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Subsurface Stratification and Aquifer Characterization of Federal College of Education (Technical), Gusauusing Geoelectric Method

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Abstract: *The determination of subsurface stratification and aquifer characterization were carried out at Federal College of Education (Technical), Gusau using the Schlumberger electrical resistivity array with maximum current electrode separation of 200m. Twenty four Vertical electrical soundings (VES) were conducted along six profiles.WinGlink software has been used in interpreting the results. Two and three subsurface layers exist in the study area. The topmost geoelectric layer has resistivity mostly within the range of 1-522Ωm.The lithology of the topsoil is mainly clay to sandy clay. The topsoil thickness ranges from 0.40 to 4.0 m while the overburden thickness of the surveyed area ranges from 0.40 to 18.0 m. The aquifer thickness of the study area ranges from 1.00 to 19.32m. The interpreted results suggest that the main aquifer in the area appears to be the weathered and fractured basements. Productive boreholes can be located around VES 3, 10, 16 and 17. The stratification of the survey revealed mainly clay, sandy clay, weathered and fractured sand which show the formation characterization obtained through interpretation of VES curves and this corroborate with the borehole log of the area.*

Keywords*: Vertical electrical sounding, Stratification, Aquifers, Overburden, geoelectric section and geologic section.*

I. Introduction

This paper describes geoelectric investigations undertaken at Federal College of Education(Technical),Gusau to investigate: the basement structure, geologic characteristics of the overburden of the area and groundwater potential of the area. On the basis of increasing economic activities and booming construction works coupled with the incidence of collapsed building and structures in the country, this investigation is expected to provide detailed information on the characteristic of the subsurface and ground condition prior to the commencement of the construction work. Since every civil engineering structure, bridge, tunnel, tower and dam must be founded on the surface of the earth,it is appropriate to provide detailed information on the strength and fitness of the host earth materialsthrough investigation of the subsurface at the proposed site (Muranaet al., 2011).

Generally, numbers of geophysical techniques are available which enable an insight to obtain the nature of water bearing layers. These include geoelectric, electromagnetic, seismic and geophysical borehole logging. The choice of a particular method is governed by the nature of the area and cost consideration.

The success of any geophysical technique in groundwater exploration depends largely on the relationship between the physical parameters such as conductivity/resistivity, magnetic permeability and density, and the properties of the geologic formations such as porosity.

Geoelectric methods are based upon the correlation of subsurface electrical properties with the occurrence of geophysical targets such as groundwater (quality) zone, fracture (discontinuity) zone, and mineralized zone e.t.c. (Telfordet al., 1976, Dobrin, 1976,Mussett and Khan, 2000, andSharma 2002). In locating suitable electrical conditions, this method makes use of resistivity contrast, which exists between fresh unproductive rock and saturated zones.Groundwater is water located beneath the ground surface in the soil pore spaces and in the fractures of lithologic formations. Groundwater is of major importance to civilization because it is the largest reserve of drinkable water in the regions where humans live.

Although, water from seas and oceans: the surface bodies of virtually inexhaustible water sources are available for exploitation. None of these surface sources can be as naturally suitable and economically exploitable as groundwater (Garg, 2003 and Singh, 2004). Groundwater is relatively safe from hazards of chemical, radiogenic and biological pollution for which surface water bodies are badly exposed. Groundwater is also free from turbidity, objectionable colours and pathogenic organisms and hence requiring not much treatment.

II. Geomorphology, Vegetation And Geology Of The Area

The study area is gently undulating without outcrop. The elevation varies between 476 to 486m. The area experiences two distinct seasons: the dry season (November – April) and rainy season (May – October).
The vegetation consists of desert of bread leaved savannah with some scattered trees. The surveyed area is entirely underlain by rocks of the Nigerian-basement complex. The main rock types of the area are the biotite and biotite-hornblende-granite (medium grained). The migmatites and granites of the area are dominantly banded tonallitic gneisses with minor granite gneisses viewed by granodioriticneosomes (Murana, 2011).
Topography of the study area consists of low-lying terrains and was fairly flat.

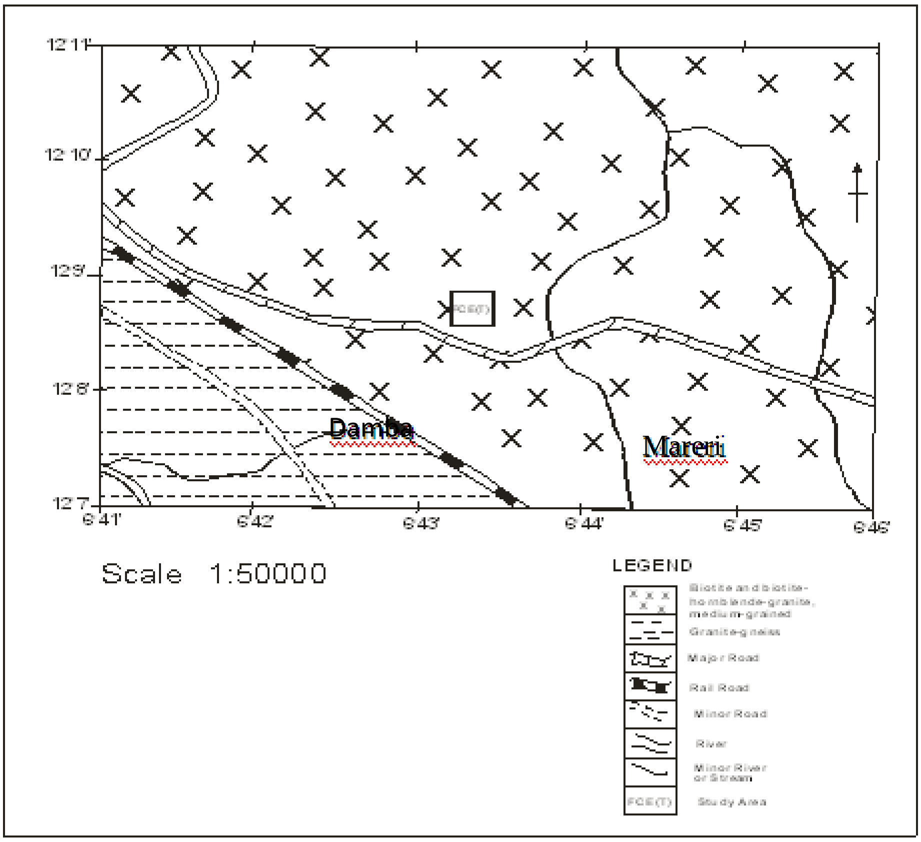

Figure 1. Geological map of part of Gusau showing the study area(Adapted from GSN,1965)

III. Methodology

The equipment used in this study was ABEM SAS 300 Terrameter with its accessories. This was a resistivity meter with a reasonably high sensitivity. The equipment was rugged, portable, user friendly and powerful for deep penetration.

The resistivity survey was completed with 24 sounding stations. The vertical electric sounding was conducted by using the Schlumberger array with a maximum current electrode spacing (AB) of 200m. Measurements were taken at expanding current electrodes distances such that in theory, the injected electrical current should be penetrating at greater depth. The basis of this method is that current is applied by conduction into the ground through electrodes. The subsurface variation in conductivity alters the current flow within the earth and this in turn affects the distribution of electrical potential to a degree which depends on the size, location, shape and conductivity of the material within the ground. Also the electrical conductivity of any geological strata depends on the conductivity of the rock formation, its porosity, degree of saturation, the salinity of water etc; the most important factor being its water content.
Below is the figure showing the figure showing the Schlumberger arrangement.

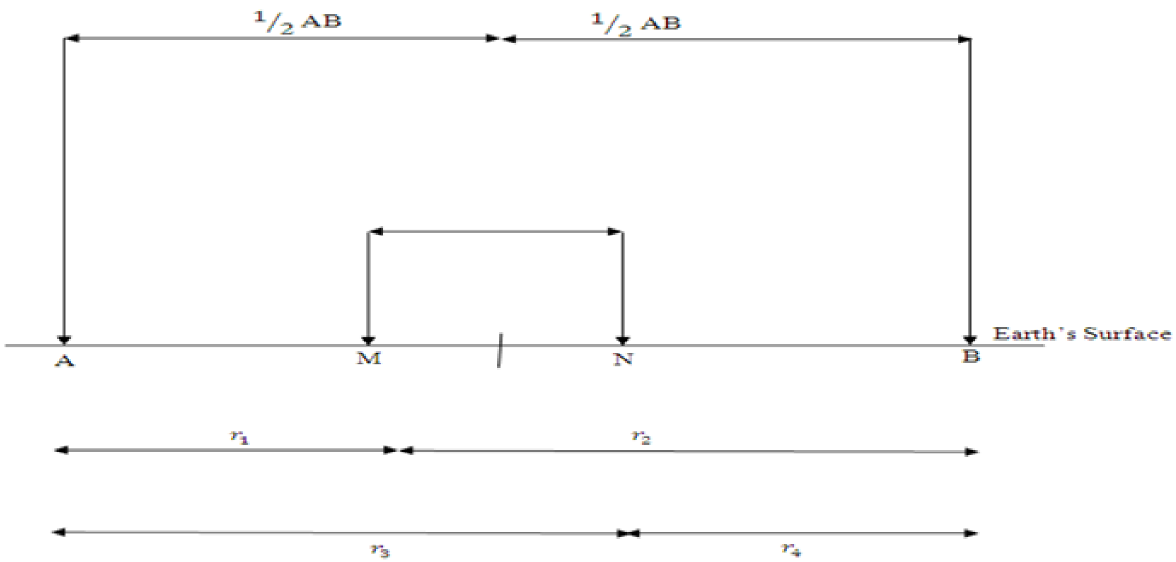

Figure 2 is a schematic illustration of the Schlumberger array

Where A and B are electrodes through which current is driven into the ground while M and N are two potential electrodes (to record the potential distribution in the subsurface). The principle underlying the resistivity method is embodied in Ohm's law.

From Ohm's law, the current I and potential difference V in a metallic conductor at constant temperature are related as follows:

$$V = I R \qquad (1)$$

R is the constant of proportionality termed resistance measured in ohms.

The resistance R of a conductor is related to its length L and cross sectional area A by:

$$R = \frac{\rho L}{A} \qquad (2)$$

whereρ is the resistivity and it is the property of the material considered.

From equations (1) and (2),

$$V = \frac{I\rho L}{A} \qquad (3)$$

For simple treatment, a semi-infinite solid with uniform resistivity,ρ, is considered. A potential gradient is measured between M and N when current I is introduced into the material through A and B on the surface. The surface area is $2\pi L^2$. Thus equation (3) becomes:

$$V = \frac{I\rho}{2\pi L} \qquad (4)$$

By deduction then, the potential at M (V_M), due to the two current electrodes,is

$$V_M = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \qquad (5)$$

Similarly, the potential at electrode N (V_N) is given by:

$$V_N = \frac{I\rho}{2\pi}\left(\frac{1}{r_3} - \frac{1}{r_4}\right) \qquad (6)$$

where r_1 ,r_2, r_3 and r_4 are as shown in Figure 2.

Absolute potential are difficult to measure (Keareyetal., 2002) so the potential difference ΔV between M and N is measured. When the subsurface is inhomogeneous, apparent resistivity ρ_a is considered.

Thus:

$$\Delta V = (V_M - V_N) = \frac{I\rho_a}{2\pi}\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right\} \qquad (7)$$

Then,

$$\rho_a = \frac{2\pi\Delta V}{I\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right\}} \qquad (8)$$

where ρ_a is apparent resistivity in ohm-metre. From equation (8),

$$\rho_a = K\left(\frac{\Delta V}{I}\right) \qquad (9)$$

i.e. $K = 2\pi\left[\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right]^{-1}$

where K is the geometric factor in metres which depends on the electrode array used.

For Schlumberger array, if MN= b and ½ AB = a then,

$$K = \pi\left(\frac{a^2}{b} - \frac{b}{4}\right) \qquad (10)$$

Data Processing And Presentation

To minimize erroneous interpretation due to human error, the WinGlink software was utilized for processing the acquired data. The processed data were presented in the form of 1-D models resistivity curves and 2-D geoelectric sections.

IV. Results And Discussion

1-D Models Resistivity Curves: The apparent resistivity values were plotted against half the current electrode separation (AB/2) in meter on a computer based log-log graph using the winGlink software for a computer iterated interpretation. These iterations were presented as 1-D iteration models. Figures3 show the representative samples of these curves.

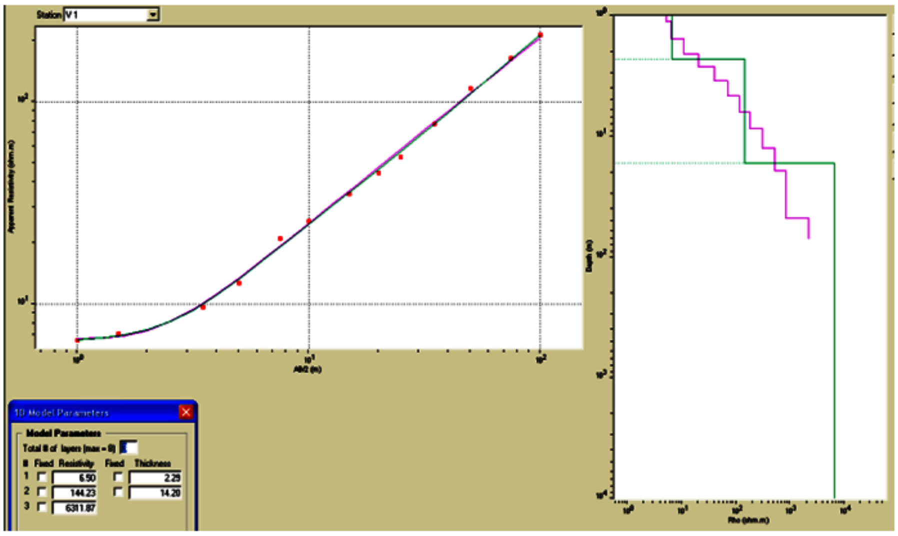

Figure 3a: Sounding Curve for VES 1

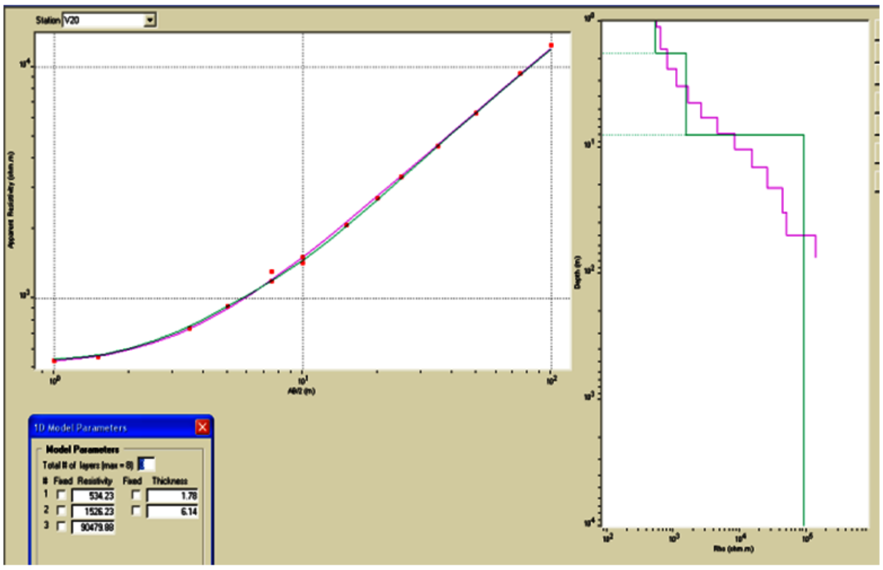

Figure 3b: Sounding Curve for VES 20

Geoelectric And Geologic Sections

At each VES station, 1-D model has been produced using the WinGlink software. The models have been used to produce geoelectric and geologic sections for the various profiles which are discussed below.

Profile AA′

The geoelectric section across A to A′ is made up of data from VES 1,2 and 3. It shows three subsurface layers. The top geoelectric layer has resistivity values ranging from 3 to 6 Ωm with thickness that varies from 0.65 to 2.29 m and is composed of clay.

The second geoelectric layer has resistivity values that vary from 6 to 144 Ωm and thickness values that range from 0.84 to 14.20 m. Beneath VES 1 at this layer is weathered sand which constitute aquifer unit.

The third geoelectric layer has resistivity values that vary from 197 to 6003 Ωm. The lithology of this layer is weathered basement except beneath VES 1 which has encountered fresh basement. There is no thickness value because the current terminates in this zone.

Profile BB′

This is a short profile with only VES 4 and 5. There are three subsurface layers. The first layer is the topsoil, which has resistivity values of 1 to 6 Ωm and thickness of 0.63 to 0.74 m, clay predominates in this layer.

The second geoelectric layer has resistivity values between 5 to 17 Ωm and thickness 0.74 to 7.92 m. This layer composed of clay material.

The third geoelectric layer has resistivity values that vary from 50 to 95 Ωm with no thickness because the current terminates in this zone. This layer contains sandy clay with no potential for groundwater because sandy-clay has poor retention for water.

Profile CC′

The geoelectric section across CC′ consists of VES 3, 6 and 7. It is made up of three subsurface layers. The top soil is an indicative of clay with low resistivity values between 2 and 6 Ωm and thickness values between 0.47 and 0.63 m.

In the second geoelectric section, clay material still dominates except underneath VES 6 which composes of weathered basement. The resistivity values in this layer range from 5 to 129 Ωm with thickness ranging from 0.84 to 2.62m.

Fresh basement is encountered in third layer underneath VES 7 while VES3 and 7 consists of weathered and fractured basements with resistivity values of 197 and 586 Ωm respectively. There is potential for groundwater development in this area.

Profile DD′

The geoelectric section across D to D′ is made up of data from VES 8,9,10 and 14. This section reveals three subsurface layers.

The top layer has resistivity values ranging from 19 to 545 Ωm with thickness 0.8 to 1.64 m.

The fresh basement is encountered right from the second layer underneath VES 8 and 14. Beneath station 9, the fractured basement with resistivity of 733 Ωm forms the aquifer unit with thickness 16.47 m while clayey sand with resistivity 44 Ωm and thickness 6.14m is underneath VES 10.
The third layer is composed of fresh bedrock except underneath VES 10 which contains weathered bedrock with resistivity of 292 Ωm, this constitute an aquifer unit and can be drilled for productive borehole.

Profile EE′

The VES 11,12 and 13 constitute this profile. The geoelectric section reveals two to three subsurface layers.
The lithology of the topsoil contain weathered and fractured basement with resistivity values between 128 to 332 Ωm and thickness values of 0.4 to 3.39 m.
Fresh basement has been encountered in the second layer in this section with the exception of VES 13 which consists of fractured basement with resistivity value of 529 Ωm and thickness 1.33 m. Although, fractured basement constitute aquifer unit, it is not so thick to retain enough water.

The third layer composed of fresh basement with resistivity values between 8580 and 24004 Ωm with no thickness because current terminate in this zone.

Profile FF′

This is the longest profile consisting of VES points 14,15,16,17 and18. The geoelectric section revealed two to three subsurface layers.

The topsoil lithology ranges from clay to fractured bedrock with resistivity values ranging from 1 to 545 Ωm and thickness between 0.45 and 1.33m.
In the second geoelectric layer, fresh basement is being encountered beneath VES 14 and 18. Fractured bedrock with resistivity value 485 Ωm is encountered beneath VES 16 with no thickness because the current terminates in the zone. Beneath VES 15 is the weathered basement having resistivity value of 160 Ωm and thickness 0.37 m while clay predominates underneath VES 17 with resistivity value of 20 Ωm and thickness 7.71 m.

The third layer has resistivity which ranges from 150 to 99993.1 Ωm.

Profile GG′

The geoelectric section across G to G′ consists of data from VES 18, 19, 20 and 21. Three subsurface layers are revealed across this profile.

The first layer reveal weathered and fractured basement with resistivity values ranging from 226 to 510 Ωm and thickness between 0.47 and 3.5 m.
In the second layer high values of resistivity is an indication of fresh basement especially beneath VES 18, 19 and 20. Beneath station 21, the fractured bedrock with resistivity of 670 Ωm forms the aquifer unit with thickness 15.88 m and constitutes a favourable location for groundwater development.

The third layer is fresh basement having resistivity values between 1900 and 99999 Ωm.

Profile HH′

The geoelectric section across H to H′ is made up of data from VES 22, 23 and 24. It reveals three subsurface layers. The topsoil lithology ranges from clay to sandy clay with resistivity values ranging from 2 to 96 Ωm and thickness values 0.44 to 0.66 m.

Beneath VES 23 in the second layer, low resistivity value of 9 Ωm is an indication of clay. It has thickness of 6.37 m. The layer is composed of weathered / fractured basement beneath VES 22 and 24 with resistivity value in the range of 225 to 660 Ωm and thickness ranging between 2.58 and 14.99 m. These constitute good aquifer for groundwater exploitation along this traverse.
The lithology of the third layer ranges from sandy clay to fresh basement with resistivity variation from 80 to 23030 Ωm.

Maps Produced From The Interpreted Data

Contour maps were produced from the interpreted layer parameters for all VES stations established. This was done in order to study specific aspects such as the degree of weathering and fracturing of the subsurface rocks, as well as other structures within the study area. These maps include: isoresistivity maps at various pre-selected depths, topsoil map, overburden thickness map and aquifer thickness map of the study area.

Isoresistivity Maps

The maps were produced by contouring the interpreted resistivity values for any particular depth taken. The isoresistivity maps were at the following depths (1m, 5m, 10m,) were drawn with the aid of the WinGlink software. The isoresistivity at 1m depth (Figure 4.1) was meant to see if there is possibility of water saturation at this depth. The regions around VES (1, 2, 3, 4, 5, 7, 17) are saturated at this depth (based on the low resistivity values) while regions around VES (16, 17, 18, 19) have high resistivity values. However, the highly resistive areas may indicate high content of sand and silt mixed together with topsoil at this depth.

The isoresistivity map at 5m depth (figure 4.2) shows high resistive values at many stations which is an indication of outcrop from of fresh basement. This situation extends while the areas like VES (10 and 23) still have low resistivity values. This indicates that the topsoil has been passed, and weathered basement that are water- bearing (aquifer) have been approached in some areas. These conditions persist down to 25m depth as shown in isoresistivity map at 10 m when other areas of high resistivity values are becoming prominent.

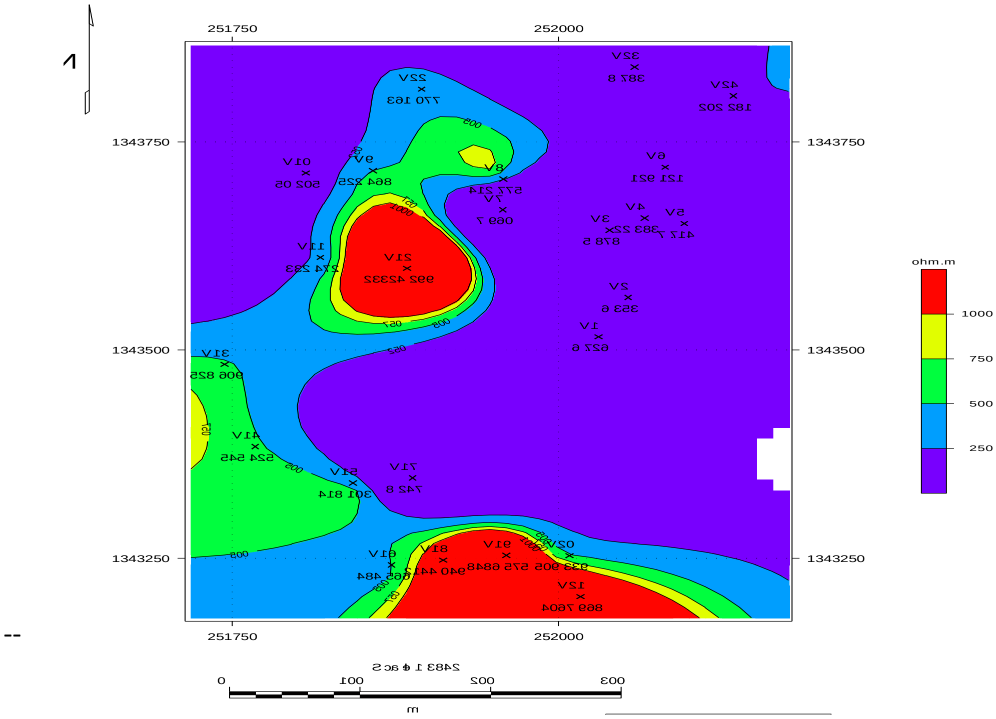

Figure 4.1: Isoresistivity map at 1m depth

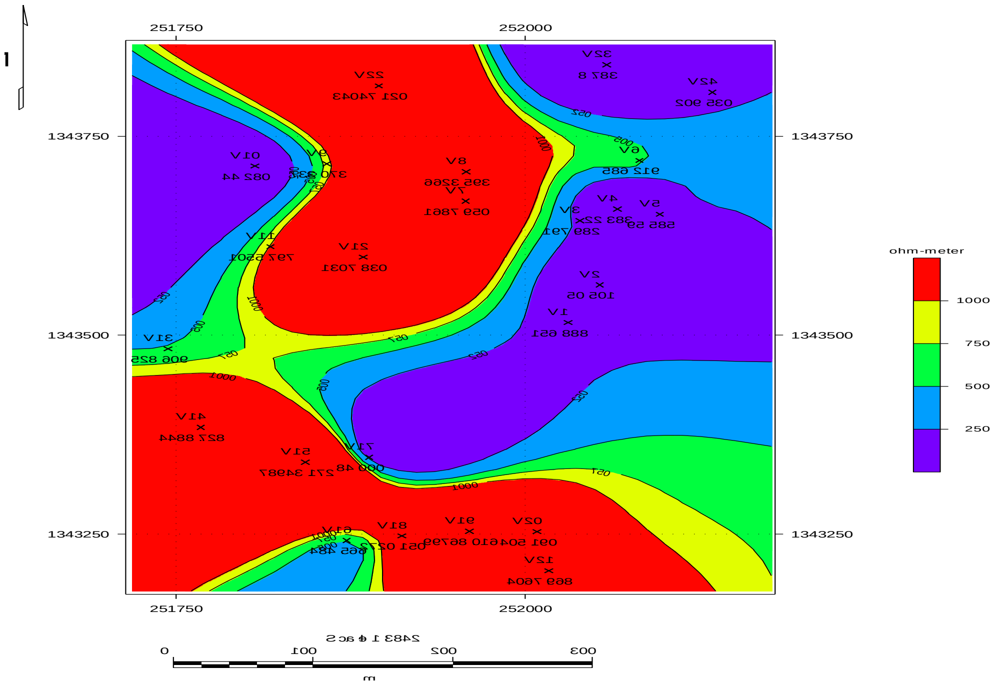

Figure 4.2: Isoresistivity map at 5m depth

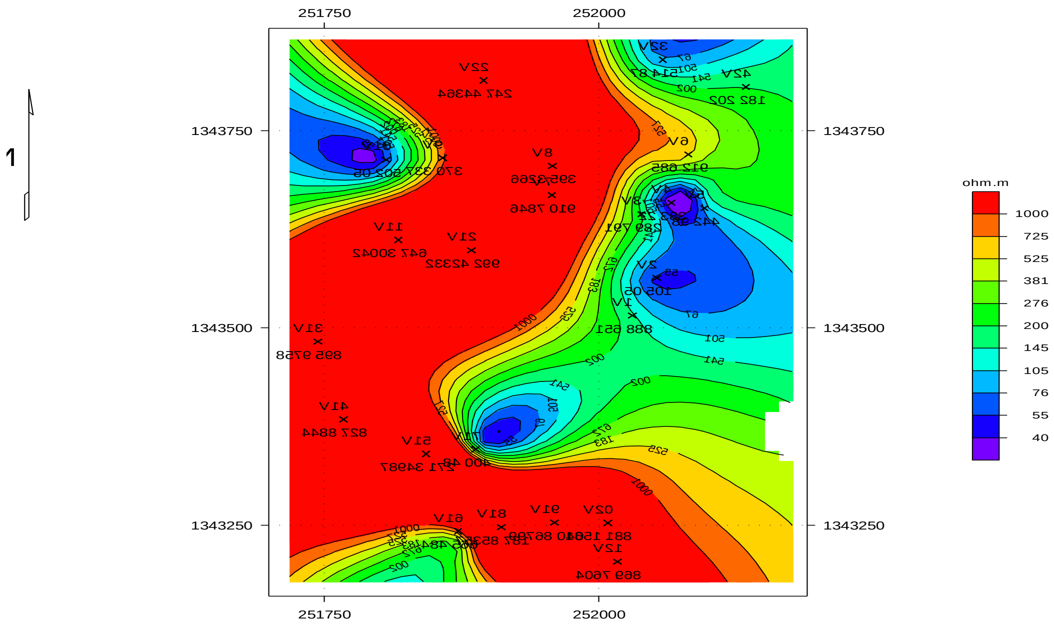

Figure 4.3: Isoresistivity map at 10m depth

Topsoil Thickness Map

The topsoil thickness map of the study area (Figure 5) shows that the topsoil thickness ranges from 0.4 to 4 m. This implies that the first geoelectric layer in the area is not so thick. The analysis of the interpreted results implies that the topsoil is majorly clay though there are some areas in which weathering has reached an advance stage.

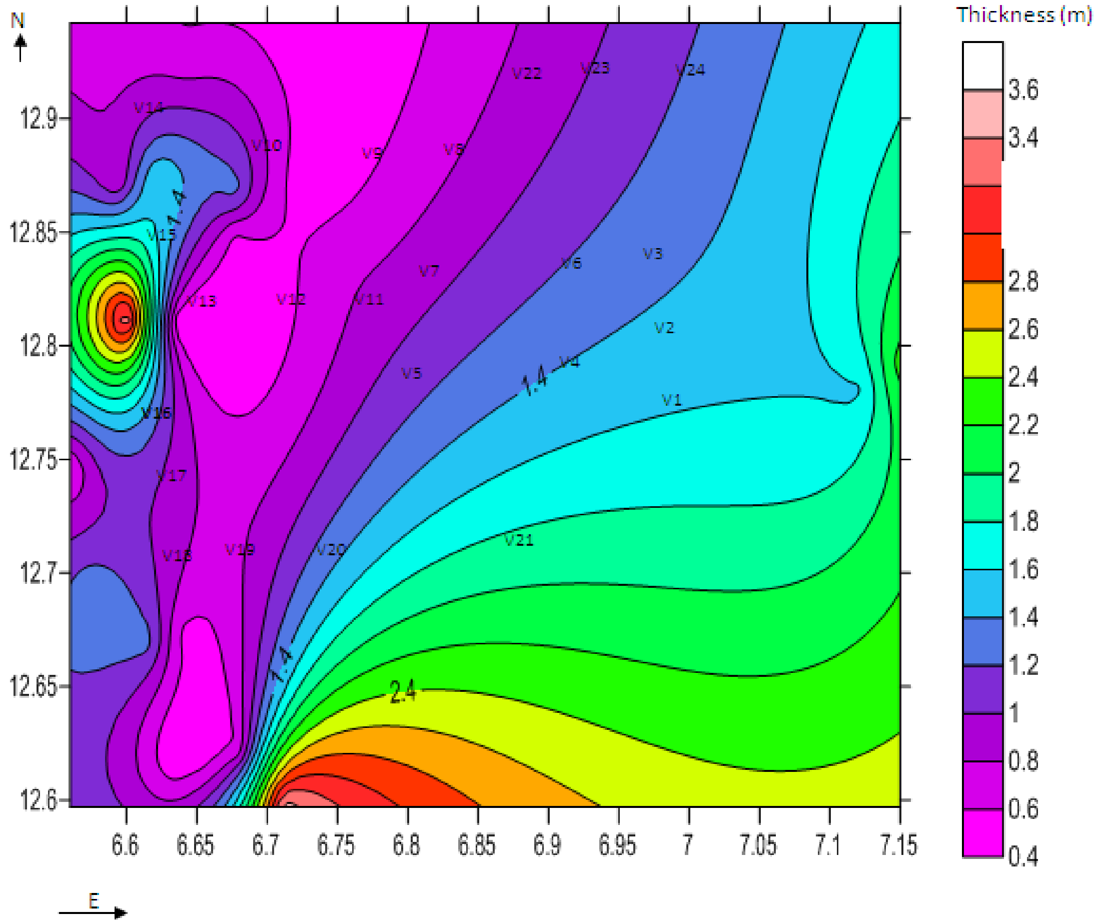

Figure 5: Topsoil Thickness map contoured at 0.2m interval.

Overburden Thickness/ Depth to Basement

All the surface layers above the fresh basement are considered to constitute the overburden (regolith). This includes the topsoil, clayey sand/sandy clay layer, the weathered / fractured basement. The depth to fresh basement in each VES station were calculated and contoured as shown in figure 6. The overburden thickness map range from 0.4 to 18m.

As depicted by the map, there are thick overburden cover around VES 1, 9, 20, 21, 23 and 24 while thin overburden cover around VES 11, 12, 13, 18 and 19. The areas with thick overburden correspond to basement depressions, while those with thin overburden correspond to basement high. Olorunfemi and Okhume, (1992) have established that the areas with thick overburden and not much of clay, which is highly impermeable, has high groundwater potential in a basement complex area.

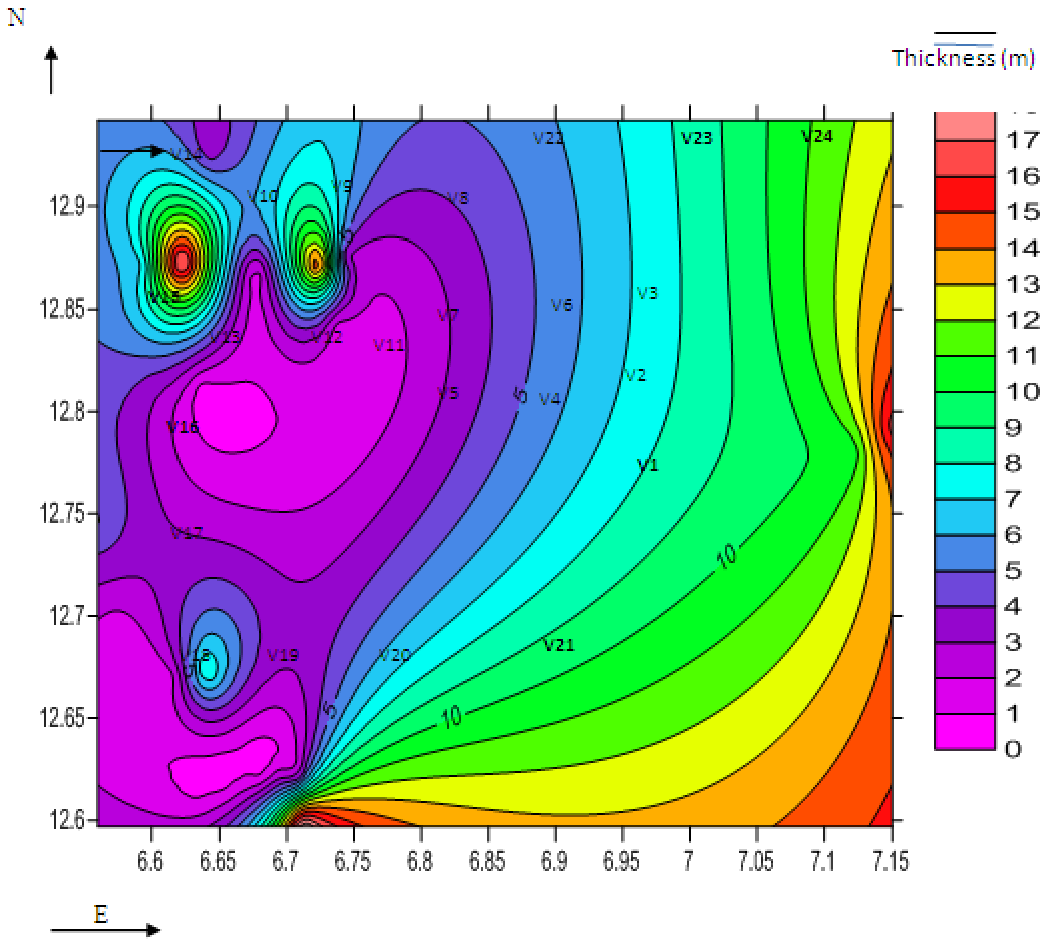

Figure 6: Overburden Thickness map at 1m contour interval.

4.6.4 Aquifer Thickness map

Identifying the aquifer types in the surveyed area is a major part of this research work. Weathered and fractured basements have been identified as the aquifer units which characterize the study area.

The map has been produced using the thickness of finely weathered / fractured basement obtained at each VES station. The aquifer is shallowest around VES 12.

The map (Figure 7) shows that the thickness of aquifer varies from 1.00 to 19.32m. As expected, a comparison of aquifer thickness and overburden thickness maps show that the low thickness values correlate well with the areas of shallow basement while larger thickness values correlate with basement depressions. Such large aquifer thicknesses are more likely to retain a good quality of groundwater, and as such are of prime importance to groundwater exploration.

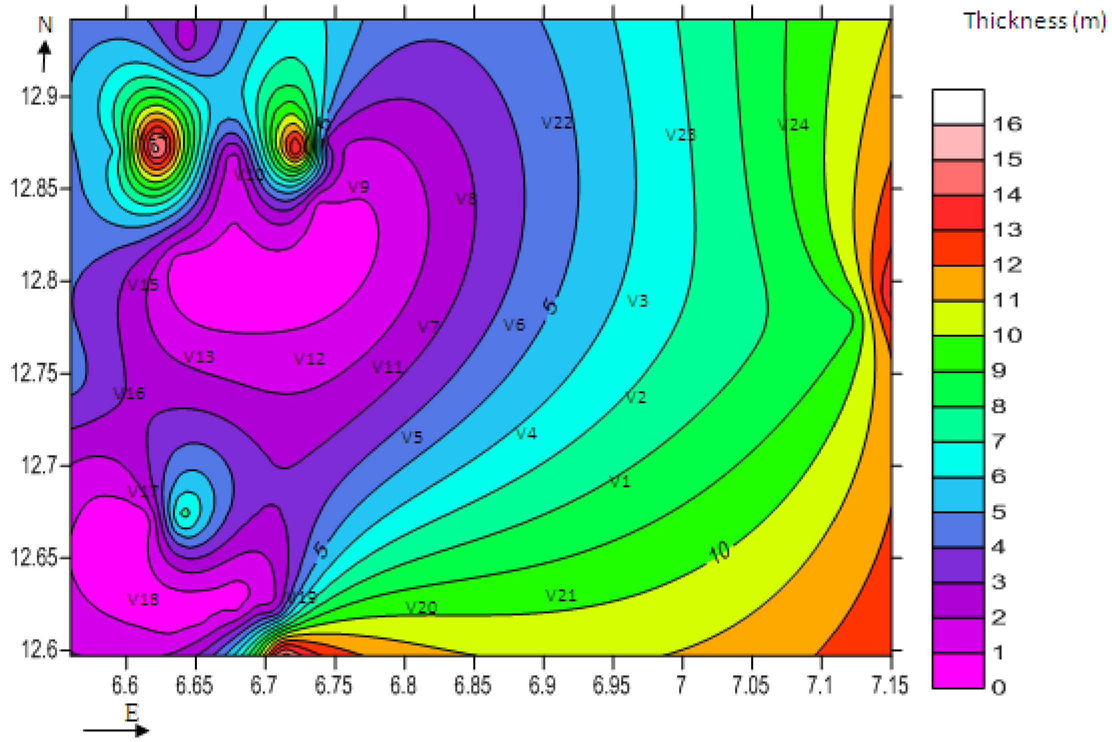

Figure 7 Aquifer Thickness map contoured at 1m interval.

V. Conclusion

The foregoing presentation and discussion have shown that it is possible to make inferences on the subsurface stratification as well as identify possible aquifer of Federal College of Education (Technical), Gusau. The study revealed two to three geoelectric layers. The geoelectric sections have clearly shown the vertical distribution of resistivity values within a particular volume of the earth. Based on the results of the interpreted resistivity measurements and the 2D geoelectric sections, the areas under these Vertical Electric Sounding (VES) stations 1, 3, 6, 10, 16, 17, 21 and 24 constitute good aquifers for groundwater exploitation in the area. Although eight VES points listed above may be promising for groundwater development, the 2-D sections indicated that fresh basement is encountered when drilled to depth between 16 – 18 m at VES 1, 9, 21 and 24. Hence productive borehole can be located at VES 3, 10, 16 and 17 by drilling between 25 to 30 m down.

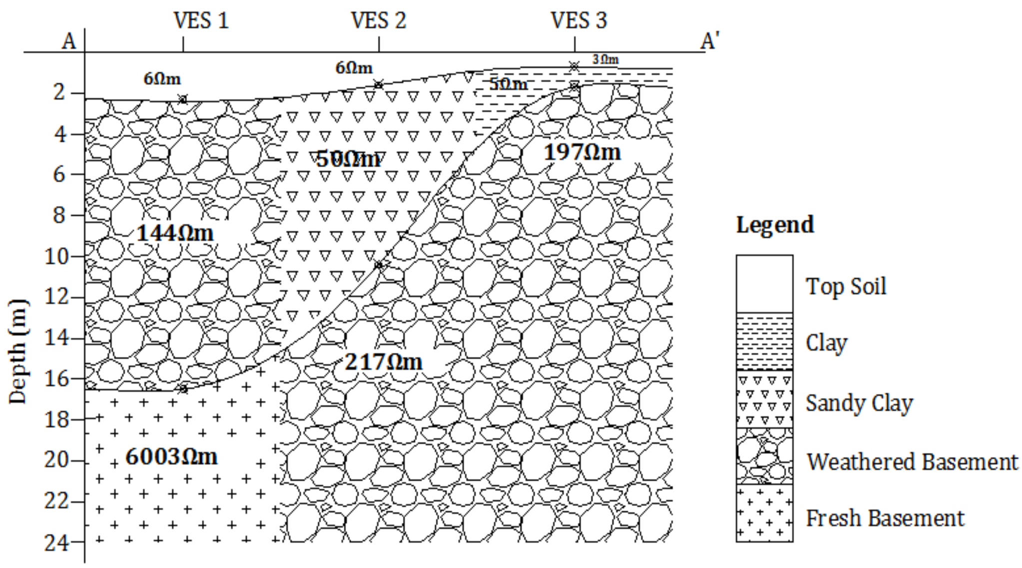

Figure 4 a: Geoelectric and geologic sections beneath VES 1- 3.

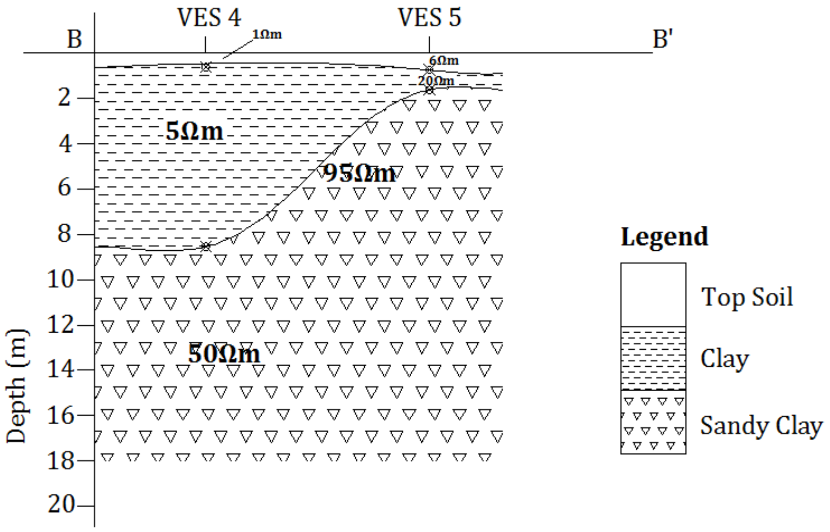

Figure 4 b: Geoelectric and geologic sections beneath VES 4 and 5.

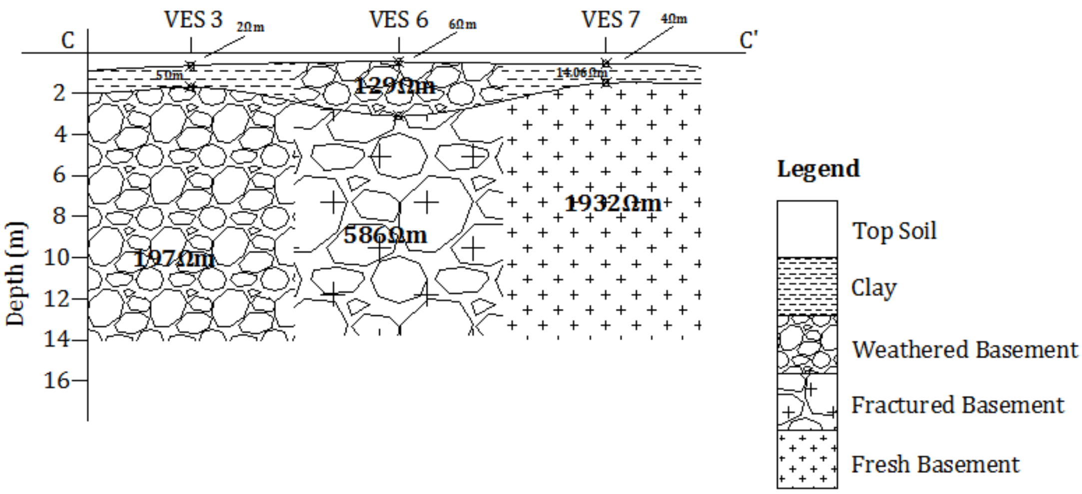

Figure 4 c: Geoelectric and geologic sections beneath VES 3, 6 and 7.

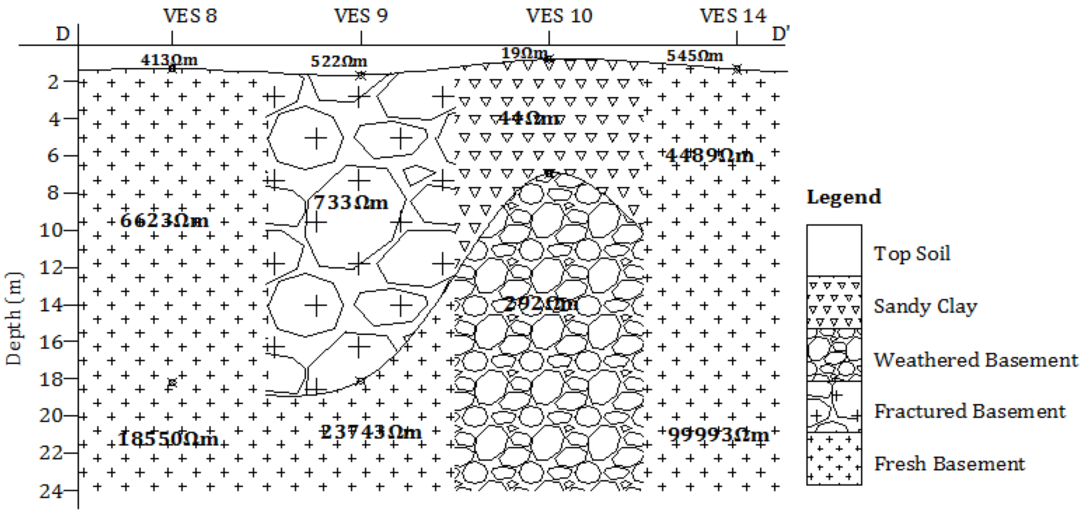

Figure 4 d: Geoelectric and geologic sections beneath VES 8, 9, 10 and 14.

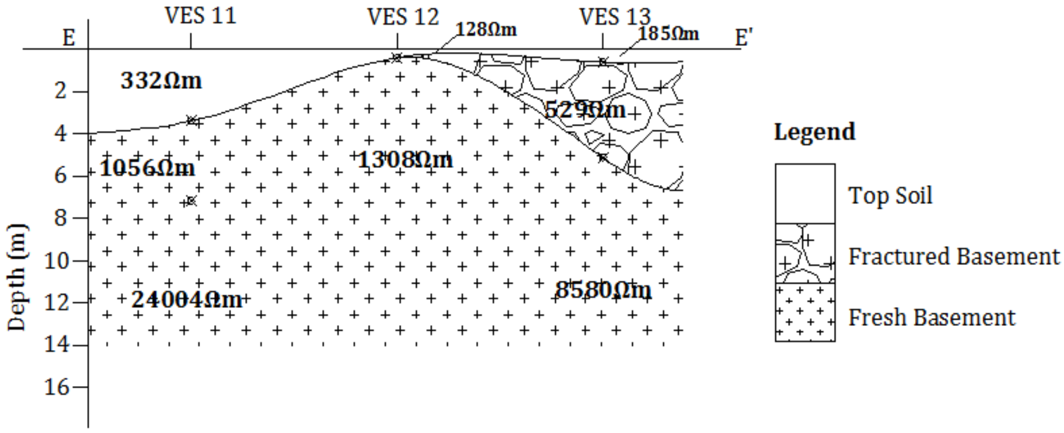

Figure 4 e: Geoelectric and geologic sections beneath VES 11 - 13.

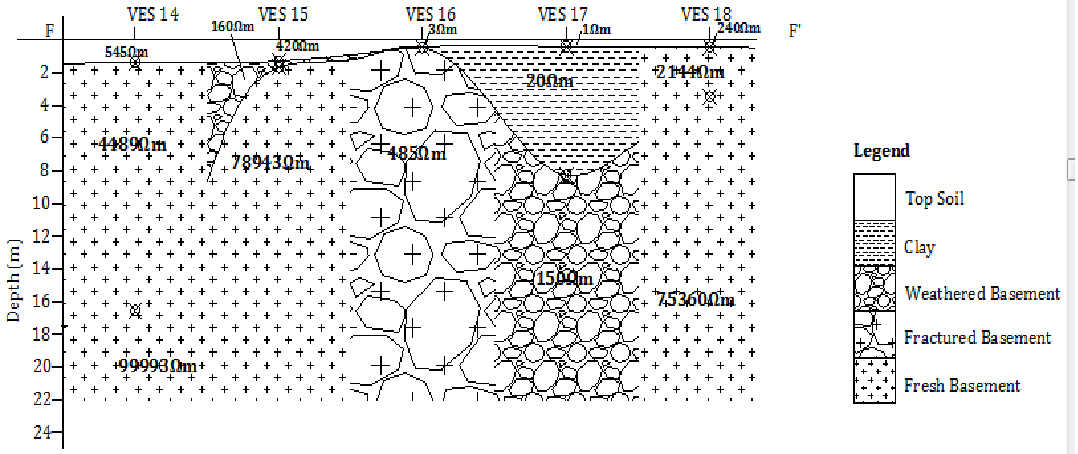

Figure 4 f: Geoelectric and geologic sections beneath VES 14 -18.

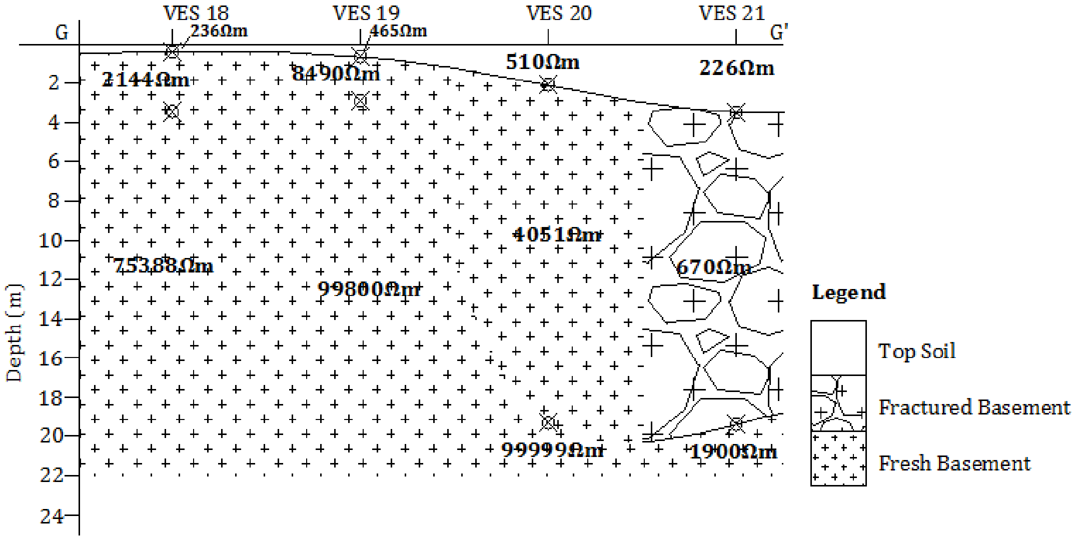

Figure 4 g: Geoelectric and geologic sections beneath VES 18-21.

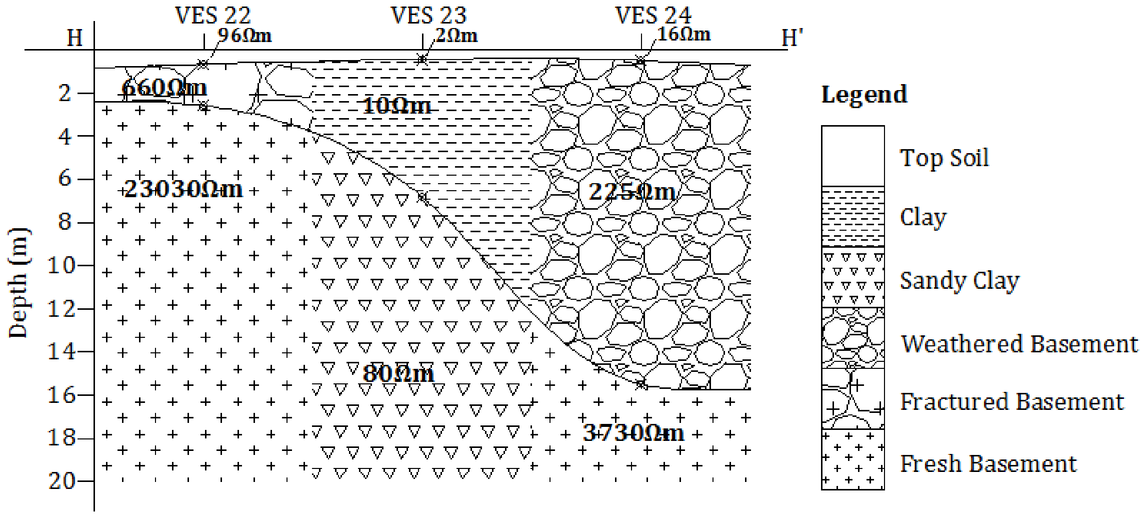

Figure 4 h: Geoelectric and geologic sections beneath VES 22- 23.

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