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Geoelectrical Investigation Using Schlumberger Array for Groundwater Occurrence in Part of Bosso Estate Minna Sheet 164 SW North-Central Nigeria

Ochekpo John Emmanuel[1*] and Alkali Yahaya Baba[1]

[1]*Department of Geology, Federal University of Technology Minna, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Author OJE designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AYB managed the analyses of the study and literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Inadequate potable water supply remains one of the challenges of residents of Bosso Estate in Minna Metropolis, Niger State, Nigeria owing to the Basement Complex terrain underlying the area. Rapid increase in population in the area over the years, which is due to its proximity to Federal University of Technology Minna (Bosso Campus) and the nation's capital city (Abuja) among others. This has led to increase in the demand for potable water supply for domestic use since public water supply by government is inadequate. Consequently, in a quest to seek for Groundwater as a reliable source of water supply for domestic need, various abortive boreholes have been drilled without proper geophysical survey. This has led to loss of valuable time, energy and money. Therefore, Geoelectrical investigation using Schlumberger array was carried out with a view to delineate zones with good groundwater occurrence.
A locally made Terrameter (resistivity meter) of high precision was used for data acquisition. Schlumberger array was used to obtain geophysical data at ten (10) VES stations in the area. Field data obtained were analysed and interpreted using Win RESIST and Surfer Software which gives

**Corresponding author: Email: profjohnbull4sciences@gmail.com*

an automatic interpretation of the apparent resistivity data. Results from the interpretation revealed these curve types: the HK, H KH and A whereas three to four (4) geoelectric layers which consist of Topsoil layer, Lateritic clay, Weathered/fractured basement and Fresh basement. Fractured/weathered basement has resistivity values ranging from 35.5 to 841.62 Ωm and thickness variation of 13.5 to 48.5 m. This weathered /fractured layer constitutes the aquifer zones in the area. The fresh basement has resistivity values as high as 7336 Ωm and above. The groundwater potential in the study area was classified into high, medium and low/non groundwater potentially occurring zones. High groundwater potential zones were found at VES station 01, 02, 03, 04, 07 and 08 corresponding to the North-Eastern, Central and North-Western parts. This survey revealed aquifer zones having thickness ranging from 20 to 40 m and depth to bedrock ranges from 8.7 to 55 m. A recommended minimum depth for drilling borehole in the study area is about 46 to 60 m. The study however recommends an integrated geophysical method for future groundwater exploration in the area.

Keywords: Geoelectrical investigation; schlumberger array; groundwater potential; basement complex terrain; aquifer.

1. INTRODUCTION

Niger state has 10% of the total landmass of Nigeria with the state capital located in Minna. Due to infrastructural developments and as a result of its proximity to the nation's capital city, Abuja among others the area has witnessed a high increase in population. Niger State's population growth rate of 3.4% annually higher than the overall national growth rate of 3.2% [1] has led to rapid increase in the demand for potable water for domestic, irrigational and industrial uses which public water supply by government could not meet. As a result of inadequate water supply by the government, some inhabitants have resorted to making alternative arrangements for water through wells and boreholes and others that could not afford that get water of uncertain quality from water vendors in carts and tankers and also from surface water sources. However, available bodies of water on the Earth's surface which include streams, rivers, oceans and lakes are often not very safe for direct consumption due to their exposure to atmospheric pollutants (from natural and anthropogenic sources) and pathogenic organisms that make these water sources not as clean as the groundwater, and this has necessitated subjecting them to chemical treatments before consumption or industrial use. Groundwater, the water held in porous and permeable rocks deep within the earth (occurring at zone of saturation below the water table) called aquifers, is relatively pure and grossly protected from surface pollutants due to their depth of storage and natural filtration through different subsurface layers (soil horizons). Groundwater is enormous and therefore its development is essential to supplement the expensive surface water to relieve stress which population growth often places on water availability and supply [2].

Many researchers have worked on the groundwater potential of Minna and its environs. [3] worked on the hydrogeology and water quality of southwestern part of Minna and it was indicated that the water is of good quality and occurs in the regolith and fractured bedrock. Further work by Amadi et al. [4] on Evaluation of Groundwater Potential in Pompo Village, Gidan Kwano, Minna exhibits two types of aquifers- the weathered basement and fractured basement aquifer characterised the Hydrogeology of the area of study. [2] also conducted a study on the occurrence and chemical composition of groundwater in Minna Metropolis and from this study, they discovered that the degree of weathering in granitic bedrock ranges from 3 – 25 m and constitutes the main source of water for shallow dug wells, chemically the water shows a gradual enrichment in manganese, arsenic and lead. Owing to the fact that no previous work has been carried out in Bosso Estate, this study, Geoelectric investigation for groundwater occurrence using sclumberger array was therefore carried out to delineate zones with good potential for groundwater occurrence in part of Bosso Estate sheet 164 SW Minna Niger state and will further add to the existing geophysical database for groundwater development activities in Minna area.

1.1 Location of the Study Area

The study area forms part of Minna sheet 164 SW (Fig. 1). It lies between LAT 9°38'41.2''N to

9°39’34.01”N and LONG 6°30’35.37”E to 6°30’29.85”E and covers an area extent of about 1.8 Km^2. The area is accessible through the Western bypass that runs from Kpakungu to Maikunkele and Bosso road which runs from City gate to Maikunkele and it is mainly drained by culverts built parallel to the roads passing through the Estate and has a relatively plain (low relief) terrain with no high lands or batholiths. Bosso Estate falls within the Guinea Savanna Belt, characterised by a climatic condition of an alternating wet and dry season. Heavy rainfall is associated with wet season and little or no rain during the dry season. The Harmattan usually known as dry North-Easterly air stream, dominates from November to March with low relative humidity, temperatures of magnitudes higher than 35°C and general absence of rainfall (Ochekpo, 2018).

1.2 Geology and Hydrogeology of the Study Area

Bosso Estate falls within North-Central Nigeria where three major lithologic subdivisions make up the Precambrian basement complex rocks: the migmatite-gneis complex; the Schist belts and the Older Granite suites (also called the Pan-African granite suites, 600 Ma).

According to Rahaman [5], more than 50% surficial area of the Nigerian basement complex is composed of the Migmatite-gneiss complex and it has undergone polycyclic orogenic episodes of deformation, metamorphism and remobilization. Varying texture, composition and structure seen on migmatite-gneiss were as a result of progressive regional metamorphism of metasedimetary rocks [6]. The schist belts on the

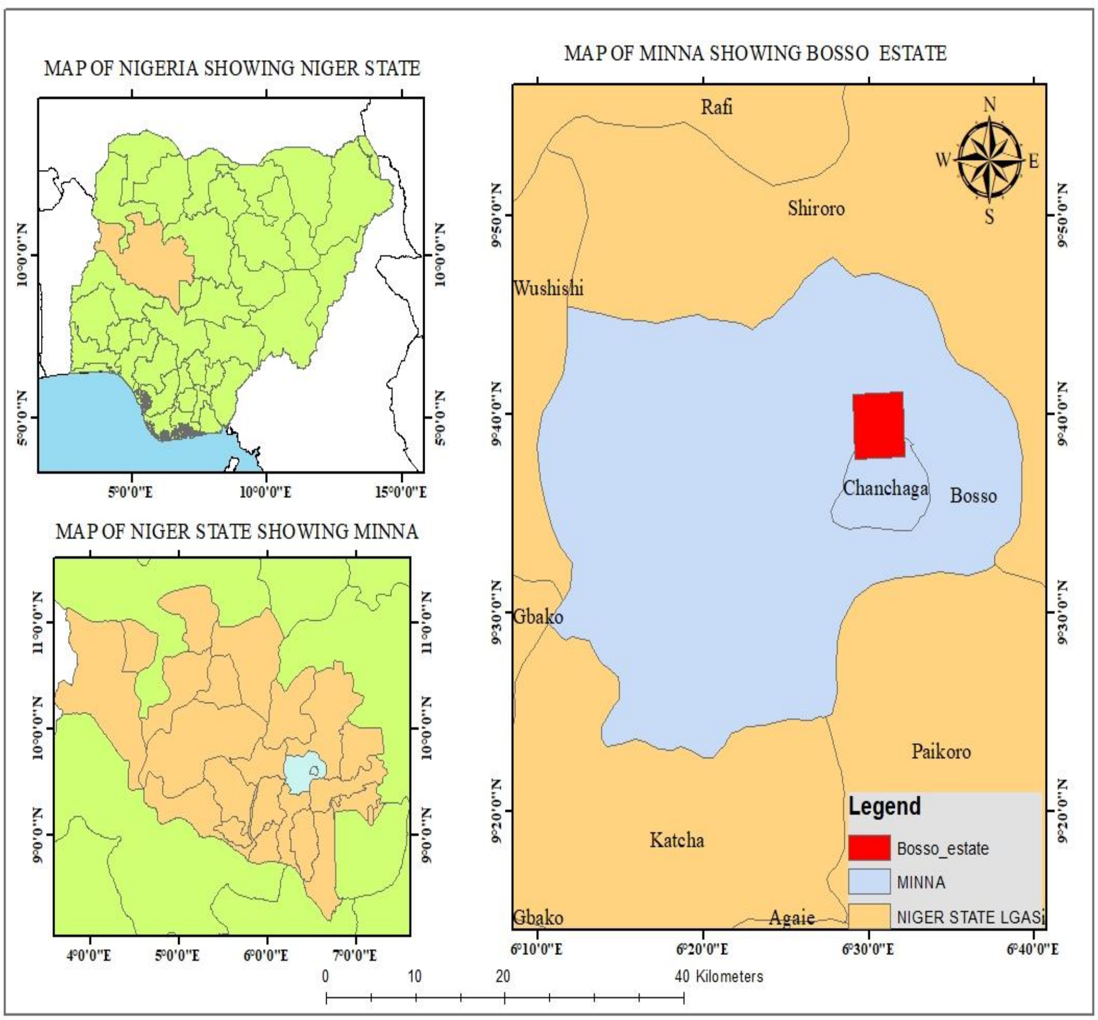

Fig. 1. Location map of Bosso Estate sheet 164 SW North Central Nigeria

other hand are composed of metamorphosed pelitic and psammatic assemblages and are considered to be Proterozoic Supracrustal rocks infolded into the migmatite-gneiss complex trending north-south occurring prominently in the western part of Nigeria. Secondary/minor lithologies are ferruginous iron (banded iron formation), carbonates and mafic-ultramafic bodies. The Older Granite underlies Bosso Estate (Fig. 2) and comprises rocks whose texture varies from medium-grained to coarsely-porphyritic; and composition varies from granite to tonalite [7].

Hydrogeology basically concerns the study of the occurrence of groundwater, its movement and interaction with rocks, quality, storage, exploration and overall development for economic use. Hydrogeophysically, Bosso Estate in Minna is made up of only the crystalline rocks characterised by team secondary porosity, as there is a complete absence of Sedimentary rocks in the study area. This Crystalline hydrogeological province is made up of two interconnected aquifers, namely:-

i. the aquifer within the overburden/ weak zone and
ii. the partial Weathered/ Fractured Basement aquifer.

In Basement complex aquifers, water is stored in the saturated part of the weathered zone and transmitted via the basal permeable zone of dislocated rock and via joints in almost fresh rock [8,9].

2. MATERIALS AND METHODS

A Nigerian made Terrameter of a very high precision and its component, metal electrodes, cables, hammers, measuring tapes, global positioning system (GPS), an external 12 Volt

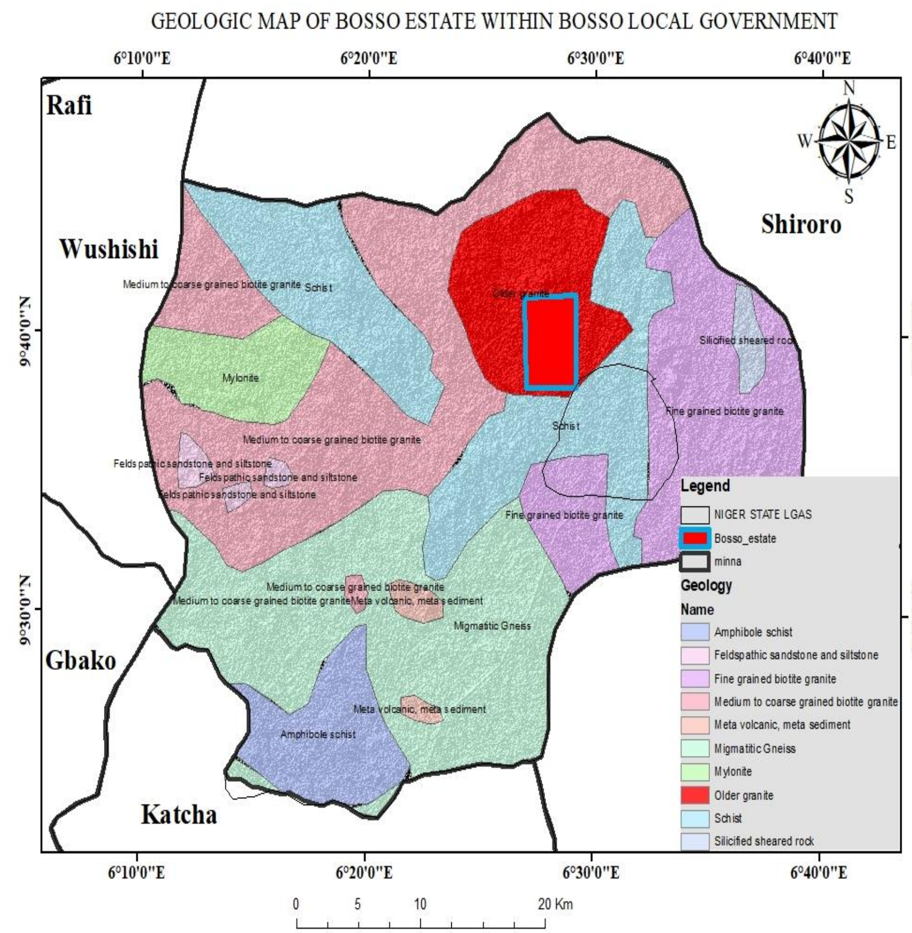

Fig. 2. Geologic map of Minna area showing Bosso Estate underlained by older granite

capacity battery and field datasheets were the materials used for data acquisition and a total of ten (10) Vertical Electrical Sounding (VES) points were carried out in the area. The electrical resistivity configuration employed in the field was Schlumberger array with a maximum half electrode spread AB/2 of 80 m and with a maximum electrode potential separation MN/2 which was maintained between 0.5 m, 2.5 m, 7.5 m and 15 m in the ratio 1:5 to 1:7 respectively to minimize loss of electric current due to telluric properties of the earth.

Electrical current (10 mA – 20 mA) was passed into the ground through the two outer current electrodes and the resulting potential difference was measured across the two inner potential electrodes that were arranged in a straight line, systematically about a centre point. The electrode spacing was progressively increased, keeping the centre point of the electrode fixed, the potential difference to the current ratio was displayed by the terrameter as resistance, measured in ohms (Ω). The resistance values were taken from the terrameter and multiplied by the standard geometric factor (k), which is calculated as a function of the electrode spacing, to give the apparent resistivity values (Ωm) which are the resistivity values in homogenous earth. The apparent resistivity values were plotted against the distance (AB/2 in m) using computer software (Win RESIST) which gives an automatic interpretation of the apparent resistivity data. Consequenty, Surfer 10.0 software was used to generate isoresistivity contour at 30 m interval, Aquifer thickness and depth to bedrock contour maps.

3. RESULTS AND DISCUSSION

Plots of apparent resistivity versus depth were made using Win resist software to generate different curves. From Win resist plot, these curve types were identified: KA, KH, H and A. The interpretation of these curves was based on a principle by Telford et al. [10] which states that all points of maximum and minimum apparent resistivity changes (that is sudden rise or fall in magnitude of resistivity values) are indications of different lithologies. Similarly, where resistivity values tend towards infinity, this is an indication of a fresh basement rock. Names were assigned to each Lithologic unit/layer according to ranges of resistivity properties for some materials of the earth as described in Table 1. Interpretation for geoelectric horizons in each VES points is given in Table 2.

Table 1. Typical resistivity values of common rock materials and selected ore minerals (after Olorunfemi and Fasuyi, 1993)

Rock type	Resistivity range (Ωm)
Clay	1-100
Gravel	100-600
Weathered bedrock	100-1000
Sandstone	200-8000
Granite	200-100000
Basalt	200-100000
Galena	0.001-0.1
Chalcopyrite	0.005-100
Magnetite	0.01-1000
Hematite	0.01-1000000
Fadama loam	20-100
Laterite	60-1000
Silt and sand	80-400
Fresh basement	>1000

Three layer curve-H and A curve types covered 65% of the study area while the four layer curve KA and KH curve type covers 35% of the study area. The observed geo-electric sections include the top soil layer, the Lateritic clayey regolith layer, weathered basement layer, fractured basement layer and the fresh basement. The topsoil is the first geo-electric layer. It is a thin, highly resistive layer, with resistivity ranging from 26.3 Ωm to 347.2 Ωm. The difference in the resistivity values was due to the variation in the amount of organic content. The thickness of the top soil layer ranges from 1.1 m to 4.6 m. The clayey regolith layer is a resistive dry layer, with resistivity ranges from 116.2 Ωm to 493.8Ωm. The thickness of this layer varies from 0.7 m to 4.3 m. The weathered basement layer which is saturated is a lower resistivity layer with values ranging from 21.1 Ωm to 346.2 Ωm. Low resistivity values also indicates substantial clay content. Higher resistivity implies lower clay proportions and increased permeability. The thickness of this layer varies from 2.7 m to 45.4 m, and it is dependent on the degree of Bedrock weathering. The fractured basement layer is the fourth geo-electric layer which developed below the weathered basement layer. It has a resistivity of about 62.5 Ωm to 1807.5Ωm. Its thickness ranges from 12.7 m to 48.5 m. It was distinguishable from the fractured or weathered basement in most of the locations because of its considerable thickness and sufficiently contrasting resistivity. Fresh Basement rock is characterized by high resistivity values exceeding 7000 Ωm in virtually all the locations. The fresh basement is a hard rock of an usually high resistivity with no permeability, and hence it is not a water bearing zone. Depth to fresh rocks from the interpretation of sounding curves is found to range between 8.7 m and 48.5 m.

3.1 Contour Plots of Isoresistivity at 30 m and Aquifer Thickness

Isoresistivity value taken at 30 m depth in each VES station was produced by contouring the resistivity values at all VES point in the study area. The purpose of this is to show lateral distribution of resistivity along equal depths in the area and this depth is the average thickness of soft overburden for Minna and its environs as reported by Mohammed et al. [1] and Adeniyi [11]. From the Isoresistivity plot, South- Eastern, South-Western, Central and some little part of North-Western areas show low resistivity values indicating presence of water (Fig. 6).

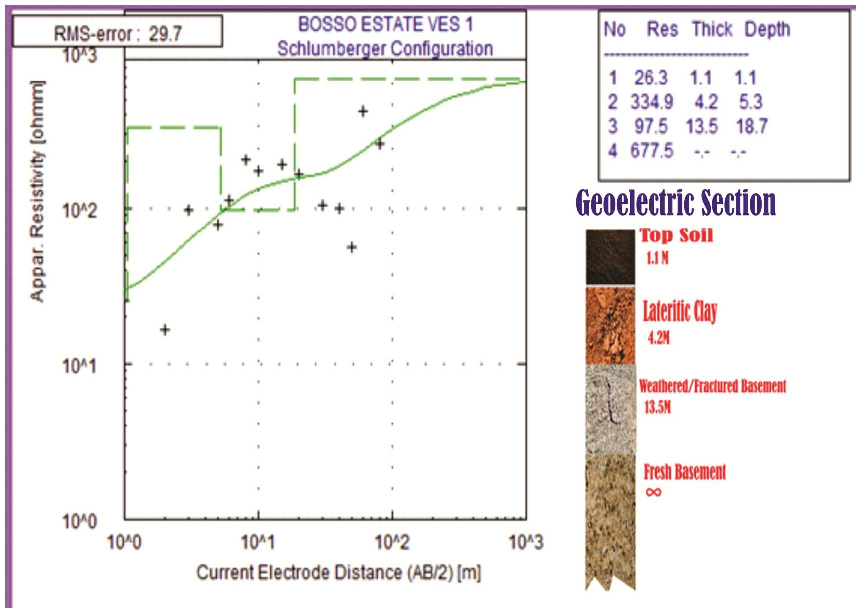

Fig. 3. A KA curve type obtained from VES 1

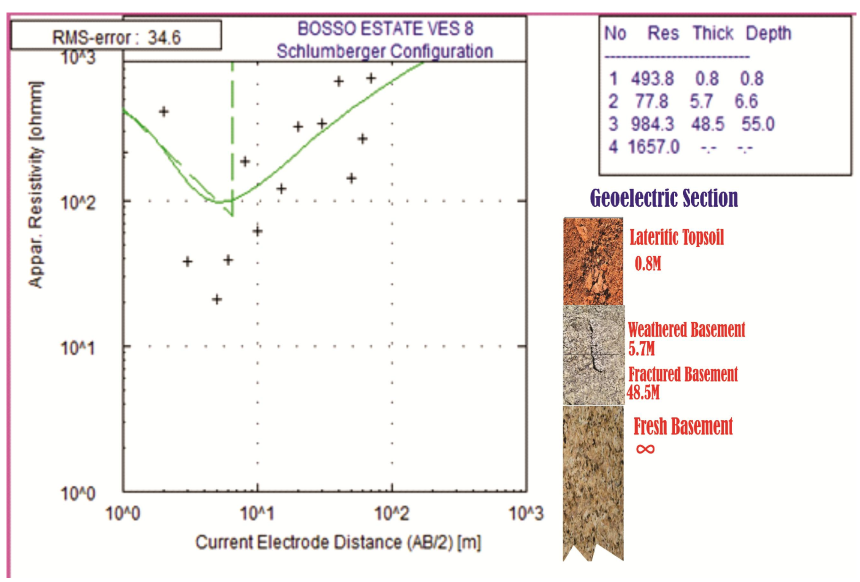

Fig. 4. Example of an H curve type

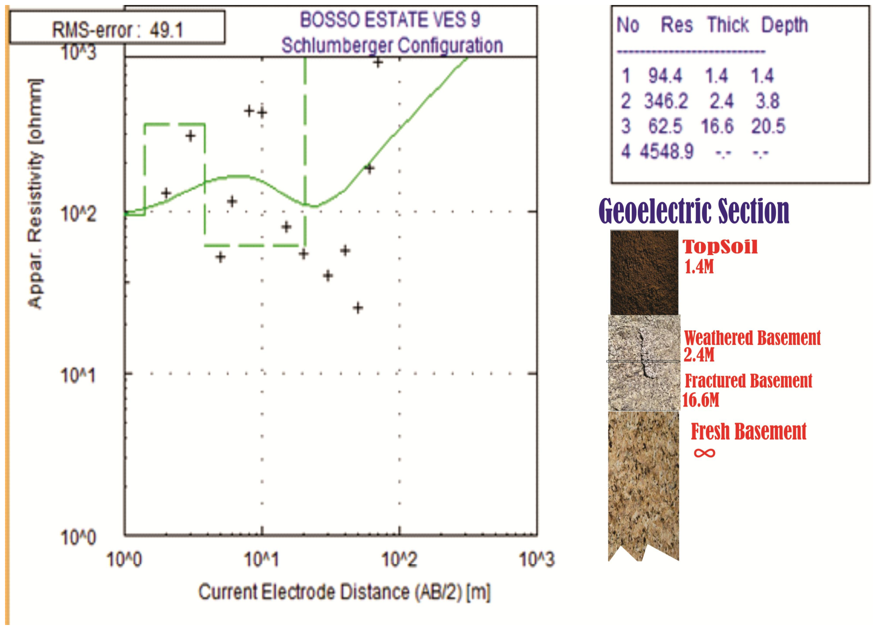

Fig. 5. A KH curve type obtained from VES 9

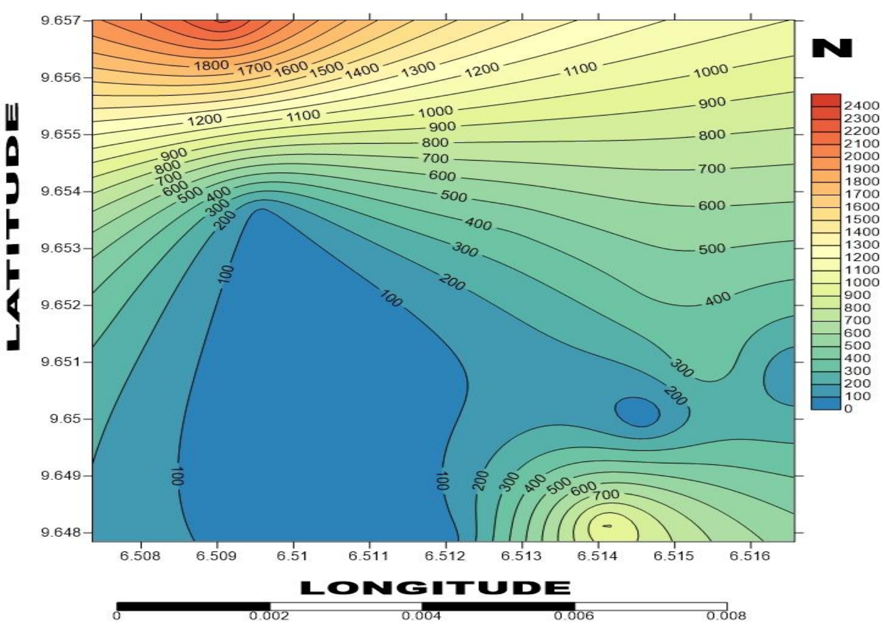

Fig. 6. Isoresistivity contour of part of Bosso Estate at 30 m depth

Weathered and fractured basement usually constitute aquifer units in Basement areas [12]. Thus, Aquifer thickness map is produced using the thickness of the weathered and fractured basement obtained at each VES station. The aquifer is shallow around Eastern, South-Eastern and Southern parts with thickness of 10 m-24 m. A comparison between aquifer thickness map and depth to bedrock map reveal that areas of low aquifer thickness correspond to shallow fresh basement complex rocks and areas with large aquifer thickness (North-Eastern, North-Western and South-Western parts, Fig. 5) correspond to great depths to fresh basement complex rocks. Areas of large aquifer thickness having low resistivity values are more likely to retain quality groundwater. Fig. 8 shows the aquifer thickness and resistivity map. The aquifer thickness in the study area ranges between 28 to 48.5 m.

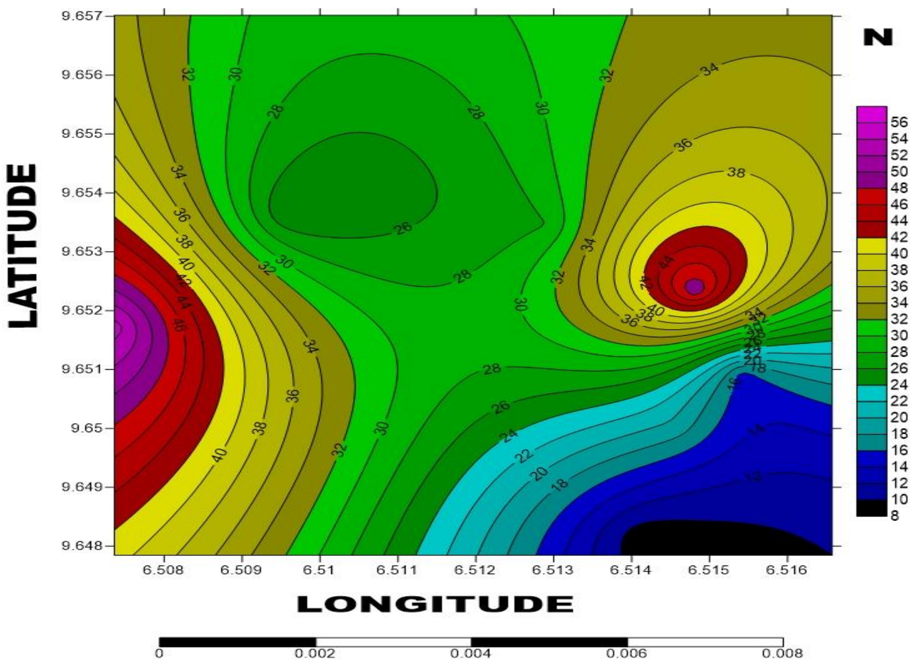

Fig. 7. Aquifer thickness contour map of part of Bosso Estate

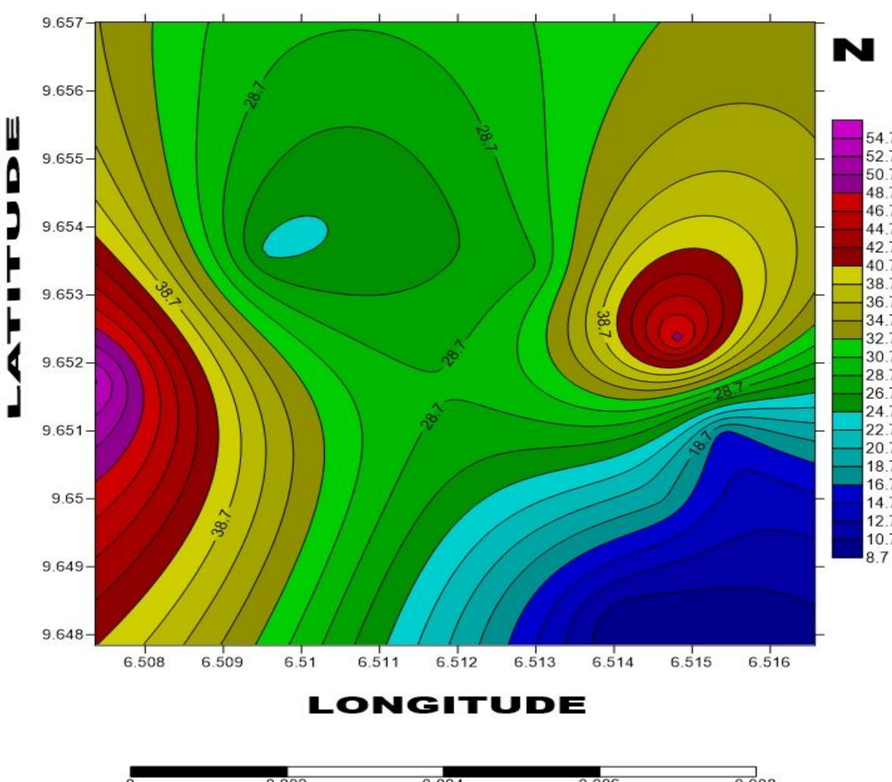

Fig. 8. A depth to bedrock contour map of part of Bosso Estate

Table 2. Interpreted model and lithology for each VES station

Ves stations	Latitude (°N)	Longitude (°E)	Layers	Resistivity (Ω*m*)	Thickness (m)	Depth (m)	Lithology
01	9.65085	6.516573	1	26.3	1.1	1.1	Top soil
			2	334.9	4.2	5.3	Lateritic clay
			3	97.5	13.5	18.7	Highly weathered/fractured basement
			4	677.5	---	---	Fresh basement
02	9.650028	6.514581	1	25.2	2.4	2.4	Sandy clay
			2	21.1	2.7	5.1	Weathered rock
			3	493.2	14.2	19.3	Fractured weathered rock
			4	1305.5	---	---	Fresh basement
03	9.650936	6.515414	1	66.5	2.6	2.6	Silty sandy clay
			2	755.4	12.7	15.4	Fractured basement
			3	2938.0	---	---	Fresh basement
04	9.652342	6.514817	1	120.1	4.3	4.3	Top soil
			2	749.7	45.4	49.7	Weathered rock/fractured basement
			3	2992.7	---	---	Fresh basement
05	9.653461	6.512914	1	26.3	2.6	2.6	Sandy clay
			2	97.1	3.5	6.2	Weathered rock
			3	839.8	21.9	28.0	Fractured basement
			4	1907.5	---	---	Fresh basement
06	9.657017	6.509086	1	28.9	3.0	3.0	Top soil/sandy clay
			2	104.9	5.0	8.0	Weathered rock
			3	1337.0	22.0	30.0	Fractured basement
			4	4147.8	---	---	Fresh basement
07	9.653653	6.509564	1	347.7	3.4	3.4	Lateritic top soil
			2	32.5	5.2	8.7	Highly weathered rock
			3	682.5	15.5	24.1	Fractured rock
			4	19961.7	---	---	Competent basement rock
08	9.651719	6.507361	1	493.8	0.8	0.8	Lateritic top soil
			2	77.8	5.7	6.6	Weathered basement
			3	984.3	48.5	55.0	Fractured basement
			4	1657.0	---	---	Fresh basement
09	9.647844	6.512022	1	94.4	1.4	1.4	Top soil
			2	346.2	2.4	3.8	Weathered rock
			3	62.5	16.6	20.5	Highly fractured rock
			4	4548.9	---	---	Fresh basement
10	9.648156	6.514097	1	116.2	0.7	0.7	Lateritic top soil
			2	9868.4	8.0	8.7	Competent rock
			3	17072.1	---	---	Very competent Fresh basement

4. CONCLUSION

The Geoelectrical method of investigation adopted in this study has given some insight in understanding groundwater condition of part of Bosso Estate by providing aquifer dimensions especially its thickness, the depth to bedrock and fractured zones. Thus, VES stations with high potentials for groundwater in the study area were identified.

Results from interpreted data using Win RESIST computer program revealed three to four geo-electric layers. These are: Topsoil/Lateritic clay, weathered layer, fractured layer and fresh basement. The weathered/ fractured basement constitutes the aquifer zones with thickness ranging from 20 to 40 m and average thickness of 20 m. Depth to bedrock ranges from 8.7 to 55 m having its shallowest at VES 10 with a depth of about 8.7 m and deepest at VES 08 with a depth of about 55 m.

The following stations were identified as the most favourable areas for groundwater development: VES 01, VES 03, VES 04, VES 07 and VES 08 corresponding to the North- Eastern, North-Western and South-Western parts (Fig. 7).

In conclusion, the study area can be said to have a good potential for groundwater occurrence.

5. RECOMMENDATIONS

This research work was accomplished using only one geophysical method-the electrical resistivity method. However, for a better result, combined geophysical techniques should be used for future groundwater exploration so that weathered/ fractured zones in the study area would be identified and characterised in detail.

A recommended minimum depth for drilling borehole in this study area for domestic water supply is about 46 to 60 m.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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