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Investigation of the inhomogeneity of subsurface structures at various VES points at Samaru-Zaria, Northern-Nigeria

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ABSTRACT

Vertical electrical sounding (VES) data was carried out at Samaru-Zaria, Sabongari Local government area of Kaduna State, Nigeria. This was aimed to investigate the inhomogeneity of the subsurface structures as it varies from one location to the other. The groundwater potential and the geologic characteristics of the overburden of the area were also delineated. The VES curves were interpreted using IPI2Win resistivity computer software. The survey area is dominated by mainly four layers, namely: Overburden (topsoil), weathered layers, fractured layers and Fresh basement. Five subsurface layers were noticed at VES 09, 12 and 30. The overburden consists of indurated laterites, clay and sandy soil. VES Points 01, 02, 03, 04, 07, 13, 15, 25, 26, 27, 28, 29, 31 and 32 has topsoil resistivity values ranging from 200 ohm-m to 370 ohm-m, this is taken to be indurated laterites.VES Points 06, 08, 14, 18, 20 and 23 has topsoil resistivity values ranging from 28 ohm-m to 98 ohm-m which is taken to be clay. While VES Points 05, 10, 11, 12, 17, 19, 21, 22 and 30 has topsoil resistivity values of 100 ohm-m to 190 ohm-m which is taken to be Sandy Soil. Generally, the thickness of the topsoil ranges from 0.34m to 5.54m with the highest thickness at VES 19 and the lowest at VES 13. The aquifer thickness varies from 6m to 20m with the highest value at VES 11. There is variation in the topsoil thickness from one place to another within the survey Area, which is an indication of the inhomogeneity of the subsurface structures. VES Points where the thickness of the topsoil is large also have large aquifer thickness and vice-versa. There is also correlation between the topsoil thickness and depth to basement; Areas where the topsoil thickness is low have low depth to basement.

1. Introduction

The two major petro-lithostratigraphic components of the geology of Nigeria are: Basement complex and Sedimentary Basins [1]. A characteristic feature of the Basement Complex tectonics is the widespread occurrence of fractures [2]. Thus, varieties of structural features such as foliations, folds, faults, joints, fractures and fissures exists in the Basement Complex environment. Approximately half of Nigeria is covered by the crystalline basement complex of Nigeria [3]. The basement complex of Nigeria forms a part of the African crystalline shield. The number of outcrops varies considerably from one area to another which is accounted for partly by differing resistance to weathering presented by the various rock types; homogenous and massive rocks being less likely to be weathered than the others [4]. The Samaru College of Agriculture, Zaria is located at a latitude of 11º09'48.60"N to 11˚10'02.93"N and at a longitude of 7º38'06.45"E to 7˚39'20.54"E in the Sabongari local government area (L.G.A) of Kaduna state, Nigeria (Figure 1).

The college is part of the Ahmadu Bello University, Zaria, and it is bounded in the east by the estate management department of the university and Institute of Agricultural Research (I.A.R), and in the west by Area G Staff quarters. The study area has dry season (November to April) and wet season (May to October) with rain falling mainly during the wet season with an average annual rainfall of about 109cm [5]. The college is accessible mainly through the Zaria-Shika main road. (Figure2).

The goal of the study is outlined as follows:

- Determination of aquifer thickness at different VES points within the survey area.
- Determination of resistivity of topsoil at different VES points.
- Determination of overburden thicknesses at different VES points.
- Contour the overburden thicknesses at different VES Points within the survey area.

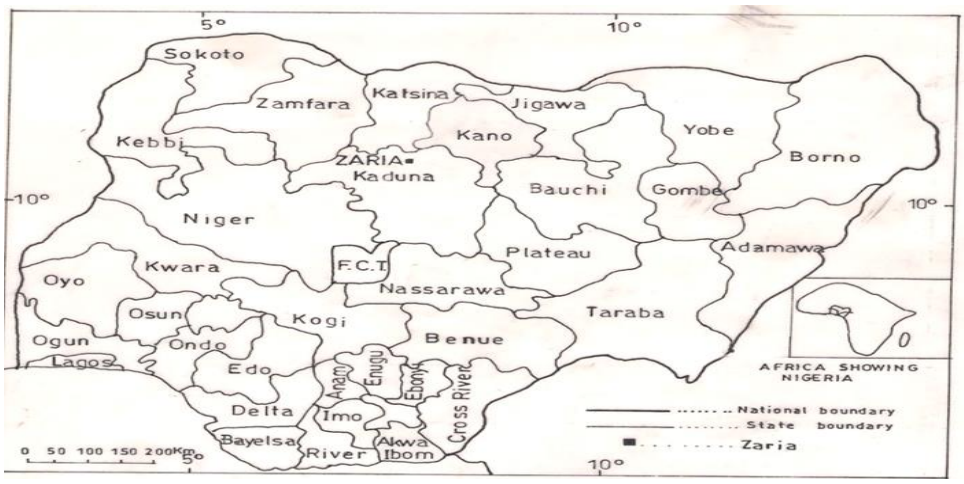

Figure 1. Map of Nigeria showing Zaria-Kaduna [6]

Figure 2. Satellite image of the study area. Source: [6].

2. Materials and Method

In the DC resistivity surveying, an electric current is passed into the ground through two outer electrodes (current electrodes), and the resultant potential difference is measured across two inner electrodes (potential electrodes) that are arranged in a straight line, symmetrically about a centre point. The ratio of the potential difference to the current is displayed by the terrameter as resistance. A geometric factor $\boldsymbol{k}$ in metres is calculated as a function of the electrode spacing. The electrode spacing is progressively increased, keeping the centre point of the electrode array fixed. A and B are current electrodes through which current is supplied into the ground, **M** and **N** are two potential electrodes to measure the potential differences between the two electrodes and P is the VES station to be sounded. The potential difference between the two potential electrodes is measured. The apparent resistivity is given by

$$\boldsymbol{\rho_a = k\left(\frac{\Delta V}{I}\right)} \qquad (1)$$

With K a geometric factor which only depends on electrode spacing and is given by

$$\boldsymbol{K = \pi\left(\frac{L^2}{2b} - \frac{b}{2}\right)} \qquad (2)$$

Electrical resistivity method is defined by their frequency of operation, the origin of the source signals and the manner by which the sources and receivers are coupled to the ground. The method is generally governed by Maxwell's equations of electromagnetism [7]. In the direct-current (DC) frequency, the diffusion term is zero and the field is thus governed entirely by Poisson equation. Electrical methods of geophysical investigations are based on the resistivity (or its inverse, conductivity) contrasts of subsurface materials. The electrical resistance, $\boldsymbol{R}$ of a material is related to its physical dimension, cross-sectional area, $\boldsymbol{A}$ and length, $\boldsymbol{l}$ through the resistivity, $\boldsymbol{\rho}$ or its inverse, conductivity, $\boldsymbol{\sigma}$ by

$$\boldsymbol{\rho = \frac{1}{\sigma} = \frac{RA}{l}} \qquad (3)$$

Low-frequency alternating current is employed as source signals in the DC resistivity surveys in determining subsurface resistivity distributions. Thus, the magnetic properties of the materials can be ignored [8] so that Maxwell's equations of electromagnetism reduced to:

$$\boldsymbol{\nabla . \vec{E} = \frac{1}{\varepsilon_\circ} q} \qquad (4)$$

$$\boldsymbol{\nabla \times \vec{E} = 0} \qquad (5)$$

Where $\boldsymbol{\vec{E}}$ is electric field in *V/m, q* is the charge density in C/m^3 and $\boldsymbol{\varepsilon_\circ}$ (8.854 X 10^{-12} *F/m*) is the permittivity of free space. These equations are applicable to continuous flow of direct current; however, they can be used to represent the effects of alternating currents at low frequencies such that the displacement currents and induction effects are negligible. Usually, a complete homogeneous and isotropic earth medium of uniform resistivity is assumed. For a continuous current flowing in an isotropic and homogeneous medium, the current density $\vec{J}$ is related to the electric field, $\vec{E}$ through Ohm's law

$$\boldsymbol{\vec{J} = \sigma\vec{E}} \qquad (6)$$

The electric field vector $\vec{E}$ can be represented as the gradient of the electric scalar potential,

$$\boldsymbol{\vec{E} = \nabla\Phi} \qquad (7)$$

The apparent resistivity is the ratio of the potential obtained in-situ with a specific array and a specific injected current by the potential which will be obtained with the same array and current for a homogeneous and isotropic medium of 1Ωm resistivity. The apparent resistivity measurements give information about resistivity for a medium whose volume is proportional to the electrode spacing [9]. Resistivity is affected more by water content and quality than the actual rock material in porous formations. While aquifers that are composed of unconsolidated materials their resistivity decreases with decrease in saturation and increase salinity of the groundwater [9]. The apparent resistivity is the ratio of the potential obtained in-situ with a specific array and a specific injected current by the potential which will be obtained with the same array and current for a homogeneous and isotropic medium of 1Ωm resistivity [9]. The apparent resistivity measurements give information about resistivity for a medium whose volume is proportional to the electrode spacing. Resistivity is affected more by water content and quality than the actual rock material in porous formations. Since the measured resistivity is usually a composite of the resistivity of several layers, the apparent resistivity may be smaller or larger than the real resistivity or in rare cases identical with one of the two resistivity values in a homogeneous surface. The apparent resistivity is the same as the real resistivity in a homogeneous subsurface, but normally a combination of contributing strata. The value of the apparent resistivity obtained with small electrode spacing is called the surface resistivity. Terrameter SAS300 was the primary equipment used in this study.

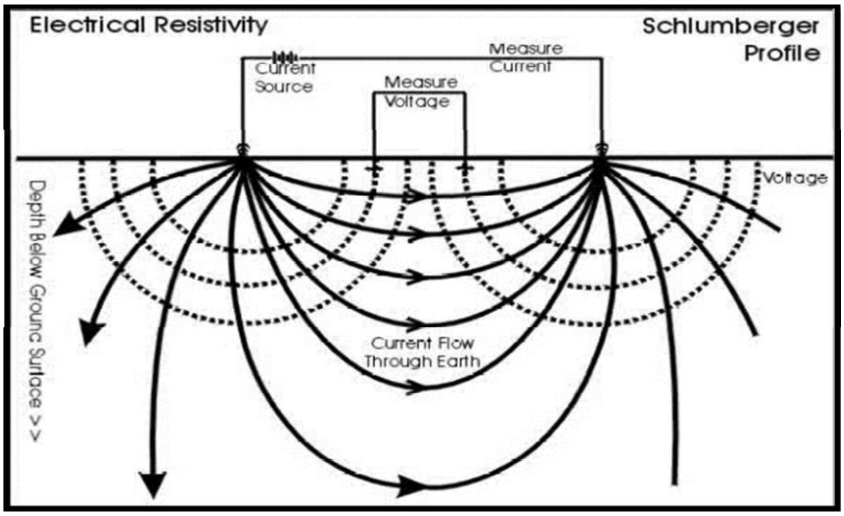

Figure 3. Schematic diagram of the schlumberger array used in the survey

A and B are current electrodes through which current is supplied into the ground, M and N are two potential electrodes to measure the potential differences between the two electrodes and P is the VES station to be sounded. The potential difference between the two potential electrode is measured. The apparent resistivity is given by $\rho_a = K \frac{\Delta V}{I}$ with K a geometric factor which only depends on electrode spacing. The apparent resistivity is the ratio of the potential obtained in-situ with a specific array and a specific injected current by the potential which will be obtained with the same array and current for a homogeneous and isotropic medium of 1Ωm resistivity. The apparent resistivity measurements give information about resistivity for a medium whose volume is proportional to the electrode spacing [8]. Resistivity is affected more by water content and quality than the actual rock material in porous formations. While aquifers that are composed of unconsolidated materials their resistivity decreases with the degree of saturation and salinity of the groundwater [10].

3. Results and Discussion

The data analysis for the VES was performed using IPI2Win's new method for the automatic interpretation of schlumberger sounding curves. This method was used to obtain the model for the apparent resistivity of each sounding. The survey area is dominated by mainly four layers, which are: overburden (topsoil), weathered layer, fractured layer and fresh basement. Five subsurface layers were noticed at VES 09, 12 and 30. The overburden consists of indurated laterites, clay and sandy soil. VES points 01, 02, 03, 04, 07, 13, 15, 25, 26, 27, 28, 29, 31 and 32 has topsoil resistivity values ranging from 200 ohm-m to 370 ohm-m, this is taken to be indurated laterites.VES points 06, 08, 14, 18, 20 and 23 has topsoil resistivity values ranging from 28 ohm-m to 98 ohm-m which is taken to be clay. While VES points 05, 10, 11, 12, 17, 19, 21, 22 and 30 has topsoil resistivity values of 100 ohm-m to 190 ohm-m which is taken to be sandy soil. Generally, the thickness of the topsoil ranges from 0.34m to 5.54m with the highest thickness at VES 19 and the lowest at VES 13. The aquifer thickness varies from 6m to 20m with the highest value at VES 11. Here, the aquifer thickness is taken to be the sum of the thicknesses of the weathered and fractured layers [9]. The survey area has an average depth to basement rock of 18.3m. The lowest overburden thickness is at VES27 where the depth to basement is as low as 10m. A map was produced by contouring all the thicknesses of the overburden layers at each VES point at an interval of 0.5m. The map shows the variation of the topsoil thickness from one place to another within the survey area which is an indication of the inhomogeneity of the subsurface structures. The interpretation of all the VES points (01 to 32) is shown in Table 2.Based on the IPI2Win's method, the field curves were found to be averagely four (4) layers. Table1 shows the interpretation of VES point 01, and Figure4 shows a typical digitized curve for VES point 01. The interpretation of all the VES points (01 to 32) is shown in Table2.

Table 1: Interpretation of VES point 01
Depth to basement at VES point 01 is 11.24m.

Layer no.	Resistivity (ohm-m) ρ	Thickness (m) h	Depth (m) d
1	367.8	1.561	1.561
2	411.9	0.3184	1.879
3	143.9	9.365	11.24
4	672.9	-	-

In Figure4; Apparent resistivity (ρ_a) in ohm-metres is plotted against the electrode spacing (AB/2) in metres by the computer software IPI2Win on a log-log scale. The blue color gives the number of layers, the red color indicate the synthetic curve while the black color shows the curve for the field data.

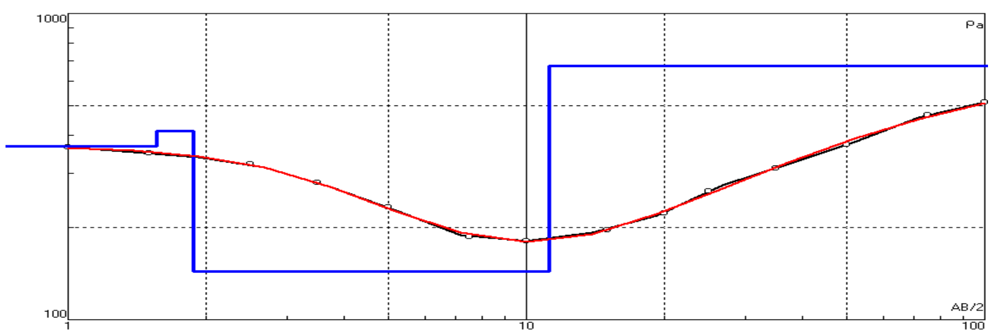

Figure 4. typical digitized curve for VES point 01

Table 2. Interpretation of VES Points 01 to 32

VES	AZIMUTH	ρ_1 (Ωm)	h_1 (m)	ρ_2 (Ωm)	h_2(m)	ρ_3(Ωm)	h_3(m)	ρ_4(Ωm)	h_4(m)	ρ_5(Ωm)	h_5(m)
01	NW-SE	367.8	1.561	411.9	0.3184	143.9	9.365	672.9	-	-	-
02	NE-SW	258	1.48	137	2.65	62.1	8.05	558	-	-	-
03	N-S	283	0.566	186	2.13	49.1	9.85	611	-	-	-
04	E-W	290	1.27	578	2.88	1413	2.16	3821	-	-	-
05	N-S	130.6	2.633	1713	2.856	516.5	5.97	738.9	-	-	-
06	N-S	97.9	0.6	139	1.62	1068	4.86	1963	-	-	-
07	E-W	333	1.26	181	4.23	69.6	7.77	2009	-	-	-
08	E-W	55	0.7	73.2	3.7	1273	2.99	114	-	-	-
09	E-W	58.4	1.13	76.3	3.62	679	4.5	141	-	-	-
10	N-S	116	0.915	292	0.457	101	1.77	568	13.3	316	-
11	E-W	148	0.409	754	0.368	69.3	18.3	10512	-	-	-
12	E-W	136	0.6	313	0.654	69.2	4.24	155	45	419	
13	E-W	219	0.342	8518	0.374	1059	25.5	511	-	-	-
14	E-W	86.2	0.37	2400	0.478	319	-	-	-	-	-
15	E-W	207.2	0.6	364.7	0.7719	693.1	1.765	744.3	-	-	-
16	E-W	50.4	0.385	1001	0.916	76.2	53.1	3779	-	-	-
17	E-W	151	1.89	1957	1.67	392	74.5	447	-	-	-
18	E-W	98.2	2.6	258	6.92	674	14.5	720	-	-	-
19	E-W	105	5.54	300	1.67	486	-	-	-	-	-
20	E-W	97.9	2.62	133	8.88	432	80.6	527	-	-	-
21	E-W	163	0.45	89.1	4.99	316	8.42	373	-	-	-
22	E-W	148	2.36	165	1.07	444	21.2	1290	-	-	-
23	N-S	90	2.47	208	5.67	462	77.4	576	-	-	-
24	N-S	28.4	0.343	197	0.454	38.5	4.14	80.8	-	-	-
25	N-S	362	0.684	88.5	3.96	773	-	-	-	-	-
26	N-S	208	3.79	82.2	10.6	37.1	14.8	54.9	-	-	-
27	N-S	357	0.241	179	1.63	33.5	8.55	54	-	-	-
28	N-S	293	4.87	79.4	17	189	-	-	-	-	-
29	N-S	266	0.789	204	5.53	44.7	-	-	-	-	-
30	E-W	124	0.505	367	0.651	123	8.05	24.7	21.9	4751	-
31	E-W	221	0.364	153	6.66	1303	64.7	1676	-	-	-
32	N-S	324	2.63	108	7.59	458	3.26	1063	-	-	-

The overburden thickness map was produced by contouring all the thicknesses of the first layer at each VES point at an interval of 0.5m. The map is shown in figure5. The map shows the variation of the overburden thickness from one place to another within the survey area. The thickness varies from 0.2 to 5.2m, with an average of 2.1m. The lowest thickness is at VES27 where the depth to basement is as low as 10m. The surface plot in Figure 6 shows a clearer variation in the overburden thicknesses within the area.

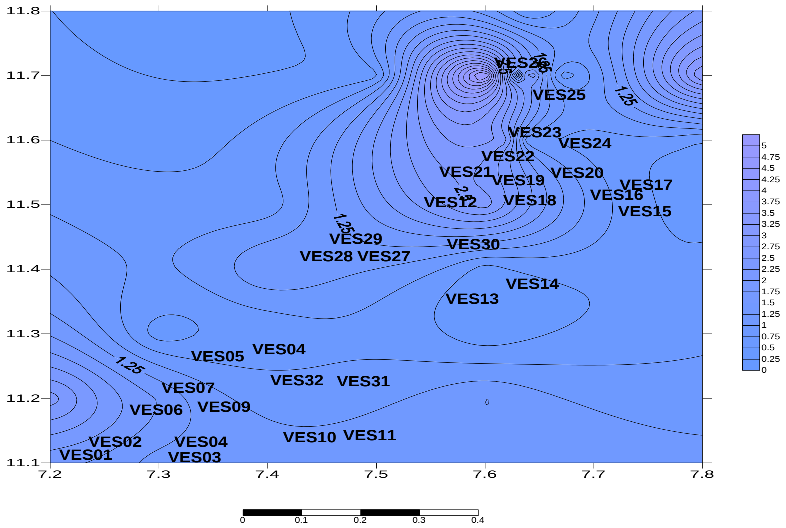

Figure5. Contour map of the overburden thicknesses within the survey area

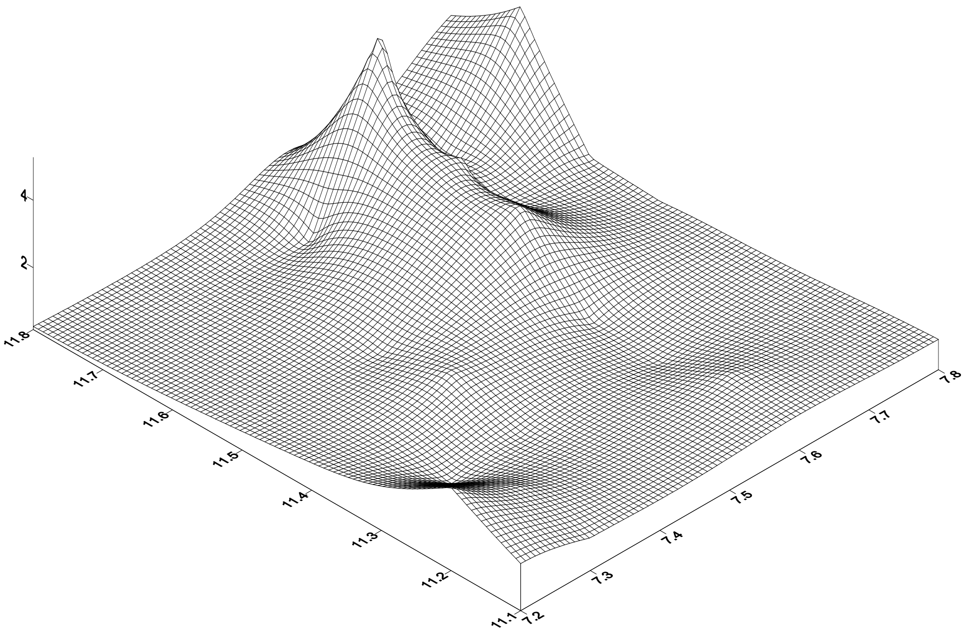

Figure 6. Surface plot of the overburden thickness

4. Conclusion

The survey area is dominated by mainly four layers, which are, overburden, weathered layer, fractured layer and fresh basement. Five subsurface layers were noticed at VES 09, 12 and 30. The overburden consists of indurated laterites, clay and sandy soil. VES Points 01, 02, 03, 04, 07, 13, 15, 25, 26, 27, 28, 29, 31 and 32 has topsoil resistivity values ranging from 200 ohm-m to 370 ohm-m, this is taken to be indurated laterites.VES Points 06, 08, 14, 18, 20 and 23 has topsoil resistivity values ranging from 28 ohm-m to 98 ohm-m which is taken to be Clay. While VES Points 05, 10, 11, 12, 17, 19, 21, 22 and 30 has topsoil resistivity values of 100 ohm-m to 190 ohm-m which is taken to be sandy soil. Generally, the thickness of the topsoil ranges from 0.34m to 5.54m with the highest thickness at VES 19 and the lowest at VES 13. The aquifer thickness varies from 6m to 20m with the highest value at VES 11. There is variation in the Topsoil thickness from one place to another within the survey area, which is an indication of the inhomogeneity of the subsurface structures. VES points where the thickness of the topsoil is large also have large aquifer thickness and vice-versa. There is also correlation between the topsoil thickness and depth to basement; areas where the topsoil thickness is low have low depth to basement.

5. Acknowledgement

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6. Conflict of Interest

There is no conflict of interest associated with this work.

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