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Assessment of Groundwater Potential and Aquifer Protective Capacity at Proposed Filling Station Site, Federal University Oye-Ekiti, Southwestern Nigeria

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Abstract

Keywords:

Aquifer, Evaluation, groundwater potential, resistivity, weathered layer, protective capacity.

The potentiality of groundwater and aquifer protective capability at the proposed Filling Station Site, Federal University Oye-Ekiti, Southwestern Nigeria were evaluated using geoelectrical method. The geoelectric investigations involved 2-D tomography using dipole-dipole configurations and Vertical Electrical Sounding (VES) technique adopting the Schlumberger array. Fifteen (15) VES stations were occupied on five profiles using Min-Res resistivity meter measuring current electrode spacing (AB/2) of 50 m. The data were plotted on a bi-log graph to produce VES curves. Four curve types H, A, HA and HKH were delineated. The H type curve occurred most in the area with 53.3%. A curve type consists of 6.7%, HA occupied 33.3% while curve HKH occupied 6.7% of the study area. The study revealed three to five geoelectric layers as: topsoil, weathered layer, partly weathered layer, partly weathered/fractured basement and fresh basement. The layers presented the following resistivity values: topsoil (124 – 547 Ω -m), weathered layer (49 to 505 Ω -m), partly weathered layer (330.3 to 2619 Ω -m), partly weathered/fractured basement (212.9 Ω -m) and fresh basement (668 - 236839 Ω -m). The longitudinal conductance ranging from 0.055-0.061 mhos was delineated in the study area. The aquifer potentials of the area revealed good protective capacities having 80% protective capacity rating and poor protective capacity rated about 20%. Groundwater potential were recommended in six VES stations with resistivities ranging between 66 to 981 Ω m with depths ranging from 10.5 to 15.0 m in the study area. The area assessed could be classified as having low to moderate groundwater potential.

INTRODUCTION

Water is a very important natural resource that man cannot do without, playing vital roles in ecological, physiological, and geological processes (Mishra, 2023). Water availability and its quality are critical factors that influence the health and stability of ecosystems and human societies. Water is categorized into two main types in terms of source as surface water and groundwater (Mishra, 2023). While surface water is water on surface of the Earth like streams, rivers, dams, lakes, ponds and oceans, groundwater is the water stored underground in aquifers or porous rocks and fractures. It is a vital source of portable water to a large number of people all over the world. About 3 billion people (UN/WWAP, 2003) depend on ground water supplies as source of drinking water. Groundwater also lends itself as the source water for 40% of self-supplied Industrial uses and 20% for agricultural uses through irrigation (UN/WWAP, 2003).

Groundwater is characterized based on its movement through aquifers. The major properties include permeability, porosity, and hydraulic conductivity, which affect its storage and flow behavior in the subsurface. It serves as a vital water supply for domestic, agricultural, industrial, and environmental needs. Groundwater has been identified as the commonest source of fresh water (Venkateswaran *et al.*, 2014) even in most cities where pipe borne water is available, though not reliable. It may be obtained at the earth's surface by digging wells/boreholes or as springs (Salako *et al.* 2009; Bello *et al.*, 2019). The quality of groundwater is influenced by geology, climate and human activities (pollution, over-extraction). Contaminants such as nitrates, heavy metals, pesticides and herbicides pose significant threats to groundwater quality and human health. Due to the deep location of aquifers, they act as natural filters thereby making groundwater to be good for drinking (Rao and Chaudhary, 2019) and also available for agricultural purposes.

Groundwater as a geologic material is found in the subsurface. The subsurface materials are found at different depths. The fracture, weathered layer, weathered/fracture basement (Omorinbola 1984; Bello *et al.* 2019) are the lithological units as found in basement complex terrain which the study area is thereof. The kind of geologic material found within the subsurface lithology to a large extent depends on the permeability and porosity of the constituents. This goes further to determine the groundwater potentiality of the area under investigation.

The presence and movement of groundwater below the surface in any area are affected by a number of geological variables, including aquifer properties, the composition of surrounding rocks, existing geological formations, porosity, water saturation levels, among others (Aizebeokhai and Oyeyemi,

2018; Martinez-Pagan *et al.*, 2009; Sunkari *et al.*, 2020). Mapping and interpretation of the subsurface structure gives knowledge on the geologic formations and physical characteristics of the geologic materials (George *et al.*, 2015).

On the quest to search for groundwater, one looks for the properties of aquifer like overburden thickness, direction of water flow, availability to determine the groundwater status (quantity and quality). Since attention is not only on the quantity but also on the quality of the groundwater the question now becomes how susceptible are the aquifers delineated to pollution? Evaluation of susceptibility is mainly concerned with the assessment of a particular aquifer to contamination that can reduce the groundwater quality (Al-Abadi *et al.*, 2017). Vulnerability information is a vital tool for location of some activities that are inimical on groundwater thereby reducing those negative effects to ensure the protection of groundwater. Hence, vulnerability investigations are employed to locate/determine areas that are prone to contamination.

Geophysical methods are employed in most explorations due to their rapidness and ability to cover large area in a limited time and also the ability to dig deep into the subsurface. For groundwater investigations geoelectrical methods readily come to mind because of properties like permeability and porosity that could easily be tied to electrical resistivity (Loke *et al.*, 2013; Helaly, 2017). Many researchers (Oyedele *et al.*, 2017; Akinlalu *et al.*, 2017; Bello *et al.*, 2019; Akintorinwa *et al.* 2020) have successfully carried out groundwater potential investigation using electrical methods. The choice for electrical resistivity method is because it is easy to use, reliable, less expensive and provides useful information on aquifer properties like depth, lithology, e.t.c. (Telford *et al.*, 1990; Mehmood *et al.*, 2020; Ezema *et al.*, 2020; Jamal and Singh, 2020). When a given amount of current is supplied to the subsurface the resistivity method measures the potential difference across the surface. The application of one-dimensional vertical electrical sounding (VES) technique to investigate groundwater resources has been successful (Adagunodo *et al.*, 2018). Also, in some cases, two-dimensional electrical resistivity tomography (ERT) technique are employed particularly where there is heterogeneity in resistivity. The adoption of both methods has equally been successful (Muchingami *et al.*, 2012). Hence, the adoption of both VES and ERT (geoelectrical) methods in the present study.

The research environment, Federal University Oye-Ekiti is found in a basement complex terrain of Southwestern Nigeria. The research is designed to determine the groundwater potential of the proposed Filling Station Site, located beside the Mosque at Federal University Oye-Ekiti, Nigeria, as regular water supply is one of the major requirements for the

operation of such facility. To ensure that there is adequate supply of water, it becomes paramount that a thorough geophysical investigation be made before groundwater exploitation, to get the necessary details of the connected water systems such as weathered layer, fractures, joints, faults and subsurface lithology needed for quantity and quality groundwater. The study therefore aims to evaluate the site for groundwater potential and aquifer vulnerability using geoelectrical methods for location of viable boreholes devoid of groundwater contamination.

Location and Geology of the Study Area

The study area, Federal University Oye-Ekiti is situated in Oye Local Government Area of Ekiti State. It falls within the geographical coordinates of latitudes 6°57'N -7°00'N and longitudes 3°58'E – 4°00'E as illustrated in Figure 1. The terrain exhibits a gentle slope, with elevations ranging from 528 m to 532 m above sea level. Access to the research area is facilitated by a combination of footpaths and a network of roads.

The area is within the Tropical Rain Forest of southwestern Nigeria with two distinguished seasons known as wet and dry seasons. The dry season is observed between November and March while the wet season lasts between April and October (Ngomanda *et al.* 2005, Li and Qian, 2018). The temperature of the area lies between 21°C and 28°C with high humidity.

The research site is characterized by the presence of the Basement Complex of Southwestern Nigeria. In certain areas, these basement rocks are overlain by varying thicknesses of different materials. Predominantly, the primary lithological formation in the study zone consists of migmatite gneiss, as depicted in Figure 1.

MATERIALS AND METHOD

Materials

The data acquisition was executed using the Min-Res resistivity meter for resistivity parameters while Global Positioning System (GPS) was employed for measurement of the coordinates of the VES points and elevations. Measuring tape, metal electrodes and hammer were used as well.

Figure 2 is the data acquisition map as developed for this research. The separation between the electrodes AB/2 was varied from 1 to a maximum 50 m was executed using Schlumberger array.

The resistances gotten were multiplied by the corresponding geometric factors (Equation 1) to get the values of apparent resistivity. The plot of apparent resistivities against electrode spread on a bi-log graph was done to produce sounding curves. The field curves obtained were curve matched and interpreted (Koedoe, 1979). The parameters obtained, that is, thickness of the layers and their respective resistivity values were employed for a quantitative computer iteration Winresist software (Vander, 2004) to minimize the interpretation errors to allowable values (Baker, 1989). The VES interpretation produced parameters like depths and thickness of the lithological layers, number of layers, resistivity of layers. 2-D geoelectric sections and maps were generated based on the values gotten using surfer 12 software.

The following relation

$$\rho_a = KR \tag{1}$$

was used, where

ρ_a - apparent resistivity, K - geometric factor and R - resistance.

From literature, $R = \frac{\Delta V}{I}$ 2

Geometric factor, $K = \pi \left\{ \frac{(AB)^2 (MN)^2}{4MN} \right\}$ 3

where AB is the current separation and MN is the potential separation respectively.

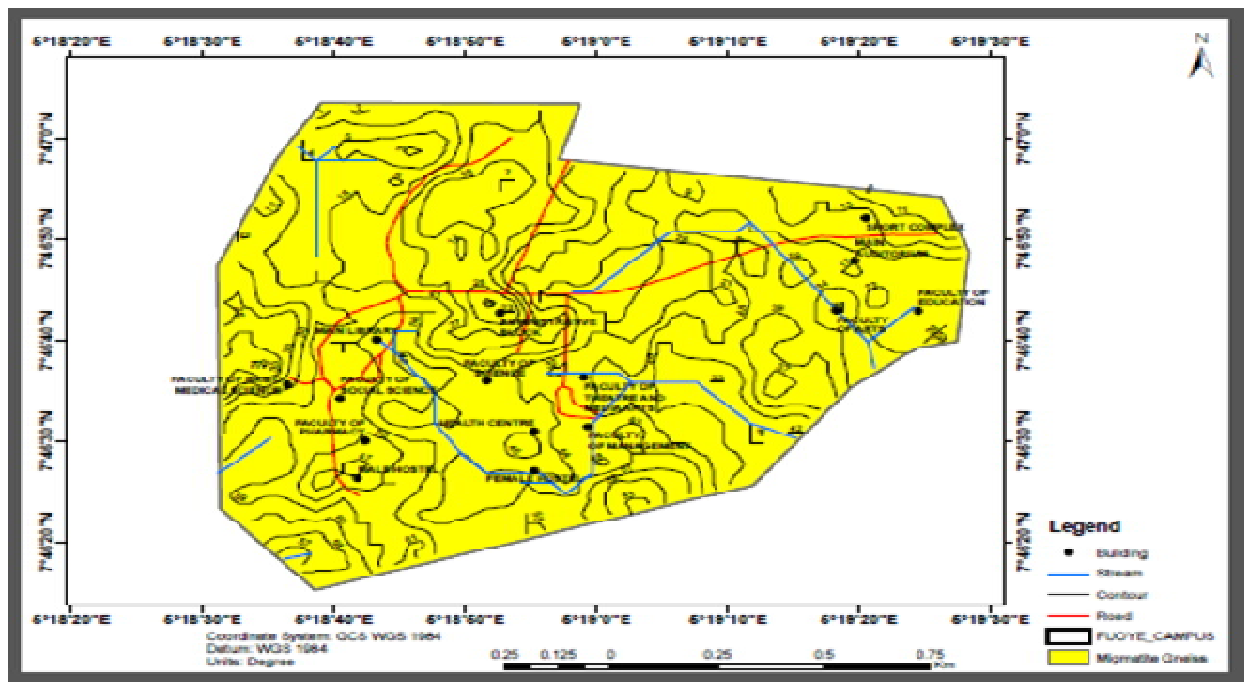


Fig. 1: Geological map of the Federal University, Oye-Ekiti.

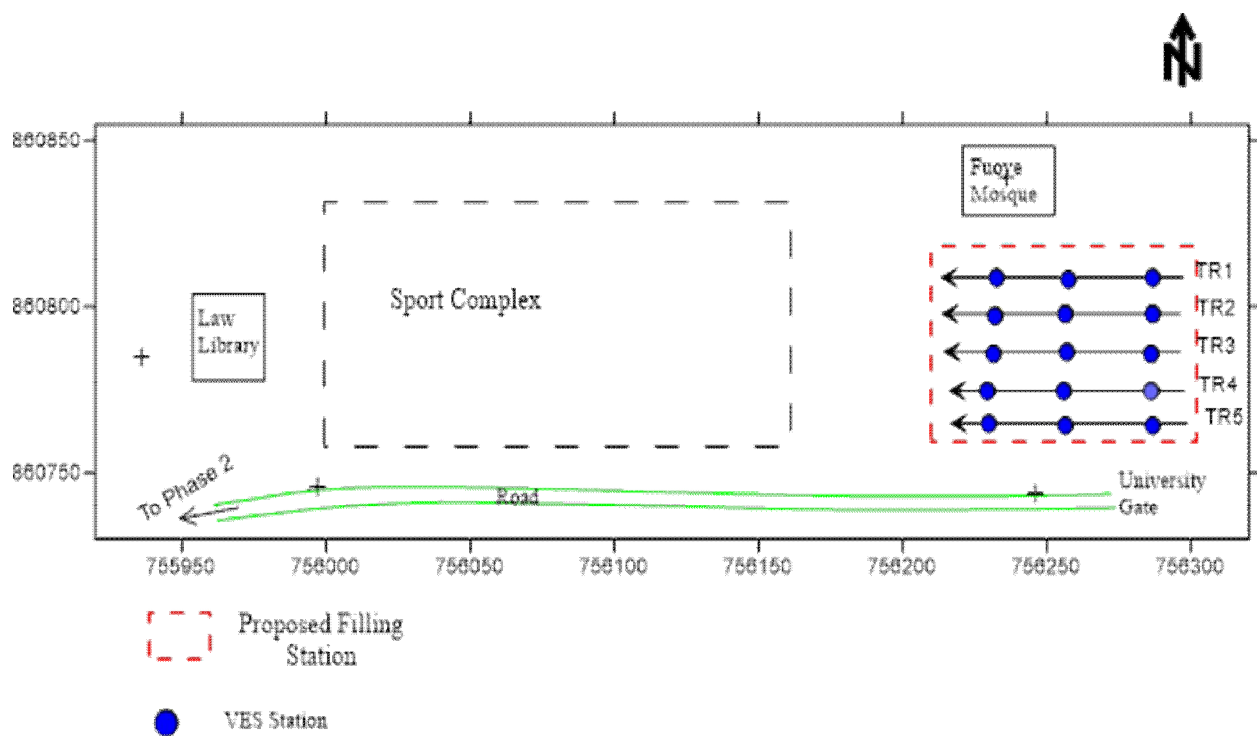


Figure 2: Base map of the Study area.

The aquifer protective capacity characterization was employed to obtain longitudinal unit conductance of the overburden rock units in the area. Equation 4, was applied to calculate the longitudinal layer conductance (S) of each VES station overburden.

$$S = \sum_{i=1}^n \frac{h_i}{\rho_i} \tag{4}$$

where h = saturated thickness and ρ = layer resistivity.

According to Adelusi,2009, the longitudinal unit conductance and protective capacity rating could be classified as in Table 1.

Table 1: Rating of Protective Capacity and Longitudinal unit conductance value, Adelusi, 2009

Longitudinal Unit Conductance	Protective Capacity rating
>0.5	highly protected (clay)
0.1-0.5	fairly protected
0.05-0.1	poorly protected
<0.05	highly protected (laterite).

The acquisitions of 2-D data also used the Schlumberger array. The data acquired were inverted smoothed using least-square method with Res2Dinv software. Root mean square (RMS) values were determined between calculated and observed data to ensure correct fitness.

Result and Discussion

The data acquired in this study was interpreted qualitatively and quantitatively. Table 2 is the summary of the results obtained showing curve type, number of layers, resistivity of each layer, thickness, depth and lithology.

Typical VES curves type (Figure 3a-3d) identified in the study are A, H, HA, and HKH. The dominant VES curve is the H curve type. The curve type A is identified by an increased characterized resistivity from the topsoil to the bedrock, the, whereas the HKH is associated with weathered/fractured aquifer (confined) systems (Olorunfemi and Fasuyi 1993).

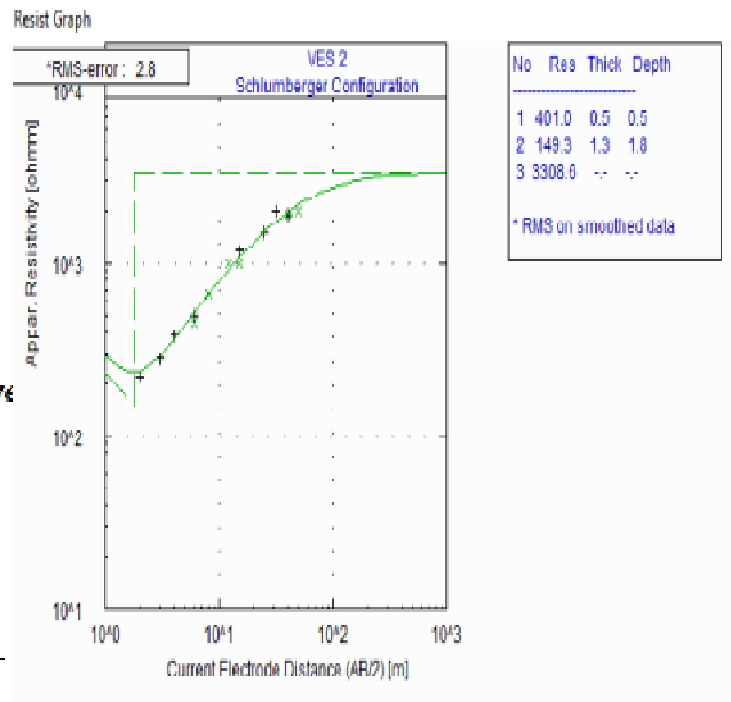


Figure 3a: Typical VES curve H from the study area

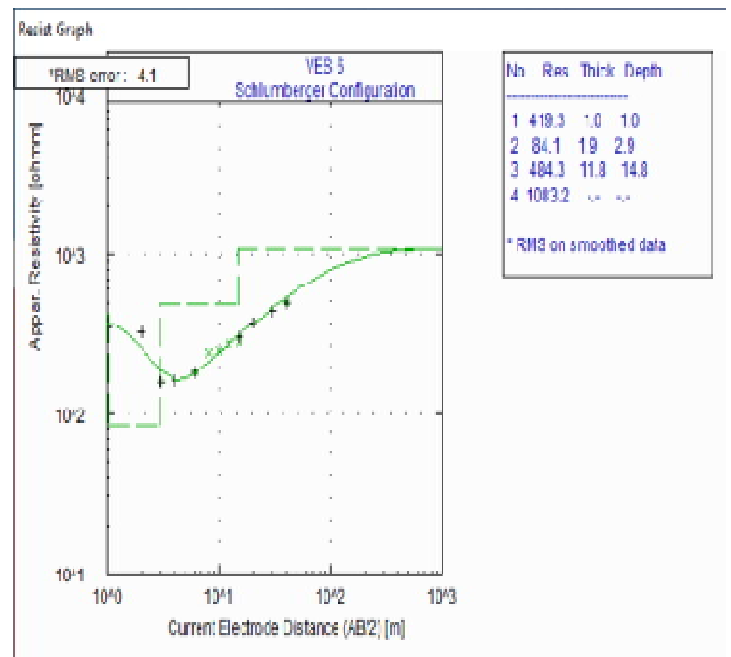


Figure 3b: Typical HA curve from the study area

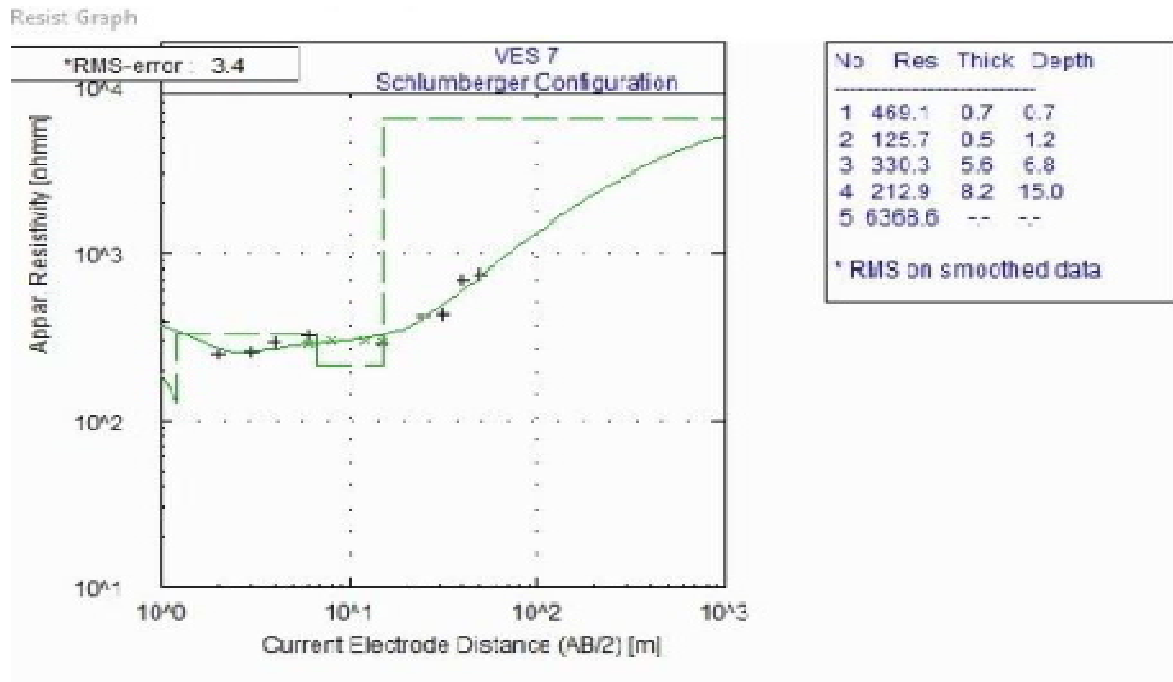


Figure 3c: Typical HKH curve from the study area

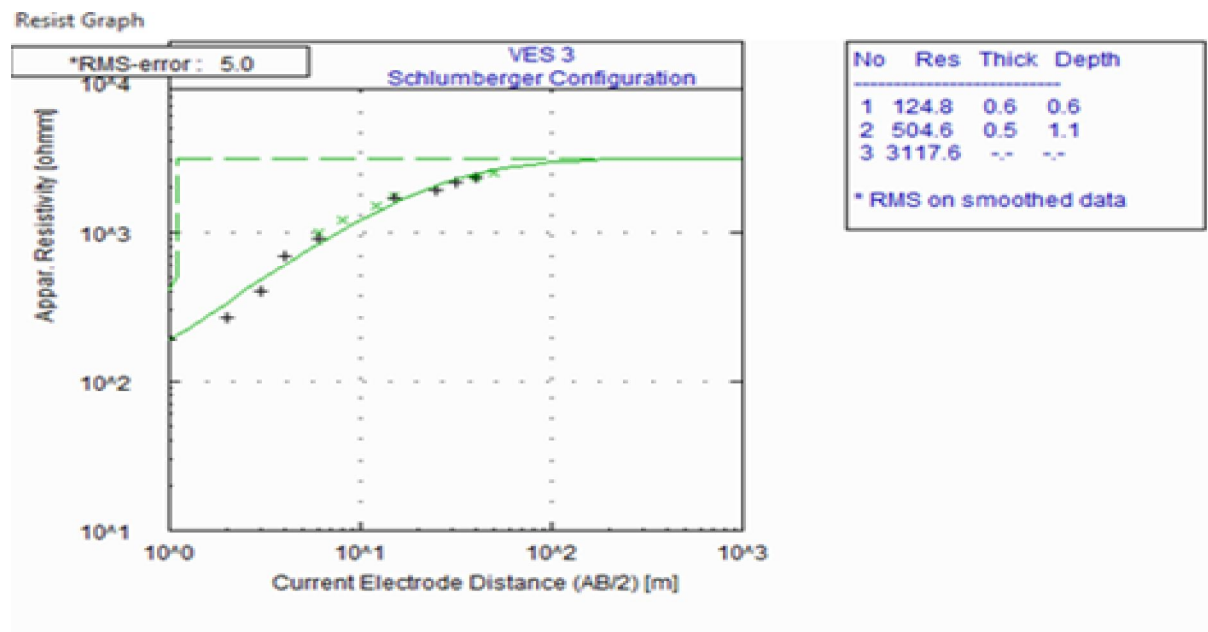


Figure 3d: Typical A curve from the study area

Table 2: Results of Layers Resistivity's

VES no	Curve Type	No of Layer	Resistivity value (Ωm)	Thickness (m)	Depth (m)	Lithology
1	H	1	308	0.6	0.6	Topsoil
		2	49	2.6	3.2	Weathered layer
		3	668	----	----	Fresh basement
2	H	1	401	0.5	0.5	Topsoil
		2	149	1.3	1.8	Weathered layer
		3	3309	----	----	Fresh basement
3	A	1	124	0.6	0.6	Topsoil
		2	505	0.5	1.1	Fresh basement
		3	3118	----	----	Fresh basement
4	H	1	213	1.0	1.0	Topsoil
		2	130	3.6	4.6	Weathered layer
		3	5657	----	----	Fresh basement
5	HA	1	393	0.4	0.4	Topsoil
		2	69	0.6	1.0	Weathered layer

		3	2619	1.0	1.9	Fresh basement
		4	4100	----	----	Fresh basement
6	HA	1	419	1.0	1.0	Topsoil
		2	84	1.9	2.9	Weathered layer
		3	484	11.8	14.8	Fresh basement
		4	1083	----	----	Fresh basement
7	HKH	1	469.1	0.7	-0.7	Topsoil
		2	125.7	0.5	1.2	Weathered Layer
		3	330.3	5.6	6.8	Partly Weathered
		4	212.9	8.2	15.0	Weathered/Partly Fractured Basement
		5	6368.6	-----	-----	Fresh Basement
8	H	1	235.0	1.0	1.0	Topsoil
		2	179.1	6.6	7.6	Weathered Layer
		3	1392.5	----	-----	Fresh Basement
9	HA	1	393	1.1	1.1	Topsoil

		2	66	2.3	3.4	Weathered layer
		3	1942	21.5	24.9	Fresh basement
		4	10019	----	----	Fresh basement
10	HA	1	545.5	0.8	0.8	Topsoil
		2	211.7	0.9	1.7	Weathered Layer
		3	441.8	8.8	10.5	Partly weathered
		4	23683.9	----	----	Partly weathered
11	HA	1	509	1.3	1.3	Topsoil
		2	106	1.8	3.1	Weathered layer
		3	981	9.7	12.8	Partly Weathered Layer
		4	7966	-----	-----	Fresh basement
12	H	1	335.1	1.0	1.0	Topsoil
		2	156.0	5.8	6.8	Weathered layer
		3	2833.9	-----	-----	Fresh basement
13	H	1	335.1	1.0	1.0	Topsoil
		2	156.0	5.8	6.8	Weathered layer
		3	2833.9	-----	-----	Fresh basement
14	H	1	547	0.9	0.9	Topsoil
		2	204	4.9	5.8	Weathered layer

						d layer
		3	1735	-----	-----	Fresh basement
15	H	1	282.3	1.3	1.3	Topsoil
		2	166.2	9.4	10.7	Weathered layer
		3	6086.4	-----	-----	Fresh basement

Overburden Thickness

The thickness of overburden of the weathered layer in the investigated area varied between 0 and 15 m (Figure 4). Ademilua and Eluwole (2013) suggested depth of overburden of 25 m for good groundwater development around the region (of study). Only VES 9 could be associated with high overburden thickness of 25 m but without fracture. VES 7, 10, 11 and 15 are associated with moderate overburden thickness (10.0 - 15.0 m). The rest (VES 1, 2, 4, 5, 6, 8, 12, 13 and 14) could be classified as having thin overburden with thickness (0.6-9.4 m), though there were presence of weathered/fractured layer in almost all the VES except VES 3.

This implied that about 66% of the occupied VES has low groundwater potential while about 27% is associated with moderate groundwater storage capacity and about 7% lack groundwater potential. In all, greater than half of the researched area has low groundwater potential.

Iso-resistivity map (Figure5) of the weathered layer was produced. It showed resistivity distribution that varied from 40 Ω m to 500 Ω m across the study area.

Five (5) geo-sections were established on the study area. Figures 6 and 7 showed 2-D geo-sections along Traverses 1 and 2 respectively. Figure 6 is the geo-section covering VES 1-3 while Figure 7 is the geo-section for Traverse 3 with VES 7-9. The geo-sections delineated three to five layers as: topsoil, weathered layer, partly weathered layer, partly weathered/fractured basement and fresh basement. Each geo-section has its thickness and associated resistivity.

The topsoil has resistivity that ranged between 124 – 547 ohm-m and thickness of 0.4 – 1.3 m. The weathered layer identified as the second layer has resistivity values of 49 to 505 Ω -m and thickness of 0.5 to 9.4 m. The third layer with resistivity of 330.3 to 2619 Ohm-m and associated thickness of 1.0 to 9.7 m is classified as partly weathered layer. The fourth section is classified as partly weathered/fractured basement has resistivity value 212.9 Ω m and thickness of 8.2 m. The last layer identified as the fresh basement has resistivity values of 668 to 236839 Ω m

Geoelectric Sections

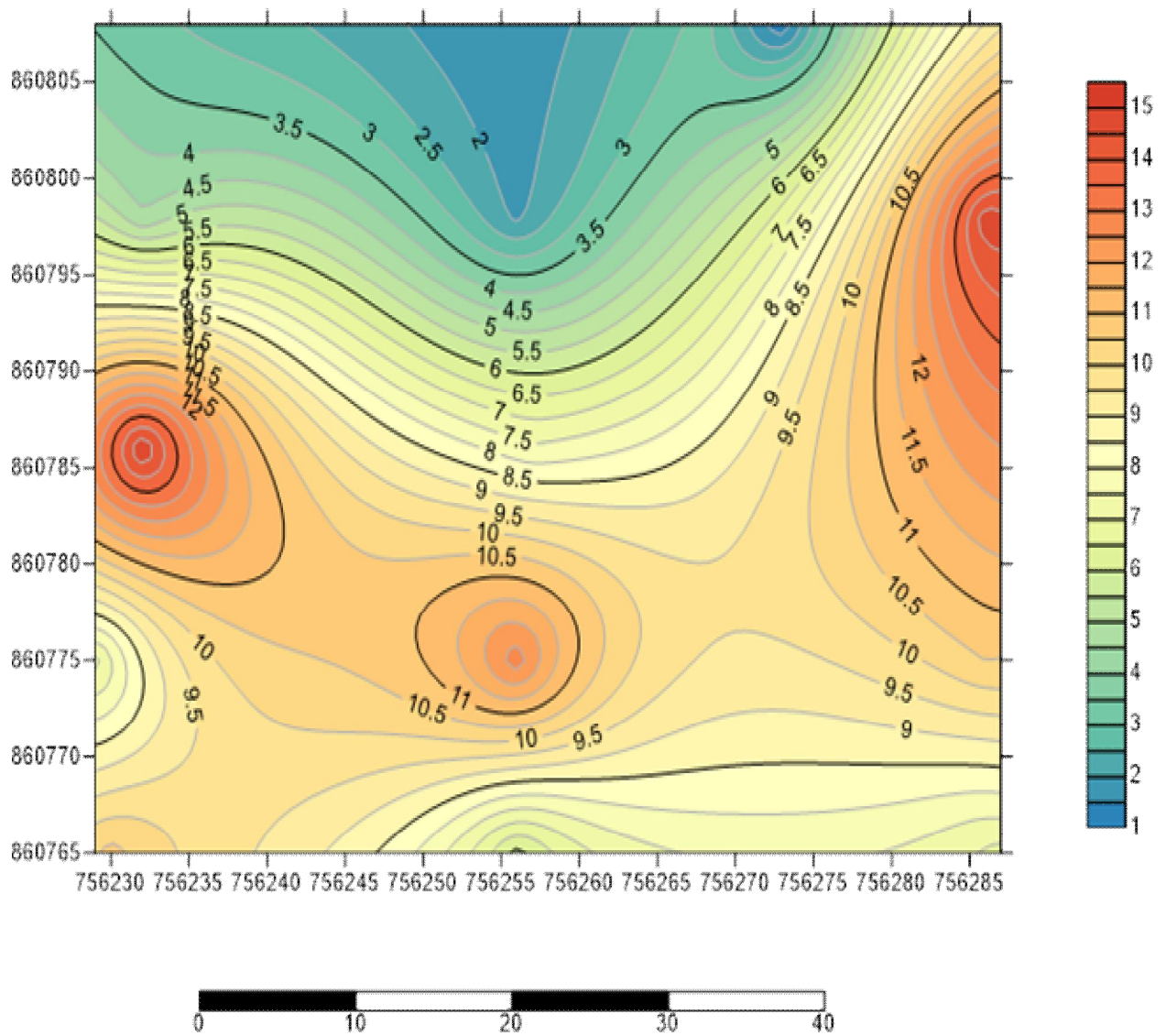


Figure 4: Weathered Layer Thickness Map

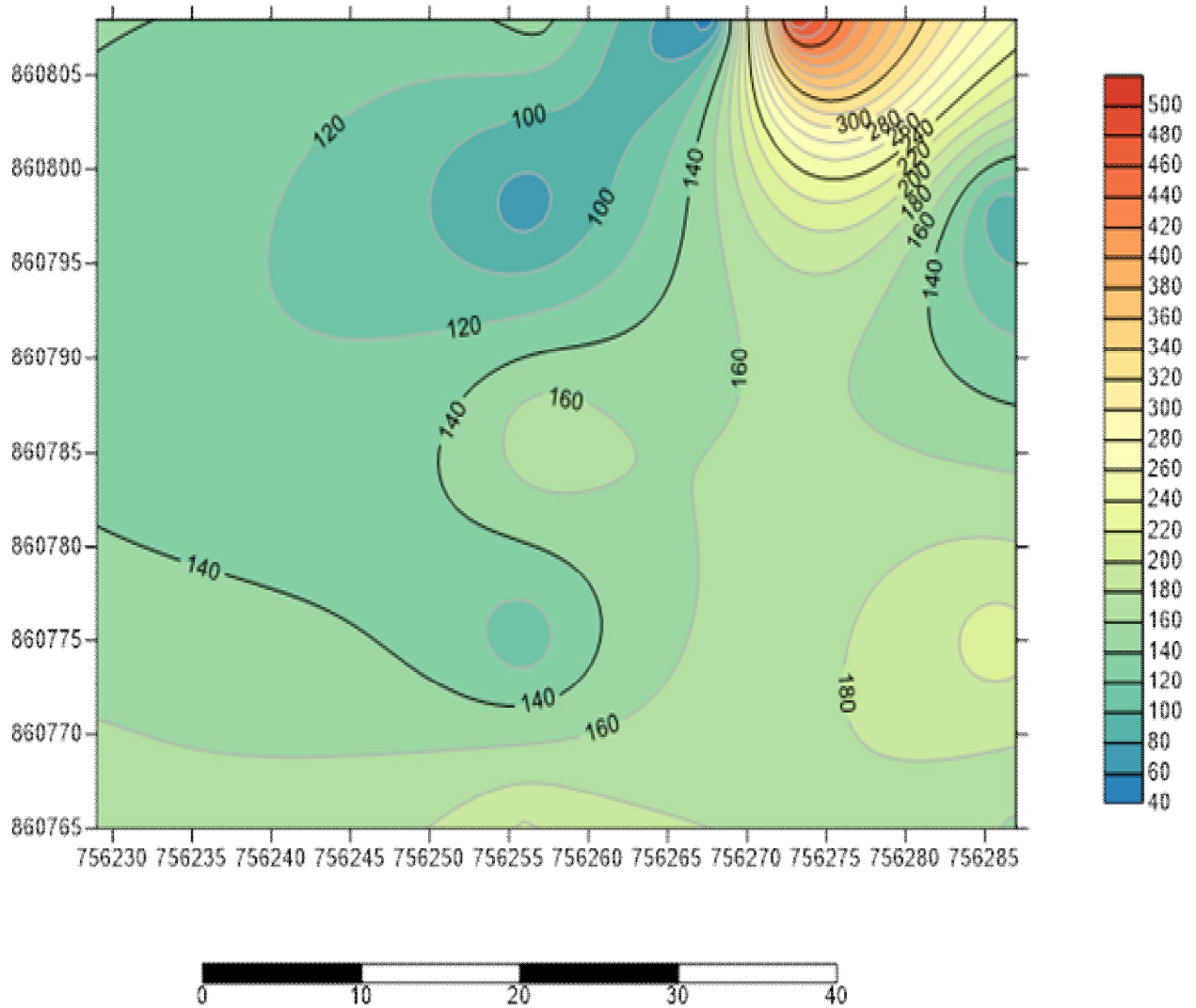


Figure 5: Iso-resistivity Map of the Weathered Layer

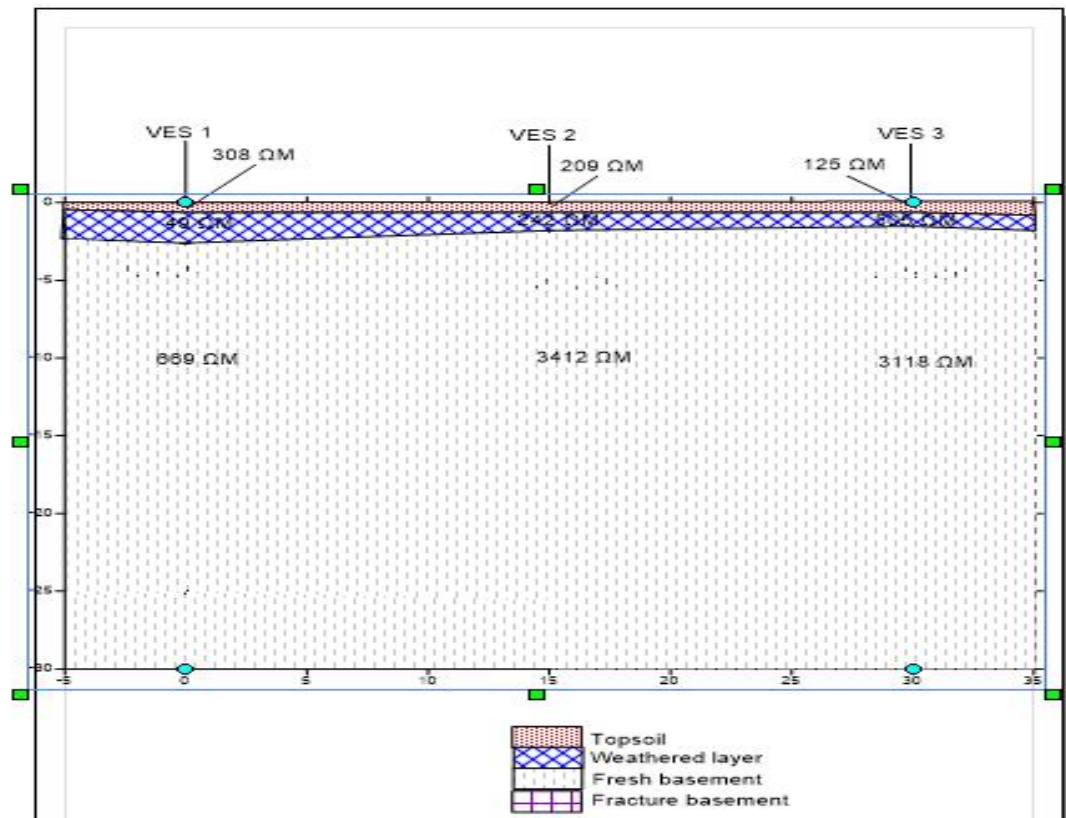


Figure 6: Traverse 1 geoelectric section

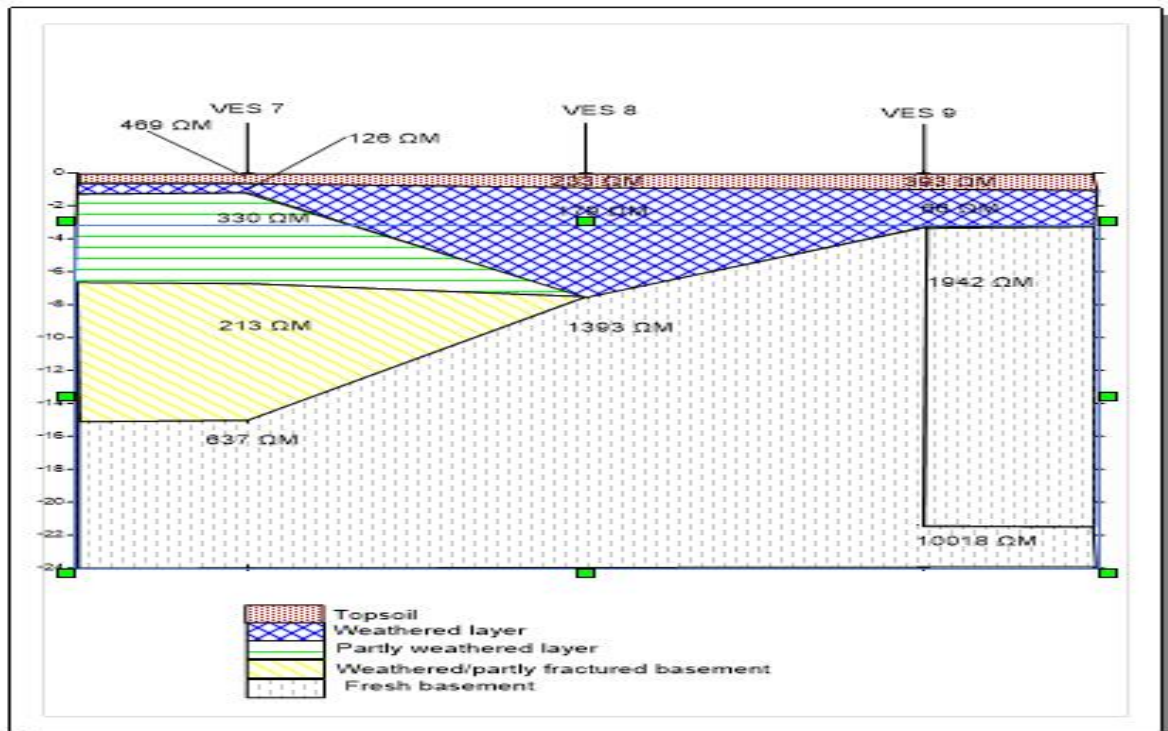


Figure 7: Geoelectric section of Traverse 3

Curve Types

Figure 8 is the frequency of the curve types as obtained in the area of investigation. The distribution (Figure 8) indicates four curve types as H, A, HA and HKH (Sunmonu et al., 2015). H type curve occurred most in the area with 53.3%. H curve type is usually associated with weathered/fractured layer comprised of sandy clay or clayey having low resistivity value, and most often water saturated and highly porous (Olorunfemi et al., 1999). The A curve type consists of 6.7%. Usually, they do not show groundwater potential as they do not possess fracture network or weathered layer (Sunkari et al., 2021). Curve HA occupied 33.3% in the area, they groundwater bearing layers in these are limited to weathered basement while curve HKH occupied 6.7% of the study area. The HKH curve type has groundwater potential as they contain weathered layer/partly fractured network.

Assessment of Aquifer Protective Capacity

To determine the longitudinal unit conductance (S) of the area, Equation 4 was employed to calculate overburden protective capacity rating. The longitudinal unit conductance (S) rating obtained ranged between 0.0060 to 0.0610 mhos (Figure 9). The protective capacity rating identifies about 80% of the area to fall within the highly protective capacity rating, with values of 0.006 to 0.0490 mhos being lateritic in nature while about 20% could be associated the poor protective capacity rating. Figure 9 depicts values that ranged between 0.055-0.061 mhos, (Adelusi, 2009). This suggest that the study area is made up of geologic materials that inhibit infiltration of contaminants at the surface and near-surface

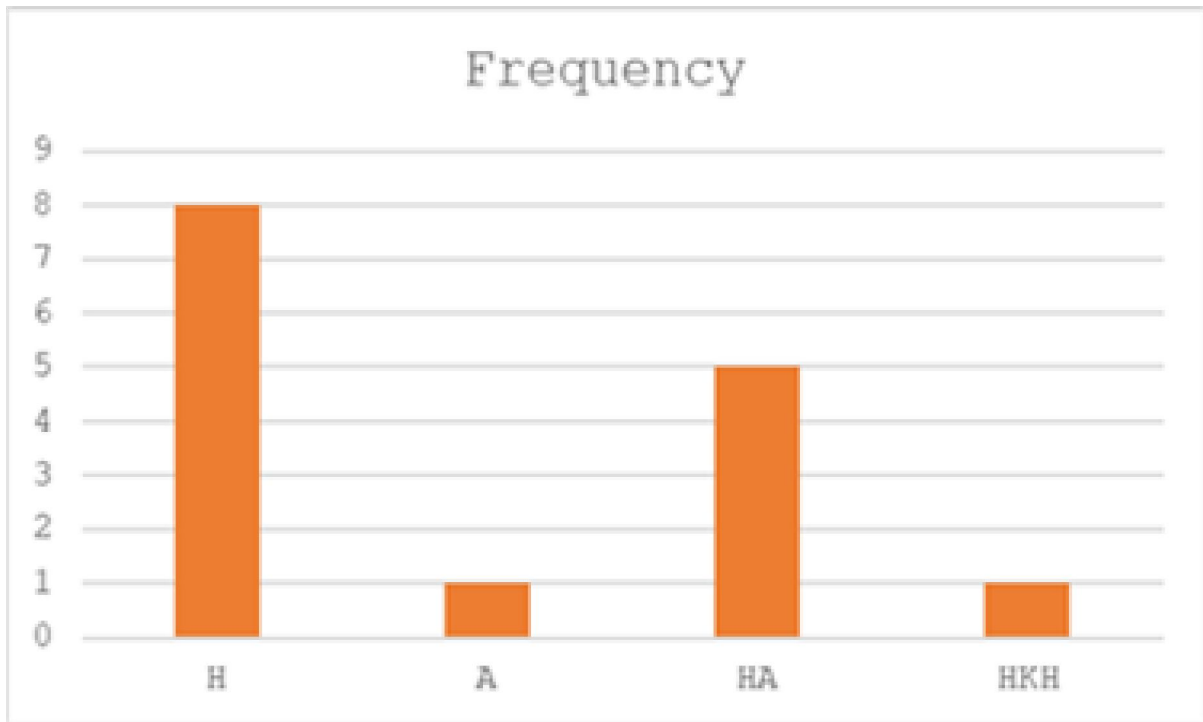


Figure 8: Frequency of Curve Types

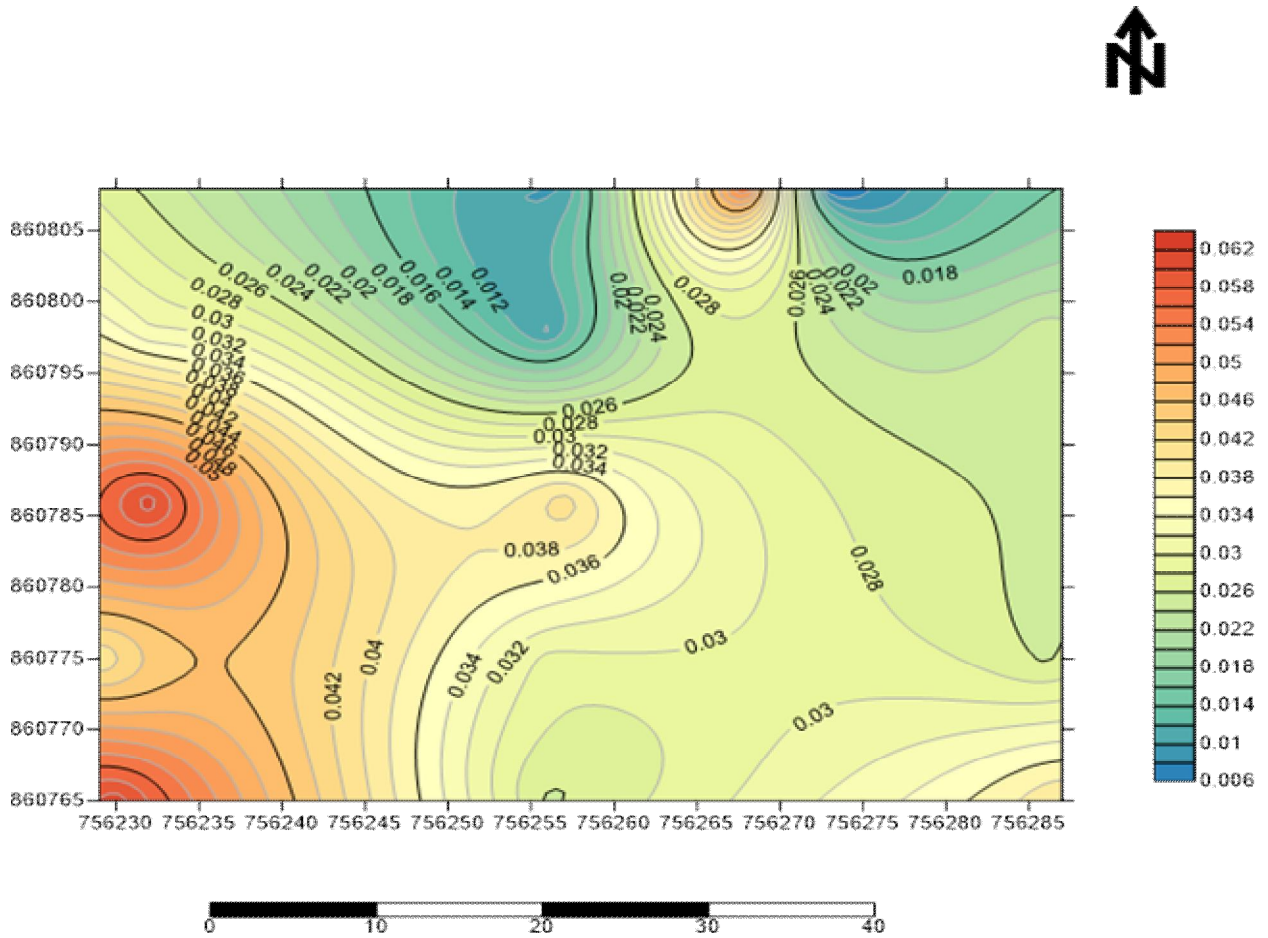


Figure 9: Longitudinal conductance distribution

Dipole-Dipole Resistivity Result

The inversion of the dipole-dipole data along Traverse 1 produced the 2-D structure shown in Figure 10. Three lithological layers were identified by the 2-D resistivity structure as: topsoil (blue colour band) with thin overburden, weathered layer (green and yellow colour band) and the fresh basement rock (red and purple colour band). The

topsoil has low resistivity value and thickness that ranged between 7.5 to 21 Ωm and 5 to 7.5 m which could be due to presence of clay. The second layer (weathered layer) has a relatively thin thickness of about 2.5 m. The 2-D resistivity was structured along the W-E direction. Traverse 1 was observed to have low resistivity values ($< 100 \Omega\text{m}$) at many station points with depth less than 5 m. The low resistivity values were characterized by blue color band, could be an indication of clay with enriched water absorbing region. There is evidence of shallow basement depth within the study area which has a relatively high resistivity and thickness. This result is similar to what was obtained with the VES method.

(2-D Resistivity Structure)

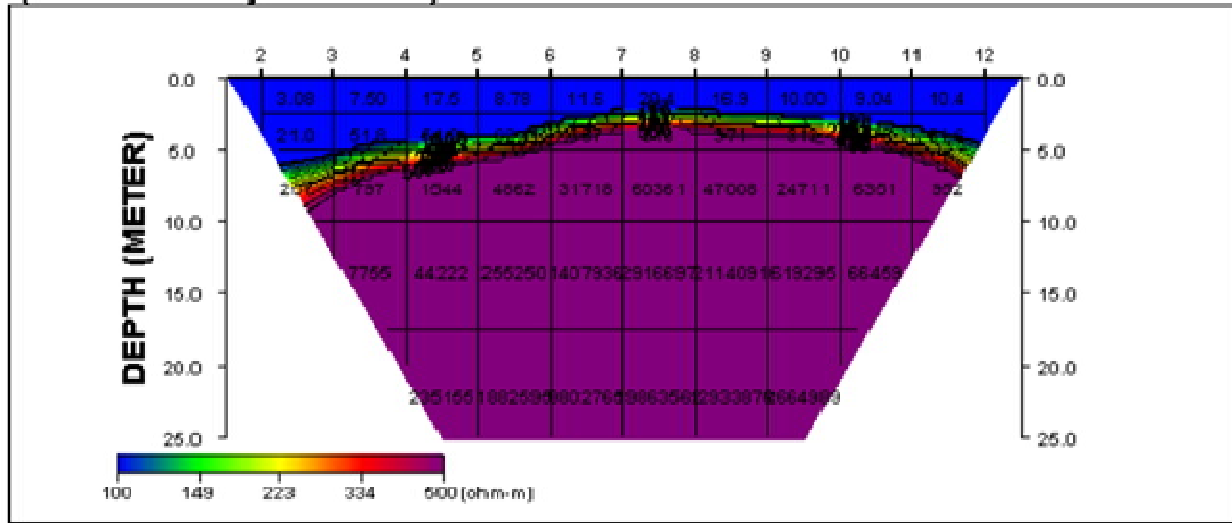


Figure 10: Dipole–Dipole along Traverse 1

CONCLUSION

The availability of groundwater in the proposed site was evaluated by considering the electrical resistivity of the fractured layer/weathered layer, thickness and depth of the layer. The study delineated 3-5 lithologic layers as topsoil, weathered layer, partly weathered layer, partly weathered/fractured basement and fresh basement. The curve types identified by the study are H, A, HA and HKH with H curve occupying about 53% of the area. The aquifer potentials of the area revealed good protective capacities having 80% rating and about 20% rated as poor protective capacity. 0.055-0.061 mhos were ascertained in the study area as the longitudinal conductance.

The study revealed four VES stations as having moderate potentials for groundwater as they have weathered/fractured layer whose resistivity values ranged between 66 to 981 Ωm. The weathered/fractured layers with depths ranging from 10.5 to 15.0 m could suggest moderate potential. In all, the area under study could be classified as having low/moderate groundwater potential capacity due to thin overburden and absence of connective fracture basement.

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