Investigation of Groundwater Development in four Areas of Ido Local Government South-Western, Nigeria Using Electrical Resistivity Method

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Abstract

This study focuses on the use of geo-electrical sounding for groundwater prospecting in four areas namely Ido Motor Park, (N 07° 18' 40.3", E 003° 50' 29.2") Elere- Apata (N 07° 18' 40.3", E 003° 50' 29.2") Bakatari (N 07° 18' 40.3", E 003° 50' 29.2") and Apete Market (N 07° 18' 40.3", E 003° 50' 29.2") in Ido local government area Southwestern Nigeria. Two (2) Vertical electrical soundings (VES) were carried out using Schlumberger configuration at each of the selected area making a total of eight VES in the four selected areas of the local government. The field resistivity data acquired were plotted on bi-logarithm paper and preliminary interpretation was carried out using partial curve matching involving two – layer master curves and the appropriate auxiliary chart. The layered models obtained were subjected to computer iteration using WIN RESIST Version 1.0. The results of the sounding reveal a system of three to four geo- electric layers of resistivity ranging from126.7Ωm to1418.8Ωm Deeply weathered material is quite evident within the premises. Groundwater development in the study area would be feasible if the deeply weathered / fractured basement is fully penetrated.

Introduction

Apart from electricity, good road networks in which government have been battling with in developing countries, drinkable water or portable water is another amenity that also requires attention by the Government. Failure of the government to provide portable water from the supply boards for the teeming population has forced people to travel several kilometers in search of ponds and mess streams whose supply are hardly portable. This has resulted in the construction of shallow hand - dug wells, which usually dries up in the dry season. The development of bored wells to tap aquifers has become the only alternative. Crystalline basement rocks, which have a relatively low permeability and a low storage capacity, pose some water supply problems for sources from bored wells. Last decades has witnessed a tremendous increase in the application of geo-physical techniques to locate groundwater supplies particularly in crystalline rock terrain where scrupulous geological and geophysical investigations are needed to accurately site productive wells. (Ehinola et al., 2006). A number of researchers have made research on the evaluation, exploitation and exploration of groundwater in the crystalline basement complex

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of Nigeria (Amadi and Teme, 1989, Olayinka, 1990, 1992, Edet, 1990 Nurudeen and Amadi 1990, Olayinka and Weller 1997, Ehinola et al., 2006). The use of Electrical Resistivity Method has been extensively used for groundwater exploration because it is simple, low cost, cost effective, speedy and accurate to locate a high yield aquifer. This work aims at locating suitable site(s) for borehole drilling where groundwater development is considered feasible in four areas of Ido local Government Area employing the Electrical Resistivity Method.

Materials and Methods

Geological and Hydro Geological Properties of the Study Areas

The study areas (Ido Motor Park, Elere Apata, Bakatari and Apete) are all in Ido local Government of Oyo State, South-West of Nigeria. These study areas lies between latitudes 7° 22.424'N and 7° 28.391'N and longitude 3°42.009'E and 3°.52.504'E. The study areas are accessible by road. Fig.1 shows the location map of the study areas.

South - West Nigeria is underlain by Crystalline Basement Complex rock of Precambrian age. This Basement Complex rock is divided into four major groups (Jones and Hockey 1964, Oyawoye 1970, Grant 1971, Elueze 1980, Rahaman and Malomo 1983). These include the gneiss-migmatite complex of the Eburnean, the metasediment of the Kibarian and the younger granite of the Pan African Orogenies. However, two of these group gneiss-migmatite complex and metasidiments underlie most of Ibadan and the neighbouring towns. Found in the study areas is the metasediments which occur as quartzite and quartz schist. The schists usually occupy the low-lying areas while the quartzite forms the ridges. Samples are medium to coarse grained, jointed and fractured and contain minerals such as quartz, feldspar and mica. Quartzites usually develop an integrated network of fractures, joints and planes of schistocity that aid the weathering processes. In general, the various rock types of the basement complex weather to a regolith rich in sand and clay. The clay content varies in relation to the ferromagnetic and feldspar content of the parent material. Schist tends to weather into a clay rich resolution with a sand fraction high in quartz.

Within the crystalline basement rock region, two types of aquifer system present are the fractured basement rocks and the weathered basement rocks (Greenbaun1985, Beeson and Jones 1988). These two types usually occur in the same profile and are not mutually exclusive since in some places only one form occurs. The fracturing of the crystalline basement rocks is caused mainly by earth movement (tectonism). The capacities of the crystalline basement rocks to store water allow its movement and yield water chiefly depends on the extent, size, aperture and continuity of the fractures are hydraulically connected. Basement rocks are known to have very low porosity and negligible permeability. Consequently, the development of aquifers is limited to the overburden resulting from in – situ chemical weathering of the basement rocks and the fissures/fracture system in the underlying bedrock. In order to form a productive aquifer, the weathered profile must attain a minimal areal extent and thickness and have sufficient hydraulic conductivity and storage to yield groundwater to wells and boreholes that tap its fracture and/ or fissures (Acworth 1987). Recharge is dependent on the variation in rainfall between the raining and dry seasons being dominant in the raining seasons. The depth of weathering, saturated thickness and dimensions of the aquifers on the overburden determine the volume of water that can be held in storage. The most productive boreholes in the basement rock terrain are always those that penetrate the fractured and fissured rock (Beeson and Jones 1988). The fractures account for a high permeability while the weathered overburden provides a high storability. A pre- drilling investigation should therefore focus on how effectively those narrow zones/fractured basement could be located. The present investigation aims at locating aquifers at depth within the study areas for borehole drilling. Fig. 2 shows the geological map of Ido Local Government Areas.

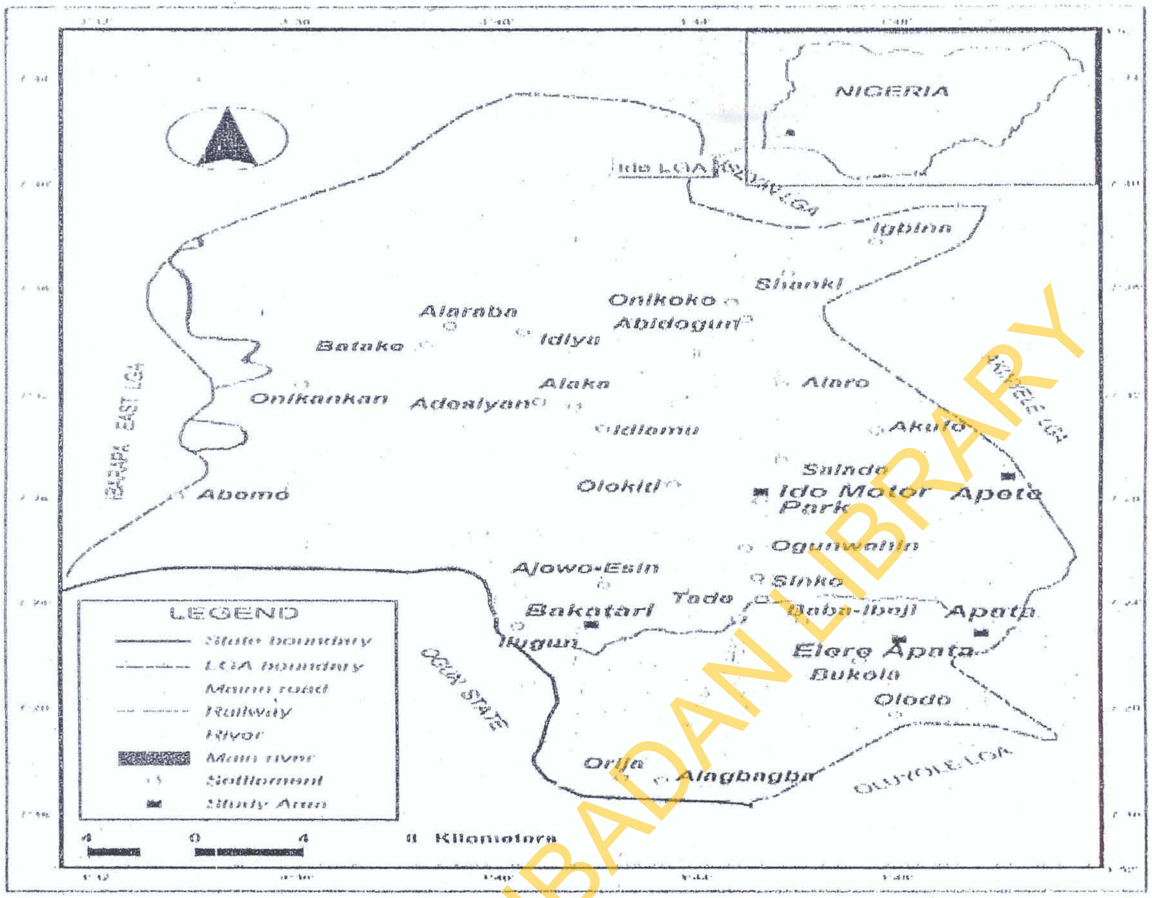

Figure1: Location Map of the study Areas

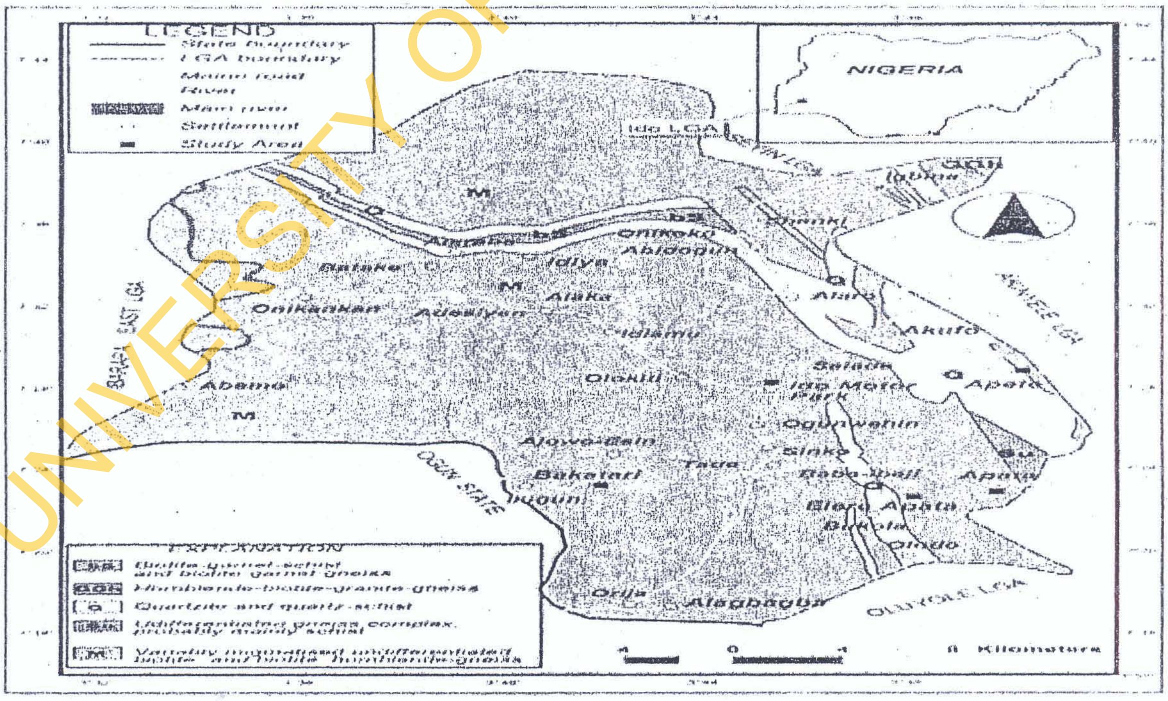

Figure 2: Geological map of Ido L.G.A. showing VES locations (modified from Grant, 1970)

Theory of Electrical Resistivity Method

In resistivity, measurement, the earth was approximated to be composed of horizontally stratified, isotropic and homogeneous media in such a way that the change of resistivity is a function of depth (Zohdy, 1965). Resistivity method employs an artificial source of current which is injected into the ground through pair of point electrodes called current electrodes; their potential drop is measured through another pair of electrodes called the potential electrodes. The electrodes have practically zero resistance for metals of suitable dimensions. The principle of operation depends on the fact that any subsurface variation in conductivity alters the forms of current flow within the earth and in turn affects the distribution of electric potential. It is possible to have information about the subsurface formations from the potential measurement made at the surface. Measurements were taken whenever the outer (current) electrodes are moved further apart so that current penetrates deeper into the ground, while the inner (potential) are fixed unless the signals become too small to be readable. Apparent resistivities were then calculated.

Let the current passing into the earth through one of the current electrodes be +I and if we assume that the earth is homogeneous, and extend to infinity in the downward direction and has a resistivity ρ. The resistance (R) of a conducting material is related to its length (ℓ) and cross-sectional area (A) by

$$R = \rho \ell / A \qquad (1)$$

Ohm's law relates the electric current I, potential difference V and resistance R together

$$R = \Delta V / I \qquad (2)$$

Combining *1* and *2*

$$\rho = \frac{\Delta V . A}{I . \ell} \qquad (3)$$

where ρ = Resistivity

Equation 3 can be used to determine the resistivity of any homogeneous or isotropic medium provided the geometry is simple.
For a semi – infinite medium the resistivity at every point must be defined if A and ℓ is of infinitesimal size then

$$\rho = \frac{\lim_{I \to 0} \Delta V / I}{\lim_{A \to 0} I / A} \qquad (4)$$

Where E = electric field, J = current density and

$$J = \sigma E$$

Since, $\rho = \frac{1}{\sigma}$ σ is called the conductivity

If we consider a single current electrode, a point source of current, on the surface of a homogeneous, isotropic half space, injecting current I into the earth. The flow of electric current is radially symmetric in the half space. Because of the radial symmetry, the current density (J) will be constant at a distance r, from the current electrode; the total current flow across the hemispherical surface is given as

$$I = \int_{hemisphere} J.ds = 2\pi r r^2 J \qquad (5)$$

ds = Surface element
Since the current is always normal to the hemisphere, the integration is simply the surface area of the sphere times the (constant) current density. So, we have at any distance r, the current density is

$$J = I / 2\pi r^2 \qquad (6)$$

Equating and rearranging 4 and 6, E becomes

$$E = \rho I / 2\pi r \qquad (7)$$

The potential at a distance R is obtained on integration of (7) from infinity to R

$$V_R = -\int_{\infty}^{R} E.dr = -\int_{\infty}^{R} \frac{\rho I}{2\pi r^2} \qquad (8)$$

$$V_R = -\frac{\rho I}{2\pi R}$$

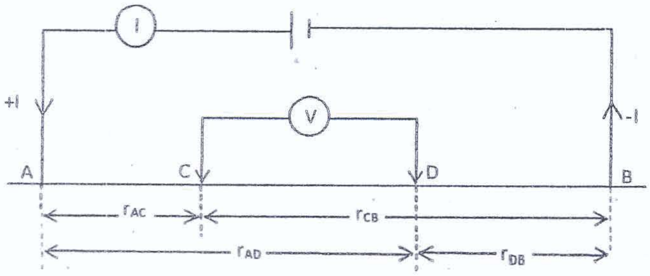

Figure 3: General four electrode array. A and B are current electrodes while C and D are potential electrodes

The potential difference ΔV measured by a terrameter connected between electrodes C and D is given by

$$\Delta V = \left[\frac{\rho I}{2\pi}\left(\frac{1}{r_{AC}}-\frac{1}{r_{CB}}\right)\right]-\left[\frac{\rho I}{2\pi}\left(\frac{1}{r_{AD}}-\frac{1}{r_{DB}}\right)\right]$$

$$= \frac{\rho I}{2\pi}\left[\left(\frac{1}{r_{AC}}-\frac{1}{r_{CB}}\right)-\left(\frac{1}{r_{AD}}+\frac{1}{r_{DB}}\right)\right]$$

$$= \frac{\rho I}{2\pi}\cdot\frac{1}{K} \qquad (9)$$

K is called geometric factor of the electrode configuration.

$$K = \left[\frac{1}{\left(\frac{1}{r_{AC}}-\frac{1}{r_{CB}}\right)-\left(\frac{1}{r_{AD}}+\frac{1}{r_{DB}}\right)}\right] \qquad (10)$$

From 9
$$\rho = \frac{2\pi\Delta V.K}{I} \qquad (11)$$

Given a measurement of ΔV, equation (11) would correctly yield the true resistivity of a homogeneous, isotropic half space. In practice the earth is not a homogeneous, isotropic half space so (11) becomes the apparent resistivity ρ_a

$$\rho_a = \frac{2\pi\Delta V.K}{I} \qquad (12)$$

It is basically a way of normalizing away the geometry and current magnitude for the electrical measurement. There are numerous types of electrode arrangement for resistivity measurements. In this work Schlumberger electrode arrangement was used in this study because of the fact that for a given electrodes separation, current penetrate deeper, more economical in terms of manpower, less sensitive to the influence of near surface lateral heterogeneities as well as stray current. Using the array, smoothing and interpreting are much more developed than other arrays. The spacing between potential electrodes is very much smaller than the current electrode spacing. In this array, the potential and current pairs of electrode also have a common mid-point but the distance between adjacent electrodes differs.

The apparent resistivity value (ρ_a) therefore becomes

$$\rho_a = R.\frac{\pi a^2}{b}\left(1-\frac{b^2}{4a^2}\right) \quad a \geq 5b$$

$$= \frac{\Delta V}{I}\cdot\frac{\pi a^2}{b}\left[1-\frac{b^2}{4a^2}\right] \quad a \geq 5b \qquad (13)$$

Geophysical Investigation and Data Analysis

To locate productive sites for groundwater potential in Ido Local Government Area, a total of eight (8) vertical electrical sounding (VES) were conducted in different parts of the local government namely, Ido Motor Park, Elere – Apata, Bakatari and Apete. The resistivity sounding surveys electrodes are distributed along a line, centered about a midpoint that is considered the location of the sounding. The electrode arrangement used in data acquisition was the Schlumberger array of electrodes since it is the most time effective in terms of field work and are sensitive to the lateral position and depth characteristics of the resistivity distribution. The electrodes were expanded from a minimum current electrode spacing (AB/2) of 1.0 m to a maximum of 75.0 m. The location of each VES as well as each traverse line was recorded with the aid of Global Positioning System (GPS) meter. Good quality data were obtained with the observational errors being less than 1%. Data were collected with an ABEM resistivity meter.

The fields Apparent Resistivity data obtained were plotted against Current Electrode Spacing (AB/2) on bi – logarithmic coordinate paper. The best smooth curve through the points were interpreted using curve matching involving two – layer master curves and the appropriate auxiliary charts. The layered model thus obtained now serves as input for initial models and was subjected to repeated iterations using WIN RESIST VERSION 1.0 software developed by Vander Velpen (1988) until a satisfactory fit to the data was obtained.

Results and Discussion

The results of the computer interpretation of the VES data for the four areas are presented in Figures 4 to 7. On the basis of the VES results, three and four layers were identified within the areas traversed. In Ido Motor Park, four layered formation was revealed. The first layer is topsoil. The resistivity of this layer ranges from 16.5 to 19.2 Ω m reflecting the various compositions and moisture content of the topsoil (Figs. 4(a) and (b)). The thickness of this layer ranged from 0.5 to 0.6 m. The areas which showed high resistivity in this layer are fractured basement. The first aquifer was found in the second layer with resistivity ranged from 32.3 Ω m to 43.5 Ω m. It composed of lateritic clay formation with thickness range from 1.8 m to 2.4 m. This is a very thin unconfined bed and will therefore be prone to contamination. Consequently, this aquifer is unreliable and will not yield portable water for the residents. The third layer composed of weathered basement with resistivity ranged from 12.9 Ω m to 15.2 Ω m and its thickness ranged from 12.8 m to 12.9 m. This is a good aquifer potential. The thickness of this aquifer is an indication of the presence of potable groundwater. Viable boreholes for portable water are therefore recommended to be sunk up to the depth of 21.0 m and even to the fourth layer since fourth layer is a fractured basement.

The Elere- Apata Vertical Electrical Sounding (VES) interpretation revealed a three layered formation. The first layer is the topsoil with

Table 1: Recommended VES Station for borehole drilling and the Expected Depth of Aquifer.

S/N	Site	Recommended VES Position	Expected Depth of Aquifer/m
1	Ido Motor Park	VES 1	21.0
2	Elere – Apata	VES 4	20.0
3	Bakatari	VES 5	10.0
4	Apete Market	VES 8	12.0

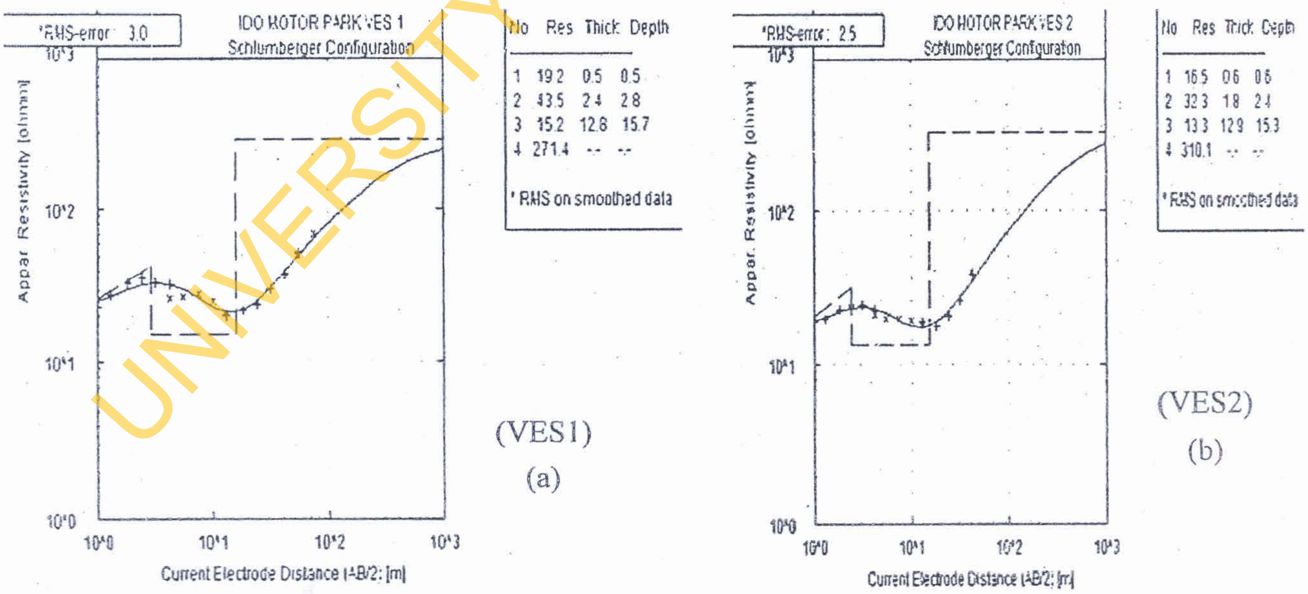

Figure 4: Layer model interpretation of VES 1(Fig.4a) and VES 2 (Fig.4b) of Ido Motor Park. The resistivity, thickness and of the layers were obtained from the graphs.

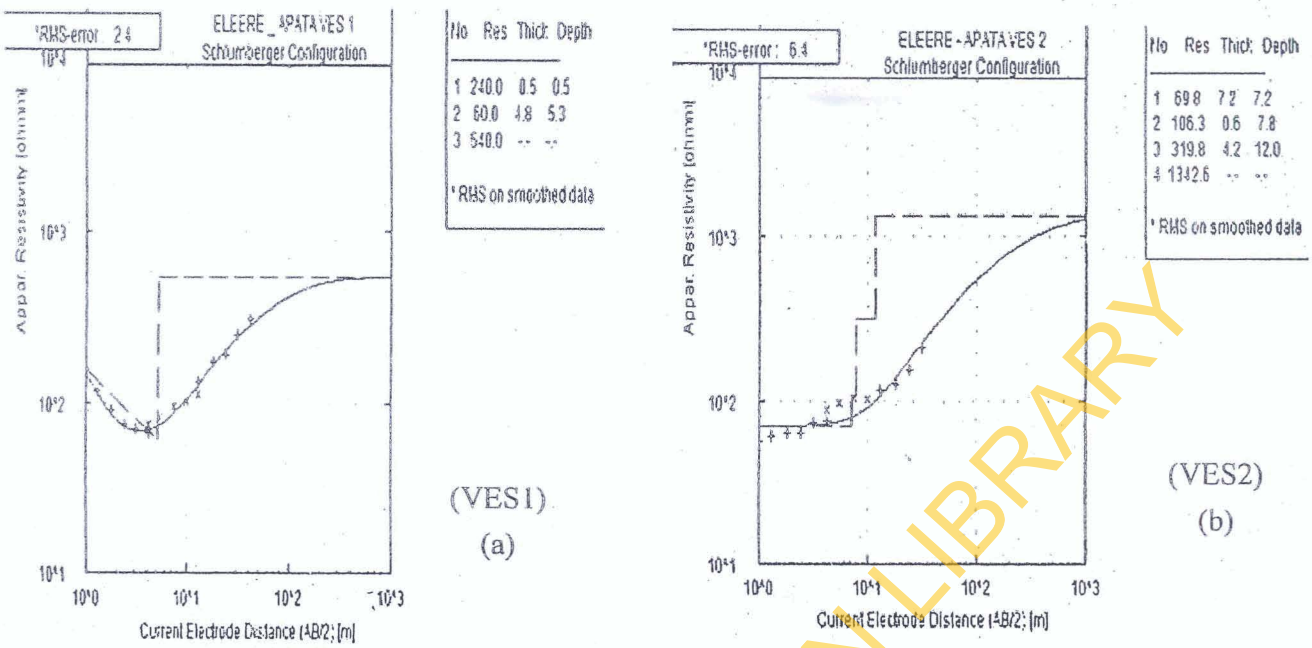

Figure 5: Layer model interpretation of VES 1 (Fig. 5a) and VES 2 (Fig 5 b) of Eleere – Apata. The resistivity, thickness and of the layers were obtained from the graphs.

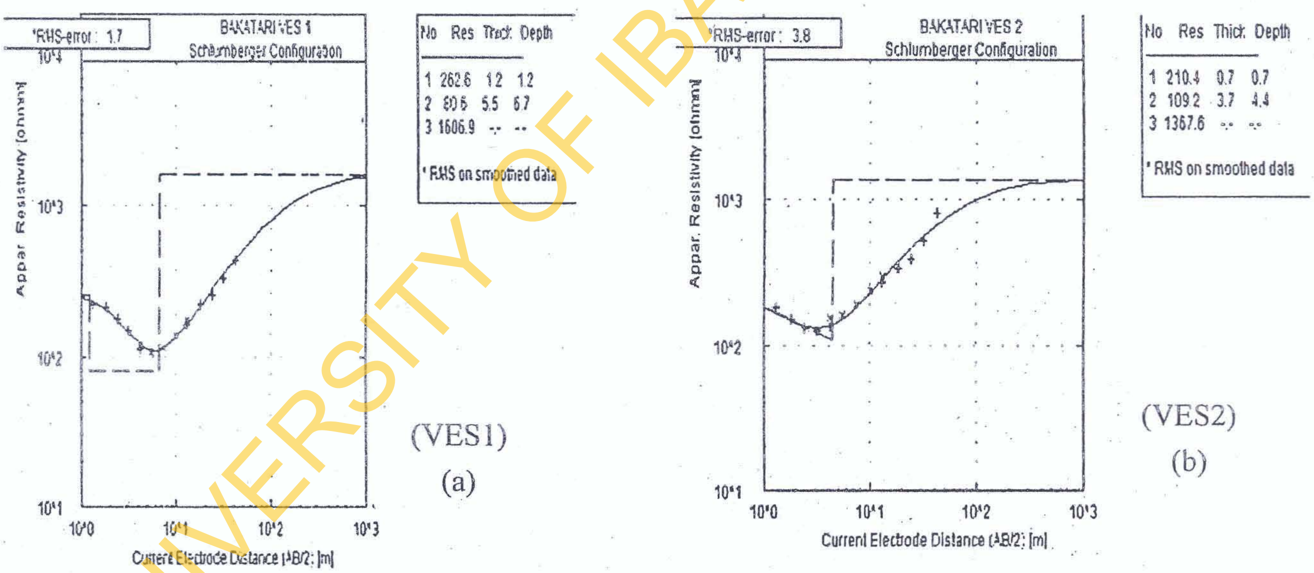

Figure 6: Layer model interpretation of VES1 (Fig. 6a) and VES 2 (Fig.6b) of Bakatari. The resistivity, thickness and of the layers were obtained from the graphs.

resistivity ranged from 69.8 m to 240.0 m and thickness ranged from 0.5 m to7.2 m (Figs.5 (a) and (b)). The first aquifer is found in the second layer with resistivity ranged from 60.0 Ω m to 106.3 Ω m and its thickness ranges from 0.6 m to 4.8 m. This layer is diagnosed to be lateritic clay. This aquifer is unreliable and will not yield portable water for the residents since it may be prone to pollution. The second aquifer occurred in the third layer whose resistivity ranged from 319.8 Ω m to 540.0 Ω m while its thickness is more than 4.2 m. This layer is made up of weathered

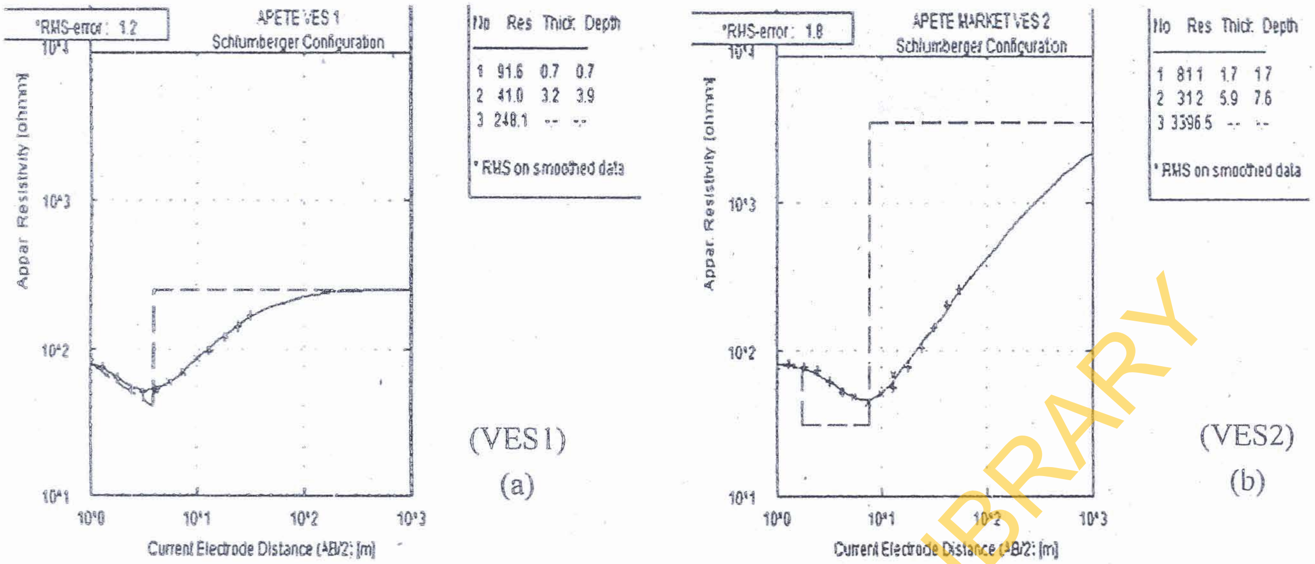

Figure 7: Layer model interpretation of VES 1 (Fig 7a) and VES 2 (Fig. 7b) of Apete. The resistivity, thickness and of the layers were obtained from the graphs.

basement. It is a good aquifer potential and can be use to abstract portable groundwater at the depth of about 20.0 m.

The results of Bakatari soundings revealed a three layered formation. The first layer is mainly topsoil with resistivity ranged from 210.4 Ω m to 262.6 Ω m. Its thickness is from 0.7 m to 1.2 m (Figs. 6 (a) and (b)). The second layer is made up of lateritic clay. The resistivity of this layer ranged from 80.0 Ω m to 109.2 Ω m. The thickness of this layer ranged from 4.7m to 6.7 m. This layer is the first aquifer and may not yield portable groundwater because it might be prone to pollution. To abstract portable groundwater, a depth of more than 10.0 m is suggested.

The sounding results of Apete showed a three layered formation (Figs.7 (a) and (b)). The first layer is the topsoil, the resistivity of this layer ranges from 81.1 Ω m to 91.6 Ω m. The thickness of this layer ranged from 0.7 m to 7.6 m. The first aquifer is found in the second layer with resistivity ranged from 31.2 Ω m to 41.0 Ω m. This layer is of lateritic clay formation and its thickness varied from 3.9 m to 7.6 m. This layer may not be use to abstract portable water since it may not yield enough water quantity. The second aquifer is located in the third layer with resistivity ranging from 241.1 Ω m to 3396.5 Ω m. The layer is a weathered basement. Viable boreholes for portable water are therefore recommended to be sunk up to the depth of 12.0 m.

Table 1 shows the recommended VES positions for borehole drilling and the expected depth of aquifer.

Conclusion

Deeply weathered material is quite evident in the different parts of the study of the local government. Groundwater development in the study areas would be feasible if this deeply weather/fractured basement is fully penetrated. This study has revealed the groundwater potential and the hydro electrical properties of the area. The output of this work will no doubt be of benefit to the people of the study areas.

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