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Geoelectrical Investigation of the Groundwater Potential in Mowe, Ogun State, Nigeria

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Research Article

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ABSTRACT

Electrical resistivity survey was carried out to delineate subsurface layers and to determine the ground water potential in the study area. The study was carried out using the ABEM SAS 1000 terrameter which worked on 16 vertical electrical sounding (VES) points within the area. A maximum distance of 550m current electrode spread was adopted for this survey. The result showed the presence of four geoelectric layers with the resistivity of the first layer ranging from 25.54Ωm to 619.45Ωm and thickness of 0.14-9.21m representing topsoil. The second geoelectric layer has resistivity ranging from 20.94Ωm to 706.82Ωm and thickness of 2.58 to 35.36m representing laterite. The third geoelectric layer has resistivity ranging from 12.29Ωm to 598.93Ωm and thickness of 3.33 to 58.06m representing sandy clay. The fourth geoelectric layer has resistivity ranging from 12.1Ωm to 1980.52Ωm and thickness of 11.4 to 45m representing sand. The depth to the aquifers are 13.11m, 55.31m, 6.35m, 50.28m, 51.08m and 28.01m in VES 1, 2, 6, 9, 11 and 16 respectively.

Keywords: Electrical resistivity; survey; geophysical investigation; aquifers; delineates; subsurface layers.

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1. INTRODUCTION

Water, a major source of life is required by all and sundry either in small or large quantity. The quality of water required for domestic and industrial use also needs to be taken into consideration. Underground Water Exploration using Electrical Resistivity Method in a sedimentary environment was done in Edo State (Alile et al., 2008). Electrical method uses direct current or low frequency alternating current for subsurface investigation (Brooke and Kearey, 1984). Probing involves the adoption of the current and the potential electrode spread is used to delineate the apparent resistivities and it follows that the deeper the probing, the farther away from the current source is the measurement of the potential difference regardless of the electrode array utilized (Zohdy et al., 1980).

In homogeneous layer the depth of current penetration increases with increasing separation of current electrodes. In view of this, the vertical electrical sounding is expected to be carried out in order to study the horizontal and near horizontal interfaces. In effect, this helps to determine the horizontal zones of porous strata.

The area being a developing residential area with good surface sandy soil and considerable distance to the main road needs all the amenities and infrastructure required to make habitation conducive. Unfortunately water supply by the water corporation might not be readily available; it can also sometimes be inaccessible since settlers have to walk long distances to get good potable water. Since the area is developing and human habitation is springing up, the study therefore, seeks to provide good potable water for human and industrial use, hence knowing the best possible location for sinking borehole in order to access the quantity and quality of ground water supply becomes very necessary.

Another inherent issue that prompted this study is to determine the subsurface lithology which will help us delineate the depth to which boreholes can be sunk to obtain potable water and thus determining the depth to each layer.

In Umuahia region, Nigeria, aquifer characterization was carried out using electrical resistivity method (Mbonu et al., 1991). The basement structures of the south central Bida Basin was delineated using electrical resistivity method (Idornigie and Olorunfemi, 1992). Ojelabi and Onuoha, 2002 reported the use of electrical resistivity as a vital tool in environmental geophysical studies and site investigation.

Many electrode configurations have been designed to carry out the method effectively (Habberjam, 1979). In sedimentary rocks the resistivity of interstitial fluid is probably more important than that of the host and this was why Archie developed an empirical formula to determine the effective resistivity of rock formation. Since Archie’s law is most applicable in borehole logging, Korvin (1982), proposed a theoretical basis of account for Archie’s law and hence suggested that saline water may have a very low resistivity (0.05Ωm) and some ground water and glacial melt water can have resistivities in excess of (1000Ωm). The core of the earth was also analyzed using electrical resistivity method (Archie, 1947).

Some rocks have gradational facies and this affects the resistivity to the extent that they reflect varying proportions of the constituent materials. This account for the resistivity of sandy material in northern Nigeria was about 100Ωm. This value decreases with increasing clay content to about 40Ωm. At this value, clay becomes the dominant constituents and the value decreases further to a range between 1 to 10Ωm (Reynolds, 1997).

In view of these facts the study area was chosen, being a residentially developing area, hence settlers here will require water for their day to day activities. Thus our study seeks to prospect for high yield ground water which is equally potable for consumption. The electrical resistivity method used in this study is aimed at studying the horizontal and vertical discontinuities in the electrical properties of the ground. This will also help us to investigate the shallow subsurface geology of the area (Tearpock and Bischke, 1991).

2. THEORETICAL BACKGROUND

Electric current generated through artificial means are introduced into the ground in order to obtain potential differences which is then be measured at the surface. The deviation from the pattern of potential difference expected from homogeneous ground gives information on the form and electrical properties of subsurface inhomogeneities (Philip and Micheal, 2002). Considering elements of homogeneous material, a current I is passed through the earth and a potential drop –δV can occur between the ends of the element. From Ohm's law ρδR = δL/δA.

Since, V=IR (ohm's law)

It follows that,

$$\frac{\delta V}{\delta L} = -\frac{\rho I}{\delta A} \tag{1}$$

Where V= potential difference, L= current electrode separation, A= cross sectional area, I= current and ρ= resistivity.

The current density in any direction within a material is generally given by the negative partial derivative of the potential in that direction divided by the resistivity.

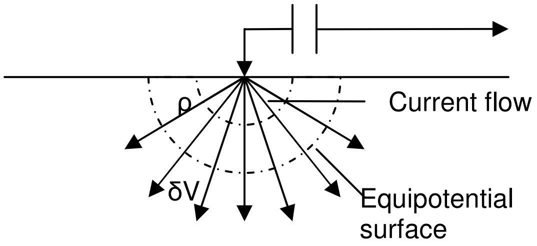

Figure1. Current flow using a single surface electrode

From the above it is observed that current flows radially away from the electrode, so that it gets distributed uniformly over hemispherical shells centred on the source (Telford et al., 1990). Hence, current density can be derived with respect to surface area:

$$i = \frac{I}{2\pi r^2} \tag{2}$$

From equation 2 the potential gradient associated with current density is given as:

$$\frac{\delta V}{\delta r} = -\rho i = -\frac{\rho I}{2\pi r^2} \tag{3}$$

Then the potential with respect to distance r is given as:

$$V_r = \int \delta V = -\int \frac{\rho I \delta r}{2\pi r^2} = \frac{\rho I}{2\pi r} \tag{4}$$

Equation (4) can be said to allow any calculation of potential at any point on or below the surface of homogeneous half space. The hemispherical shell in Figure 1 mark surfaces of constant voltage hence called equipotential surfaces. Furthermore, we can consider a case where the sink is at a finite distance from source (Figure 2).

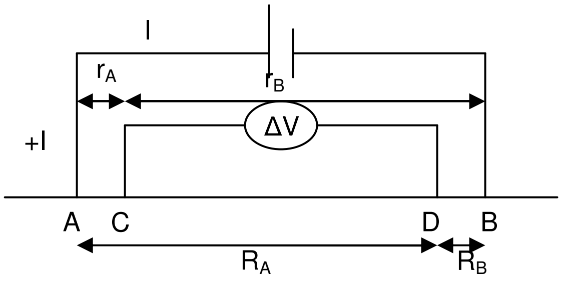

Figure 2. Electrode configuration, used in resistivity measurements

From Figure 2 the potential V_C at an electrode C is the sum of the potential contributions V_A and V_B from current source at A and the sink at B.

$$V_c = V_A - V_B$$

From equation (4)

$$V_c = \frac{\rho I}{2\pi}\left(\frac{1}{r_A} - \frac{1}{r_B}\right) \tag{5}$$

Similarly

$$V_D = \frac{\rho I}{2\pi}\left(\frac{1}{r_A} - \frac{1}{r_B}\right) \tag{6}$$

But absolute potentials can be difficult to monitor hence the potential difference ΔV between electrode C and D is given as

$$\Delta V = V_c - V_D = \frac{\rho I}{2\pi}\left\{\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right\}$$

then

$$\rho = \frac{2\pi \Delta V}{I\left\{\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right\}} \tag{7}$$

Equation (7) is viable when the ground is uniform, giving a constant resistivity which is independent of both electrode spacing and surface location. In the case of subsurface inhomogeneities the resistivity obtained is the apparent resistivity ρ_a which is a function of the inhomogeneity.

In effect therefore, depth of current penetration increases with increase in current electrode separation in homogeneous layers (Telford et al., 1990).

The current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a central fixed point. Therefore in hydrogeology it helps to define horizontal zones of porous strata (Osemeikhian and Asokhia, 1994), the Schlumberger configuration can be represented by:

$$\rho_a = \frac{\pi \Delta V L^2}{2l} \tag{8}$$

3. LOCATION

The study area is located in the heart of Mowe/Ofada, Ogun State off Lagos-Ibadan expressway and is 2.3km southeast of Mowe town in Obafemi-owode local government area of Ogun State. It is bounded in the south by Lagos State and the Atlantic Ocean, in the north by Oyo State, in the west by Benin Republic and in the east by Ondo State. The area lies on a latitude of 6° 51'N and a longitude of 3°27'E, westward to the Lagos-Ibadan expressway.

4. GEOLOGY OF THE STUDY AREA

Generally, the soil type associated with the study area is sandy in nature combining with small amount of clay which results from intense weathering causing leaching, this happens throughout the area. This is associated with the tropical climatic condition with 2 major seasons being the dry and rainy season. The average rainfall is between 40mm to 60mm, peaking between May and August within the year. It can also be allotted an average temperature between 25°to 27℃ (Odemerho and Onokerheraye, 1994). The area is located within the equatorial rain forest of the world and it can be allotted guinea savanna vegetation due to its tall grasses, shrubs and scattered trees which are well grown in the area.

In the sandy Abeokuta formation, which happens to be the oldest formation in the study area underlain by the basement complex harbours an aquifer zone, which can be termed unattractive since it cannot be considered as good prospect for ground water exploration because of the impending low yield capacity. However, the Abeokuta formation is overlain by the Ewekoro formation that also bears similar aquifer characteristics and this is further overlain by the Akinbo formation, which has been found to be a good source of ground water exploration. The structural features that occur within the basement rocks are due to tectonic activities and they include joints, faults and fractures. It is the fractures that influence the ground water in crystalline rocks, hence, the water bearing zones consist of weathered materials. Deeply weathered zones occur usually in pockets as they rarely exceed 40m in depth.

5. METHODOLOGY

Three traverses were worked on and vertical electrical sounding (VES) was carried out over sixteen (16) different points. The instruments used are cables, steel electrodes, hammers, ABEM SAS 1000 Terrameter, D.C battery, GPS, measuring tapes, umbrella, and rain boots. The instruments were connected and the measurement carried out appropriately.

Data set were obtained with the use of the ABEM SAS 1000 terrameter and the values of the apparent resistivity and the current electrode spacing (AB/2) were obtained, partial curve matching was carried out using the standard and the auxiliary curves to give insight to what is to be expected from the computer iterated interpretation. The computer iteration was carried out on the data obtained, using the RESIST software. This software then simulates the values of the apparent resistivity and that of the current electrode spacing to obtain a one dimensional (1D) layered model. Consequently, different parameters were estimated, parts of which are the resistivities, the thicknesses of each layer and the number of layers.

6. RESULTS AND DISCUSSION

From the 1D-layered model generated, the resistivities associated with each layer were derived together with corresponding thicknesses. There are sixteen different resistivity curves obtained from the computer iteration. Three different geoelectric sections were obtained based on the 3 different traverses worked on using the values from the 1D-layered model. Different geoelectric layers were delineated as well as possible corresponding lithologies. These were substantiated by the well drilling information within the vicinity of the study area provided by Hydro Construction Ltd. (1993).

Table 1. Qualitative results of resistivity data

VES Stations	Curve type	Resistivity Combination
1	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$
2	KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$
3	KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$
4	KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$
5	H	$\rho_1 > \rho_2 < \rho_3$
6	H	$\rho_1 > \rho_2 < \rho_3$
7	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$
8	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$
9	H	$\rho_1 > \rho_2 < \rho_3$
10	H	$\rho_1 > \rho_2 < \rho_3$
11	H	$\rho_1 > \rho_2 < \rho_3$
12	QHA	$\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$
13	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$
14	QH	$\rho_1 > \rho_2 > \rho_3 < \rho_4$
15	H	$\rho_1 > \rho_2 < \rho_3$
16	KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$

Relatively, the curve types obtained from the computer iteration are AKQ type. Therefore qualitatively, VES 2, 3, 4 and 16 are the KH type curves ($\rho_1 < \rho_2 > \rho_3 < \rho_4$), while VES 1, 7, 8, 13 and 14 are the QH type curves ($\rho_1 > \rho_2 > \rho_3 < \rho_4$) but VES 5, 6, 9, 10, 11, 15 are the H type curves ($\rho_1 > \rho_2 < \rho_3$). VES 12 indicates a QHA type curve ($\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$) as indicated in Table 1. Hence the QHA type curves consist of 5 layers, the H type curves has 3 layers and the QH type curves has 4 layers.

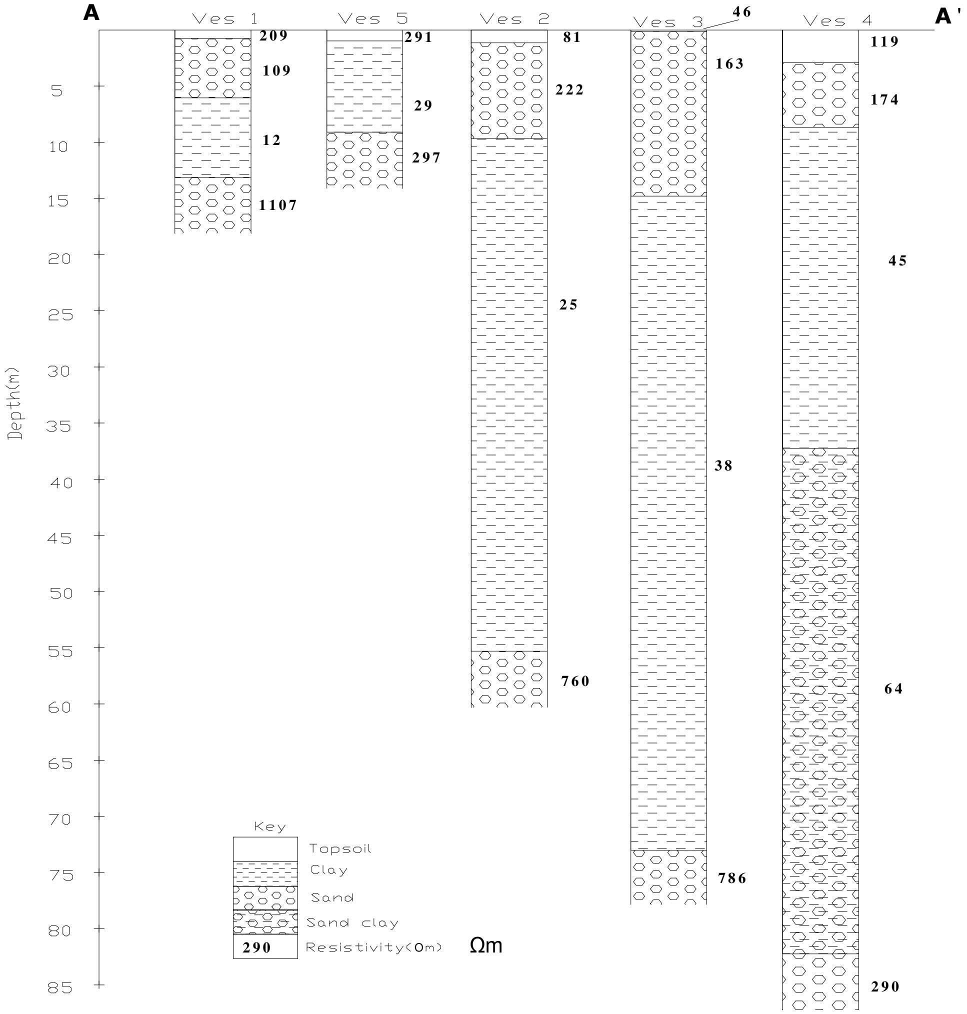

Figure 5a: Geoelectric section along traverse AA'

From the computer iteration five different layers were delineated. This section encompasses VES 1, 2, 3, 4, 5 on traverses AA' with the highest number of layers attributed to VES 4 which has 5 different geoelectric layers, although only 4 different lithologies were delineated and this include, topsoil, laterite, clay and sand. In effect therefore, the resistivity of this VES station ranges from 45.92Ωm to 290.19 Ωm such that the highest resistivity is identified as possible sand. For layer 1 in this section we have a thickness ranging from 0.14m to 2.92m and corresponding resistivities ranging from 46.35Ωm to 291.31Ωm. In the same vein, layer 2 has thicknesses ranging from 5.29m to 14.67m and corresponding resistivities ranging from 29.44Ωm to 222.21Ωm. For layer 3 the thickness ranges from 7.07m to 58.06m, while the corresponding resistivities range from 12.29Ωm to 496.58Ωm. For layer 4 therefore, the thickness is about 45m and the corresponding resistivities from 64.42Ωm to 1107.18Ωm. Layer 5 has a resistivity of about 290.19Ωm.

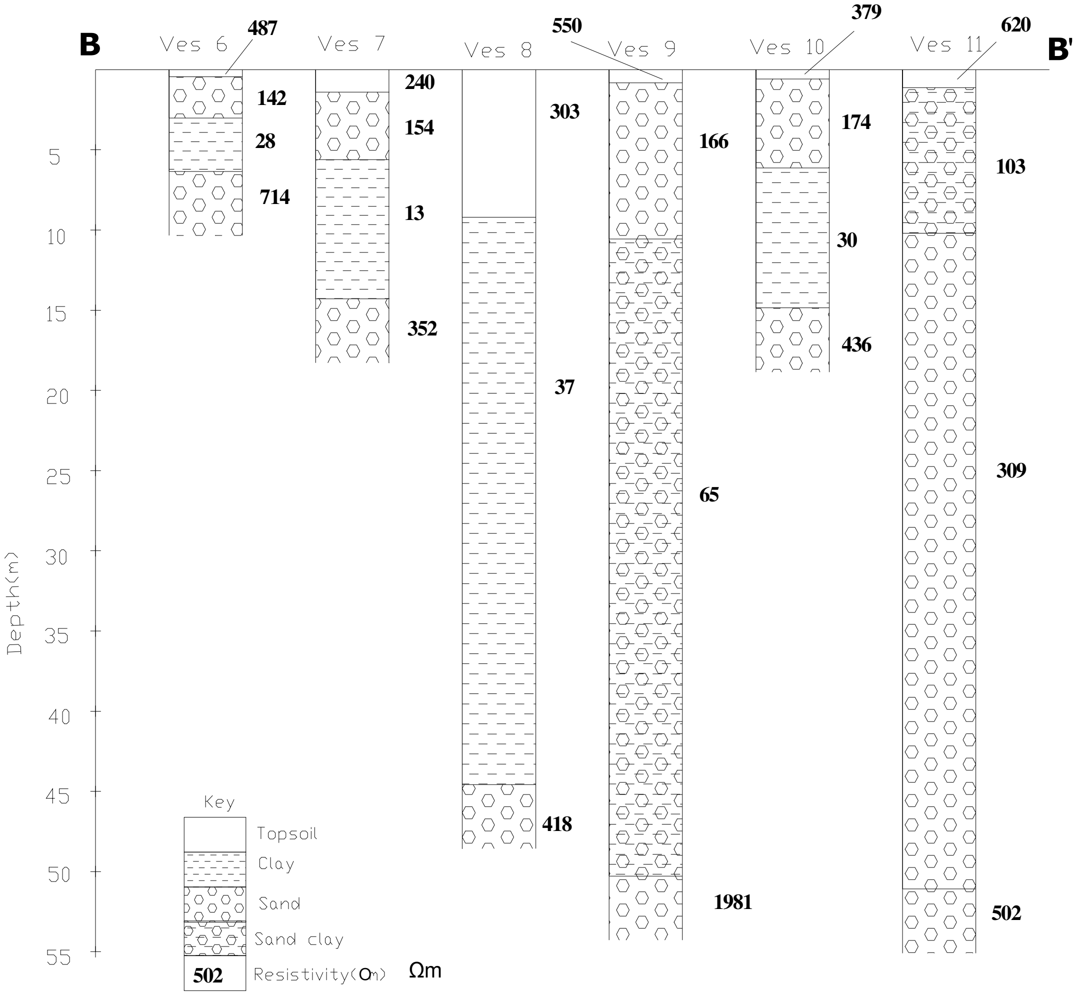

Figure 5b: Geoelectric section along traverse BB

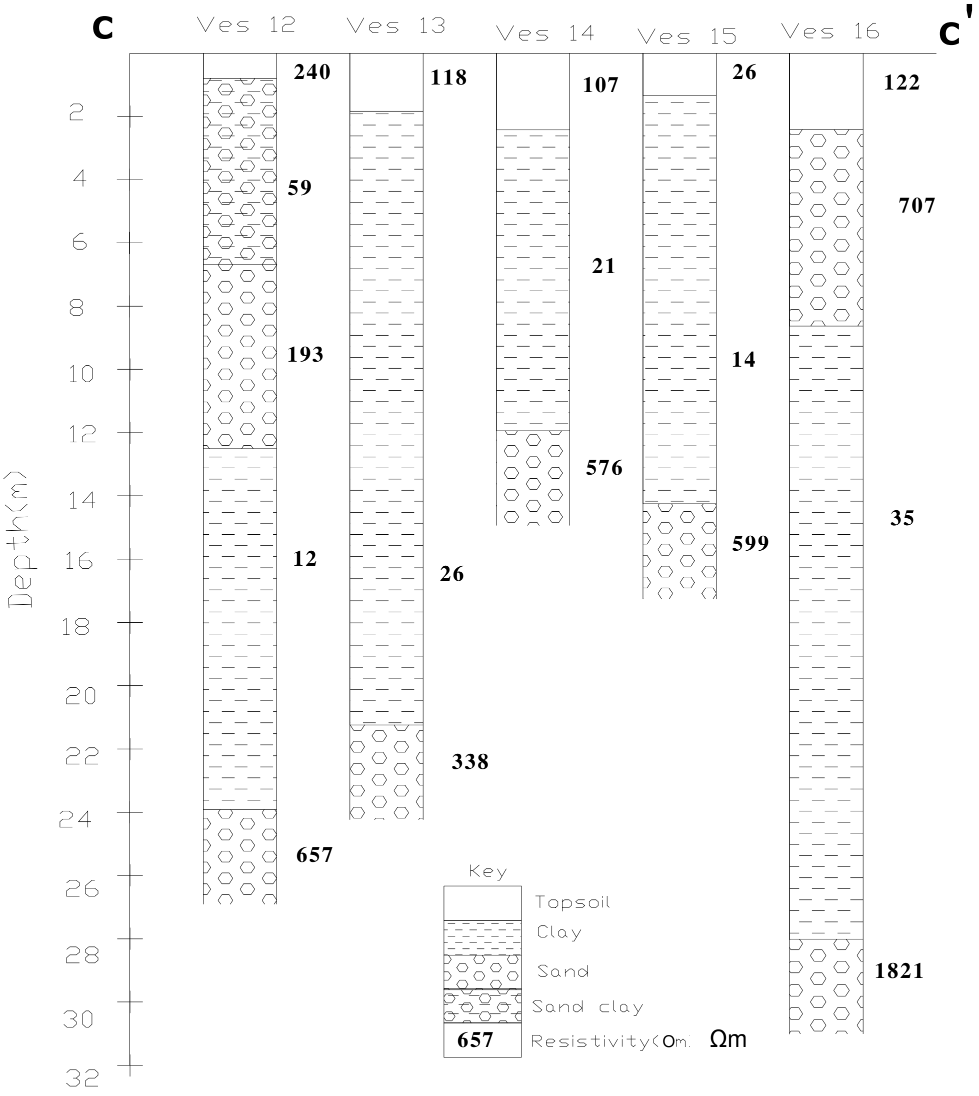

Figure 5c. Geoelectric section along traverse CC'

Six (6) different VES stations make up this geoelectric section which includes: VES 6, 7, 8, 9, 10, 11 (Figure 5b). The maximum number of geoelectric layers delineated at each VES station within this section is 4 layers and the lithologies delineated are sand, clayey sand, lateritic clay, topsoil in that direction.

Layer 1 has thicknesses ranging from 0.44m to 9.21m with corresponding resistivities between 239Ωm to 619.45Ωm. Layer 2 has thicknesses ranging from 2.58m to 35.36m and corresponding resistivities from 37.13Ωm to 174.39Ωm. Layer 3 therefore has thicknesses ranging from 3.33m to 40.89m and corresponding resistivities from 13.24Ωm to 417.49Ωm. Layer 4 has resistivities ranging from 351.71Ωm to 1980.52Ωm.

Five different VES stations make up this geoelectric section which includes: VES 12, 13, 14, 15 and 16 (Figure 5c). The maximum number of geoelectric layers delineated at each VES station within this section is 5 layers and the lithologies delineated are sand, clay, laterite and topsoil in younging direction. Except for the lithology in VES 16 which is a little bit of a deviant having sandy clay, clay, laterite and topsoil in younging direction.

Layer 1 has thicknesses ranging from 0.8m to 2.42m with corresponding resistivities between 25.54Ωm to 239Ωm. Layer 2 has thicknesses ranging from 5.88m to 19m and corresponding resistivities from 20.94Ωm to 706.82Ωm. Layer 3 therefore has thicknesses ranging from 5.83m to 19.38m and corresponding resistivities from 35.3Ωm to 598.93Ωm. Layer 4 has thickness of about 11.4m and corresponding resistivities ranging from 12.1Ωm to 1821.03Ωm. Layer 5 only has a resistivity of about 657Ωm.

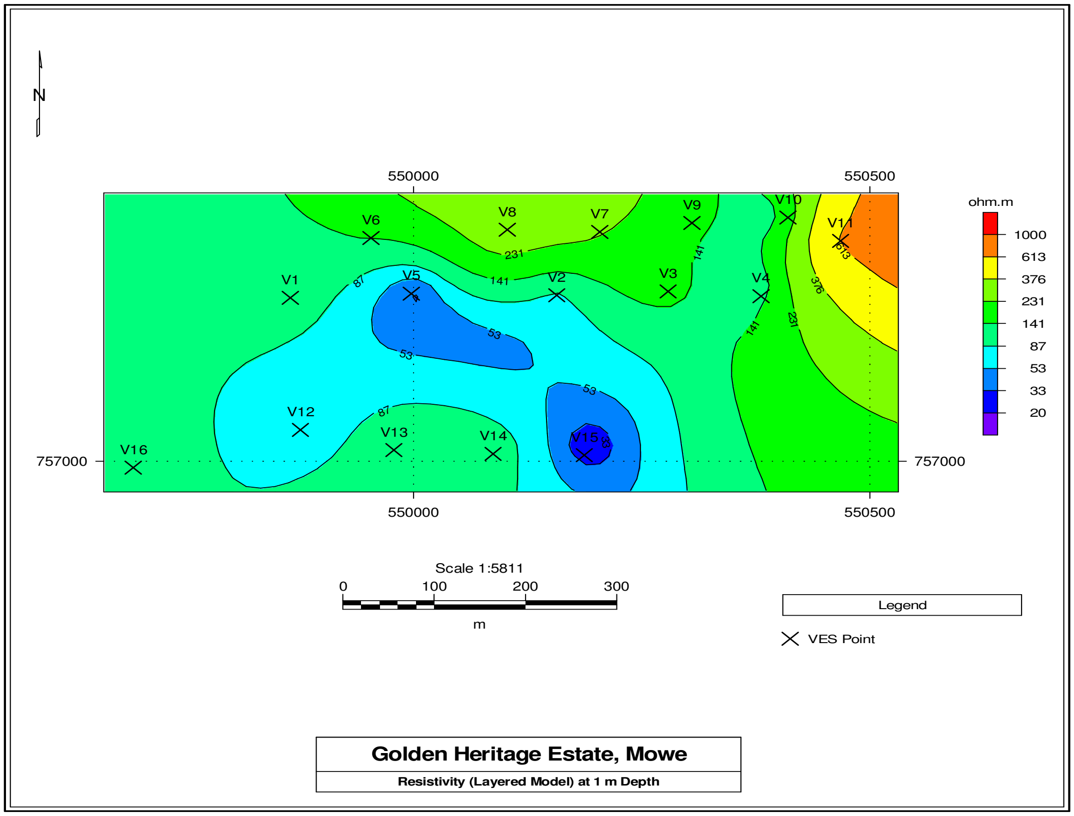

Figure 6a. Isoresistivity Contoured Map for 1m depth

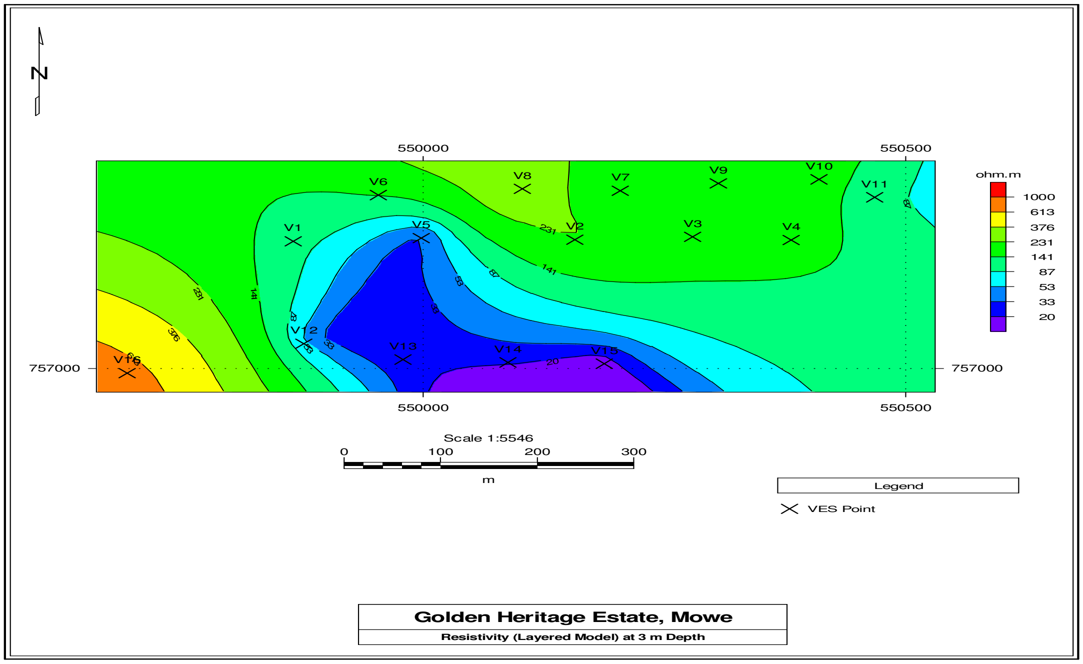

Figure 6b. Isoresistivity Contoured Map for 3m depth

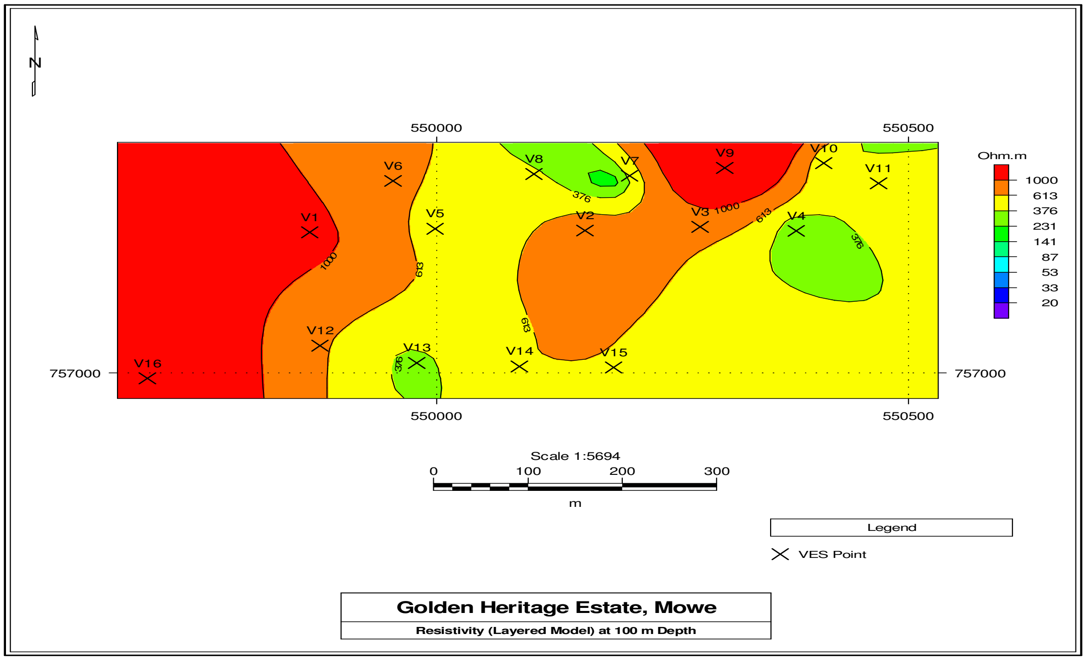

Figure 6c. Isoresistivity Contoured Map for 100m depth

From the data presented, making use of the resistivity values such that all the VES points are considered at different depth instances, depth contouring was carried out so as to delineate the best probable water bearing zones and these are presented in contoured maps as shown in Figures 6(a, b & c) which denotes the correlation of resistivity information at depths of 1m and 3m and 100m respectively. It is revealed in these maps that portions bearing colours yellow to red have high resistivity but those bearing colors purple to green have low resistivity values. These contour maps help in viewing the subsurface to a depth of 100m over an area marked by sixteen different VES stations.

In effect therefore, layers 1, 2, 3 and 4 for geoelectric section AA' has resistivity values of 46.35Ωm to 291.31Ωm, 29.44Ωm to 222.21Ωm, 12.29Ωm to 496.58Ωm and 64.42Ωm to 1107.18Ωm respectively. For geoelectric section BB', layers 1, 2, 3 and 4 has resistivity values of 239Ωm to 619.45Ωm, 37.13Ωm to 174.39Ωm, 13.24Ωm to 417.49Ωm and 351.71Ωm to 1980.52Ωm respectively. For geoelectric section CC', layers 1, 2, 3 and 4 has resistivity values of 25.54Ωm to 239.6Ωm, 20.94Ωm to 706.82Ωm, 35.3Ωm to 598.93Ωm and 12.1Ωm to 1821.03Ωm respectively.

The thicknesses of layers 1, 2, 3 and 4 for geoelectric section AA' are 0.14m to 2.92m, 5.29m to 14.67m, 7.07m to 58.06m and 45m respectively. For geoelectric section BB', the thicknesses of layers 1, 2 and 3 are 0.44m to 9.21m, 2.58m to 35.36m and 3.33m to 40.89m respectively. Then for geoelectric section CC', the thicknesses of layers 1, 2, 3,4 are 0.8 to 2.42m, 5.88 to 19m, 5.83 to 19.38m and 11.4m respectively.

Although some second layers are also made up of sand, but sand is prominent in the third layer and below due to the high resistivity values and this can be said to contain good quality ground water. Therefore, different but due to spread used the depths to these aquifer units were determined such that only the overburden thickness was gotten, with the depth to the aquifers being 13.11m, 55.31m, 6.35m, 50.28m, 51.08m and 28.01m in VES 1, 2, 6, 9, 11 and 16 respectively. This accommodates fresh water aquifers from which potable water in commercial quantity can be obtained. Since this will likely give a very productive aquifer the clay overburden serves as a protective cover to conserve these ground water resources. Based on these values it can be confirmed that the first horizon is composed of decomposed organic matter or superficial deposits and second horizon is mostly made up of lateritic clay having undergone compaction due to overburden pressure.

The isoresistivity contoured maps indicates that zones with high resistivity is more probable for good ground supply hence we can then infer that at very shallow depths ranging from 1m to 5m the probable areas for good ground water supply is towards the northeast and southwest corners of the area under study. This invariably indicates that areas around VES 16 only are good sites for our boreholes. For depths ranging from 10m to 60m more VES stations prove to be good sites for ground water supply, mostly from the mid-section of the area towards the west, which has VES stations 1, 5, 6, 7, 8, 12, 13, 14, 15 and 16. Further down, to a depth of 100m shows that the area is generally good for ground water supply, such that boreholes can be sunk to this depth to give ground water output.

7. CONCLUSION

From these results two aquifer units have been identified both of which falls into the sandy region. Different aquifer units are embedded within the subsurface in the study area but only the depth to each of those aquifers could be delineated due to the spread used such that the electrical current terminated within the aquifer zones. Depth wise, it can also be inferred from our isoresistivity maps that when a borehole is sunk to a depth of about 100m the area is generally a good site for location of borehole with high tendency for good water supply.

The study of Golden Heritage Estate, Mowe/Ofada reveals that there is a good quality water resource which is pollution free, with deep aquifer having a tendency of high productivity. It is suggested that boreholes should be sunk within the study area since it has a high yield aquifer.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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