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Full Length Research Paper

Hydrogeophysical Mapping of Oke-Badan Estate, Ibadan, SW Nigeria

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ABSTRACT

The groundwater potential of Alegongo around Oke-Badan Estate, Ibadan, South-western, Nigeria was investigated using Electrical resistivity method. The area is underlain by Basement complex rocks that comprise of Undifferentiated Gneiss, Pegmatite and Quartzite. About 21 Schlumberger vertical electrical sounding (VES) were covered using ABEM Terrameter SAS 1000 system. The interpretation showed three distinct layers overlying the fresh Basement rock. These layers are the top soil with resistivity values that range between 42 and 4209 Ohm m and thickness values that vary between 0.4 and 1.7m.The depth to the top of the Basement range between 5.8 and 32.9m across the entire area. The interpreted resistivity data were used to prepare the longitudinal conductance map, hydraulic conductivity map, transimissivity map, overburden thickness map and aquifer thickness map. These maps were used to evaluate the groundwater potential as well as groundwater protective capacity rating of the study area. On the above bases, The portion having conductance values ranging from 0.002 to 0.018 mhos were classified as weak protective capacity (north-eastern to south-western portion) while region with conductance values that vary from 0.2 to 0.28 mhos were grouped as moderate groundwater protective zones (south-eastern portion). In a similar manner, area beneath VES stations 10, 12, 14, 15, 17 and 19 whose overburden thickness values were greater than 24.0m was zoned to be good groundwater bearing potential while areas with 10 to 24m overburden thickness values were classified as moderate groundwater bearing potentials. These areas lie beneath VES 1, 3, 5, 6, 7, 8, 9, 11, 20 and 21.

Key words: *Vertical electrical Sounding (VES), geoelectric parameters, groundwater potential zones.*

INTRODUCTION

Ibadan, the largest city in sub-Sahara Africa and largest urban centre in West Africa (Olayinka et al, 1999) with several settlements (Figure 1), is not just large in area but equally thickly populated. In this area, potable water supply is a major and common problem and as such inhabitant only find solace by drilling shallow wells to meet their water demands for domestics and agricultural purposes. Groundwater exploration is gaining more importance in Ibadan owning to the ever increasing demand for water supply, especially in areas with inadequate pipe-borne and surface water supplies (Olayinka et al, 1999).

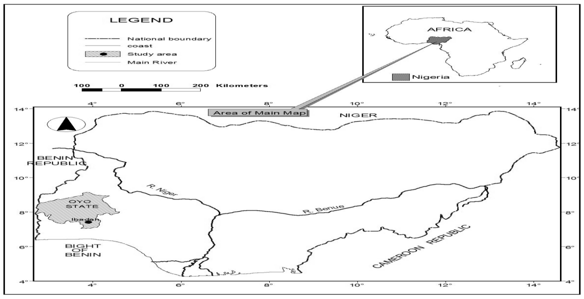


Fig. 1. Map of Nigeria Showing Study Area (inset map of Africa)

The Oke-Badan is a new developing area of Ibadan, Nigeria, and as such lacks some basic amenities. Many of the plots of land are still open fields and it is neither fed by pipe-borne water nor by surface water supplies. The area is mainly inhabited by the elites of the upper and middle class. The geology of the area does not make groundwater exploration exercise an easy task and as a result several attempts made in the past by individuals to have their private boreholes have proved abortive. A systematic and scientific approach to the problem is therefore essential for the study area in order to overcome these problems. This lends credence to the submission of Ajayi and Adegoke-Anthony (1988) that the water, which exists in such abundance in the earth, is unevenly distributed in both time and space and in circulation.

Hard rocks occupy the entire area studied. These rocks are devoid of primary porosity and permeability. Most crystalline rock areas of Nigeria are located in areas of high relief; as a result, run-off is high and infiltration rates very low. Most often, the occurrence of groundwater in this terrain is localized and confined to weathered/fractured zones. Hence detailed pre-drilling geophysical investigations become inevitable.

Use of geophysical methods provides valuable information with respect to distribution, thickness, and depth of groundwater bearing formations. Various surface geophysical techniques are available but the most commonly used in Nigeria for rural/urban water supply is the Electrical Resistivity Method because of its low cost and relatively high diagnostic value.

The highest groundwater yield in basement terrains is found in areas where thick overburden overlies fractured zones. These zones are often characterized by relatively low resistivity values. (Olorunfemi and Fasuyi,1993). The most probable use of the electrical resistivity survey is in hydrogeological investigation in relation to aquifer delineation, lithologic boundaries and geological structures to provide subsurface information (Bose et al., 1973). However groundwater occurs either in the weathered mantle or in the joints and fractured system in the un-weathered rocks (Olorunfemi and Olorunniwo, 1985; Ako and Olorunfemi,1989; Olayinka and Olorunfemi, 1992).

The study area lies within the southwestern part of the Nigerian Precambrian basement complex. The dominant rock types in the locality of the study area are quartzite, banded gneiss and granite gneiss. Associated rock suites found in almost all the VES points in the study area is undifferentiated gneiss complex probably mainly schist, while pegmatite and quartz veins are found in VES points 12 and 13 only (Figure 2).

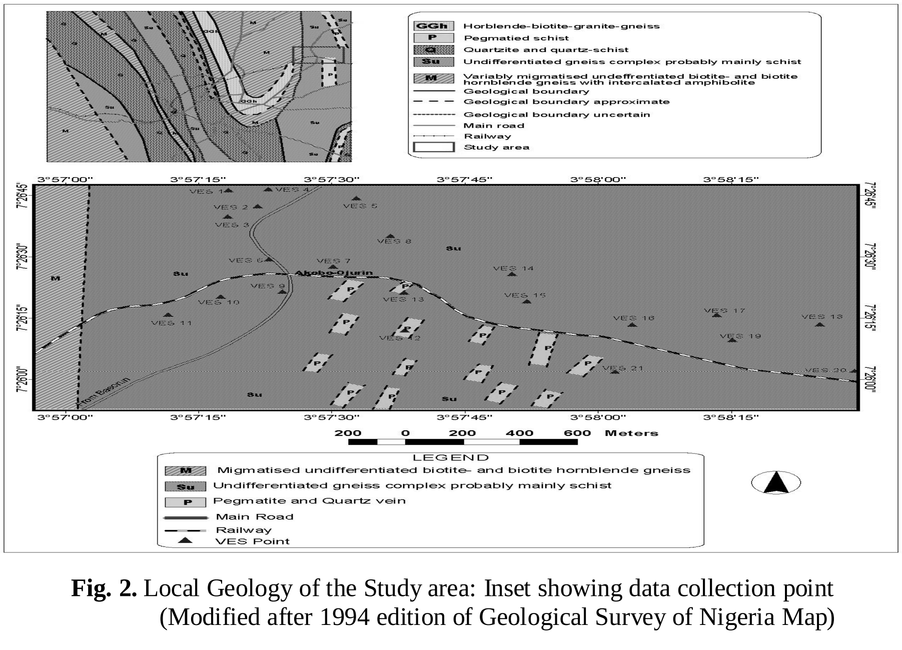


Fig. 2. Local Geology of the Study area: Inset showing data collection point (Modified after 1994 edition of Geological Survey of Nigeria Map)

Quartzite outcrops occur as ridges with relatively high elevation and are commonly Schistose in form. Their strike line runs in the north-south direction, dipping eastwards with characteristic cross--cutting features. The dominant minerals are quartz (78%), muscovite (21%), iron oxide (0.9%) and biotite (0.1%) (Akintola, 1994). Generally, wells from quartzite underlain areas which produced more water than wells from other rock types; this is possible because, their transmissivity and permeability are higher as a result of the large presence of fissures and quartz veins (Olorunfemi and Okhue, 1992). Palacky et al (1981) said that, the localization of groundwater in fractured and weathered zones will make the yield of wells in crystalline bedrock terrain highly variable. This was buttressed by the works of Shemang (1990) and Makinde (1996), who independently worked in the Kubanni Basin of Zaria.

METHOD OF INVESTIGATION AND DATA ANALYSIS

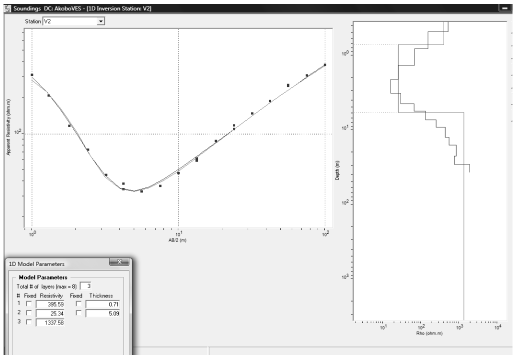
According to Todd (1980), the electrical resistivity method of all the surface geophysical methods, has been applied most widely in groundwater exploration studies; this is because it can clarify the subsurface structure, delineate groundwater zone and inexpensive (Mazae et al, 1985). The electrical resistivity method can be best employed to estimate the thickness of overburden and also the thickness of weathered/fractured zones with reasonable accuracy (Zohdy et al., 1974).

The data collection points of the study area are shown in figure 2. The four electrode Schlumberger array with a maximum current electrodes spacing AB of 200m was used for this survey. A rod is hammered into the ground when a site is located, which serves as the mid point from which AB/2 spacing can be measured in both directions by means of measuring tape with respect to the required spacing from 1m to 100m.

The two current and two potential electrodes are now driven down into the ground at the desired spacing as indicated along the measuring tape. The rechargeable 12V battery is connected to a SAS 2000 Terrameter; also the current and potential electrodes are connected to an ABEM Terrameter SAS 1000 with the four short cables by their clips to connect the positive and the negative terminals on the Terrameter to the two potentials reels and current cables.

AB/2 was measured in both directions from 1.0m to 100m using the base station as the mid point. Similarly MN/2 was also measured on both sides with values varying from 0.25m to 5m where, MN is the potential electrodes spacing. The number of cycles of averaging desired is then set on the Terrameter and the current is turned down to the least ampere value i.e. 0.5 Amps, this passed through the current electrodes into the ground while Terrameter is turned ON to measures electrical resistance R in Ohms i.e. the first reading after the measure button has been depressed.

Depending on the number of cycles set (say 3), at the end of the third beep the last value of resistance is recorded. After each reading, the current electrodes are moved to a pre-calculated position or electrode spacing before subsequent reading, the potential electrodes are also moved from time to time.



Soundings DC: AkoboVES - [1D Inversion Station: V2]

Station V2

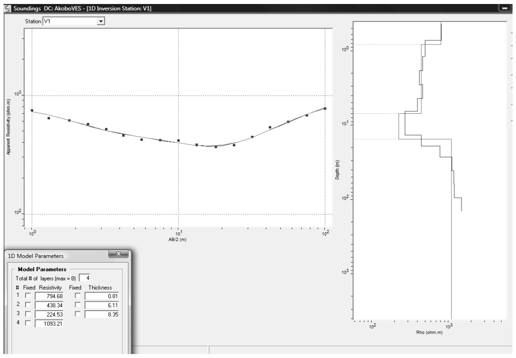
1D Model Parameters

Model Parameters

Total # of layers (max = 8) 3

#	Fixed	Resistivity	Fixed	Thickness
1	☐	395.59	☐	0.71
2	☐	25.34	☐	5.09
3	☐	1337.58		

Fig.3 a. Representative example of three layered VES curves



Soundings DC: AkoboVES - [1D Inversion Station: V1]

Station V1

1D Model Parameters

Model Parameters

Total # of layers (max = 8) 4

#	Fixed	Resistivity	Fixed	Thickness
1	☐	794.68	☐	0.81
2	☐	438.34	☐	6.11
3	☐	224.53	☐	8.35
4	☐	1093.21		

Fig.3b. Repsentative example of four layered VES curves

For each electrode combination, a sounding was made and reading of resistance R of the volume of earth material within the electrical space of the electrode configuration was obtained, a configuration factor K was calculated using equation 1. The product of K and R was then made to obtain the apparent resistivity of the said earth material. This was subsequently done on all the points data obtained for each VES station to give the set of apparent resistivity values supplied for computer modeling using WinGLink program for the iteration to obtain the geoelectrical parameters.

$$R=\frac{V}{I}$$

……………………………………………. (1)

$$K=\pi\left[\frac{AB^2}{MN}-\frac{MN}{4}\right]$$

…………………………….. (2)

$$\rho_a = KR$$

…………………………….. (3)

where MN is the voltage electrode spacing.

Interpretations

Table 1 shows the typical view of the parameters of the subsurface as obtained from the interpreted result. If the curve is taken to be one with three layers, it can be determined if it falls into one of the four types of VES curves.

(i) Type H curve ($p_1 > p_2 < p_3$).
(ii) Type K curve ($p_1 < p_2 > p_3$).
(iii) Type A curve ($p_1 < p_2 < p_3$).
(iv) Type Q curve ($p_1 > p_2 > p_3$).

Where there are more than three layers, we have combination curves. For n layers, the letter combination is n – 2, for example, a four – layer curve has a 2 – letter combination like HA ($p_1 > p_2 < p_3 > p_4$), Koefoed, 1984.

From Table 1, it is evident that the only type of three–layer VES sounding curve obtained in this area is the H-type, however there also existed pockets of a number of four–layered type of VES curves namely QH, HA and KH (Figures 3a and b) meaning that in this area the types of curves obtained are H-type, HA–type, QH–type and KH-type (which is the least).

In basement complex terrains, the intermediate layer of H-type is commonly water saturated and is often characterized by low resistivity, high porosity, low specific yield and low permeability (Jones, 1985).

The results of the VES interpretations were used to generate various basement maps such as: 2D and 3D (a). Longitudinal unit conductance map (b). Hydraulic conductivity map (c). Transmissivity map (d). The overburden thickness map (e). The aquifer unit(s) thickness map as discussed below:

VES Station Curve Type	Layer	Resistivity (-Ohm m)	Thickness (m)	Overburden Thickness (m)	Interpreted Lithology from Resistivity Inversion Results
1 QH	1	794.68	0.81	0.81	Topsoil
	2	438.34	6.11	6.92	Fractured layer
	3	224.53	8.35	15.27	Partially weathered layer
	4	1093.21	∞	-	Fresh Basement
2 H	1	395.59	0.71	0.71	Topsoil
	2	25.34	5.09	5.8	Weathered layer
	3	1337.58	∞	-	Fresh Basement
3 QH	1	805.48	0.27	0.27	Topsoil
	2	183.45	6.41	6.68	Partially weathered layer
	3	24.73	6.41	13.09	Weathered layer
	4	1319.92	∞	-	Fresh Basement
4 H	1	2186.45	0.38	0.38	Topsoil
	2	42.87	5.98	6.36	Weathered layer
	3	353.09	∞	-	Fractured layere
5 QH	1	1697.76	0.33	0.33	Topsoil
	2	171.79	3.28	3.61	Partially weathered layer
	3	60.78	6.99	10.6	Weathered layer
	4	5489.94	∞	-	Fresh Basement
6 HA	1	2713.13	0.8	0.8	Topsoil
	2	239.32	7.86	8.66	Partially weathered layer
	3	407.33	5.89	14.55	Fractured layer
	4	1532.56	∞	-	Fresh Basement

7 HA	1	1488.86	0.43	0.43	Topsoil
	2	388.05	3.27	3.7	Fractured layer
	3	770.68	8.42	12.12	Fractured Basement
	4	5236.94	∞	-	Fresh Basement
8 HA	1	1015.82	0.31	0.31	Topsoil
	2	186.2	1.99	2.3	Partially weathered layer
	3	378.45	9.43	11.73	Fractured layer
	4	714.75	∞	-	Fractured Basement
9 HA	1	1859.64	0.29	0.29	Topsoil
	2	232.35	2.84	3.13	Partially weathered layer
	3	551.46	11.35	14.48	Fractured Basement
	4	1264.4	∞	-	Fresh Basement
10 KH	1	185.09	1.74	1.74	Topsoil
	2	861.6	3.46	5.20	Clayey sand
	3	199.26	19.84	25.04	Partially weathered layer
	4	869.8	∞	-	Fractured Basement
11 HA	1	634.71	3.18	3.18	Topsoil
	2	53.45	8.12	11.30	Weathered layer
	3	295.16	2.29	13.59	Fractured layer
	4	552.95	∞	-	Fractured layer
12 HA	1	261.01	0.92	0.92	Topsoil
	2	168.25	11.83	12.75	Partially weathered layer
	3	795.67	20.16	32.91	Fractured Basement
	4	1187.95	∞	-	Fresh Basement
13 KH	1	184.84	1.77	1.77	Topsoil
	2	383.7	1.76	3.53	Fractured layer
	3	30.22	5.12	8.65	Weathered layer
	4	3072.27	∞	-	Fresh Basement
14 H	1	236.64	0.78	9.78	Topsoil
	2	85.53	17.06	26.84	Weathered layer
	3	1084.08	∞	-	Fresh Basement
15 KH	1	290.44	0.49	0.49	Topsoil
	2	468.26	5.18	5.67	Fractured layer
	3	241.47	22.06	27.73	Partially weatherd layer
	4	491.59	∞	-	Fractured Basement
16 QH	1	4209.29	0.15	0.15	Topsoil
	2	120.54	9.61	9.76	Partially weathered layer
	3	28.45	16.74	26.5	Weathered layer
	4	1983.45	∞	-	Fresh Basement
17 QH	1	355.75	0.82	0.82	Topsoil
	2	189.01	5.12	5.94	Partially weathered layer
	3	59.76	22.91	28.85	Weathered layer
	4	210.31	∞	-	Partially weathered layer
18 H	1	200.58	1.05	1.05	Topsoil
	2	80.36	16.52	17.57	Weathered layer
	3	511.11	∞	-	Fractured layer
19	1	701.83	0.67	0.67	Topsoil

QH	2	165.81	5.56	6.23	Partially weathered layer
	3	32.55	21.91	28.14	Weathered layer
	4	319.42	∞	-	Fractured basement rock
20 H	1	224.55	0.89	0.89	Topsoil
	2	26.18	12.31	13.2	Weathered layer
	3	1113.79	∞	-	Fresh basement rock
21 H	1	42.38	1.04	1.04	Topsoil
	2	24.61	13.11	14.15	Weathered layer
	3	1249.4	∞	-	Fresh basement

Table 1. Summary of Results

Groundwater Protective Capacity Evaluation

a). Longitudinal Unit Conductance Map

The longitudinal unit conductance map (Figure 4), prepared from equation below for all the VES locations, was used for the overburden protective capacity rating of the study area. The total longitudinal unit conductance values can be utilized in evaluating overburden protective capacity in an area. This is because the earth medium acts as a natural filter to percolating fluid. Its ability to retard and filter percolating ground surface polluting fluid is a measure of its protective capacity (Olorunfemi et al., 1999). The highly impervious clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer.

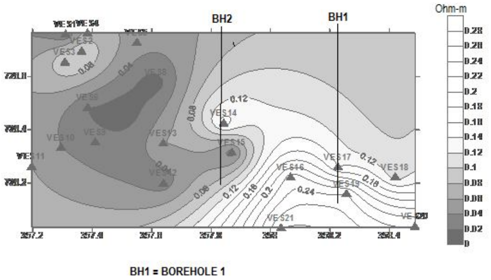


Figure 4a. Longitudinal conductance 2D map ($m\Omega^{-1}$)

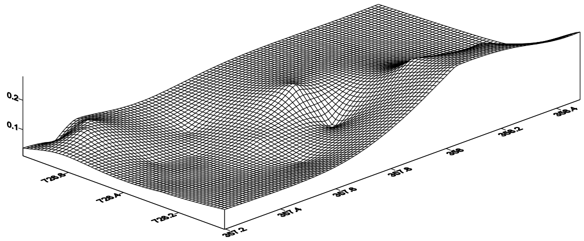


Figure 4b. Longitudinal conductance 3D map

Consider a prism of aquifer materials having a unit square of cross-sectional area A, thickness h, the total longitudinal conductance S can be calculated for each VES station from the interpreted VES data. Its S.I. unit is metre per ohms ($m\Omega^{-1}$). The longitudinal conductance of each subsurface layer Si, can be determined for each VES site from the interpreted VES data and this gives the total longitudinal conductance S, using equations 1 and 2 (Onuoha and Mbazi 1988, and Mbonu et al 1991).

$$Si = \frac{hi}{\ell i} \quad \text{where } i = 1,2,3,\ldots\ldots\ldots\ldots\ldots,n \qquad \text{------------------------1}$$

$$Si = \sum_{i=1}^{n} \frac{hi}{\ell i} \quad \text{where } i = 1,2,3,\ldots\ldots\ldots\ldots\ldots,n \qquad \text{-----------------2}$$

Longitudinal unit conductance	**Proctective capacity rating**
>10	Excellent
5 - 10	Very Good
0.7 - 4.9	Good
0.2 - 0.69	Moderate
0.1 -0.19	Weak
< 0.1	Poor

Table 2. Modified Longitudinal Conductance/Protective Capacity rating (After Oladapo and Akintomiwa, 2007)

The conductance increases towards the south-eastern part of the 2-D map and decreases towards the western part as shown in Figure 5. Based on the reciprocal relationship of resistance and conductance, it is understood that the more a geological formation is conductive, the less it is resistive indicating a permeable formation (Devi et al 2001). As the conductance increases the resistivity naturally decreases pointing towards groundwater potential aquifers (Gowd, 2004).

The longitudinal unit conductance obtained from the studied area range from 0.002 to 0.28mhos. Using the information on the above Table 2, the area could be zoned as weak to moderate groundwater protective capacity. The portion having conductance values ranging from 0.002 to 0.018 mhos are classified as weak protective capacity (north-eastern to south-western portion) while region with conductance values that vary from 0.2 to 0.28 mhos are grouped as moderate groundwater protective zones (south-eastern portion).

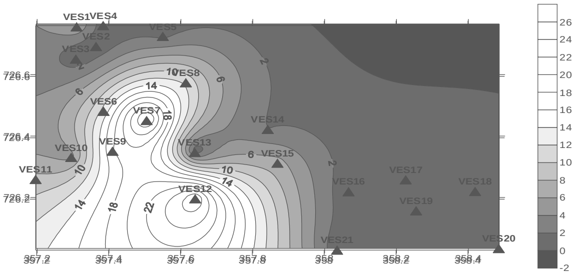


Figure 5a. Hydraulic conductivity 2D map (ms^{-1})

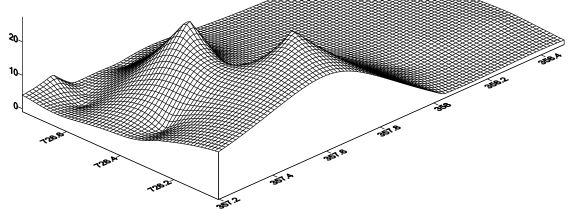


Figure 5b. Hydraulic conductivity 3D map

b). Hydraulic Conductivity Map

The hydraulic Conductivity K is obtained using relation T = h x ℓ where T is the aquifer transmissivity, h is the thickness and ℓ is the resistivity. It is measured in metre per second (ms^{-1}).

Based on the Darcy's law and Ohm's law, Niwas and Singhal, (1981) derived the following relations for the modeling of the groundwater resources of an area:

Tr = KσT = $\frac{K}{\ell}$ **T =** 1. where Tr is the transverse resistance and σ =1/ ℓ is the electrical conductivity.
KT = ℓ. :. K = ℓ/T

The hydraulic conductivity has a range of value between 0.44×10^{-5} and 27.92×10^{-5} m/s. The conductivity increases towards the western part, confirms by two prominent peaks of 3-D map, and it decreases towards the eastern part of the map (Figure 5).

Hydraulic K is directly proportional to resistivity ℓ. Therefore as K increases; ℓ also increases unlike in longitudinal conductance where the reverse is the case. The relevance of this map is that it can be used to select alternate areas with moderate amount of groundwater in the absence of completely weathered basement rocks with appreciable thickness values that contain good amount of groundwater potentials. Here, it can be seen that the south-western portion of the study area (beneath VES 6,7 and 9) having fractured basement rock show the occurrence of appreciable amount of water with hydraulic conductivity values that range between 14 to over 26 ms^{-1} and resistivity values that range between 388 and 500 Ohm m.On the other hand good occurrence of groundwater has been delineated beneath VES 10, 12, 14, 15, 17 and 19 with hydraulic conductivity values that range between less than 1.0 to over 10.0 $ms^{-1}$and resistivity values that vary from 100 to 300 Ohm m.

c). Transimissivity

The transmissivity (T) is directly proportional to hydraulic K using equation T = Kh where h is the aquifer thickness. Its S.I. unit is metre square per second (m^2s^{-1}). Thus, the same relationship is obtained as in hydraulic conductivity. The value increases towards the western part of the map (Figure 6). The transimissivity value is high at VES 7, 9, and 12 stations and low at VES 3, 4, 5, 20 and 21 stations. Hence, value T is low at the eastern part and at the top of north-west while it is high at the west depicts by moderately high peak in 3-D map. The relevance of this map is similar to that of hydraulic conductivity map.

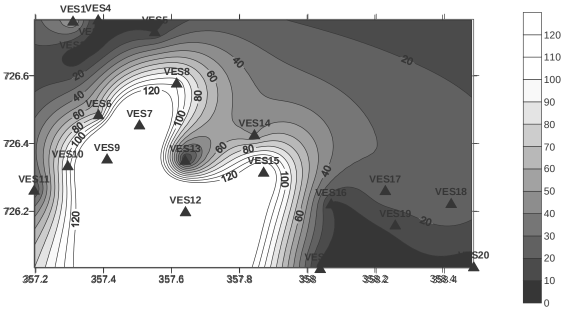


Figure 6a. Transmissivity 2D map (m^2s^{-1})

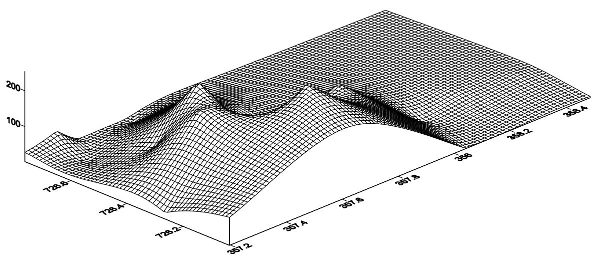


Figure 6b. Transmissivity 3D map

d). Overburden Thickness Map

Generally, areas with thick overburden and low percentage of clay in which inter-granular flow is dominant are known to have high groundwater potential particularly in basement complex terrain (Okhue and Olorunfemi, 1991). The overburden is assumed to include all materials above the presumably fresh basement. Occurrence of groundwater in Basement complex area is rather shallow and its movement is controlled largely by topography. At Bedrock depressions in a typical Basement Complex area in Nigeria are groundwater collecting centers. They also show relatively high overburden thickness while bedrock ridges are characterized by thin overburdens. Consequently the groundwater flows away from the crest of the basement ridges into bedrock depressions.

The overburden thickness map is showing in figure 7 and it was used to classify the area into moderate to good groundwater bearing potentials. The area beneath VES stations 10, 12, 14, 15, 17 and 19 whose values are greater than 24.0m was zoned to be good groundwater bearing potential. On the other hand areas with 10 to 24m overburden thickness values were classified as moderate groundwater bearing potentials. These areas lie beneath VES 1, 3, 5, 6, 7, 8, 9, 11, 20 and 21.The north-western part of the 3-D map depicts the area with lowest overburden thickness values and it occurs beneath VES 2 and 4.

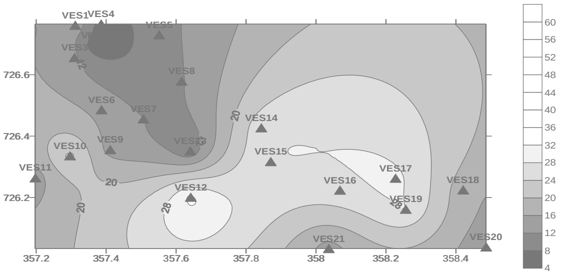


Figure 7a. Overburden thickness 2D map (m)

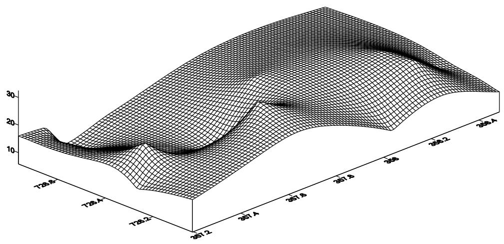


Figure 7b. Overburden thickness 3D map

e). Aquifer Unit(s) Thickness Map

The aquifer unit(s) thickness map shown in figure 8 bears close resemblance with that of overburden thickness map (figure 8) and it can be used in ranking geology formation that contains enough water. This is because volume of water from each VES stations is a function of aquifer thickness.

The entire study area can also be classified as good, moderate and poor groundwater potential zones. The study reveals that the good water-bearing zone occurs at the central eastern part (beneath VES 10, 12, 14, 15, 16, 17 and 19) of the study area with a thickness value greater than 20m.

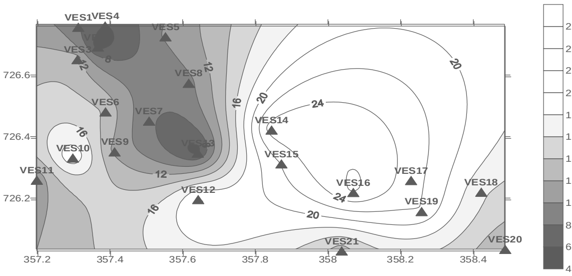


Figure 8a. Aquifer Unit(s) Thickness 2D map (m)

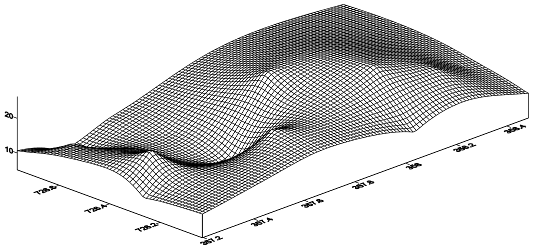


Figure 8b. Aquifer Unit(s) Thickness 3D map

A range of value of an aquifer thickness 10m to 20m gives a moderate groundwater potential zone. The remaining parts of the area were demarcated as moderate to low saturated zone with an aquifer thickness less than 10m as shown by the valley pattern displayed on 3-D map.

CONCLUSION

Vertical Electrical Sounding (VES) method has been carried out in twenty-one (21) stations in the Alengongo area of Ibadan, southwest, Nigeria. Weathered and fractured horizons constitute the aquifer zones and as such, have been identified in the area underlying the VES stations. Good prospects therefore exist for groundwater development in the study area where the depth to basement is relatively thick and has low resistivity values.

Based on the interpreted results of the electrical resistivity survey conducted in the study area, the depth to basement within the area was found to vary from a little less than 5.8m to a little greater than 32m. This was further broken down into three categories to isolate areas of high, moderate, and low capacities thus delineating the area into groundwater potential zones. The productive groundwater potential zones are identified at the southeastern, northeastern, and isolated patches at the western part of the study area.

The study reveals that fairly over 50% of the study area has good groundwater potential and thus wildcat drilling should be avoided as much as possible. A properly conducted geophysical survey is certain to increase the prospect of locating high yield zones and minimizing failures, dry holes, and the attendant financial losses and frustration this might cause the client.

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