62.82705	I9	400	400	150.8
G10	300	450	188.5	I10	400	450	188.5
G11	300	500	75.4	I11	400	500	157.0771
G12	300	550	113.1	I12	400	550	101.5638
G13	300	600	154.2119	I13	400	600	314.041
G14	300	650	62.82705	I14	400	650	106.0313
G15	300	700	102.8079	I15	400	700	188.5
G16	300	750	62.82705	I16	400	750	113.1
G17	300	800	62.82705	I17	400	800	188.5
G18	300	850	75.4	I18	400	850	72.96835
G19	300	900	107.7089	I19	400	900	75.4
G20	300	950	188.5	I20	400	950	125.541
H1	350	0	106.0313	J1	450	0	125.541
H2	350	50	100.5271	J2	450	50	150.8
H3	350	100	43.48695	J3	450	100	82.94
H4	350	150	62.82705	J4	450	150	125.541
H5	350	200	226.2	J5	450	200	131.95
H6	350	250	62.82705	J6	450	250	131.95
H7	350	300	113.1	J7	450	300	150.8
H8	350	350	242.3545	J8	450	350	85.97485
H9	350	400	94.25	J9	450	400	141.375
H10	350	450	107.7089	J10	450	450	141.375
H11	350	500	56.55	J11	450	500	125.6541
H12	350	550	43.48695	J12	450	550	141.375
H13	350	600	150.8	J13	450	600	94.25
H14	350	650	137.0772	J14	450	650	62.82705
H15	350	700	125.6541	J15	450	700	62.82705
H16	350	750	150.8	J16	450	750	141.375
H17	350	800	188.5	J17	450	800	94.25
H18	350	850	35.34375	J18	450	850	188.5
H19	350	900	88.68925	J19	450	900	62.82705
H20	350	950	86.99275	J20	450	950	94.25

Table 2: Summary table for general VES results

VES Points	Curve Type	No of Layers	Depth (m)	Thickness (m)	Resistivity (Ωm)
A17	H	1	0.0	0.6	58.9
		2	0.6	5.4	11.6
		3	6.0	∞	370.0
A18	H	1	0.0	0.8	1008.3
		2	0.8	21.4	35.2
		3	22.2	∞	355.6
B2	A	1	0.0	11.5	64.7
		2	11.5	6.5	96.6
		3	18	∞	2139.1
B12	K	1	0.0	8.1	28.0
		2	8.1	2.8	51.7
		3	10.9	∞	33.66.0
C11	H	1	0.0	1.1	67.7
		2	1.1	6.7	18.2
		3	7.8	∞	4052.0
C19	H	1	0.0	0.4	445.6
		2	0.4	9.1	16.6
		3	9.5	∞	265.4

Table 3: Summary table for general VES results

VES Points	Curve Type	No of Layers	Depth (m)	Thickness (m)	Resistivity (Ωm)
D13	H	1	0.0	1.2	187.6
		2	1.2	25.0	32.2
		3	26.2	∞	534.6
D17	A	1	0.0	5.6	32.4
		2	5.6	4.7	165.3
		3	10.3	∞	662.7
E9	H	1	0.0	0.6	842.5
		2	0.6	6.5	41.3
		3	7.1	∞	302.1
E18	H	1	0.0	0.8	319.7
		2	0.8	23.9	40.5
		3	24.7	∞	212.4
F9	H	1	0.0	0.8	856.8
		2	0.8	11.0	47.8
		3	11.8	∞	6650.4
F19	H	1	0.0	0.4	615.7
		2	0.4	1.3	20.9
		3	1.7	∞	855.3
G14	H	1	0.0	1.7	803.9
		2	1.7	18.3	82.4
		3	20.0	∞	2352.4

Table 4: Summary table for general VES results

VES Points	Curve Type	No of Layers	Depth (m)	Thickness (m)	Resistivity (Ωm)
G17	H	1	0.0	1.6	242.4
		2	1.6	13.5	47.9
		3	15.1	∞	1052.4
H3	H	1	0.0	1.3	132.1
		2	1.3	7.1	14.2
		3	8.4	∞	981.7
H12	H	1	0.0	0.7	547.9
		2	0.7	7.0	52.6
		3	7.7	∞	147.9
I18	H	1	0.0	3.7	405.6
		2	3.7	8.5	28.2
		3	12.2	∞	839.1
I19	H	1	0.0	1.6	355.0
		2	1.6	8.7	77.0
		3	10.3	∞	1193.9
J14	H	1	0.0	1.6	94.8
		2	1.6	3.3	10.8
		3	4.9	∞	8200.5
J19	H	1	0.0	5.6	277.9
		2	5.6	8.2	31.1
		3	13.8	∞	2243.5

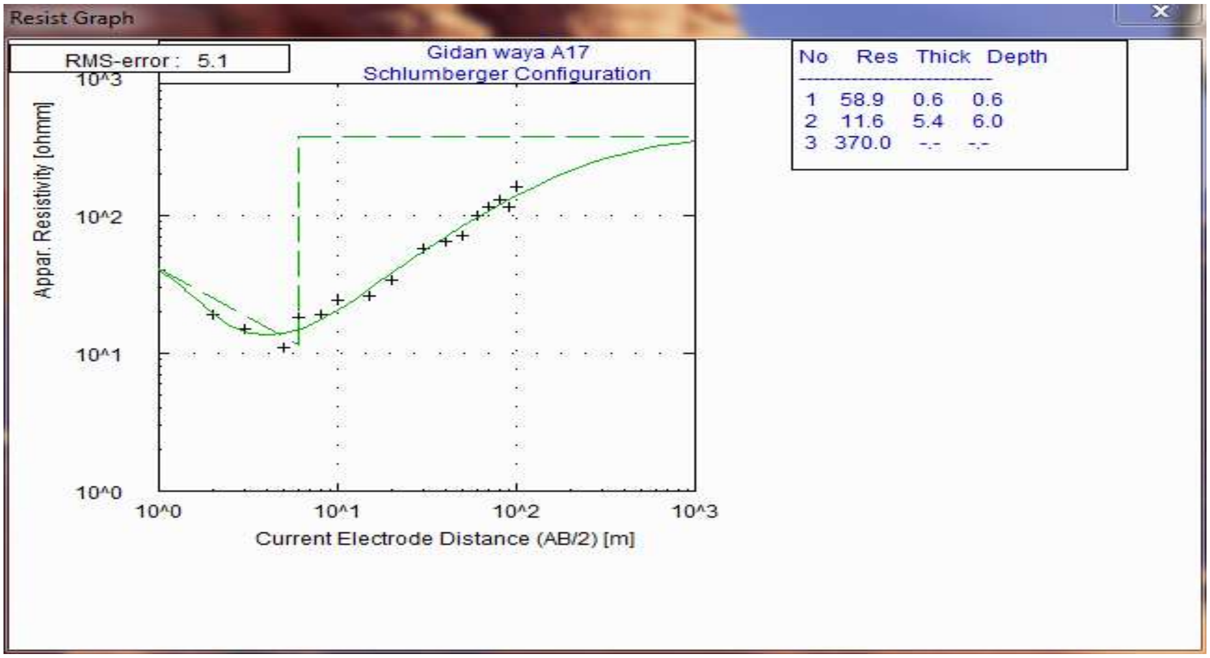

Fig. 5a: VES curve for A17.

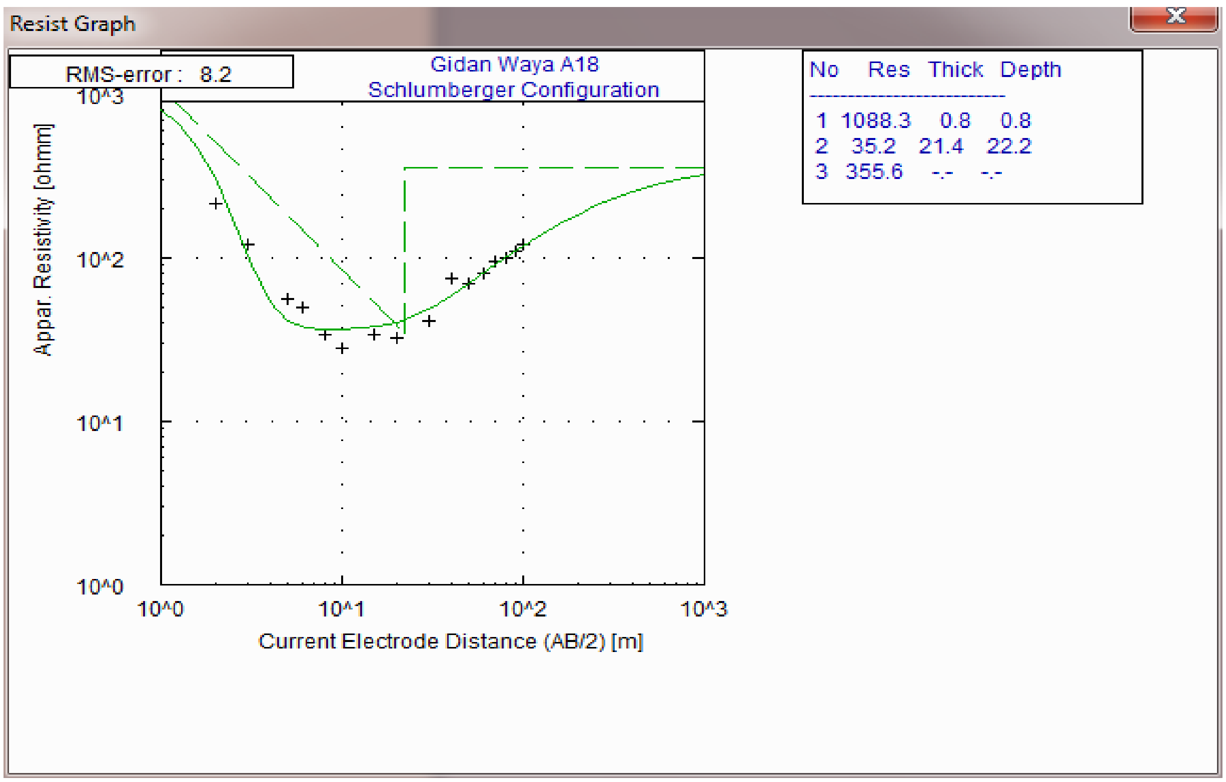

Fig. 5b: VES curve for A18.

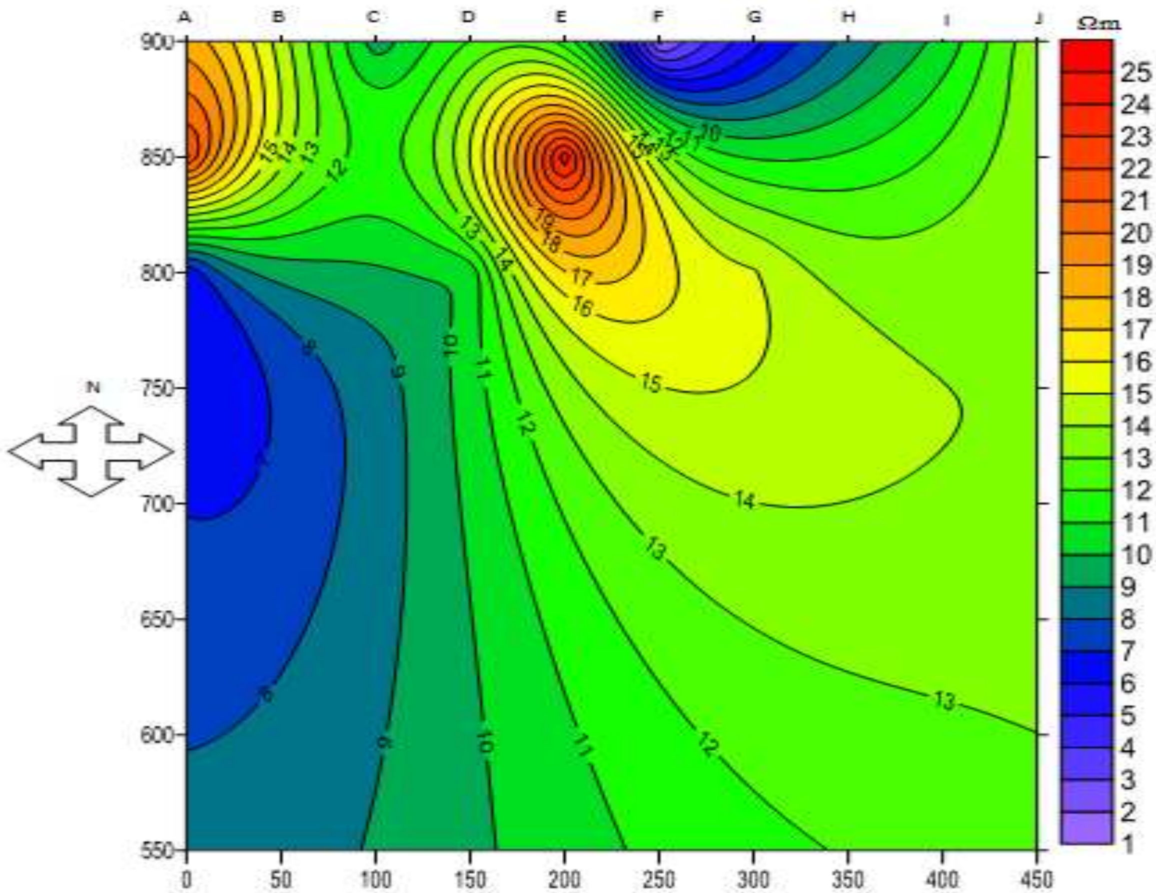

Fig. 6: Contour Map for Depth to Basement.

CONCLUSION

This research was carried out with the aim of investigating the subsurface features for building construction and other Civil Engineering works at Airport Housing Estate, Maikunkele, Minna, Niger State, Nigeria. A total of ERP 200 points were established out of which 20 points were picked and successfully sounded using the conventional Schlumberger array configuration. Maximum current electrode separation (AB/2) of 100 m was investigated for each point having 50 m distance separation between points.

Apparent resistivity values varying with depth and thickness were determined from the VES plots and were analysed in order to achieve the objectives of the research. The resistivity-depth curves were plotted using an iterative computer program known as WinResist version 1.0 for automatic interpretation of Schlumberger soundings.

Number of layers, depth, thickness and average resistivity for each VES points were determined from the plotted VES curves. ERP Iso-resistivity contour map was produced. Three distinct geologic layers were observed for the study area which include; top soil, weathered/fractured layer and fresh basement.

The depth to basement zone and the range of resistivity values for each layer were also determined. The thickness contour map clearly gave indications of the nature of weathered layer with depth. This further aided the interpretation of result.

The best region identified suitable for building construction and Civil Engineering works are; South, East and extremes of North-Western and North-Eastern parts of the study area. This is due to the shallow depth of Basement from the surface.

The points identified as great threat for high rising buildings and Civil Engineering works are E18, A18, G14, D13, G17 and F9 with weathered/Clay content thickness of 23.9m, 21.4 m, 18.3 m, 25 m, 13.5 m and 11 respectively.

The research has revealed that electrical resistivity method is highly effective in investigating the subsurface features for building construction and other Civil Engineering works. This is due to its effectiveness in identifying and detecting resistivity variation which makes the interpretation effective and meaningful.

RECOMMENDATIONS

- Areas with shallow basement should be considered for building construction.
- Areas identified as threat for heavy/high rising buildings should be avoided for Civil Engineering works.

- Weathered layer/Thick aquifer should be considered for groundwater.

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