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RESEARCH PAPER

Application of Electrical Resistivity Tomography for the Delineation of Groundwater Potential at Southern Part of Maikunkele Town, Niger State, Nigeria

***[1]Muhammad, A., [1]Tsepav, M.T., [1]Umar, S., [1]Gomina, M., [2]Ibrahim, A.A., [3]Lawrence, J.O., [1]Yusuf, T.U., [1]Yakubu, A., [1]Bello, M.L., [3]Damidami, L., & [3]Nma, M.A.**

[1]*Department of Physics, Ibrahim Badamasi Babangida University, Lapai, Nigeria*
[2]*Department of Chemistry, Ibrahim Badamasi Babangida University, Lapai, Nigeria*
[3]*Department of Geophysics, Federal University of Technology, Minna, Nigeria*

ABSTRACT

Vertical Electrical sounding (VES) and 2-D Electrical Resistivity Tomography (ERT) were used to study the groundwater potential for effective development and management in Maikunkele, Niger State, Nigeria. Thirty (30) VES points were examined using Schlumberger configuration with current electrode spacing ranging from 2.0 to 200 m. The VES data obtained were interpreted using WinResist computer software. Furthermore, 2-D ERT with a 10 m interval between two sounding points was applied using a dipole-dipole configuration. The 2-D inversion modelling of the Dipole-dipole data was interpreted using RES2DINV(R) software. The VES results revealed a heterogeneous subsurface geologic sequence probe to 20.20 m and beyond. The variation in lithology consisted of Lateritic soil/sand/clay/sandy-clay/clayey-sand/topsoil with resistivity varying from 115 Ωm to 1237 Ωm and underlay by a layer of clay with resistivity varying from 41 to 461 Ωm. The third layer was a continuation of clay of resistivity ranging from 15.62 to 100 Ωm while the fourth layer in some VES points was a combination of gravely sand with resistivity varying from 2674 to 4271 Ωm with a high resistivity at the basement bedrock of 7920-16541 down to infinity. The VES results indicate that VES points A5, B4, C5 and D5 have a promising aquifer potential. The fractured layer has a thickness of 20-46 m and a resistivity value ranging from 27.2 Ωm to 409.4 Ωm. The presence of groundwater in some parts of Maikunkele was determined and that was correlated with existing borehole logs for proper sitting and development.

Keywords: Lithology, Groundwater resources, Potential, Modelling, Maikunkele

INTRODUCTION

The search for groundwater has become paramount across the entire universe. This is because groundwater is considered one of the safest sources of potable water for both man and animals which could be for drinking, industrial and agricultural use (Horque *et al.*, 2009). Groundwater is the water embedded beneath the ground filling the pore spaces between tiny grains in sediment and classic sedimentary rock and occupying every little crevice in rocks. Rain and snow are known to be the major sources of groundwater when they settle on or flow into the ground to form groundwater. However, the amount of water that finally percolates into the ground is strongly affected by climate change, soil type, the nature of rock present, topography and type of vegetation.

According to Plummer *et al.* (1999) and Water for Africa, 2010, approximately 15% of rainwater ends up as groundwater with a slight variation of about 1 to 20% for both local and regional composition. It is surprising to note that about 0.61% of groundwater of the global water distribution is 60 times the availability of water in rivers and lakes on the surface of the earth (Plummer *et al.*, 1999).

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Address Correspondence to:
mu.abdullahi@ibbu.edu.ng; *kaleabdullahi75@gmail.com*
Tel. +2348106715992

Electrical resistivity investigation is important in determining the groundwater potential of a particular area (Olasehinde, 1999; Anudu *et al.*, 2011). The resistivity of any rock is largely influenced by the presence of groundwater contained in pore spaces and this serves as electrolyte. The mineral particles that form the shape of a rock are considered good resistors than groundwater, so the greater the amount of water contained in a rock/sediment, the lower its resistivity. This deduction strongly depends on the part of the rock with more pore spaces and the fraction of this pore space filled with water (Lowrie, 1997).

The usefulness of geophysical investigation cannot be overemphasised. It is non-destructive, non-invasive and relatively cheap. It has found application in mapping out subsurface states and properties. Hence, the application of geophysical methods has enriched researchers and practitioners to have a clear picture of the subsurface and to make intellectual deductions (Furman and Huisman, 2010).

2-D resistivity imaging is usually employed in research involving relatively shallow depth anomalies, for example, geotechnical and environmental studies (Cosenza *et al.*, 2006; Chamber, 2006; Auken, 2006). A major achievement in recent times in geophysics is the introduction of 4-D electrical imaging/tomography profiling to map out regions with moderately complex geology (N. Lesparre et al., 2020). However, the VES technique probes deeper beneath the surface, especially in regions with rugged terrain (Hamza, 2006). Schlumberger electrode array gives better information about the subsurface as this method only expands the current electrode to attain deeper depth. The purpose of the research is to characterise the subsurface lithology of the region under investigation using VES and 2-D Electrical Resistivity Tomography (ERT) methods, respectively. This will be achieved through the variation of electrical resistivities at different depths.

Location and Geology of the Study Area

Maikunkele, the study area, is located between latitudes 09°40'37.17" to 09 41'37.15" N and longitudes 06°29'51.66" to 06° 30'51.55'' E (see Figure 1). The area is easily accessible by road via Minna-Zungeru road and falls within north western part of Minna. The study area lies within the basement complex region of Nigeria with distinct wet and dry seasons.

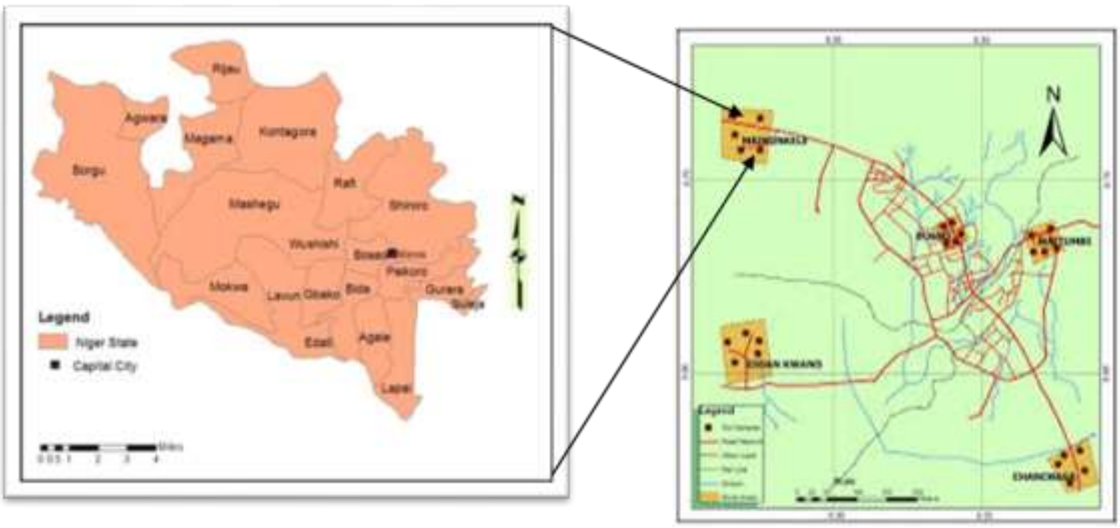


Figure 1: Location Map of the Study Area (Abdullahi and Adetona, 2017)

Maikunkele, the suburb of Minna the capital city of Niger State is underlain by Precambrian rocks of the Nigerian Basement complex and consists of crystalline rocks mainly of older granite series formed during the Pan Africa Orogeny. The older granite consisting of pegmatites, quartz veins, porphrics granites, and gneisses are present.

The hydrogeology of the study area is controlled by the vegetation rainfall, vegetation cover and evapotranspiration and the general geology of the area. The geology of the area serves as the groundwater reservoir while rainfall is the dominant source of the ground water. These factors are responsible for the number of aquifers to be encountered and the means of recharging them (Figure 2).

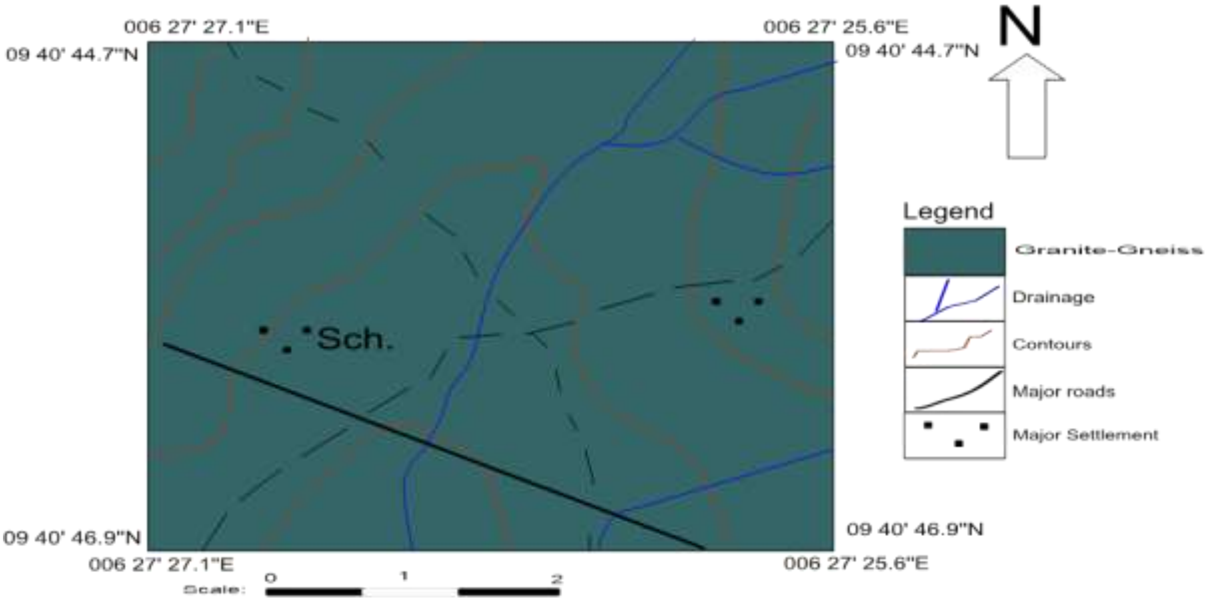


Figure 2: Geological Map of the Study Area

Theory of electrical resistivity

The process of electrical resistivity investigation involves sending electrical current, I, via current electrodes, C1 and C2 and the returning electrical signal (voltage) is measured across the two ends of the potential electrodes P1 and P2 which turns out to be the potential difference, V. The most applicable array types include Wenner, Schlumberger, Pole-pole, Dipole-dipole and pole-dipole arrays. The fundamental equation for resistivity can be derived from Ohm's law (Nwankwo, 2010).

$$\rho = \frac{RA}{L} \quad (1)$$

where ρ is the resistivity, R is resistance, L is the length of the homogenous conducting cylinder with a cross-sectional area, A. Since the earth is anisotropic in nature, equation (1) can be further transformed as:

$$\rho_a = \frac{\Delta V}{I} 2\pi r \quad (2)$$

where $2\pi r$ represents the geometric factor, K which is constant for every electrode configuration.

The Schlumberger array was employed in this research (figure 3) with a geometrical factor given as:

$$K = \pi \frac{\left[\left(\frac{AB}{2}\right)^2\right] - \left[\left(\frac{MN}{2}\right)^2\right]}{2\left(\frac{MN}{2}\right)} \quad (3)$$

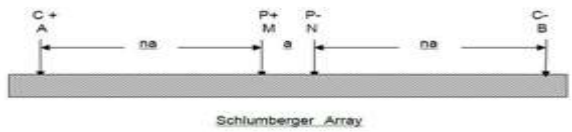


Figure 3: Schlumberger Array layout

The apparent resistivity, ρ_a is the bulk average of all rock and soil influence on the motion of the applied current. In a 2-D electrical resistivity survey, both the current and potential electrodes are placed in a linear array.

Electrical Resistivity Tomography (ERT) is a technique used to picture the bulk electrical resistivity pattern and distribution beneath the earth's subsurface. Hence, resistivity is an intrinsic property of every material used to study the characteristics of the subsurface features. On the other hand, VES uses collinear configuration to generate a 1-D vertical apparent resistivity plotted against a depth model of the subsurface at a particular sounding point.

Table 1: Resistivity of some common rocks and minerals (Telford and Sheriff, 1984).

Materials	Resistivity (Ω-m)
Clay and Marl	1-67
Topsoil	67 – 100
Clayey soil	100 – 133
Sandy soil	670 – 1330
Limestone	67 – 1000
Sandstone	33 – 6700
Sand and gravels	100 – 180
Schist	10 – 1000
Granite	25 – 1500
Surface water (in igneous rock)	30 – 500
Groundwater (in igneous rock)	30-150
Weathered laterite	200 – 500
Fresh laterite	500 – 600
Weathered/Fractured basement	100-500
Fresh Basement	>1000

This method involves acquiring several potential differences at successively greater electrode spacing while maintaining a fixed central reference point. The induced current travels farther and deeper layers at greater electrode spacing. The measured potential difference is directly proportional to the variation in lithology. The variation of apparent resistivity estimated from the potential difference can give information about overburden thickness, depth to aquifer and depth and thickness of subsurface strata. A comprehensive review of electrical properties can be found in (Schon, 2004) whereas a complete explanation of electrical methods can be found in (Telford *et al.*, 1990 and Ward, 1990).

METHODOLOGY

In this study, Vertical Electrical Sounding (VES) using Schlumberger configuration and Electrical Resistivity Tomography (ERT) employing dipole-dipole configuration were applied in order to examine the variations in resistivity of materials with depth. A resistivity meter with model number 41 manufactured by Geotron was used to acquire field resistivity data. The entire survey was carried out with the help of the Schlumberger array since it is usually characterised to delineate electrical resistivities associated with the change in lithology and/or hydrological characteristics (Hodlur, 2006). Furthermore, the Schlumberger electrode array has greater probing ability and is less affected by local heterogeneity.

Five profiles comprising location 1 and location 2 each having six (6) data points were gridded making a total sum of thirty (30) sounding points as shown in Figure 4. The maximum spacing of half current electrode spacing AB/2 (in the case of Schlumberger array) was equal to the potential electrode spacing and it varied between 1 m to 100 m which was wide enough to achieve the objectives of the research. The target parameter (apparent resistivity) was finally calculated at each sounding point using equation (2).

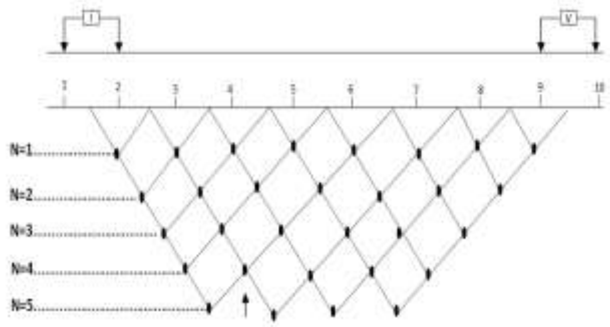


Figure 4: Electrode array for a 2-D electrical survey and the pattern of measurements used to build up a Pseudo-section.

The Electrical Resistivity Tomography method was introduced to further reveal complex subsurface structures (Griffiths and Barker, 1993). ERT method gives a high-resolution image with better contrast of earth subsurface distribution of electrical resistivity. The image obtained could give information about the change in lithology of the subsurface layers which could delineate regions of soil or bedrock clearly (Heather *et al.*, 1999). Dipole-

dipole configuration with an electrode spacing of 10 m and inter-dipole separation factor, N, which varied from 1 to 5 m (see Figure 3) along two resistivity profiles 200 m and 210 m, respectively was employed for data collection.

RESULTS AND DISCUSSION

Geophysical methods seek to reveal hidden information down beneath the earth crust. Therefore, a geophysical investigation is one of the major tools used in studying the characteristics of the earth subsurface (Nordiana *et al.*, 2012). Figure 5 shows the frequency of the different curve types that dominate the area of study. However, the qualitative hydrological deduction could be made from the different curve types to ascertain the possibility of groundwater (Singh, 1984). Furthermore, Satpathy and Kanugo, 1976, reported that H and KH are often associated with the presence of groundwater. The VES results (table 2a, 2b, 2c, 2d) presented indicate that VES points A5, B4, C5 and D5 have a promising aquifer potential. The fractured layer has a thickness of 20-46 m and a resistivity value ranging from 27.2 Ωm to 409.4 Ωm. The dominant curve types obtained in the area are AK, H, HK, KH, and QH (Figure 5).

Tables 2a, 2b, 2c, 2d and Figures 5a, 5b show the results of the VES curves at each sounding point and their corresponding geological sections. After proper interpretation of the generated geologic sections and their correlations with nearby geologic sections of borehole log samples, the area under study was underlain with four geologic layers corresponding to topsoil, sand/clayey/sandy-clay, progression of clay soil, combination of sand/gravel (fracture basement) and fresh basement with resistivity values ranging between 113-1322 Ωm, 42-462 Ωm, 16.1-92 Ωm and 7760-15342 Ωm, respectively.

Table 2a: Summary of VES results along profile A in the study area

VES Point	Layer No	Layer Average Resistivity (Ωm)	Thickness (m)	Depth (m)	Type of Curve	Inferred Lithology
A_1	1	38.3	20.0	20.0	A	Top soil (clayey sand)
	2	1065.1	20.0	40.0		Clay
	3	2915.3	∞	∞		Sand
A_2	1	3.4	0.3	0.3	AK	Top soil (clayey sand)
	2	889.05	11.65	11.95		Sandy clay
	3	5.6	∞	∞		Laterite (fine/medium), probably saturated with water
A_3	1	171.0	0.3	0.3	K	Top soil
	2	253.05	5.06	5.09		Sandy clay
	3	122.9	∞	∞		
A_4	1	1.4	7.0	7.0	A	Top soil (clayey sand)
	2	132.55	20.65	27.65		Clay
	3	2263.6	∞	∞		Sand
A_5	1	3.8	0.3	0.3	A	Top soil (clayey sand)
	2	237.4	4.7	5.00		Sandy clay
	3	1794.8	∞	∞		Bedrock
A_6	1	365.9	3.0	3.0	QH	Top soil (clayey sand)
	2	81.0	37.5	40.50		Clay
	3	76.9	∞	∞		Sand, likely saturated with water

Table 2b: Summary of VES results along profile B in the study area

VES Station	Layer No	Layer Average Resistivity (Ωm)	Thickness (m)	Depth (m)	Type of Curve	Inferred Lithology
B_1	1	179.70	5.00	5.00	A	Top soil (clayey sand)
	2	457.00	15.00	20.00		Clay
	3	38937.60	∞	20.00		Sand
B_2	1	45.00	5.00	5.00	A	Top soil (clayey sand)
	2	344.15	5.00	10.00		Sandy clay
	3	1233.6	∞	10.00		Bedrock
B_3	1	281.30	5.00	5.00	K	Top soil
	2	41057.85	5.00	10.00		Laterite
	3	884.40	∞	10.00		Bedrock(Limestone)
B_4	1	161.20	20.00	20.00	A	Top soil (clayey sand)
	2	2001.40	10.00	30.00		Clay
	3	9949.50	∞	30.00		Sand
B_5	1	94.80	0.80	0.80	A	Top soil (clayey sand)
	2	247.50	2.40	3.20		Sandy clay
	3	3369.00	∞	3.20		Bedrock
B_6	1	127.70	1.10	1.10	H	Top soil (clayey sand)
	2	93.70	1.80	2.90		Clay
	3	662.90	∞	2.90		Bedrock (Limestone)

Table 2c: Summary of VES results along profile C in the study area

VES Station	Layer No	Layer Average Resistivity (Ωm)	Thickness (m)	Depth (m)	Type of Curve	Inferred Lithology
C_1	1	216.40	0.70	0.70	A	Top soil (clayey sand)
	2	938.75	0.20	0.90		Clay
	3	78723.4	∞	0.90		Laterite
C_2	1	101.80	5.20	5.20	A	Top soil (clayey sand)
	2	5993.95	8.00	13.20		Sandy clay
	3	100000.00	∞	13.20		Bedrock
C_3	1	230.1	0.60	0.60	A	Top soil
	2	35304.50	3.50	4.10		Sandy clay
	3	100000.00	∞	4.10		
C_4	1	2.10	0.30	0.30	A	Top soil (clayey sand)
	2	150.40	0.90	1.20		Clay
	3	26918.50	∞	1.20		Sand
C_5	1	457.2	0.5	0.50	H	Top soil (clayey sand)
	2	34.45	0.5	1.00		Clay
	3	2159.7	∞	1.00		Bedrock (Limestone)
C_6	1	18.60	5.4	5.40	A	Top soil
	2	295.70	0.4	5.80		Sandy clay
	3	27586.00	∞	5.80		Sand

Table 2d: Summary of VES results along profile D in the study area

VES Station	Layer No	Layer Average Resistivity (Ωm)	Thickness (M)	Depth (M)	Type of Curve	Inferred Lithology
D_1	1	393.10	5.00	5.00	H	Top soil (clayey sand)
	2	61.70	5.00	10.00		Clay
	3	22968.80	∞	10.00		Bedrock (Limestone)
D_2	1	147.20	6.00	6.00	H	Top soil (clayey sand)
	2	115.35	4.00	10.00		Clay
	3	3143.50	∞	10.00		Bedrock (Limestone)
D_3	1	124.3	3.10	3.10	K	Top soil
	2	23092.40	16.10	19.20		Laterite
	3	804.10	∞	19.20		
D_4	1	38.50	15.00	15.00	Q	Top soil (clayey sand)
	2	32.20	5.00	20.00		Clay
	3	32.70	∞	20.00		Sand
D_5	1	3.30	5.00	5.00	A	Top soil (clayey sand)
	2	111.65	10.00	15.00		Sandy clay
	3	169.20	∞	15.00		Bedrock
D_6	1	157.60	2.00	2.00	K	Top soil
	2	793.50	2.00	4.00		Sandy clay
	3	170.70	∞	4.00		Bedrock (Limestone)

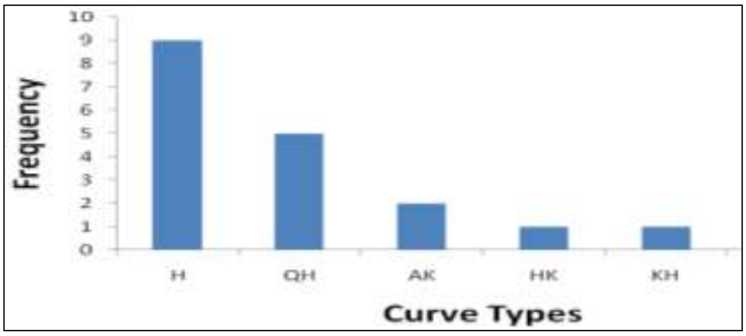
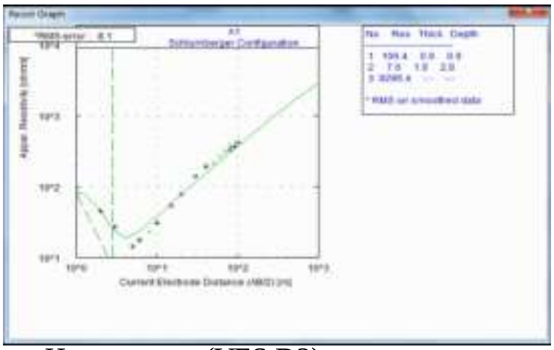
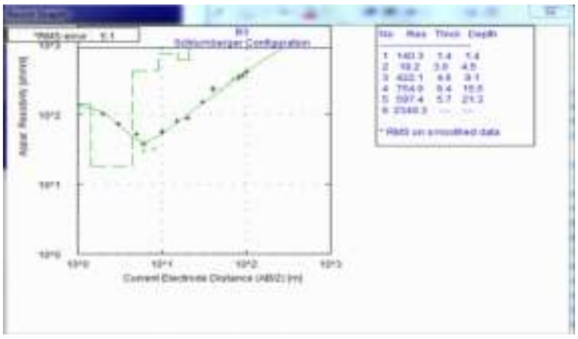


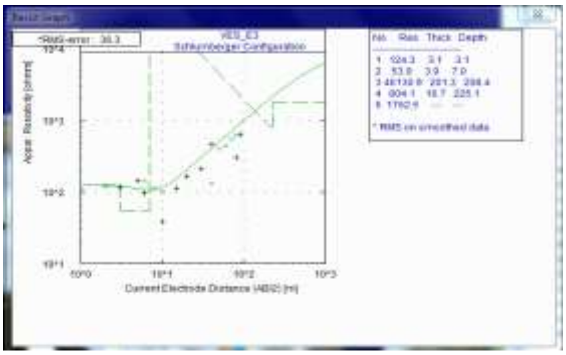
Figure 3: Frequency of predominant curve types obtained in the area of study



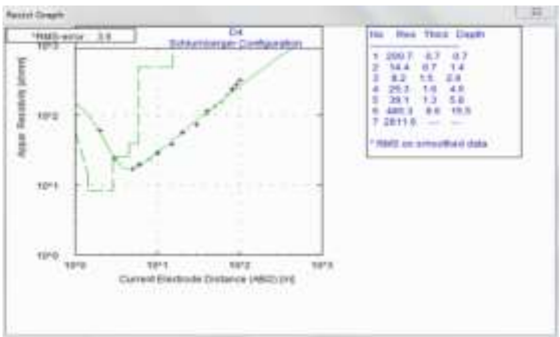
H curve type (VES D2)



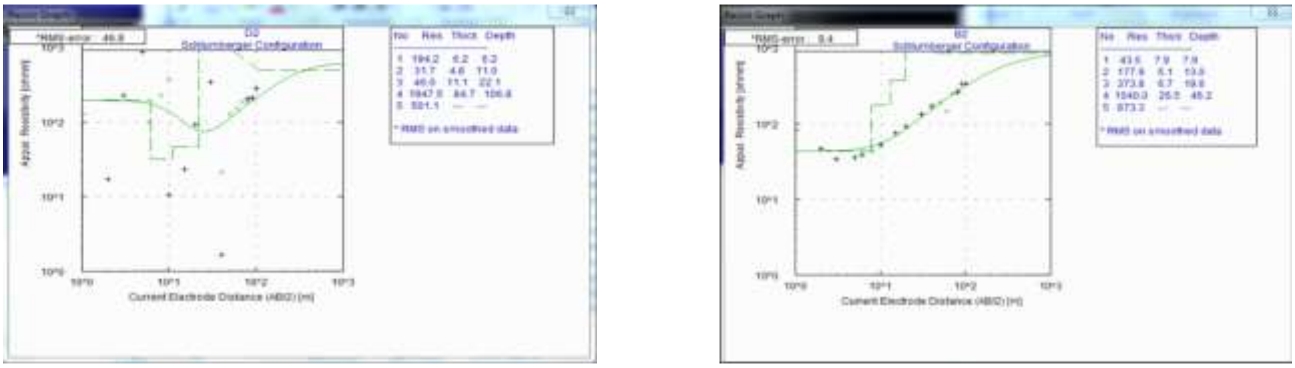
H curve type (VES D2)



HA curve type. (VES B3)



HK curve type (VES A1)



HA curve type (VES C3) A curve type (VES D4)

Figure 5**:** Samples of predominant curve types obtained in the area of study

Resistivity inversion and geologic unit results for location 1. This shows a good agreement between the measured and calculated apparent resistivity data obtained with the VES results as well as the results from the ERT analysis. The inverse 4-D resistivity model shows well-defined geological features with a maximum depth of 15.9 m which has the top layer to a depth of 1.86 m with low and moderately high resistivity values ranging from 7 Ωm to 689 Ωm suggested to be composed of geologic features showing distinct lithology by the ERT such as clay, sand, and sandy clay as evident in the study area. This is followed by a depth range between 1.86 m to 11.5 m with a resistivity range of value of about 1065 Ωm to 2915 Ωm which is suggested to be composed of clayey sand. Below this depth, 11.5 m to 15.9 m has a resistivity of 3143 Ωm to 23092 Ωm which suggests that this depth contains sandy clay and laterite. Therefore, the results indicate that regions with low electrical resistivity could be areas with groundwater potential.

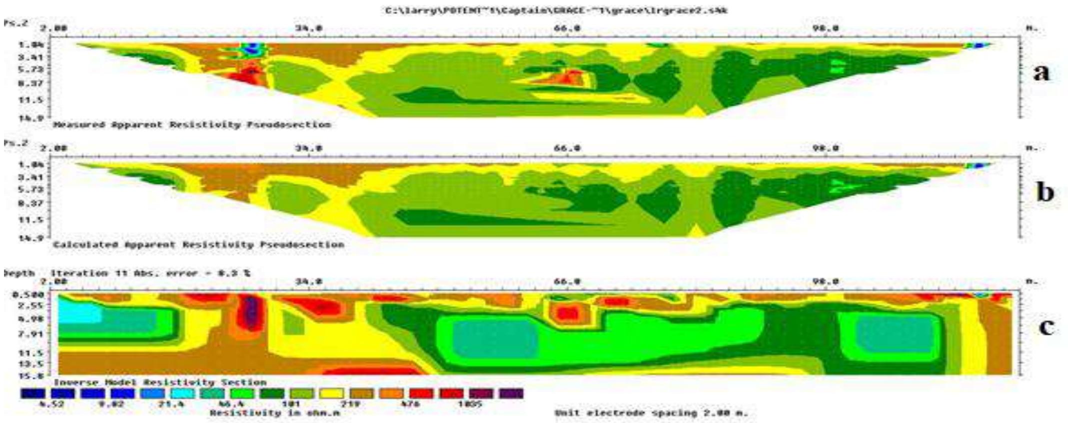


Figure 6a**:** 2-D Inversion model resistivity and geologic section in location 1

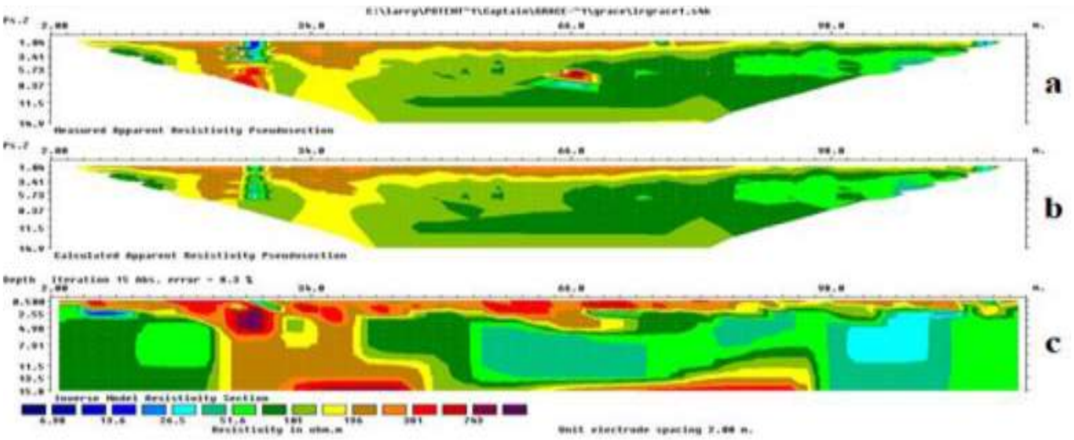


Figure 6b: 2-D Inversion model resistivity and geologic section in location 2

Figure 6b in location 2 with resistivity variation from 28-2903 Ωm at maximum depths of 15.9 m which has the first half of the geologic unit from 1.68 m to 5.73 m with depth of 1.68 m to 3.41is suggested to contain sandstone, clay and sandy clay while 5.73 m and above along the geologic line is suggested to contain wet lateritic soil and sand at depth of 11.5 m to 15.9 m.

CONCLUSION

Two geophysical methods were employed to characterise the subsurface for general lithology of rock formations in the southern part of Maikunkele town, Niger State. The Electrical resistivity results indicated that the electrical properties of rocks, soil, matric and grain size varied within the identified fractured bedrock within the investigated area. This provides information for easy sitting of boreholes for groundwater exploration. The results obtained have also revealed the lithology in the research area. The research also revealed that depressions which are overlain by relatively thick overburden are mostly regions with high groundwater potential which are more peculiar to basement complex terrains. The VES results presented indicate that VES points A5, B4, C5 and D5 have a promising aquifer potential. The fractured layer has a thickness of 20-46m and a resistivity value ranging from 27.2 Ωm to 409.4 Ωm. According to Odusanya, the zone with resistivity above 100 Ωm is characteristic of clayey sand and sand and it indicates good aquifer formation while the lower end (below 100 Ωm) indicates clay which lowers the aquifer potential.

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