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Assessment of Bedrock Depth Utilizing Vertical Electrical Sounding (DDBR)

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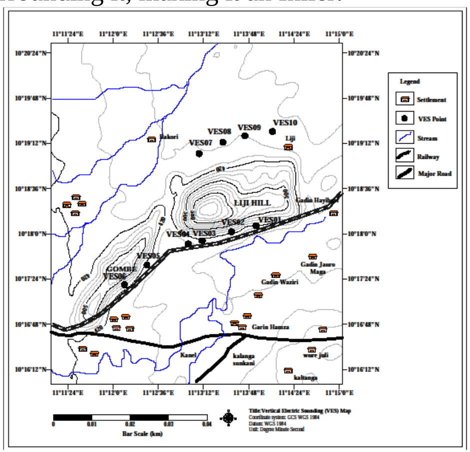
***Abstract:** This study is aimed at evaluating the depth to bed rock around Liji area of Gombe Northeastern Nigeria. The area covers 18km^2 and lies between Latitudes 11°11′20.4″, and 11°14′ 37.4″E and Longitudes 10°16′ 20.8″, and 10°19′ 16.0″N, (Gombe N.W Sheet 152). The study area consists of Basement rocks (Coarse grained Biotite Granite,), Aptian-Albian indurated Bima Sandstone, Gombe Formation and Mudrock. Ten (10) Vertical Electrical Sounding (VES) were profiled around Liji and environs, employing Schlumberger array with a maximum electrode separation of AB/2 = 100m to determine the depth to bedrock. The data obtained were processed and interpreted using WinResist program. The results showed that seven (7) VES points (VES 1, 2, 3, 5, 6, 7 and 10) displayed three layers while the remaining (VES 4, 7 and 9) had four layers. The Geo-electric sections along profiles A-A' and B-B' revealed that the area is underlain dominantly by three layers, (top soil, weathered sandstone and basement). The first layer has a resistivity value ranging from 2.3 to 193.5Ωm with a thickness that ranges from 0.4 to 7.1m. The second layer is weathered Sandstone with a resistivity range of 2.8 to 4607.6Ωm and thickness of 0.8 to 7.3m while the third layer is Basement with resistivity value of 93.6 to 37356.9Ωm with an infinite thickness. VES 4, 7 and 9 had four layers and the third layer represent the fresh Sandstone with resistivity ranges of 290.2Ωm to 4607.6Ωm and a thickness of 3.3m to 17.3m while the forth layer in the respective three VES points is basement, having resistivity ranges of 3.1Ωm to 15717.4Ωm with an infinite thickness. At the end of the study, the results revealed that Basement rocks are present at VES 1, 2, 4, 5, 6, 7 and 10 at the depth of 10m, 9.3m, 19.7m, 6.5m, 5.7m, 14.7m and 24.0m respectively with an infinite thickness, therefore these serves as the depths to be removed to reached the top of the basement for the construction of a sound foundation.*

***Keywords:** Vertical Electrical Sounding, Bedrock, Geo-electric*

I. INTRODUCTION

Rocks of different types are found everywhere in Nigeria at large. The formation of hard rocks (Igneous and Metamorphic), dates back to the Archean and Proterozoic Eon of the Precambrian. It is also believed that at that period the basement rocks of Gombe were also formed between 2.9 billion and 500 million years ago, multicellular life proliferates, along with regional sedimentation and new Igneous intrusions happened. The regional sedimentation led to the formation of Bima sandstone, Yolde Formation, Pindiga formation and kerri-kerri formation, hence making "Liji" the study area an Inlier. The aim of this research is to show the approximate depth to bedrock within Liji area. The study area is located in Gombe Local Government Area of Gombe State, Northeastern Nigeria. It covers an area of 18km^2. on the topographic map of Gombe sheet 152 NW on a scale of 1:50,000. It is located between Latitudes 11°11′20.4″ and 11°14′ 37.4″ and Longitudes 10°16′ 20.8″ and 10°19′ 16.0″. (Fig 1)

The area is easily accessible through Dadin Kowa road which is a major tarred road that passes through Gombe town. The untarred motorable road from the railway and foot paths makes the outcrop easily accessible. The mapped area lies between 420m to 670m above sea level and the topography is defined by the prominent Inlier and relatively high igneous body with gentle and steep slopes and undulating sedimentary rocks surrounding it, making it an Inlier.



[Fig.1: Topographic Map of the Study Area Showing VES Points]

The drainage of the area is controlled by the Inlier. The Inlier has no dissections except along the strike – slip fault, water flows down the rock in tributaries, some of which flow into River Magaria. The climate of the study area can be described as bi-seasonal. The dry season is comparatively longer (November – March) than the rainy season (mid-May – September). Rainfall distribution is the major factor influencing vegetation cover although topography and groundwater condition are also significant. In terms of vegetation, the research area

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can be described as exhibiting the characteristics of the Sahel Savannah type of vegetation. The vegetation comprises mainly of different types of grasses. The soil type to a large extend controls the type of vegetation that dominate the locality.

II. MATERIALS AND METHODS

Electrical methods of prospecting is one of the geophysical methods utilized in groundwater prospecting which include a large group of geophysical techniques employed for investigating the electrical fields of the earth. Such fields are generated in the earth naturally or artificially by generators or batteries. The distribution & intensity of electrical fields depend on the source of excitation as well as upon the electrical properties & geological structures in the region. The different electrical properties that influence electrical fields are primarily the resistivity ρ, the dielectric permeability and magnetic permeability. Electrical parameters vary depending upon the lithology and more influenced by the presence, content & quality of water as well as salinity.

The most common and widely used geophysical survey method is the electrical resistivity method. In groundwater exploration, depth to bedrock determination, sand and gravel exploration etc, and the electrical resistivity method can be used to obtain quickly and economically details about the location, depth and resistivity of subsurface formation. Therefore, electrical resistivity technique is a preferable geophysical technique for groundwater exploration as well as depth to basement. The resistivity is inversely proportional to the rock porosity and its water saturation. Water salinity also plays an important role as resistivity decreases when the salinity increases.

The basis of the method is that when current is applied by conduction into the ground through electrodes, any subsurface variation in conductivity alters the current flow within the Earth and this in turn affects the distribution of the electric potential. The degree to which the potential at the surface is affected depends upon the size, location, shape and conductivity of the materials within the ground. It is therefore possible to obtain information about the subsurface distribution of these materials from measurements of the electrical potential made at the surface. The usual practice is to pass current into the ground by means of two electrodes (current electrodes) and to measure the potential difference between a second pair placed in line between them (potential electrodes). From the values of the potential difference, the current applied and also the electrode separation a quantity termed the apparent resistivity can be calculated. In homogeneous ground, this is the true ground resistivity but usually it represents a weighted average of the resistivity of all the formation through which the current passes. It is the variation of this apparent resistivity with change in electrode spacing and position that gives information about the variation in subsurface layering. Most resistivity techniques define a response function called apparent resistivity, (ρa) which can be calculated from the surface measurements. This apparent resistivity is usually functions of a variable that is related to the depth of current penetration. The apparent resistivity is equal to the true resistivity only when the subsurface is homogeneous. In practice and in natural setting, it is difficult to obtain. The convenient way of representing a response of the actual distribution of lateral resistivity in the subsurface measurements is by measuring the apparent resistivity. If the electrodes are laid out along a profile as shown in Fig. 2 and their separations are increased systematically, the change in the apparent resistivity will be a function of electrode spacing. Haven said that the subsurface resistivity is measured by applying an electric current through two current electrodes and measuring the resulting voltage difference between potential electrodes. For the general four electrode spread, the potential difference ΔU between the potential electrodes is given below:

$$U_1 - U_2 = \Delta U = \frac{I\rho}{2\pi}\left\{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_1}-\frac{1}{r_2}\right)\right\} \quad .... (1)$$

$$\Delta U = \frac{I\rho}{2\pi}\left(\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_1}+\frac{1}{r_2}\right) \quad ... (2)$$

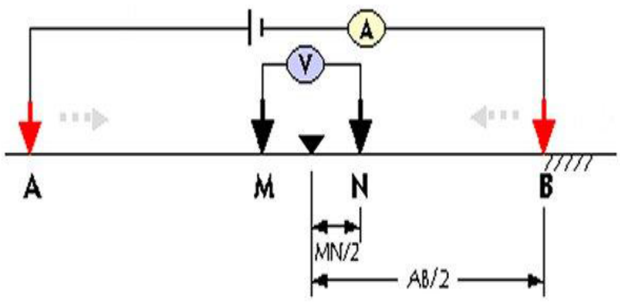
$$\rho = \frac{\Delta U}{I}\frac{2\pi}{\left(\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_1}+\frac{1}{r_2}\right)} \quad ... (3)$$

Where ρ is the resistivity, I is the current and r_1, r_2, r_3 and r_4 are the inter-electrode distances as shown in Figure

$$\rho_a = K_f\left(\frac{\Delta U}{I}\right) \quad ... (4)$$

Where K_f is the geometric factor and it depends on electrode configuration used in the field measurement. Resistivity measuring instruments normally give a resistance value, $R = \frac{\Delta U}{I}$ so in practice the apparent resistivity value is calculated by

$$\rho_a = K_f R \quad ... (5)$$



[Fig.2: Schlumberger Layout]

The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value that is the resistivity of a homogeneous ground that will give the same resistance value for the same electrode arrangement. The relationship between the "apparent" resistivity and the "true" resistivity is a complex relationship. Over uniform earth or homogeneous isotropic medium this calculated resistivity is constant for different electrode separation and any current. However, if the ground is inhomogeneous, the calculated resistivity varies as the electrode spacing is varied or the array is moved about.

This calculated resistivity is called "apparent resistivity ρa", which is diagnostic of the true resistivity of the subsurface in the vicinity of the electrode array. The apparent resistivity may be smaller or larger than the true resistivity or in rare cases identical with one of the true resistivity values.

The apparent resistivity is the same as the true resistivity in a homogeneous subsurface, but normally a combination of contributing strata of an inhomogeneous subsurface. The value of the apparent resistivity obtained with small

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electrode spacing is called the surface resistivity. In any electrode layout, the potential and current electrodes can be interchanged and from the principle of reciprocity, the apparent resistivity should be the same (unchanged) in either case. Electric current flows in earth materials at shallow depths through two main methods. They are Electronic conduction and Electrolytic conduction. In Electrolytic conduction, the current flow is via the movement ions in groundwater. In environmental and engineering surveys, Electrolytic conduction is probably the more common mechanism. Electronic conduction is important when conductive minerals are present, such as metal sulfides and graphite in mineral surveys.

(J. M. Roesset et al., 1995, [1]). Shows that the moduli of the surface layer, base, and subgrade that are back calculated from Falling Weight Deflectometer (FWD) tests are greatly impacted by the depth to bedrock. If the depth is greater than 3 m, the dynamic analysis of FWD testing is insensitive to the distance to bedrock. Motion time histories at different receivers can be used to determine the subgrade modulus and depth to bedrock, particularly for time periods longer than 0.12 seconds. Approximate equations for these computations are given by parametric studies on three types of pavements: stiff and flexible.

(E. Leblois and J. D. Referee, 2022, [2]). Shows a technique that improves bedrock depth estimates in limited data areas by modifying Gaussian statistics, offering benefits in risk and expense estimates for drilling, building, and hydrological studies.

The study revealed Kaltungo town and her environs as basement area with reasonable weathered formation ranging from a total depth of 18.1m to 54.7m which make it possible to demarcate thick soil pockets followed by considerable thickness of aquifers as recharge pockets. Interpretation of the VES, Iso-resistivity Maps and profiles identified some conductive zones which were considered as priority areas for groundwater exploration. The geo-electric parameters obtained from the inverted Vertical Electrical Sounding (VES) data were used to delineate the aquifer types of the area, fractured bedrock and/or weathered bed rock. (M. A. Garba and A. Ibrahim 2013, [3]).

S. Moon et al., 2019, [4]). Infers site-specific high-frequency vibrations (HHbR) using data and HVR frequency. It's crucial for seismically prone areas to calculate regional correction factors. A reliable reference site is essential for GIT analysis, as high-frequency amplification factors are governed by basin structures.

The resistivity pattern shows the top soil to have an average resistivity value of 73.5ohm-m with the range of 36.1Ωm as in VES4 to 162.8Ωm as in VES5 and the aquifer zone having an average resistivity value 19.7Ωm with ranges of 7.37Ωm as in VES1 and 46.9Ωm as in VES15. The average thickness of the top layer is 1.5m with ranges of 0.8m as in VES3 to 3.6m as in VES7, while the average thickness of the aquifer is 22.8m which ranges from 0.8m as in VES1 and 49.6m as in VES15. The iso- resistivity map of the study area at AB/2 = 50m indicates the southern part of the study area as favorable for groundwater exploration having a resistivity value of 28Ωm. The information gathered from qualitative interpretation of Eighteen (18) vertical electrical soundings in the study area reveals, that the curves are H-types depicting a three-layer earth model. The first layer has an average thickness of 2.4m with an average resistivity value of 126Ωm (Top soil), the second layer has an average thickness of 44m with average resistivity value of 26Ωm (Weathered/Fractured basement), the third layer has an average resistivity value of 2505Ωm, an average Longitudinal conductance of S1 = 0.048 and S2 =2.21Siemens. (M. A. Garba et al., 2021, [5]).

Curve types identified are simple H and Q, types and complex KHK, and KQ characterized by three layers. The Q curve types were the most dominant curve types suggesting high increase in resistivity from first to third layer, the H curve type indicating the low resistive layer overlain and underlain by high resistive layers. The general signature of the curves suggests alternate sequence of conductive-reflective, resistive- conductive layers, reflecting topsoil, weathered/fractured zone, porous and permeable un-weathered crystalline rocks nature of the study area. It was responsible for the discrete resistivity layers obtained in the curves. The Geo-electrical section along profile B-B', is made up of four vertical electrical sounding points which are VES3, VES6, VES8 and VES9. The first layer which is top soil has resistivity value ranging from 13.7 to 35.9Ωm. The second layer is a weathered/fractured basement and or fractured Basement at VES 3, has resistivity value ranging from 132.8 to 1661.5Ωm and the thickness of this layer at VES 6 and VES 9 is about 50 and 30m at depth of almost 55 and 35 m respectively, (K. Ezikiel, et al., 2022, [6]).

(E. Ntambakwa, 2023, [7]). Demonstrates the Horizontal to Vertical Spectral Ratio (HVSR) data that the Geotechnical Extreme Events Reconnaissance team gathered from the earthquake. Within 15 of the 61 readings, S001, the greatest sinkhole, was observed. The area's soil has a clayey blanket with occasional gravel lenses. The HVSR online platform and Python-based modules were used to evaluate the HVSR data. The findings are in line with the sinkhole depth and point to karst depths of between 12.0 and 18.0 meters.

The geologic investigation of the groundwater potential of Gadam and environs of Gombe state, Northeastern Nigeria were carried out where Fifteen (15) Vertical electrical Sounding (VES) were carried out which shows the apparent resistivity measured in the field provide a guideline for establishing Geo-electric layers, All the VES point possess layers 3 to 4 layers with resistivities ranging from 13.2Ωm to 15694.6Ωm (M. A. Garba, 2023, [8]).

A. Geophysical

All depth to bed rock investigation requires the service of Geophysical method as it aids in determining the subsurface structures. Investigation of subsurface rocks by geophysical method is termed depth to bed rock determination. Before collection of the detailed information the study area

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was assessed in details to identify the special features and characteristics influencing the ground level of the area. Profiles were carefully selected keeping in view all the possible ways of accessibility and transportation for conducting practical resistivity survey. The main reason for conducting feasibility survey was to avoid any difficulty during data collection.

B. Schlumberger Configuration for Data Acquisition

The data was collected using standard electrode configuration of Schlumberger configuration using the principle that the current electrodes vary along a straight line in both directions. However the potential electrodes are remaining constant and moved when better results of subsurface strata is needed in case of weak signals. Various types of electrode configurations like Wenner array, Dipole-dipole, Pole-pole, Pole-dipole are available but Schlumberger electrode configuration was adopted due to its flexibility, accuracy and vertical variation or profiling for data collection (Fig. 2)

For any linear symmetric array AMNB of electrodes, equation 1 can be written in the form:

$$\rho_a = \frac{\left({AB}/{2}\right)^2 - \left({AB}/{2}\right)^2}{MN} - \frac{\Delta V}{I} \quad \ldots (6)$$

The Geophysical field mapping phase, the resistivity meter used in this research was Direct Resistivity Meter (DDR-3) In view of its high resolution and depth probe, the Schlumberger configuration (Fig. 2) was used for this survey. The resistivity meter is placed at the exploration site which is suitable for lateral spreading of the cable wires in either direction. The non polarizing electrodes (inner electrodes) needed for measuring the potential differences are placed at predetermined distances on either side of chosen center near to the measuring equipment and current electrodes (outer electrodes) were also placed on either side. Covered cable is connected to the potential electrodes as also the current electrodes are connected to the proper terminals on the equipment. The power supply pack is also connected to the instrument. The current electrodes are driven into the ground at least 10 to 15 cm deep each on either side of the center with the use of hammer. The working of the instrument begins and is operated as per the principles used in the instrument instructions. Current is passed through the two extreme electrodes (current electrodes); the potential difference is received by potentiometer of DDR-3 meter between the two inner electrodes spaced at $\left({MN}/{2}\right)$ = 0.5 m, 2 m, 10m. While AB = 200m due to the fact that the overburden in the area is not as thick as to require a large current electrodes spacing for deeper penetration and current electrodes were moved equally on the either side (as the distance between electrodes increases, the depth of penetration also increases) of the station point according to designed acquisition parameters in the study, the design was 1.5, 2, 3, 4, 5, 7, 10, 10, 14, 17, 20, 25, 30, 45, 45, 60, 70, 80 and 100m.

A total of ten (10) VES points as seen in Fig. 2 were surveyed and the data of each VES point were recorded on data sheet, the locations (co-ordinates) of each VES point was also recorded with the aid of GPS (Global Positioning System) meter.

The apparent resistivity (ρ_a) was then calculated for each VES point using $\rho_a = RK_f$. Where, K_f the Geometric factor and R is the Resistance. The resistivity data were processed using WINRESIST software.

III. RESULTS AND DISCUSSION

A. Interpretation of VES Points

The acquired data was analyzed in accordance with the WINRESIST computer software. The basic working principal of which is the conventional of curve matching, data of all the VES points in the study area are presented in Table 1 which gives information regarding the interpreted VES curves. The assumption during the interpretation is that the underlying formations are horizontal and parallel to earth surface.

Table 1: Interpreted VES Curves

VES No	Location	Resistivity (Ω-m)	Later Thickness	Depth to Interface	Inferred Lithology	Curve Type
		41.1	2.7	2.7	Top soil	
VES1	N10˚18′07″ E11˚13′52″	3.5	7.3	10	Clay	H
		1495.8	Infinite	Infinite	Granite	
		193.5	4.2	4.2	Sandstone	
VES2	N10˚17′59″ E11˚13′25″	2.8	5.1	9.3	Clay	H
		1078.8	Infinite	Infinite	Granite	
		6.7	1	1	Top soil	
VES3	N10˚17′55″ E11˚13′12″	1523.6	4.9	5.9	Granite intrusion	K
		93.6	Infinite	Infinite	Sandstone	
		6.8	1.6	1.6	Top soil	
VES4	N10˚17′54″ E11˚12′54″	9.6	0.8	2.4	Clay	AK
		4607.6	17.3	19.7	Granite intrusion	

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		3833.3	Infinite	Infinite	Basement	
		2.8	0.4	0.4	Top soil	
VES5	N10°17′38″ E11°12′32″	25.2	6.5	6.9	Clay	A
		37356.9	Infinite	Infinite	Basement	
		25.9	3.7	3.7	Top soil	
VES6	N10°17′22″ E11°12′12″	329.8	2	5.7	Clay	A
		1280.1	Infinite	Infinite	Granite	
		31.5	5.9	5.9	Sandy top soil	
VES7	N10°19′03″ E11°13′00″	84	2.1	8	Sandstone	
		690.2	6.3	14.3	Clay/Sandstone	AA
		15717.4	Infinite	Infinite	Basement	
		5.6	1.3	1.3	Top soil	
VES8	N10°19′11″ E11°13′18″	317.9	1.5	2.7	Sandstone	A
		1349.2	Infinite	Infinite	Granite	
		2.3	0.5	0.5	Top soil	
VES9	N10°19′14″ E11°13′36″	1768	3.2	3.7	Basement	
		290.2	3.3	7	Sandstone	KQ
		3.1	Infinite	Infinite	Clay	
		18.3	7.1	7.1	Sandy top soil	
VES10	N10°19′22″ E11°14′02″	29.5	19.8	27	Clay	A
		1228.5	Infinite	Infinite	Granite	

Ten Vertical Electrical Soundings (VES) were conducted using the Schlumberger configuration with a maximum current electrode of 100 m using DDR-3 meter, and the results revealed the thickness of layers, resistivity of layers, fitting error and curve-types of the 10 VES points in the study area (Table 1).

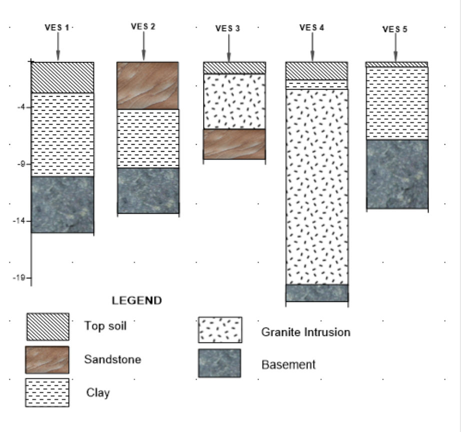
The area is underlain by three (3) and four (4) geo-electric layers. The first layer represents the top soil. The second layers are variable depending on the geologic activities that occurred in the environment; Clay as in VES1 and VES2, Sandstone as in VES5 VES6 VES7 VES10 and VES8 while Granite intrusion as in VES3 VES4 and VES9.

The third layer represents fresh Sandstone as in VES3 VES7 and VES9 and Granite being encountered at VES1 VES2 VES4 VES5 VES8 and VES10 while the fourth layer represents Clay as in VES9 and Basement in VES4 and VES7.

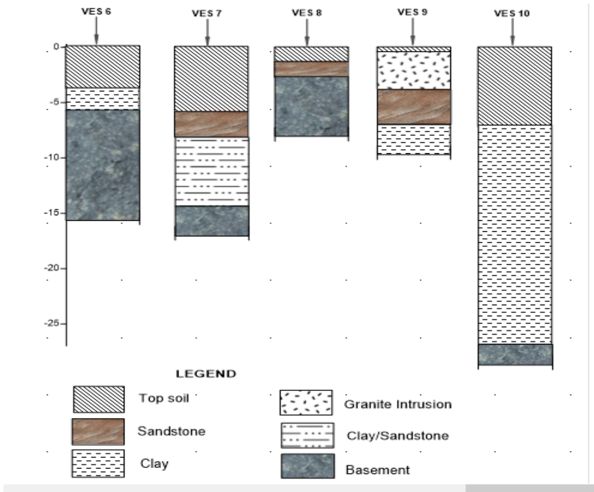
Curves identified are primary curves as in VES1 VES2 (H-type), VES3 (K-type), VES5, VES6, VES8 and VES10 (A-type) characterized by three layers while the secondary curves are VES4 (AK-type) and VES9 (KQ-type), characterized by four layers and it reflect lithological variations in the area.

The A curve types were the most dominant curve type suggesting high increase in resistivity from first, second and third layer, the H curve types indicating the low resistive layer overlain and underlain by high resistive layers.

The general signature of the curves suggests alternate sequence of resistive-conductive-resistive layers, reflecting topsoil and weathered/fractured zone. The final digital inversion results of VES interpretation (using WINRESIST software) were used for the construction of the geo-electric sections figure 3 and 4.



[Fig.3: Geo-Electric Section of VES 1, 2, 3, 4 and 5]



[Fig.4: Geo-Electric Section of VES 6, 7, 8, 9 and 10]

The area is characterized by Low, medium, fairly high and high resistivity layers. The units with low and medium resistivity values were interpreted as top soil which consists of conductive materials varying in composition from Clay and Shale derived from weathering of basement and compacted sedimentary rocks depending on the local variation of the mineralogy of the basement and sedimentary rock. Fairly high resistivity layer represents the slightly weathered and fresh Sandstone. High very high resistivity values characterized the un-weathered, fresh crystalline bedrock in the study area and are generally identified.

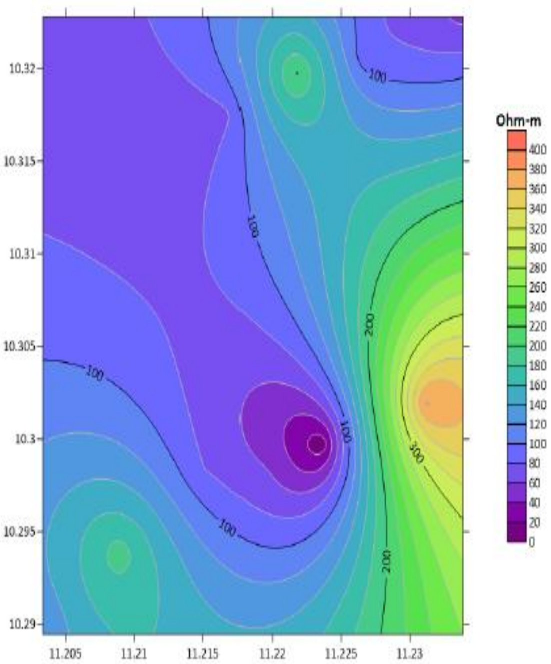
Table 2: Resistivity Data for AB/2 at 60 and 100m

Ves Number	Resistivity at mn/2= 60m	Resistivity at mn/2 100m	Latitude	Longitude
VES 1	383.6	86.0	N10°18′07″	E11°13′52″
VES 2	6.75	150.9	N10°17′59″	E11°13′25″
VES 3	56.7	622.0	N10°17′55″	E11°13′12″
VES 4	80.8	740.5	N10°17′54″	E11°12′54″
VES 5	189.6	740.5	N10°17′38″	E11°12′32″
VES 6	122.2	292.6	N10°17′22″	E11°12′12″
VES 7	75.3	914.8	N10°19′03″	E11°13′00″
VES 8	203.6	501.6	N10°19′11″	E11°13′18″
VES 9	89.4	79.7	N10°19′14″	E11°13′36″
VES 10	54.9	118.0	N10°19′22″	E11°14′02″

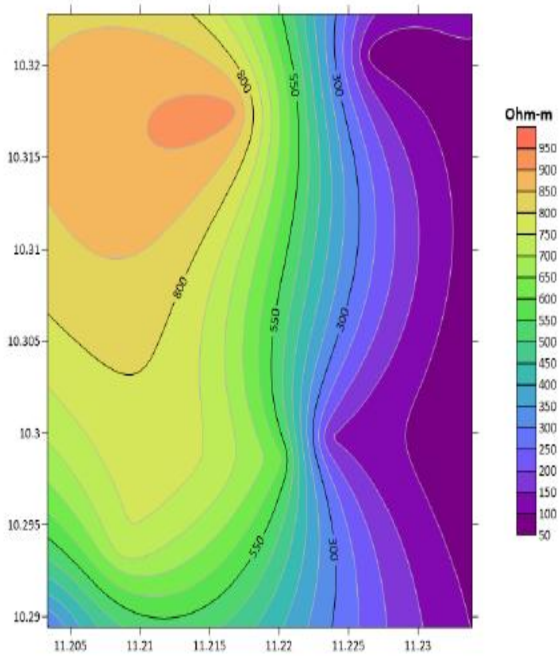
B. Iso-Resistivity Map

The Iso-resistivity map showing resistivity map of the study area was produced using surfer 9.0 software, as shown in fig 5 (AB/2 = 60m) and fig 6 (AB/2 = 100m). Resistivity values of the weathered and fresh layers from the various VES stations together with their coordinates (Longitudes and Latitudes, Table 2) were used to delineate areas of low and high resistivity.

Ideally, low resistivity refers to high conductivity and high resistivity refers to low conductivity. Therefore, areas of high resistivity are recommended for citing high level projects as the layers can withstand stress over a long period of time (bed rock).



[Fig.5: Iso-Resistivity Map of AB/2=60m]



[Fig.6: Iso-Resistivity Map of AB/2=100m]

IV. SUMMARY, CONCLUSION AND RECOMMENDATION

A. Summary

The geophysical method used in this study is used as a good method to investigate the depth to bedrock in Liji area of Gombe State. Ten vertical electrical sounding (VES) were carried out and the acquired data were analyzed using WINRESIST computer software. The apparent resistivity measured at the field provides a guideline for establishing the geo-electric layers. Most VES points posses' three geo-electric layers but some had four. The geo-electric sections obtained from VES data has provided information on the depth to bed rock in the study area. At the end of the research, the results showed that ***Basement rocks*** are present in VES 1, 2, 4, 5, 6, 7 and 10 at the depth of 10m, 9.3m, 19.7m, 6.5m, 5.7m, 14.7m and 24.0m respectively with an infinite thickness which serves as the bedrock.

B. Conclusion

The curve type obtained in the study area is dominantly A-curve type. The distinctive geo-electric layers identified were Top soil, Clay, Shale, Sandstone and Basement. The Iso-resistivity maps Fig 5 and Fig 6 clearly shows that the Western, Northwestern and extreme Eastern part of the research areas are the areas that have high to very high resistivity values.

C. Recommendation

We therefore recommend that high level projects (storey buildings) should be cited at the Western, Northwestern and Extreme Eastern part of the study area as seen from figures 5 and 6 (Iso-resistivity maps) the layers can withstand stress over a long period of time and is complimented by figures 4 and 5.

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DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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