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Article

Location of Prolific Groundwater-Bearing Zones Using 2D Resistivity Imaging and Electrical Sounding Geophysical Methods within the Premises of Ajayi Crowther University Oyo, Southwestern, Nigeria

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Abstract

Due to the need to provide potable water for the residents within the premises of Ajayi Crowther University, search for groundwater was conducted by integrating two-dimensional tomography (2-D) and the vertical electrical resistivity geophysical methods to delineate prolific groundwater zones within the basement setting of the study area. From the six inverted 2-D imaging results, probable conductive units representing groundwater zones - with resistivity between 4 and 177 Ωm extending to a depth of 12.4 m were established across the study area. The delineated areas were sounded to reveal the extent of regolith and bedrock characteristics. The sounding results revealed three main geo-electric models namely QH, KH and H curve types. The resistivities of the weathered layers ranged from 13.1 to 156.4 Ωm and the lithology were interpreted as clayey to clayey-sand. The total thickness of the regolith ranged between 7.8 and 40.8 m and the bedrock resistivities were between 48.3 and 756 Ωm. The bedrock resistivity showed that the bedrock is significantly fractured. The fractured zones occurred at an average depth of 22.8 m below the ground surface. These lithologic sequences largely support the development of prolific wells, particularly at the southeastern part of the University premises where thick regolith overlies fractured bedrock.

Keywords: Bedrock, Weathering, Fractures, Groundwater-bearing zones, Prolific-wells.

1. Introduction

Exploration for groundwater is gaining more importance in Nigeria owning to the ever-increasing demand for water supplies, especially in the areas with inadequate surface water supplies. Already, ten (10) percent of the world's population is affected by chronic water scarcity and this is likely to rise with time [1,2]. The water scarcity experienced by the people led to the search for surface water supply. Groundwater is one essential but necessary substitute to surface water in every society. It's no doubt a hidden [3], replenishable resource. The occurrence and distribution of groundwater greatly varies according to the local as well as regional geology, hydrogeologic setting and to an extent the nature of human activities on the land [4]. Groundwater occurrence in a Precambrian Basement terrain is hosted within zones of weathering and fracturing which often are not continuous in vertical and lateral extent [5,6].

Electrical resistivity survey is relevant to ground exploration [7]. The resistivity of rocks is strongly influenced by the presence or absence of groundwater, which acts as an electrolyte. The minerals that form the matrix of a rock are generally good resistors than groundwater, so the resistivity of sediment decreases with the amount of groundwater it contains. This depends on the fraction of the rock that consists of pore spaces and the fraction of this pore volume that is water-filled. Therefore, the analyses of such measurements could proffer targets for groundwater resource drilling.

The electrical resistivity profiling (ERP) is essentially employed to delineate locations for VES for further probe into deeper subsurface depths [8]. The application of VES is employed to reveal the extent of weathering development and the textural characteristic of the regolith unit from the resistivity values. Also, VES method is applicable to studying the nature of the bedrock whether fractures, weathered or fresh. Additionally, it gives the individual thickness of geoelectric layers, thereby delineating and locating the position of the permeable zones within the subsurface environment [9,10,11].

The main objective of the present work is to locate potential groundwater bearing zones within the premises of Ajayi Crowther University, Oyo using electrical geophysical techniques of electrical resistivity profiling (ERP) and vertical electrical sounding (VES). The geophysical studies of sections could assist the University to provide more prolific wells within the premises, thereby increasing the volume of water supply.

1.1 Study Area

The study area is located within Ajayi Crowther University (ACU), Oyo, in Atiba Local Government Area of Oyo State, southwestern Nigeria (Figure 1). It lies between latitude $7^{0}\ 50^{1}\ 45^{11} – 7\ 51^{1}\ 15^{11}$ North and longitude $3^{0}\ 56^{1}\ 45^{11} – 3^{0}\ 57^{1}\ 15^{11}$ East. The accessibility of the area is enhanced by major and minor roads; some of the minor roads are connected to the major road and streets or communities in Oyo Township. The area of interest/study is part of Oyo NE sheet number 224 SW Nigeria.

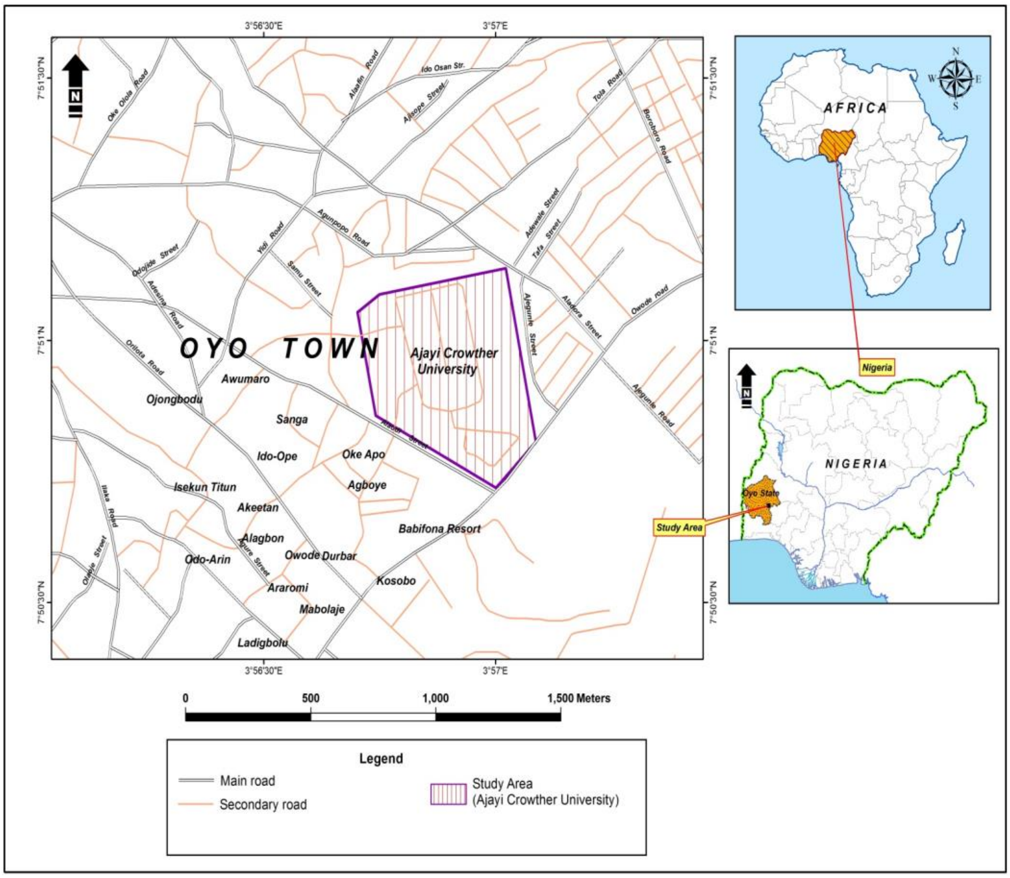


Figure 1: Location and Accessibility map of the study area

The study area has a relatively flat and low- lying surface having the minimum relief at the northern part and the maximum relief to extend towards the southern part of the studied area. The area is well drained with the drainage converging in lowland part of the study area. As typical of tropical environment, the surface water fluctuates with seasons while some of their tributaries get dried up during the dry season. Generally, Oyo township inhabitants tend to go through difficulties during the dry season when most of the river (tributaries) which serves as sources of water dries up.

1.2 Geology of the Study Area

The area is underlain by crystalline rocks mainly quartzite (Figure 2) covered by in-situ weathered regolits and vegetation. Gneissic outcrops were mapped in the southern part of the area with some pegmatite intrusions. ACU premises is already well-developed with numerous housing and Offices with a number of factories catering for the need of the University community. The need for regular supply of water for drinking and for other purposes have increased in recent times as a result of expansions and increase in human residents within the premises. Ordinarily, like most crystalline rocks quartzites and gneiss that are the bedrocks do not have capacity to store and transmit water. However, prolific groundwater-bearing zones can be sited within weathered and/or fractured zones, which warranted the present investigation.

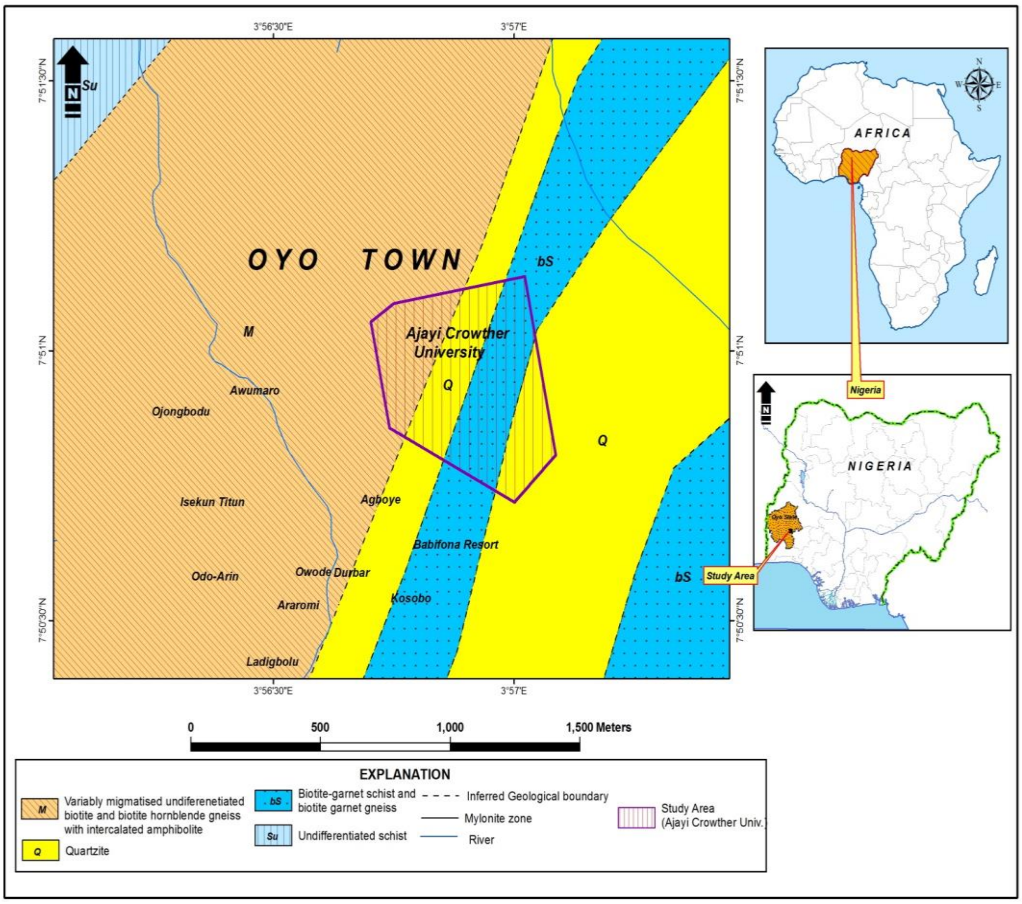


Figure 2: Geological map of the study area

2. Methodology

2.1 Principle of Electrical Geophysical Methods

Resistivity field surveys measure the apparent resistivity of the earth which assumes a homogeneous ground. It is represented by the Greek symbol and calculated by multiplying the resistance (R) by the geometric factor (k) where the latter determines the separation and the geometric arrangement of the electrodes. The measured apparent resistivity values are compared to computer-calculated apparent resistivity values to generate true resistivity values using the least square inversion method.

The physics of the electrical current flow suggests that a good contrast in electrical resistivity exists between the different lithological units (e.g. clay, sand and gravels) and between the water-saturated and unsaturated formations. Thus, the electrical resistivity method can be used successfully to differentiate lithological units in the study area. The depth of investigation and resolution of surface resistivity measurements are controlled by electrode configuration and maximum electrode spacing used in the field measurements.

Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivity, and the distribution of the surrounding soils and rocks. The usual practice in the field is to apply an electrical direct current (DC) between two electrodes implanted in the ground and to measure the difference of potential between two additional electrodes that do not carry current. Usually, the potential electrodes are in line between the current electrodes, but in principle, they can be located anywhere. The current used is either direct current, commutated direct current (i.e., a square-wave alternating current), or AC of low frequency (typically about 20 Hz). All analysis and interpretation are done on the basis of direct currents.

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various Geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys.

The resistivity measurements are normally made by injecting current into the ground through two current electrodes and measuring the resulting voltage difference at two potential electrodes (P1 and P2). From the current (I) and voltage (V) values, an apparent resistivity (*pa*) value is calculated (Apparent resistivity is defined as the resistivity of an electrically homogeneous and isotropic half-space that would yield the measured relationship between the applied current and the potential difference for a particular arrangement and spacing of electrodes.

$$pa = k\ V / I$$

where k is the geometric factor which depends on the arrangement of the four electrodes (Figure 3).

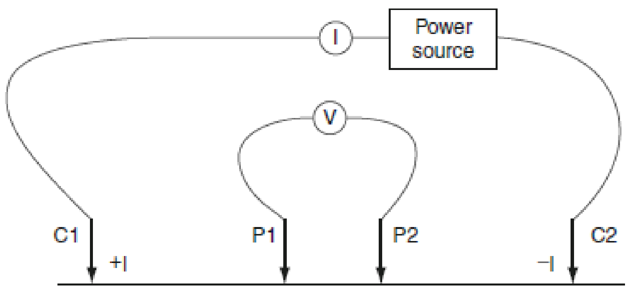


Figure 3: Basic setup for an electrical resistivity survey

The electrical resistivity method is based on the theory that when an electric current travels through a wire it experiences a resistance (R) that is proportional to the length of the wire (L) and inversely proportional to the cross-sectional area (A) of the wire as expressed in the proportionality equation below:

$$V = IR$$

Resistance is calculated by using Ohm's Law which is described as the ratio of the measured voltage to the input current.

$$R = V/I$$

Where R is the resistance, V is the voltage, and I is the current

Resistance is a variable that depends on the intrinsic property of solid and fluid bodies called resistivity. Resistivity is represented by the Greek symbol rho (ϱ) and it is related to resistance by the following equation:

$$\rho = RA/L$$

Where A is area, R is resistance and L is length.

The choice of array space will depend on the depth of the anomalous resistivity feature to be mapped. Field data may be plotted in the form of profiles or as contours on a map of the surveyed area. For a contour map, resistivity data obtained at grid points are preferable to those obtained from profile lines, unless the lines are closely spaced, because the alignment of data along profiles tends to distort the contour map and gives it an artificial grain that is distracting and interferes with interpretation of the map. The best method of data collection for a contour map is to use a square grid, or at least a set of stations with uniform coverage of the area, and without directional bias.

2.2 Interpretation of Result

To plot the data from a 2-D imaging survey, the pseudosection contouring method is normally used. In this case, the horizontal location of the point is placed at the mid-point of the set of electrodes used to make that measurement. The vertical location of the plotting point is placed at a distance which is proportional to the separation between the electrodes. The pseudosection plot obtained by contouring the apparent resistivity values is a convenient means to display the data using computer software. The pseudosection gives a very approximate picture of the true subsurface resistivity distribution. However, the pseudosection gives a distorted picture of the subsurface because the shape of the contours depends on the type of array used as well as the true subsurface resistivity. The pseudosection is useful as a means to present the measured apparent resistivity values in a pictorial form, and as an initial guide for further quantitative interpretation [12].

The data of vertical electrical sounding (VES) are usually presented in a series of graphs expressing the variation of apparent resistivity with increasing electrode separation. Several methods have been proposed by different authors to interpret the resistivity data obtained on the field. Such methods include curve matching interpretation, and computer iteration method.

The first step in the conventional method of interpretation of Schlumberger VES dataset involves the plotting of the measured apparent resistivity values (in Ωm) against half the spread length or electrode spacing (in meter) on a log-log graph sheet to obtain a sounding curve. The sounding curve is then interpreted using the partial curve matching technique which involves segment by segment matching of the VES curve with two-layer model master curves and associated auxiliary curves to obtain the layer parameters (i.e., the layer resistivity and thicknesses).

With the advent of different VES forward modeling software, some practicing geophysicists, most especially the untrained ones have virtually abandoned the partial curve matching technique for empirical asymptotes/inflection points and the type curve-controlled guess technique as a faster means of generating the starting model parameters. However, the accuracy of the final interpretation results from the computer assisted technique is dependent on the accuracy of the starting model parameters.

For this present work, a total of 6 four step horizontal electrical profiling (HEP) and corresponding six electrical soundings were conducted within the premises of the school. The traverse length for each profile is approximately 100m using Werner configuration. The first step was started with a distance of 5m and was gradually moved at a constant spacing of 5m within the electrodes on a horizontal traverse till it reached an average of 100m. This procedure was repeated four times while increasing the electrode spacing by 5m on the same traverse. Hence, the electrode spacing is 5m, 10m, 15m and 20m for each traverse. Traverses were cut through bushes and also through the settlements, hence; traverses were not strictly linear or necessarily parallel and distances between them were also not regular. The length of the traverses spanned from 100m - 320m.

3. Results and Discussion

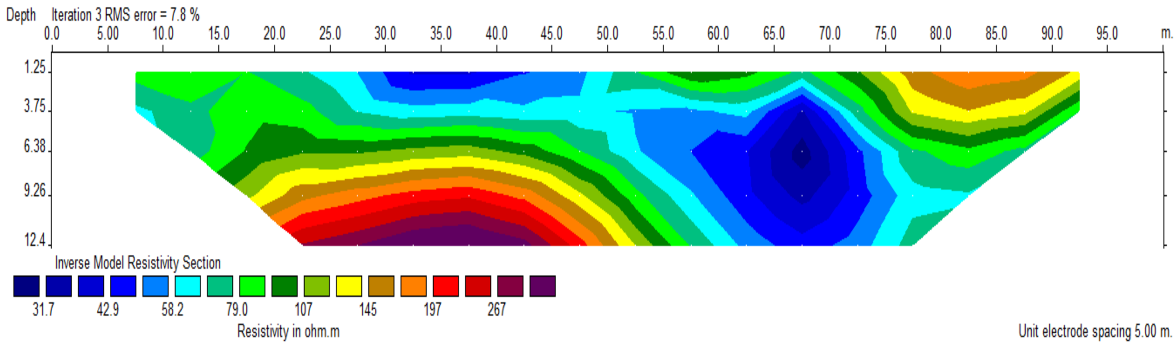
The results of the pseudo section from the profile are presented in Figure 4, while the VES curves are presented in Figure 5.

3.1 Horizontal Electrical Profiling

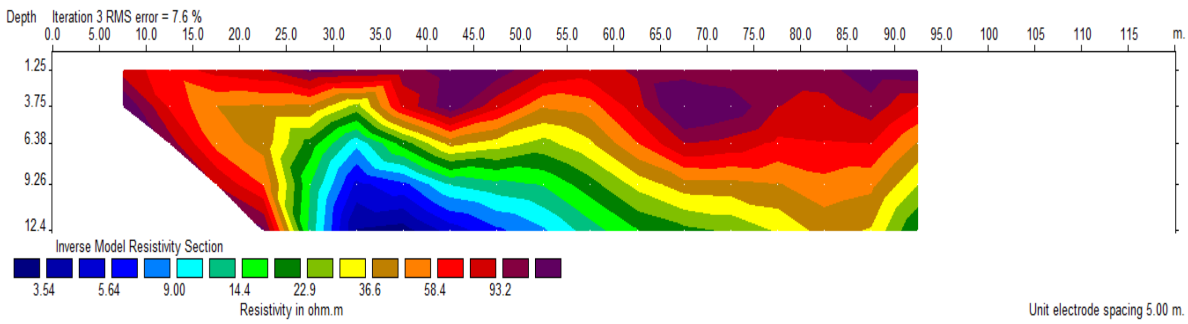
From the results of the electrical resistivity profiling conducted at six (6) locations within the southeastern and western sections of the school, remarkably useful information was deducted for further groundwater exploration using the vertical electrical sounding. The pseudosections from the resistivity contour showed resistivity range from 31.7 Ωm - 267 Ωm. The lower resistivity sections were noted from 25m to 75m lateral section but the earlier part of this section terminated on higher resistivity at depth of 4.0m. However, the later part of this highly conductive section penetrated further from the depth of 3.75m and beyond. Hence, this zone was subjected to electrical sounding. The section seen in profile 2 is so much different from profile 1 with the first three layers being covered with a highly resistive material. At 25m location, a low resistive zone is delineated and it extends laterally to 55m and extends downwards. The best location to be sounded here is the 33m location.

The resistivity in profile three ranges from 8.38 Ωm to 295 Ωm having the first two layers to have a resistivity range of 30 Ωm to 105 Ωm but quite lower around 85m to 99m location which extends downwards where a fracture trend can be noticed. The 87m position is therefore sounded.

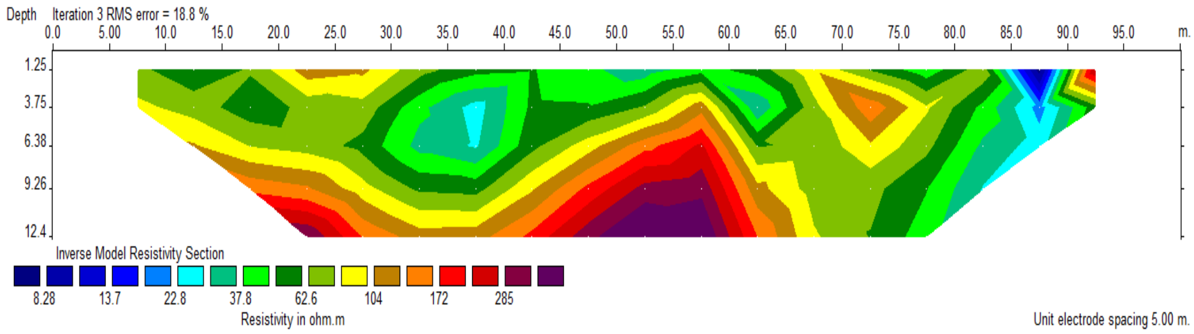
Profile 1



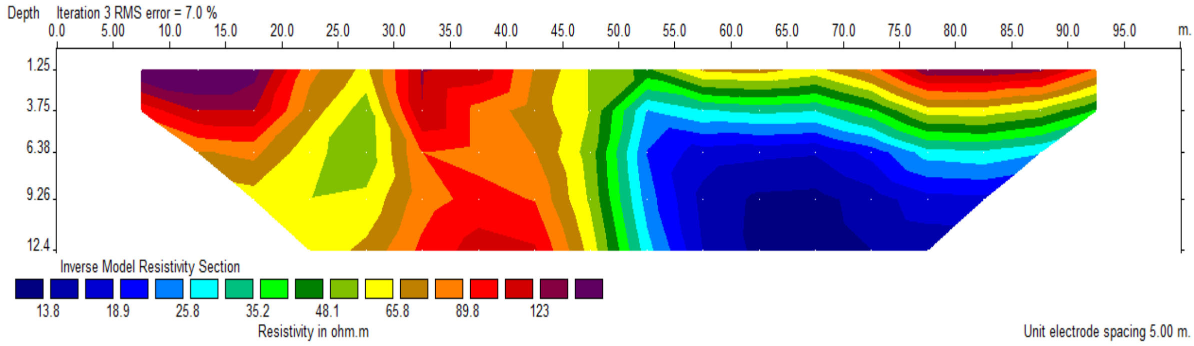
Profile 2



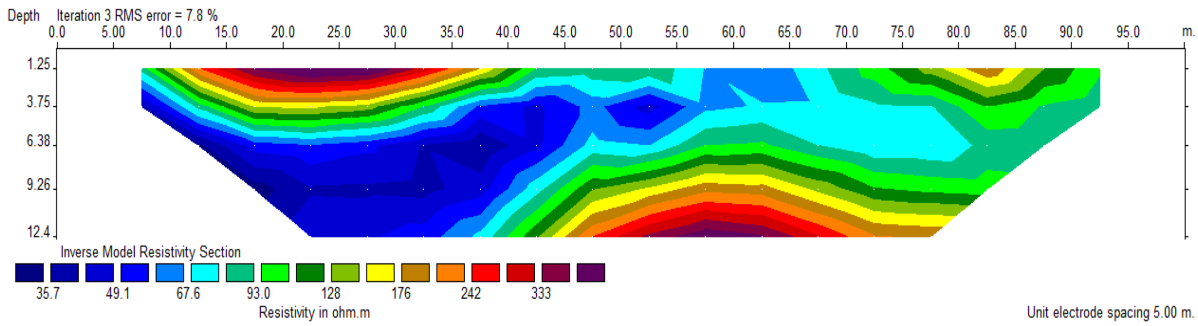
Profile 3



Profile 4



Profile 5



Profile 6

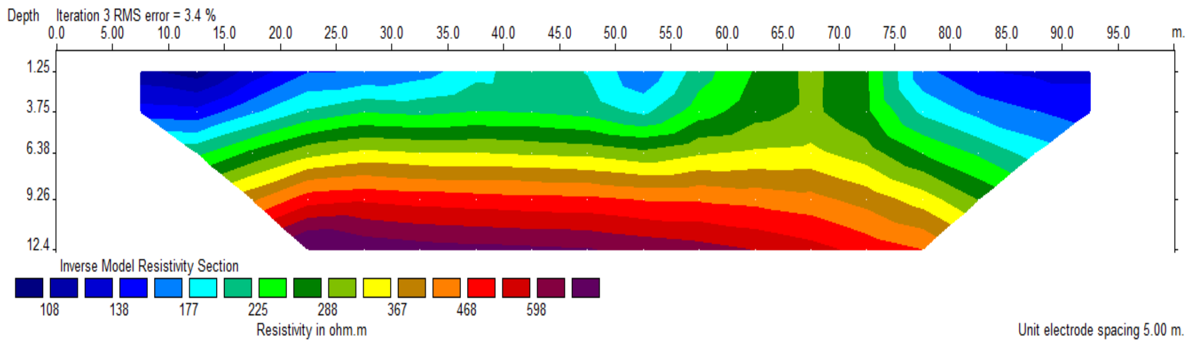


Figure 4: Pseudo-sections for horizontal Profiles.

In profile four, one half of the section is found more resistive than the other half both laterally and vertically. Laterally, the high resistive half extends from 7m to 93m and laterally, it extends downwards except around 55m at a depth of 3.75m where the resistivity reduces which extends laterally and also extends downwards. The VES points can be centered at about 68m lateral location. Profile five is quite prolific having the low resistive areas to extend laterally from 7m to about 78m and vertically from3.75m downwards but terminates around 7m as it trends laterally. Profile six has a resistivity range between 108 Ωm and 598 Ωm which is quite high compared to others. The low resistive area extends laterally from 7m increases a bit between 40m and 45m after which it reduces and increases again laterally. And vertically the resistivity is low to about 3,75m and increase downwards.

3.2 Vertical Electrical Sounding

The vertical electrical sounding (VES) was conducted after 2D interpretation of the result gotten from the horizontal profiling which shows the possible prolific zone hence, the points to be sampled. The Schlumberger array was pounded into the ground to ensure direct contact with the ground in order to measure vertical changes in resistivity of the ground. The VES curves were quantitatively interpreted using curve matching and computer iteration techniques. The curve types obtained from the study area are; H, QH and KH (Figure 5). The lithological interpretation of the VES geo-electric parameters are presented in Table 1.

3.3 Lithologic Interpretation

The lithological interpretation of the layers' resistivities obtained from VES surveys is presented in Table 1. For ACU_VES001, the total thickness is 23 m. It is a 4-layer geoelectric sequence and the VES curve is QH-type. The clayey soils are found to have a resistivity value less than 100 Ωm thereby, providing a confinement for the fractured basement with resistivity value of 200.1 Ωm. Hence, there is an artesian aquifer development.

Table 1: Lithological Interpretation of The Geoelectric Parameters

Location	Curve type	Layer No	Resistivity (Ωm)	Thickness (m)	Lithology
ACU_VES 001	QH	1	248.7	0.6	Top Soil
		2	78.7	3.5	Sandy-clayey
		3	54.3	18.8	Clayey
		4	200.1		Fractured basement
ACU_VES 002	QH	1	141.4	0.4	Top Soil
		2	92.2	3.8	Sandy-clayey
		3	13.1	14.3	Clayey
		4	330.3		Fractured basement
ACU_VES 003	H	1	86.2	2.9	Top Soil
		2	16.8	37.9	Clayey
		3	48.3		Fractured basement
ACU_VES 004	H	1	86.2	2.9	Top Soil
		2	16.8	37.9	Clayey
		3	48.3		Fractured basement
ACU_VES 005	KH	1	495.6	1.8	Top Soil
		2	772.3	0.4	Compacted Clay
		3	31.1	5.6	Clayey
		4	270.6		Fractured basement
ACU_VES 006	H	1	722.2	0.8	Top Soil
		2	156.4	8.0	Sandy
		3	756.1		Weathered Basement

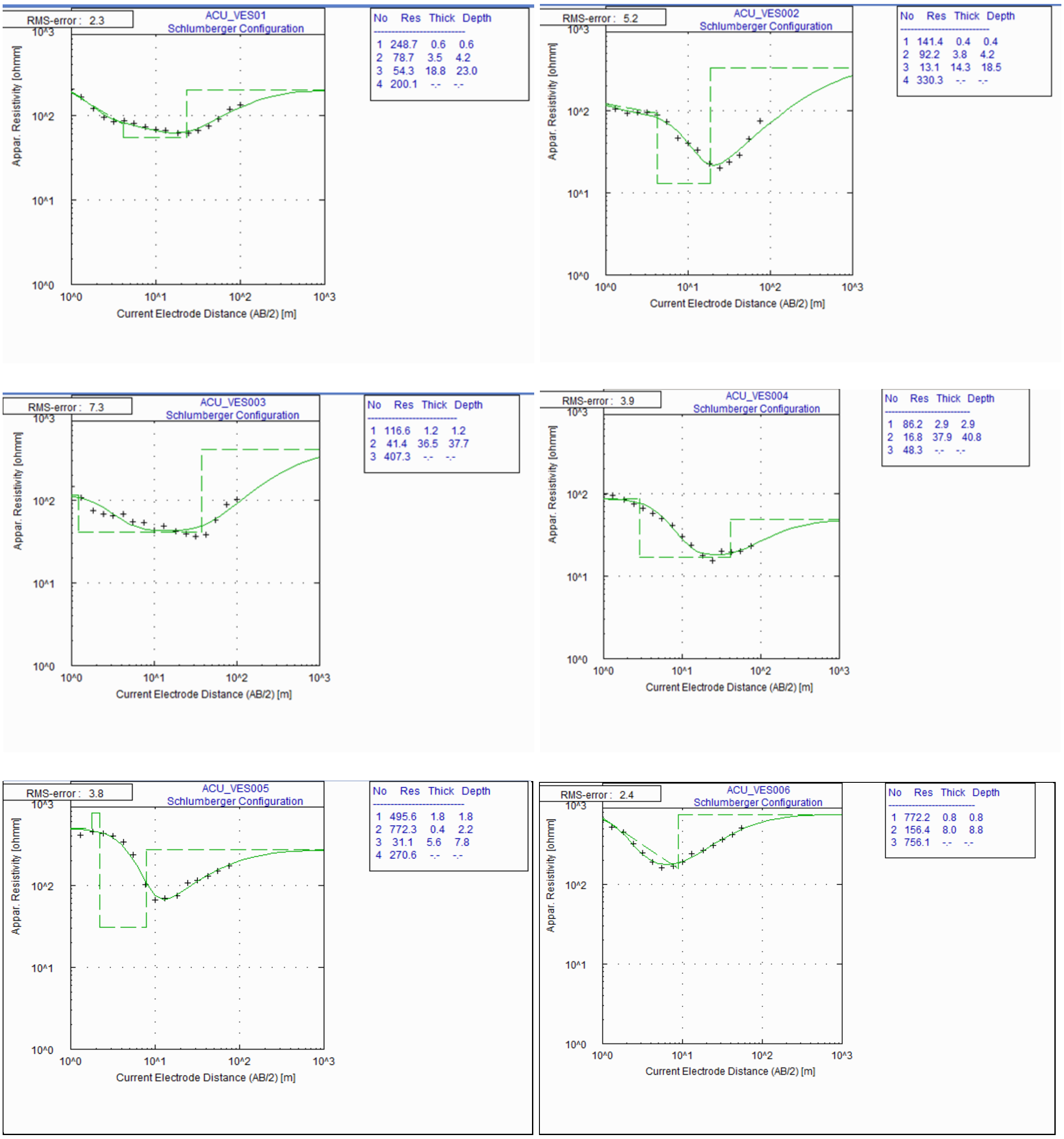


Figure 5: VES curves with quantitative interpretation

ACU_VES 002 is quite similar with a total regolith thickness of 18.5 m and also a QH curve type. The development of an artesian aquifer can also be found here which is as a result of the low resistive clayey soils forming a good confinement for the 330.3 Ωm fractured basement. Unlike others, ACU_VES 003 indicates a three-layer geo-electric section with a total regolith thickness of 37.7 m and a H curve type. The resistivity values obtained here ranges from 116.6 Ωm which is the top soil to the fractured basement of 407.3 Ωm resistivity value having a thick layer of clay of 41.4 Ωm resistivity.

ACU_VES 004 on the other hand has a regolith thickness of 40.8m with a relatively thick layer of clayey soil of 16.8 which forms a very good confinement for the 48.3 Ωm fractured basement leading to the development of a good artesian aquifer. A three-layer geo-electric section is obtained here with H curve type. ACU_VES 005 indicates a four-layer geo-electric section with a total regolith thickness of 7.8m having a compacted clayey layer which is 0.4m thick and bellow is another 5.6m thick clayey layer. These two clayey layers are found to create a confinement or serve as an aquiclude for the 270.5 Ωm fractured basement thereby, creating an artesian aquifer. The curve type obtained here is KH. ACU_VES 006 which is the last indicated a three-layer geo-electric section with a regolith thickness of 8.8m. The resistivity values here are quite high compared to others and it ranges from 772.2 Ωm which is the top soil and 0.8m thick to 756.1 Ωm which indicated a weathered basement, in between them is a sandy layer of 156.4.a H curve type is obtained from the results.

4. Conclusion

The lithological interpretation revealed after the 2D interpretation of the horizontal electrical profiling showed prominent likely groundwater pathways, which when sounded revealed deep weathering / regolith development which penetrates even to the infinite layer. Most of the sounding terminated on fractured basement, aside VES location 6 which terminates on weathered basement. This result showed the effectiveness of the application of the electrical resistivity profiling in mapping potential locations for further probing by the electrical sounding method. The middle layer is largely made up of clayey-to – sandy clayey lithology which provides confining units (or impermeable layers) upon the fractured basement. This geoelectric sequence system is favourable to producing artesian well when exploited for groundwater.

However, the regolith development in locations at ACU_VES 005 and ACU_VES 006 at the western part of the school premises are shallow with regolith thickness ranging between 7.8-8.8m compared to relatively deeper weathering zones occurring in locations at the south-east boundary section with thickness ranging between 18.5- 40.8m. Hence, there is likelihood of generation of more prolific wells at the south-east sections of the school.

With increase in population of the school, there will be a need to increase the amount of the present water supply which is mainly groundwater source. Hence, it is recommended that one or two large diameter boreholes may be drilled at any of the locations where there is an artesian aquifer development to augment the available supply. There is also the feasibility of embarking on the commercial production of groundwater at the south-east locations.

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