GROUNDWATER POTENTIAL EVALUATION USING ELECTRICAL RESISTIVITY METHOD IN A TYPICAL BASEMENT COMPLEX AREA OF NIGERIA

E.A. Ayolabi, O.B. Olatinsu and B.S. Badmus
Geophysics Programme, Department of Physics,
University of Lagos, Lagos, Nigeria

ABSTRACT
A geophysical survey employing the electrical resistivity method was carried out within the permanent site of the University of Agriculture, Abeokuta (UNAAB), Ogun state, Southwestern Nigeria. A total of 46 Schlumberger vertical electrical sounding (VES) stations were occupied using the ABEM Terrameter SAS 300B model with maximum inter-electrode spacing (AB) of 200m. The aquifer units are characterized by sand, sandy clay/clayey sand, weathered and fractured rocks. The plot of the aquifer resistivity against the coefficient of anisotropy shows that the basement in the study area is underlain by three types of rocks: Quartzite with aquifer resistivity in the range of 50 – 430Ωm and coefficient of anisotropy between 1.01 and 1.18. This weathered mainly to sand with good to high groundwater yield; Granite-gneiss with aquifer resistivity in the range of 40 – 90Ωm and coefficient of anisotropy of between 1.18 and 1.88. This weathered to a mixture of clay and sand with low to medium groundwater yield; Mica-schist with aquifer resistivity in the range of 16 – 40Ωm and coefficient of anisotropy of between 1.3 and 2.3. This weathered into more of clay because of its high ferromagnetic mineral content and as such has zero to very poor groundwater yield.

Keywords: *Aquifer thickness, Resistivity map, Coefficient of anisotropy, Groundwater*.

INTRODUCTION

The success of any geophysical technique in groundwater exploration depends largely on the relationship between the physical parameters such as conductivity/resistivity, acoustic velocity, magnetic permeability and density, and the properties of the geologic formations such as porosity. Electrical and electromagnetic techniques have been used in groundwater geophysical investigations because of the correlations that often exist between electrical properties, geologic formations and their fluid content (Flathe, 1970; Zohdy *et al.*, 1974). The direct current electrical resistivity method for conducting a vertical electrical sounding (VES) has proved very popular with groundwater studies due to the simplicity of the technique and the ruggedness of the instrumentation. The use of geophysics for groundwater studies has been stimulated in part by a desire to reduce the risk of drilling dry holes and also a desire to offset costs associated with poor groundwater production. Today, the geophysicist also provides useful parameters for hydrogeological modeling of both new groundwater supplies and for the evaluation of the existing groundwater contamination. Reynolds (1995) has shown that the failure rate of over 82% recorded for boreholes drilled for rural water supply in Northern Nigeria was dramatically reduced to less than 20% failure as a result of the use of electrical resistivity method of geophysical exploration. Beeson and Jones (1998), Hazel *et al.*, (1988) and Hazel *et al.*,(1992), and Caruther and Smith (1992) all have shown the significance of the use of electrical resistivity techniques for sitting wells and boreholes in crystalline basement aquifers in sub-Sahara Africa.

In the present study, electrical resistivity method using Schlumberger array has been employed to determine the nature of the superficial material and the subsurface rocks underlying it with a view of determining its groundwater potential and possible area for groundwater development at the University of Agriculture, Abeokuta, Southwest Nigeria.

Study site

This study was carried out within the University of Agriculture, Abeokuta (UNAAB) campus (fig. 1). Abeokuta lies between longitude 3^0 15′ E and 3^0 25′ E and latitude $7^0$15′ N and 7^0 21′ N. The approximate total area of the University campus is 100km^2, of which the survey area covers a significant part. The topography varies from flat terrain to valley/lowlands and ridge/hilly terrain. As a result, only areas with fairly flat terrain were occupied during the fieldwork.

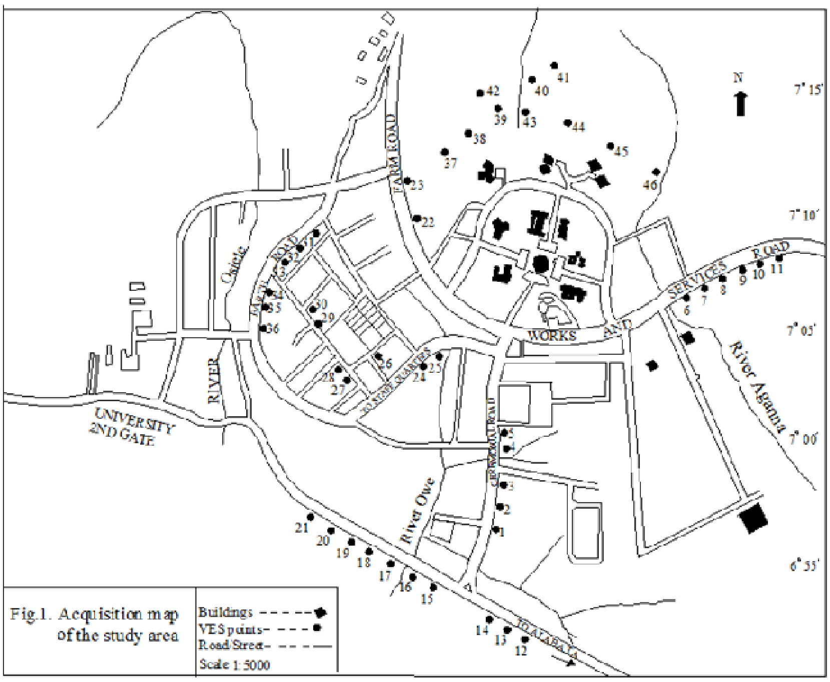

Figure 1: Acquisition map of the study area

Geomorphology, geology, and hydrogeology

The study area is generally undulating. The elevation varies from 120 to 152m above sea level. The area experiences tropical humid climate with two distinct seasons: the dry season (from November to March) and the wet season (from April to October). The vegetation is of the tropical rain forest type and the area is underlain with crystalline Precambrian basement rocks (fig. 2), mainly of the igneous and metamorphic types with few outcrops. The lithological units comprise predominantly of gneiss, granite-gneiss, migmatite-gneiss, and quartzite.

The area is possibly drained by the three rivers around it. These are River Osiele, River Agana and River Owe. These rivers and their tributaries also contribute to the surface water resources of the area.

Data acquisition and data processing

The geoelectric survey involved the vertical electrical resistivity (VES) mode of investigation. The Schlumberger configuration was employed throughout the work.

Ojelabi *et al*. (2002) have shown that this configuration has a high penetrating depth per unit current electrode spacing and that it is more suitable for subsurface delineation and groundwater exploration in a basement complex region.

A total of 46 VES points were sampled with the distribution along the eight profiles shown in figure 1. The ABEM Terrameter SAS 300B was used for the fieldwork, with a current electrode separation (AB) of 200m. Other field tools include four electrodes, compass, lead-acid accumulator, tagged twine and four cable reels. The Terrameter is used to measure the resistance of the ground. Apparent resistivity values are computed as the product of the resistance values and the geometric factor for each electrode separation.

The apparent resistivity data are presented as sounding curves. The curves are obtained by plotting the apparent resistivity against half the cur-

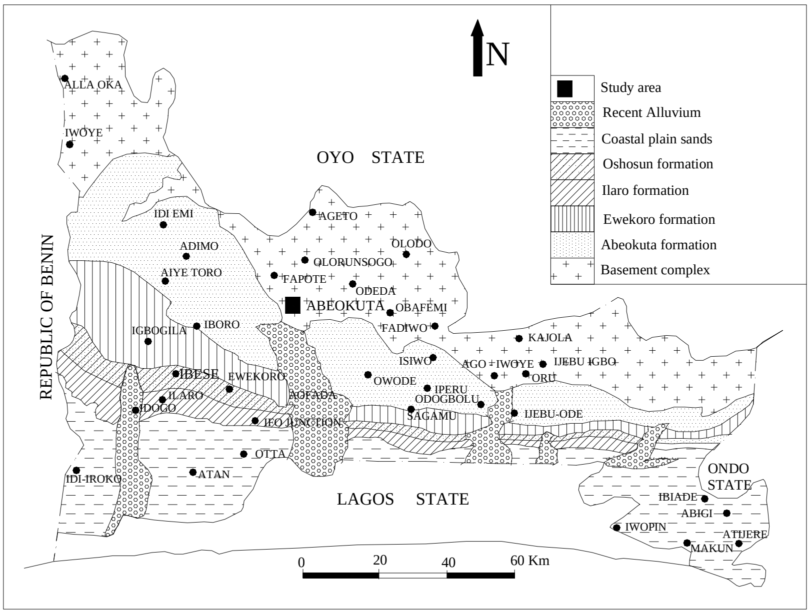

Figure 2: Geology of Ogun State showing the study area

rent electrode separation (AB/2) on a log-log graph. Best smooth curves are drawn through the set of data points. The curve type in each VES station depends on the resistivities of the subsurface layers sequence. The curve types obtained are the H, AA, HA, KH, and HKH samples of which are shown in fig.3a and fig.3b. The VES data displayed as curves was quantitatively interpreted to determine the number of subsurface layers, their resistivity, as well as their thickness. The two basic approaches used are the manual method, which employs the partial curve matching method using two layer model curves and the computer iteration technique known as RESIST. The results of the curve matching form the model for the computer iteration techniques. Summary of the analysis is shown in Table 1.

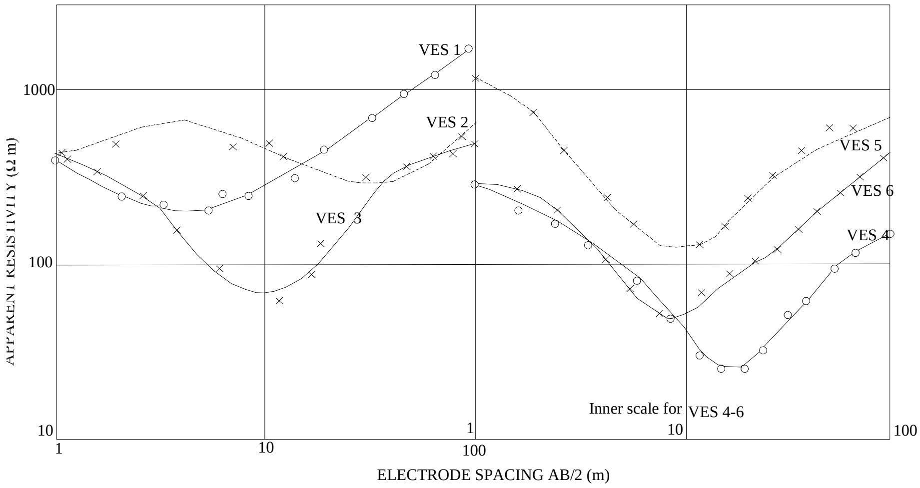

Figure 3a: Typical Schlumberger sounding curves obtained in the study area VES 1 – 6

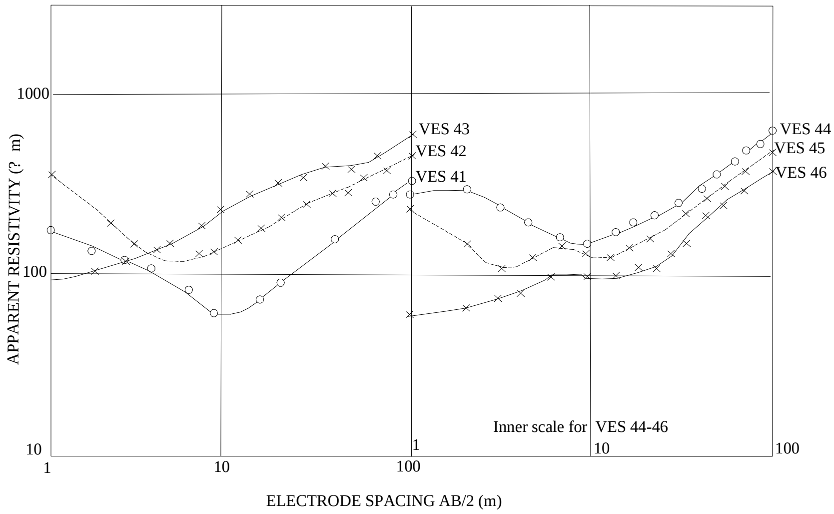

Figure 3b: Typical Schlumberger sounding curves obtained in the study area VES 41 – 46

Table 1: Summary of VES Analysis

VES	Curve type	Number of Geo-layer	Depth to Bedrock	Aquifer Resistivity (Ωm)	Aquifer Thickness (m)	Coefficient of Anisotropy, λ
1	HKH	5	43.0	151.1	33.9	1.10
2	H	3	5.9	151.6	4.9	1.07
3	H	3	14.0	42.5	12.6	1.25
4	H	3	15.3	18.1	12.7	1.53
5	H	3	10.3	51.0	9.2	1.87
6	H	3	9.2	38.1	7.9	1.44
7	H	3	11.7	92.8	10.4	1.02
8	H	3	25.5	110.9	24.8	1.02
9	H	3	31.1	113.1	29.3	1.02
10	KH	4	19.3	188.7	16.5	1.04
11	H	3	20.0	63.1	18.4	1.01
12	KH	4	31.1	78.2	21.2	1.24
13	KHK	5	27.9	68.7	16.9	1.87
14	H	3	14.4	67.0	12.5	1.17
15	H	3	26.7	202.3	26.0	1.02
16	H	3	25.9	78.9	23.8	1.11
17	H	3	13.6	25.8	12.2	1.30
18	H	3	21.4	48.7	20.3	1.06
19	KH	4	14.4	48.6	12.6	1.18
20	KH	4	14.1	23.8	11.9	2.30
21	KH	4	17.3	23.4	15.2	1.44
22	H	3	9.9	42.3	7.9	1.20
23	H	3	6.2	40.8	4.7	1.27
24	H	3	12.5	78.7	11.7	1.12
25	H	3	5.5	56.2	4.7	1.22
26	H	3	25.4	44.2	23.1	1.31
27	H	3	25.6	88.1	24.3	1.42
28	H	3	20.8	78.5	19.5	1.76
29	H	3	30.3	58.6	28.1	1.04
30	HA	4	33.5	68.4	23.9	1.31
31	HA	4	31.7	130.0	28.1	1.07
32	HKH	5	25.2	54.7	15.4	1.22
33	HKH	5	16.5	65.9	10.2	1.40
34	KH	4	15.4	53.7		1.40
35	H	3	37.4	158.1	36.1	1.11
36	H	3	17.2	68.5	16.3	1.04
37	H	3	16.5	59.4	15.5	1.29
38	H	3	7.7	19.4	6.8	1.34
39	H	3	6.3	16.5	5.2	2.06
40	H	3	13.0	98.6	11.8	1.12
41	H	3	15.1	57.1	13.6	1.05
42	HA	4	31.2	357.3	22.3	1.13
43	HA	4	21.2	428.6	18.8	1.15
44	H	3	16.1	155.1	14.9	1.03
45	HKH	5	12.4	88.6	7.8	1.10
46	AA	4	18.9	97.2	18.0	1.01

RESULTS AND DISCUSSION

The results obtained from the VES data are presented as geoelectric sections (fig. 4-11) and the resistivity – anisotropy graph (fig. 12). The VES curves are classified into different curve types. The H curve occurred most in the area accounting for 65% of the total. Other curve types and their degree of occurrence are as follow: KH, 13%; HKH, 11%; HA, 9% and AA, 2%. These curves establish the fact that the surveyed area is a typical basement terrain. The steeply rising segment of the curves at large electrode separations is indicative of fresh bedrock (Olayinka, 1990).

Geoelectric sections

The geoelectric sections beneath each VES station follow the same pattern in almost all the cases interpreted. The simpler ones such as those with curve types H, KH, HA, AA applies to areas where the subsurface sequence is less complex than those beneath the HKH curve types.

Geoelectric section along profile A-A′

This is made up of VES stations 1-5 (fig. 4) and consists of three layers. The first layer constitutes the topsoil with layer resistivity values, which range from 207 – 1427Ωm. The layer thickness ranges from 0.8 to 2.6m. The second layer with resistivity values ranging from 18 to 152Ωm is presumably composed of clay, sandy clay and weathered rock. The weathered rock constitute the aquifer unit. The third layer has resistivity values ranging from 1359 to 5227Ωm and consist of the fresh bedrock. However, beneath VES1, five geoelectric layers were identified with the fourth geoelectric layer composing of fractured/ weathered rock of resistivity 151Ωm and thickness of 33.90m. This constitutes a good location for groundwater exploration. The last geoelectric layer beneath this VES point constitutes the fresh bedrock with resistivity 4367Ωm.

Geoelectric section along profile B-B′

This consists of VES stations 6-11 (fig.5). The section shows three subsurface layers. The topsoil

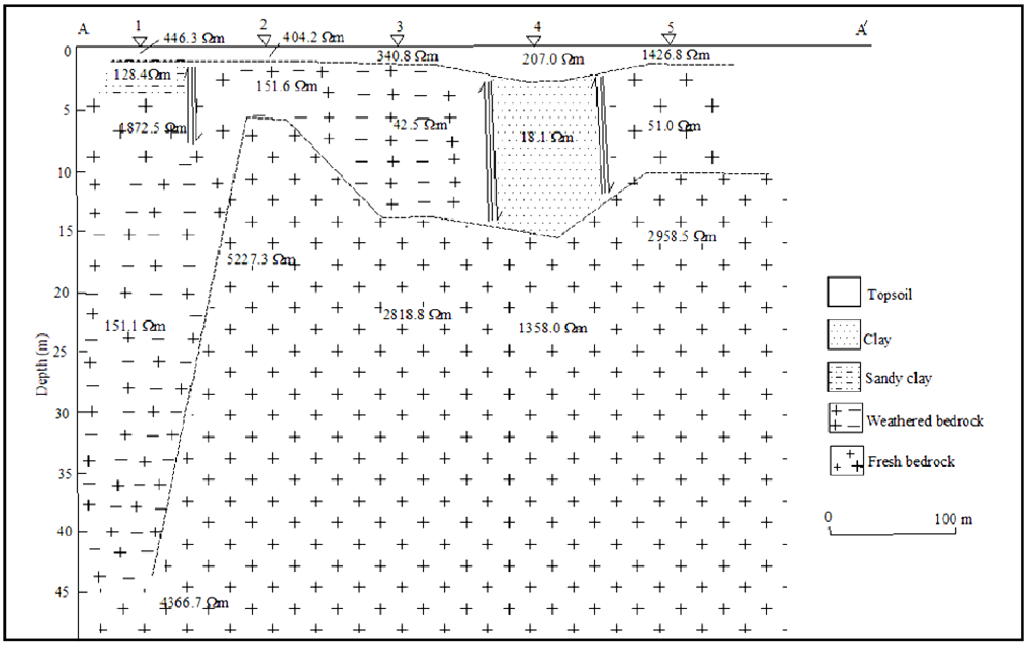

Figure 4: Geoelectric section beneath VES 1 – 5

is the first layer with resistivity values ranging from 110 to 407Ωm and thickness ranging from 0.7 to 1.6m. Beneath the topsoil is the second layer which has resistivity values ranging from 38 to 189Ωm and thickness ranging from 7.9 to 29.3m. This layer is presumably the weathered rock and constitutes the aquifer unit for this profile except beneath VES 6 where the weathered layer may compose more of clay than sand. A clayey sand layer of resistivity 468Ωm and thickness of 2.0m was observed beneath VES 10. The third layer constitutes the bedrock having resistivity values ranging between 813 and 2838Ωm.

Geoelectric section along profile C-C′

This is the longest profile with VES stations 12-21 (fig. 6). The section shows three subsurface layers at stations 14, 15, 16, 17 and 18; four subsurface layers at stations 12, 19, 20 and 21 and five subsurface layers at station 13. The top layer is the topsoil, which has resistivity values between 17 and 922Ωm and the thickness lies within 0.4 and 2.1m. The second geoelectric layer consist of sandy clay/clayey sand beneath VES 12, 13, 20 and 21 with resistivity value of 107 to 1042Ωm and thickness between 1.4 and 8.5m. The layer is composed of weathered/fractured rock beneath VES 14, 15, 16, 18 and 19 with resistivity value in the range of 49 to 202Ωm and thickness 12.5 to 26.0m and constitute good aquifer for ground water exploitation along this traverse. However beneath VES 17, 20 and 21, the layer is presumably compose of clay with resistivity in the range 24 to 26Ωm and thickness of between 11.9 and 15.2m. The clayey nature of the subsurface beneath these VES points ruled out this location from being used for drilling borehole for groundwater development. The third Geoelectric layer beneath VES 12 and 13 is composed of weathered rock with resistivity 69- 78Ωm and

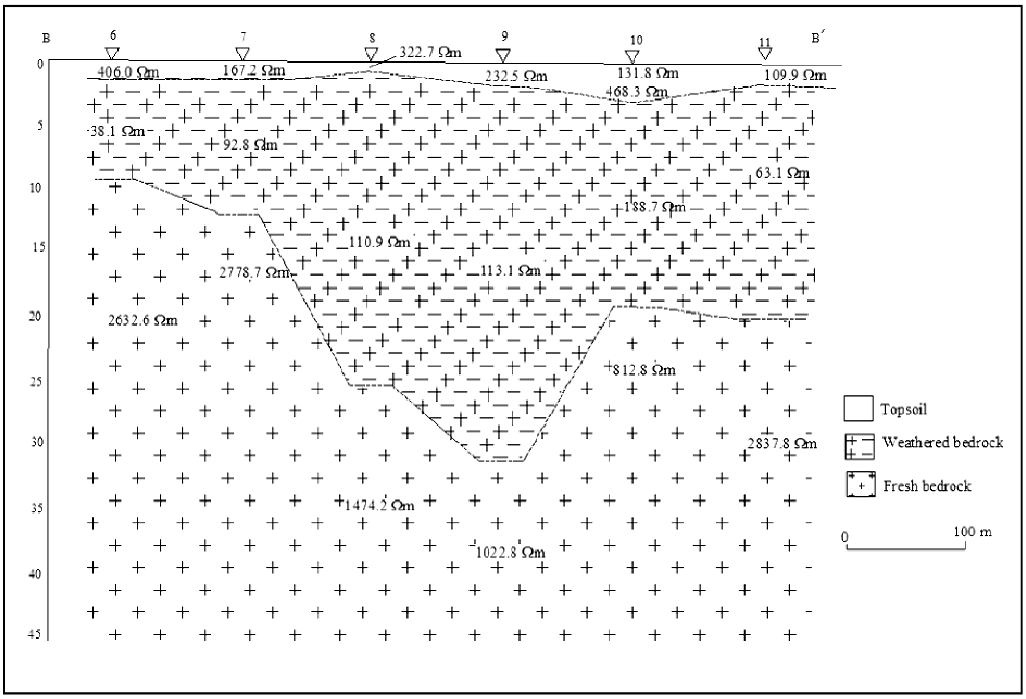

Figure 5: Geoelectric section beneath VES 6 – 11

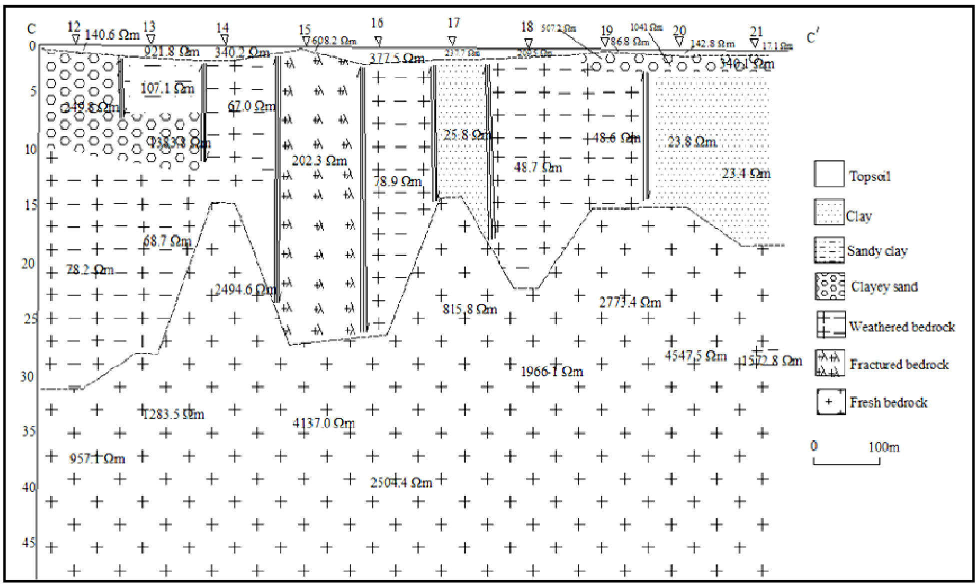

Figure 6: Geoelectric section beneath VES 12 – 21

thickness of 16.9 to 21.2m and constitute a favourable site for groundwater development. The last geoelectric layer i.e. fourth layer beneath VES 12 and 13 and third layer beneath VES 14 – 21 constitutes fresh bedrock with resistivity 816 to 4548Ωm.

Geoelectric section along profile D-D′

This is a short profile with only VES 22 and 23 (fig. 7). There are three subsurface layers. The first layer is the topsoil, which has resistivity values of 189 to 208Ωm and thickness of 1.5 to 2.0m. The second layer constitutes the weathered rock with resistivity values range from 41 to 42Ωm and layer thickness from 4.7 to 7.9m. The weathered zone represent the aquifer unit. However, the groundwater yield potential along this traverse may be very low due to its low resistivity values (41 – 42Ωm) indicating the presence of more clay than sand. The third layer represent the fresh bedrock with resistivity values ranging from 1343 to 1731Ωm

Geoelectric section along profile E-E′

This consists of VES stations 24 – 30 (fig. 8). The section reveals three subsurface layers with the exception of station 30 with four layers. The first layer is the topsoil with resistivity values ranging from 158 to 2962Ωm and thickness between 0.8 and 2.3m. The second layer is composed of weathered rock with resistivity values in the range 44 to 88Ωm. The thickness ranges from 4.7 to 28.1m and constitute the aquifer unit with probable good groundwater yield except beneath VES 24 and 25 due to the relatively small thickness. Beneath station 30, the fractured rock with resistivity 381Ωm forms the aquifer unit with thickness 23.9m and constitutes a favourable location for drilling borehole for groundwater development. The third layer is the fresh bedrock having resistivity value ranging from 999 to 1765Ωm

Geoelectric section along profile F-F′

This consists of VES stations 31 – 36 (fig. 9). The first layer is made up of the topsoil with resistiv-

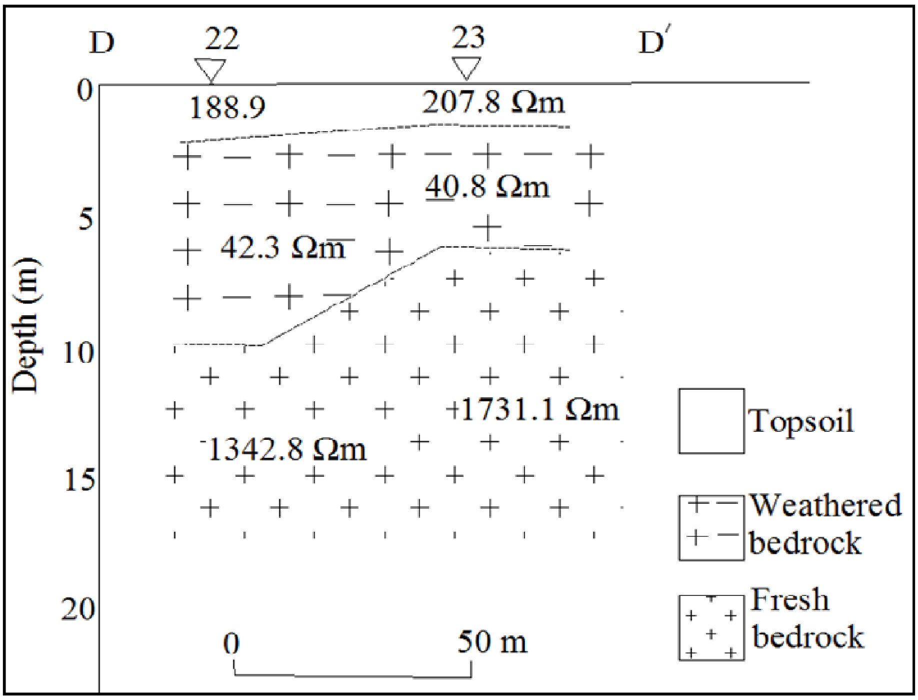

Figure 8: Geoelctric section beneath VES 24 – 30

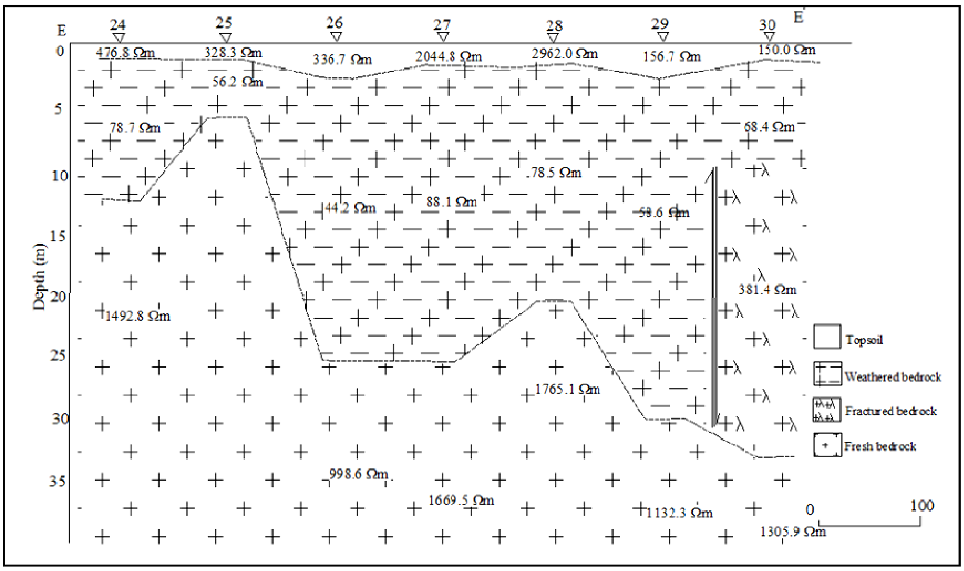

Figure 9: Geoelectric section beneath VES 31 – 36

ity values ranging from 102 to 1345Ωm. The thickness is between 0.6 and 1.4m. The second geoelectric layer beneath VES 31 and 34 is composed of sandy clay/clayey sand with resistivity 34 – 416Ωm and thickness of 6.2 – 8.9m. This layer is underlain by a weathered rock with resistivity 54 – 130Ωm and thickness of 10.2 – 28.1m with high potential for groundwater development. The second geoelectric layer beneath VES 35 and 36 with resistivity 69 – 158Ωm and thickness of 16.3 – 36.1m composed of weathered rock constitute the aquifer unit beneath these locations and has potential for groundwater development. The last geoelectric layer on this profile is the fresh bedrock of resistivity 706 – 1806Ωm.

Geoelectric section along profile G-G′

This consists of VES stations 37 – 41 (fig. 10). The geoelectric section shows three subsurface layers. The first layer constitutes the topsoil with resistivity values between 163 and 814Ωm and thickness between 0.9 and 1.5m. The second layer constitutes the weathered rock with resistivity range from 16 – 98Ωm and thickness of 5.2 to 15.5m and possible zone for groundwater development. However, beneath VES 38 and 39, the layer is presumably composed of clay due to the low resistivity values. The third geoelectric layer is composed of fresh bedrock with resistivity 933 – 3858Ωm.

Geoelectric section along profile H-H′

This consists of VES stations 42 – 46 (fig. 11). The geoelectric section reveals three to five subsurface layers. The first layer is the topsoil with resistivity values ranging from 38 to 417Ωm and thickness between 0.4 and 1.2m. The second and third geoelectric layers along this traverse presumably compose of sandy clay/clayey sand, weathered rock and fractured with resistivity ranging from 78 to 429Ωm and thickness between 10.1 and 20.8m constitute the aquifer zone with

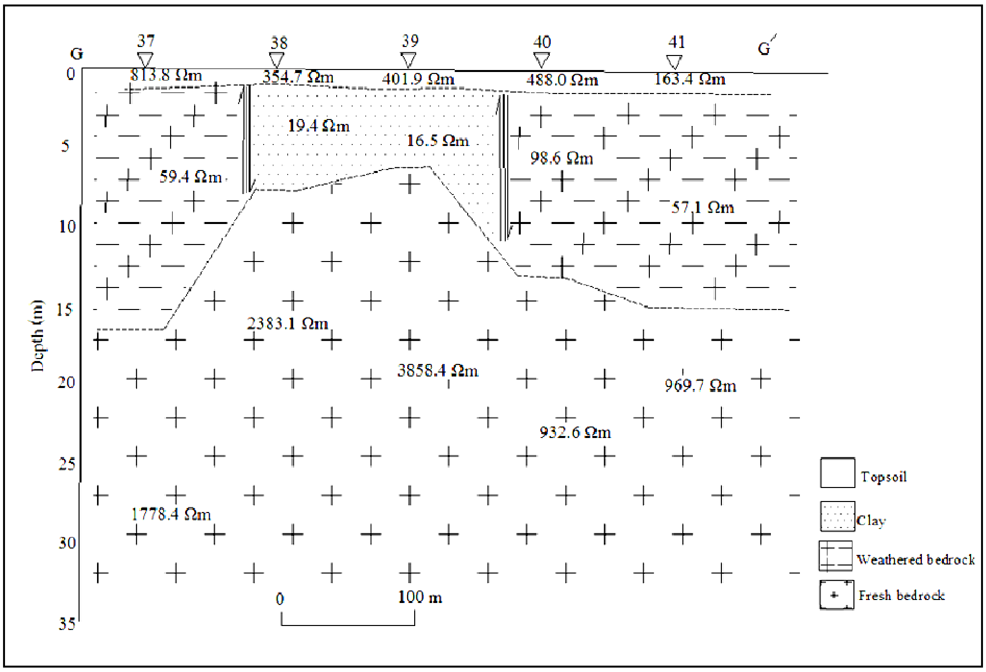

Figure 10: Geoelectric section beneath VES 37 – 41

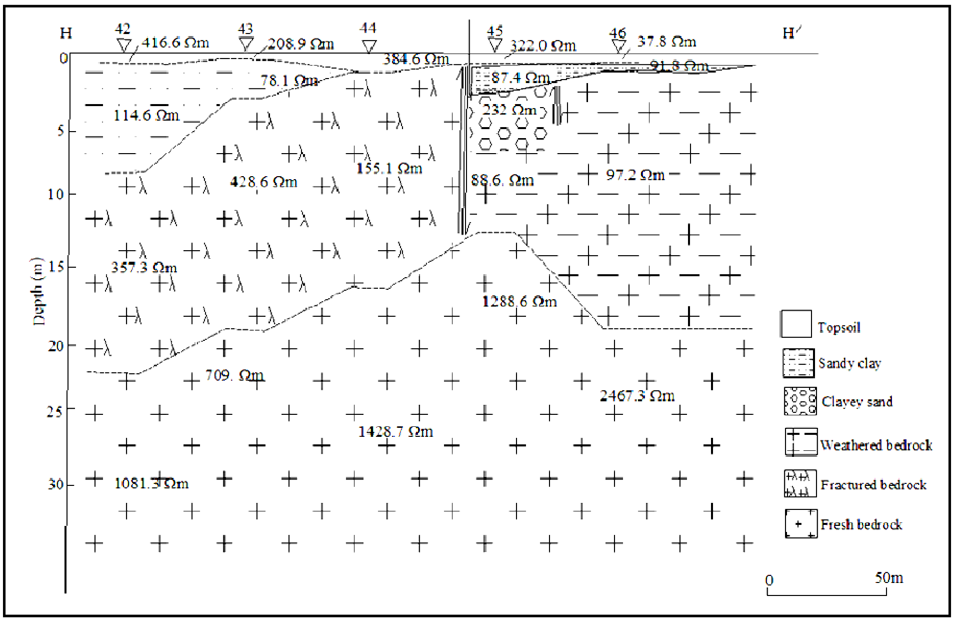

Figure 11: Geoelectric section beneath VES 42 – 46

possible high potential for groundwater development. The last layer is the fresh bedrock having resistivity values between 710 and 2467Ωm.

Coefficient of anisotropy map

The overburden coefficient of anisotropy was used for the identification of the rock type which form the underlying basement rock. The overburden coefficient of anisotrosopy was calculated for the VES station using the approach of Christensen (2000) as given below:

$$\lambda = \sqrt{\frac{\sum_{i=1}^{n-1}\left(h_i / \rho_i\right)\sum_{i=1}^{n-1}\rho_i h_i}{\left[\sum_{i=1}^{n-1} h_i\right]^2}}$$

Where ρ_i and h_i are the resistivity and thickness of the layers.

The values obtained were plotted against the presumed aquifer resistivity to form the resistivity-coefficient of anisotropy map (fig. 12). The values range from 1.01 to 2.3. Three types of ellipse were clearly mapped out from the plot of aquifer resistivity against the coefficient of anisotrosopy comprising of one vertical (ellipse I) and two horizontal (ellipse II and III).

The vertical ellipse (ellipse I) is characterized by the coefficient of anisotropy in the range of 1.01 and 1.18 and aquifer resistivity in the range of 50 to 430Ωm ($1.01 \leq \lambda \geq 1.18$ and $50 \leq \rho \geq 430$Ωm). These, couple with some surface observations made us to conclude that the basement rock at the VES locations with above properties are possibly compose of quartzite rock which weathered mainly into sand with high potential for groundwater accumulation and extraction. The first horizontal ellipse (ellipse II) is characterized by the coefficient of anisotropy in the range 1.18 and 1.88 and aquifer resistivity in the range 40 to 90Ω m ($1.18 \leq \lambda \geq 1.88$ and $40 \leq \rho \geq 90$ Ωm).

The basement rock beneath the VES point that falls into ellipse II are composed of granite-gneiss which weathered into a varying mixture of sand

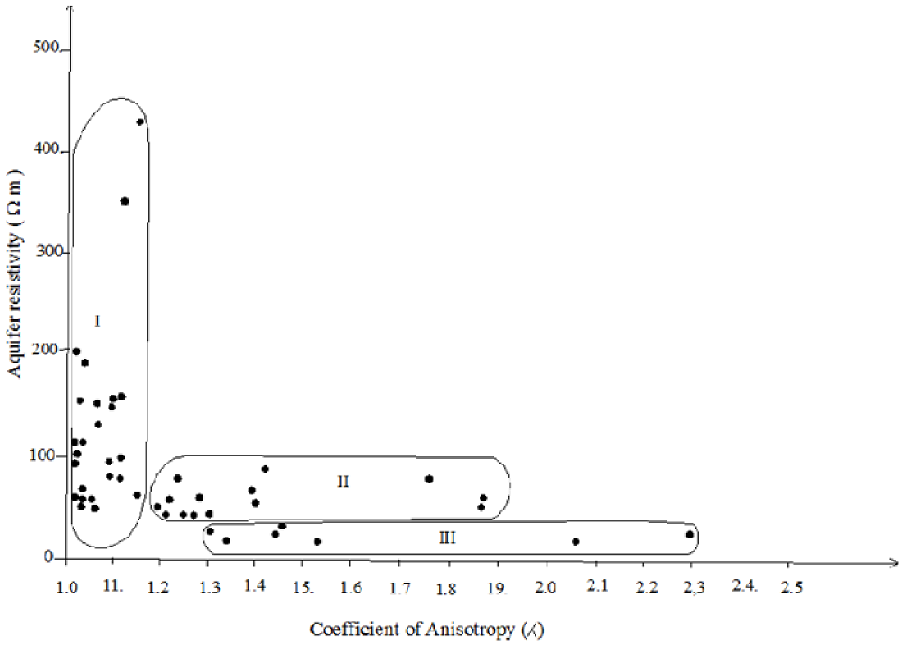

Figure 12: Resistivity – Coefficient of Anisotropy map

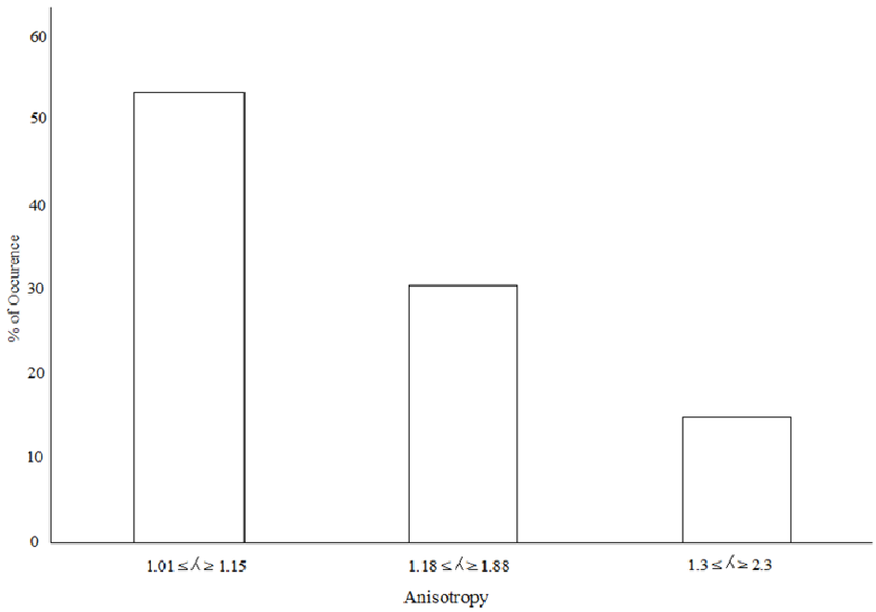

Figure 13: Bar chart showing the distribution of various ellipse

and clay with possible low to medium groundwater potential. The second horizontal ellipse (ellipse III) is characterized by coefficient of anisotropy in the range of 1.3 to 2.3 and aquifer resistivity of 16 to 40Ωm ($1.3 \leq \lambda \geq 2.3$ and $16 \leq \rho \geq 40\Omega m$). The basement rock with the above properties is believed to compose of mica-schist (Olorunfemi and Okhue, 1992) which weathered into more of clay with practically zero to very low groundwater yield. The values of λ are highest in few areas where the subsurface is underlain with mica-schist. High value of λ is associated with mica-schist (Olorunfemi and Okhue, 1992). This weathers into more of clayey soil of low permeability and resistivity, due to its high ferromagnetic mineral content and this ruled out this area from being used as a site for drilling borehole for groundwater supply.

The bar chart plot of this analysis shows that about 54% of the location under investigation has high potential for groundwater development through borehole; 31% shows low to medium potential while 15% shows zero to very low groundwater potential for borehole development (fig. 13).

CONCLUSION

The electrical resistivity survey carried out within the permanent site of the University of Agriculture, Abeokuta has yielded some useful results. The investigation has provided information on the subsurface geoelectric layers, the structural disposition of the basement rock and the groundwater potential of the area.

The results of the quantitative interpretation of the VES data reveal that the subsurface is characterized by the topsoil, sandy clay/clayey sand, weathered/fractured rock and fresh bedrock.

The study area has been broadly grouped into three in terms of the groundwater potential and the basement rock types which range from high to very low/zero potential for groundwater development. This we believe will be a guide for groundwater exploration in basement complex environment particularly where there is no surface rock outcrop.

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