Research Journal of Applied Sciences, Engineering and Technology 5(5): 1816-1829, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: August 09, 2012 Accepted: September 08, 2012 Published: February 11, 2013

The Hydro Geophysical Investigation of Oyo State Industrial Estate Ogbomosho, Southwestern Nigeria Using Vertical Electrical Soundings

[1]T.A. Adagunodo, [1]L.A. Sunmonu, [2]A. Ojoawo, [3]O.P. Oladejo and [1]E.R. Olafisoye
[1]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomosho, Nigeria
[2]Department of Mathematics, G.L. Roberts Collegiate and Vocational Institution, Oshawa Ontario L1J193, Canada
[3]Department of Physics, Emmanuel Alayande College of Education, Oyo, Nigeria

Abstract: The aim of this research is to carry out hydro geophysical study of Oyo State industrial estate Ogbomosho with a view to determining the areas that are good for groundwater prospects and the areas that are not suitable for groundwater exploration. Vertical Electrical Sounding (VES) method was used to map Oyo State industrial estate Ogbomosho which lies within latitude 08°06' 07.4" and 08°06' 25.4" North and longitude 004° 15' 03.3" and 004°15' 49.0" East of Southwestern Nigeria. Ten Vertical Electrical Soundings (VES) were carried out across the area using the schlumberger electrode array configuration with current electrode separation (AB) varying from 130 to 200 m. Nine out of the ten modeled curves were H-type where the remaining one was KH-type. The geoelectric sections obtained from the sounding curves revealed 3-layer and 4-layer earth models respectively. The models showed the subsurface layers categorized into the topsoil, weathered/clay, fractured layers and the fresh bedrock. The weathered basement and fractured basement are the aquifer types delineated for the area. Flow net and bedrock relief map showed that the Southern, Northeastern and towards the base of Northwestern direction of the study area are good for borehole development.

Keywords: Fractured basement, fresh bedrock, groundwater potential, industrial estate investigation, vertical electrical sounding

INTRODUCTION

The importance of groundwater as a supply source to the socio-economic development of a country is tremendous. Though, the state water corporations make use of some minor rivers as a means of water supply to the populace especially in the urban areas but this water is insufficient for domestic uses let alone its availability for industrial uses. Constant supply of water cannot be denied in any industrial settings, as it serves as one of the amenities to be available in industries. Therefore, groundwater has proved itself to be the only available source of water for industrial uses.

Groundwater is water contained within the open spaces between soil, sand, gravel and within fractures in rock. The water comes from rain and melting snow which soaks through the ground and seeps into formations called aquifers. It usually moves slowly from high places towards low places and ultimately discharges into a nearby surface water body. The fact remains that some 74% of the earth consists of water. But 99.4% of this water cannot be used because it's either saline or locked up in glaciers or ice sheets. Less than 0.01% is present in rivers and lakes. The remaining water is present in soils and rocks as groundwater (Adagunodo, 2011).

The study area is underlain by Precambrian rocks of the Nigerian Basement Complex where aquifers are both isolated and compartmentalized. These rocks in their deformed state posses little or no primary intergranular porosity and permeability and thus the occurrence of groundwater is due largely to the development of secondary porosity and permeability by weathering and/or fracturing of the parent rocks (Acworth, 1987; Olorunfemi and Fasuyi, 1993; Olayinka *et al*., 1997). Groundwater localization in this region is controlled by a number of factors which include the parent rock type, the depth, extent and pattern of weathering, thickness of weathered materials and the degree, frequency and connectivity of fracturing, fissuring and jointing, as well as the type and nature of the fillings in the joint apertures (Oluyide and Udey, 1965; Bianchi and Snow, 1969; Asseez, 1972; Odusanya, 1989; Esu, 1993; Eduvie and Olabode, 2001).

Corresponding Author: T.A. Adagunodo, Department of Pure and Applied Physics, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomosho, Nigeria, Tel.: +2348067360352

Considering the limited and winding characteristics of the groundwater reservoirs in the Basement Complex, the full benefit of the aquifer system can only be exploited through a well coordinated hydro geophysical and geological investigation program of the prospective area. Geoelectrical techniques are powerful tools and play a vital role in groundwater investigations particularly in the delineation of the aquifer configuration in complex geological environments. A planned geoelectrical investigation is capable of mapping an aquifer system, clay layers, the depth and thickness of aquifers, fissure or fracture location and qualitatively estimating local groundwater flow (Fitterman and Stewart, 1986; McNeill, 1987; Olasehinde, 1989) and has been adopted in this study. The most commonly used geophysical technique for groundwater exploration is electrical resistivity (Mazac *et al*., 1987) which is aimed at identifying high conductivity anomalies normally thought to be due to deep weathering. Recent developments in geoelectrical data acquisition and interpretation methodology provide electrical images of subsurface features. A properly calibrated electrical image can be used to infer the aquifer configuration: depth, thickness, horizontal and vertical extent of the aquifers. Thus by using the subsurface information obtained from Vertical Electrical Sounding investigations, one may define the subsurface features and details of aquifer geometry. In this study, these subsurface features at industrial estate Ogbomosho have been thoroughly investigated through the layers parameters, flow net and bedrock relief map gotten from the VES curves.

SITE DESCRIPTION AND GEOLOGICAL SETTING

The studied area lies within the crystalline Basement Complex of Nigeria (MacDonald and Davies, 2000). It lies within latitude 08° 06' 07.4" and 08° 06' 25.4" and longitude 004° 15' 03.3" and 004° 15' 49.0" (Fig. 1). The study area is located at the outskirt of Ogbomosho South Local Government and shares boundary with Surulere Local Government Area along old Oshogbo road. The study area is accessible with network of roads that surrounds it and very close to Aarada market.

The rock groups in the area include quartzites and gneisses (Ajibade *et al*., 1988). Schistose quartzite's with micaceous minerals alternating with quartzo-feldsparthic ones are also experienced in the area. The gneisses are the most dominant rock type. They occur as granite gneisses and banded gneisses with course to medium grained texture. Noticeable minerals include quartz, feldspar and biotitic. Pegmatites are common as

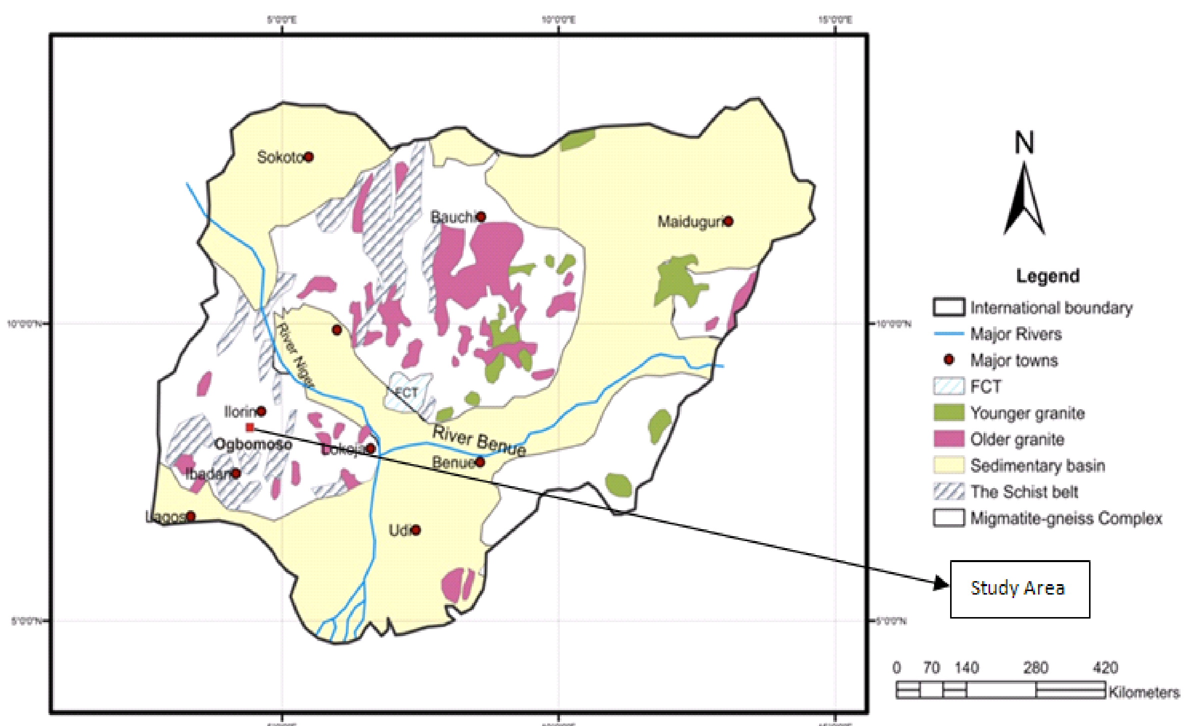


Fig. 1: Geological map of Nigeria showing the study area (Ajibade *et al.*, 1988)

intrusive rocks occurring as joints and vein fillings (Rahaman, 1976; Ayantunji, 2005). They are coarse grained and weathered easily in to clay and sand-sized particles, which serve as water-bearing horizon of the regolith. Structural features exhibited by these rocks are foliation, faults, joints and micro folds which have implications on groundwater accumulation and movement (Ayantunji, 2005).

The extent to which the rocks have been weathered or fractured determines the amount of water to be found and these in turn govern the electrical resistivity values. This forms the basis of using electrical resistivity values and pattern of distribution to work out the different rock types and structures in this study.

Theory of electrical resistivity in rocks: The foundation of electrical resistivity theory is the Ohm's law (Grant and West, 1965) which states that the ratio of potential difference (V) between two ends of a conductor in an electrical circuit to the current (I) flowing through it is a constant:

$$V = IR \tag{1}$$

where, R is a constant known as resistance measured in ohms (Ω).

If the conductor is a homogeneous cylinder of Length (L) and cross sectional Area (A), the resistance will be proportional to the length and inversely proportional to the area (Duffin, 1979):

$$R = \frac{pL}{A} \tag{2}$$

where, p is the resistivity measured in ohm-meter (Ωm).

The earth's material is predominantly made up of silicate, which are basically non-conductors. The presence of water in the pore spaces of the soil and in the rocks enhances the conductivity of the earth when an electrical current (I) is passed through it, thus making the rock a semi-conductor.

Since the earth is not like a straight wire and it is anisotropic, the Ohm's law has to be modified for use as follows:

Substituting Eq. (2) in (1):

$$V = \frac{pIL}{A} \tag{3}$$

Current density j is defined as $\frac{I}{A}$, then:

$$V = j\rho L \tag{4}$$

If the electrical field generated by the current is E across the length when a potential difference (V) is applied, then the potential difference can be defined (Evwaraye and Mgbanu, 1993) as:

$$V = EL \tag{5}$$

$$E = j\rho \tag{6}$$

where,

E : The electric field strength with dimension of volt per meter

If the current electrode is taken to penetrate a small hemisphere of radius r, then the area of the hemisphere becomes $2\pi r^2$.

Substituting for E and integrating Eq. (5) gives:

$$\Delta V = \int E.dr. \text{ (Duffin, 1979)} \tag{7}$$

or

$$\Delta V = \frac{I\rho}{2\pi r} \tag{8}$$

and

$$\rho = \Delta V.2\pi r \tag{9}$$

Since the earth is not homogeneous, Eq. (9) is used to define an apparent resistivity ρ_a which is the resistivity the earth would have if it were homogeneous (Grant and West, 1965). Equation (9) can be written in a general form as:

$$\rho_a = \frac{\Delta V}{I}.G \tag{10}$$

where,

G : A geometrical factor fixed for a given electrode configuration.

The schlumberger electrode configuration has been used in this study. In this arrangement, current is injected into the earth through two electrodes which create a potential field which is detected by another pair of electrodes. The geometrical factor for the schlumberger electrode configuration is given by:

$$G = \frac{\pi((\frac{AB}{2})^2 - (\frac{MN}{2})^2)}{2(\frac{MN}{2})} \tag{11}$$

where,

AB : The distance between two current electrodes

MN : The distance between two potential difference

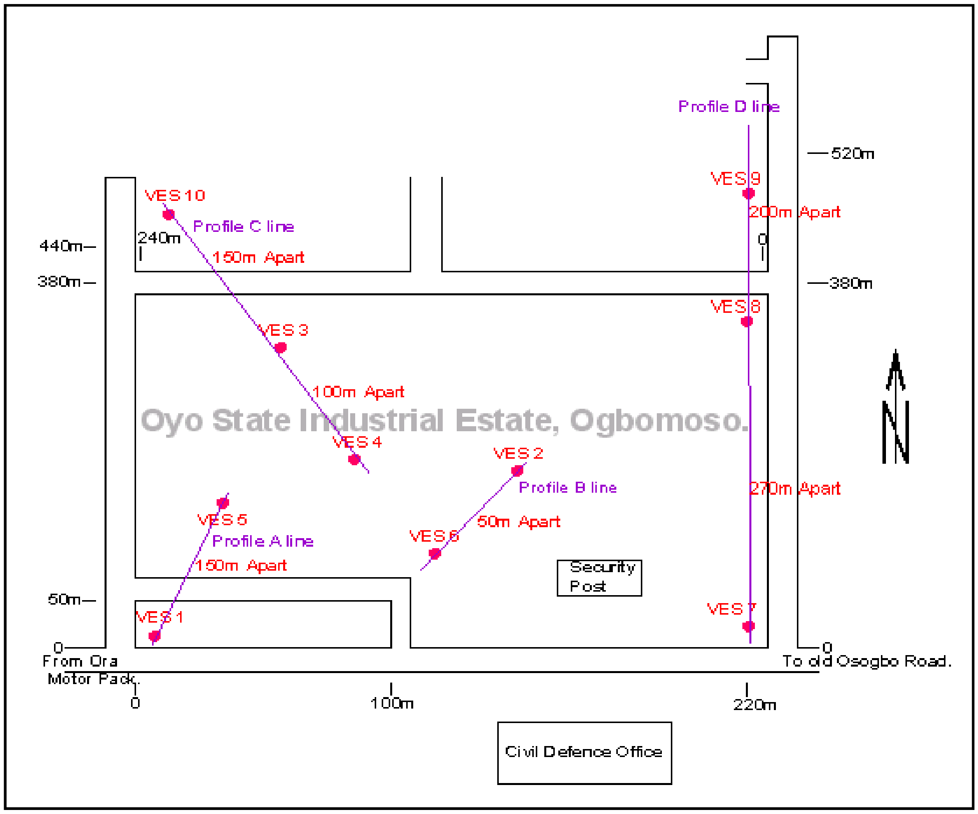


Fig. 2: Layout map of vertical electrical sounding stations

Field survey: A four day survey was carried out in October, 2011 using the electrical resistivity method. The survey was conducted with R 50 Resistivity meter. A total of 10 Vertical Electrical Sounding (VES) stations were occupied randomly to cover the area of study (Fig. 2). The schlumberger array with maximum electrode spacing (AB) of 130 to 200 m was used for the field resistance measurements.

The resistivity values were determined and plotted on a double logarithmic graph paper for quick check on the field.

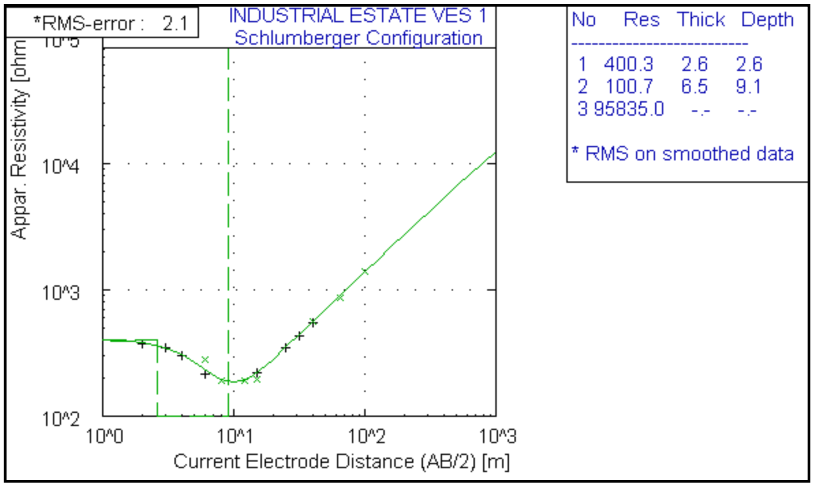
RESULTS OF THE FIELD SURVEY

Parameters such as apparent resistivity and thickness obtained from partial curve matching were used as input data for computer iterative modeling using the Win Resist software (Vander Velpen, 2004). The modeling produced series of curves as shown in Fig. 3a to j. Almost all of curves were H-type ($\rho_1 > \rho_2 < \rho_3$) except at one station which showed KH-type ($\rho_1 < \rho_2 > \rho_3 < \rho_4$). Surfer 8 software (Surfer 8, 2002) was further used on personal computer to develop geoelectric sections of four profiles (Fig. 4a to d) from layer parameters. Flow net and bedrock relief map of the area were also developed using surfer 8 software.

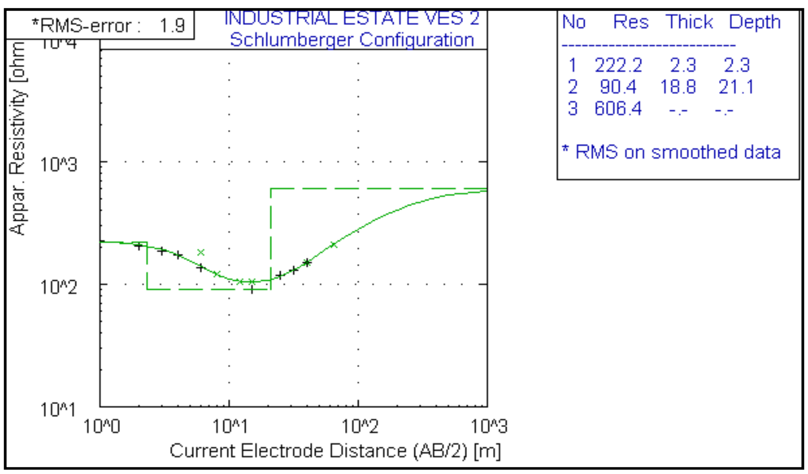
DISCUSSION OF THE RESULTS

The presence of groundwater in any rock presupposes the satisfaction of two factors: adequate porosity and adequate permeability. On account of their crystalline nature, the metamorphic and igneous rocks of the Basement Complex satisfy neither of these requirements. Basement complex rocks are thus considered to be poor aquifers because of their low primary porosity and permeability necessary for groundwater accumulation (Davis and De Wiest, 1966). However, secondary porosity and permeability imposed on them by fracturing, fissuring, jointing and weathering through which water percolates make them favorable for groundwater storage (Omorinbola, 1979).

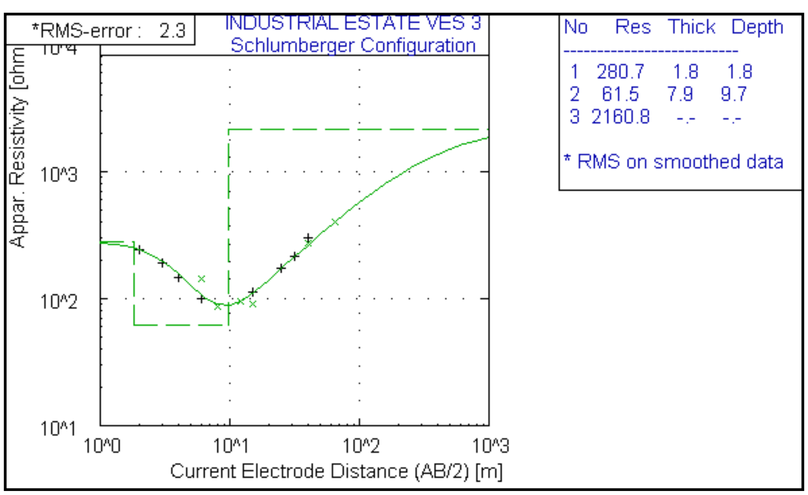
The modeled curves showed three layers in nine of the VES stations (i.e., VES 1, 2, 3, 4, 5, 6, 7, 9 and 10, respectively) and four layers in the remaining one (i.e., VES 8) (Fig. 3a to j). The result showed that 60% of the VES stations have thin overburden and fresh basement rocks (i.e., VES 1, 3, 4, 5, 7 and 10, respectively), 20% of the VES stations have thick overburden and fresh basement rocks (i.e.,



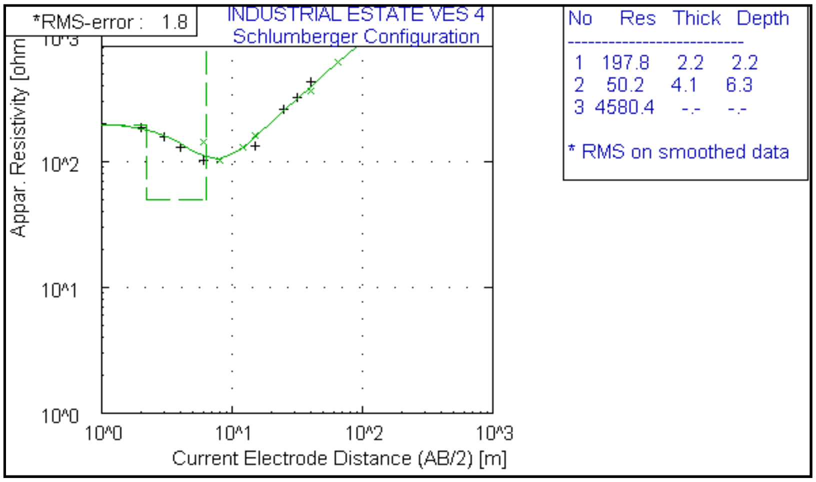
(a) The modeled curve for VES 1



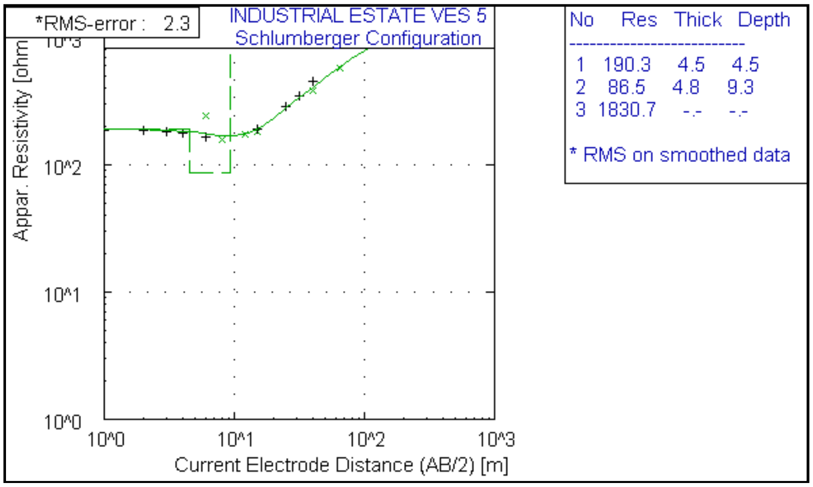
(b) The modeled curve for VES 2



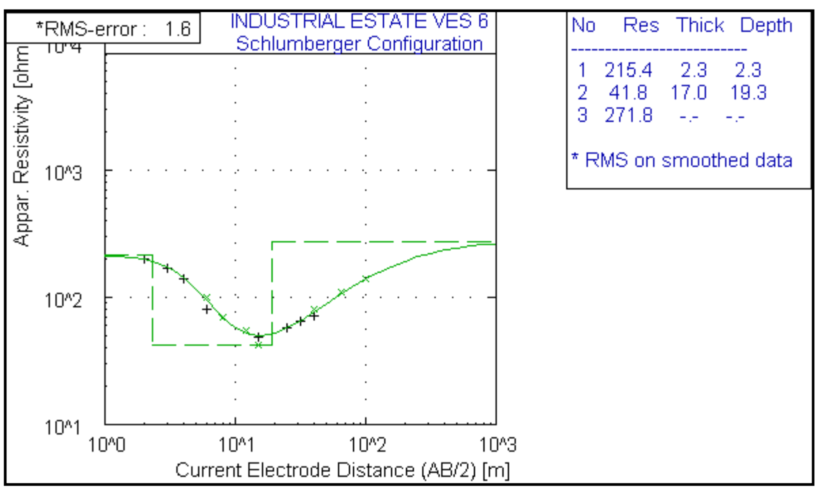
(c) The modeled curve for VES 3



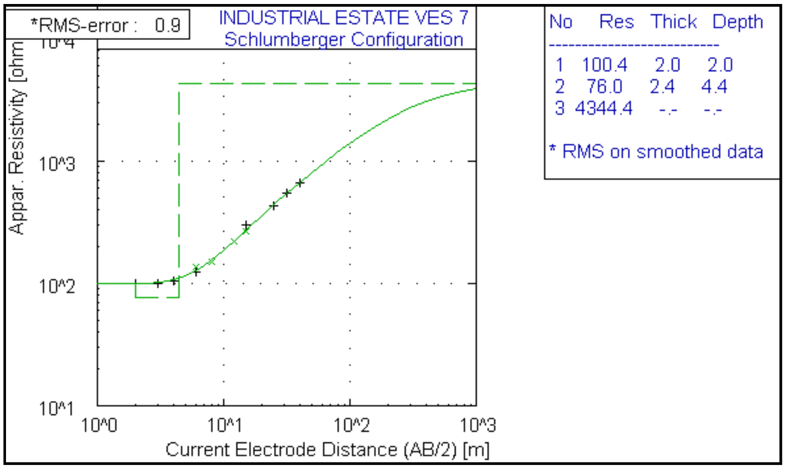
(d) The modeled curve for VES 4



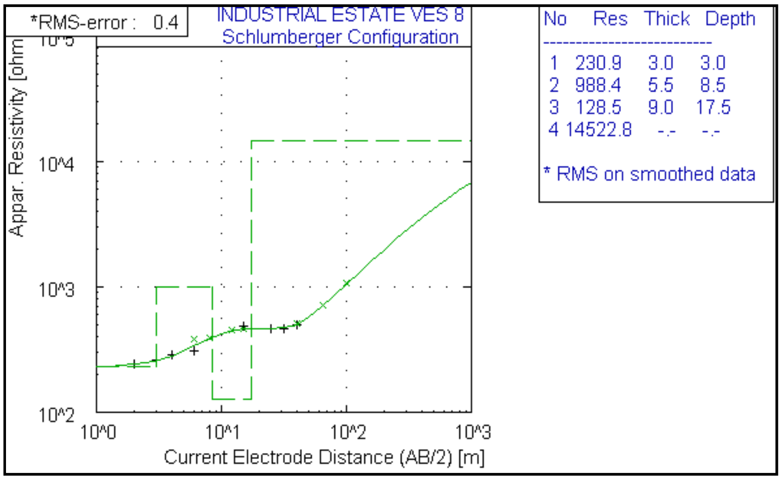
(e) The modeled curve for VES 5



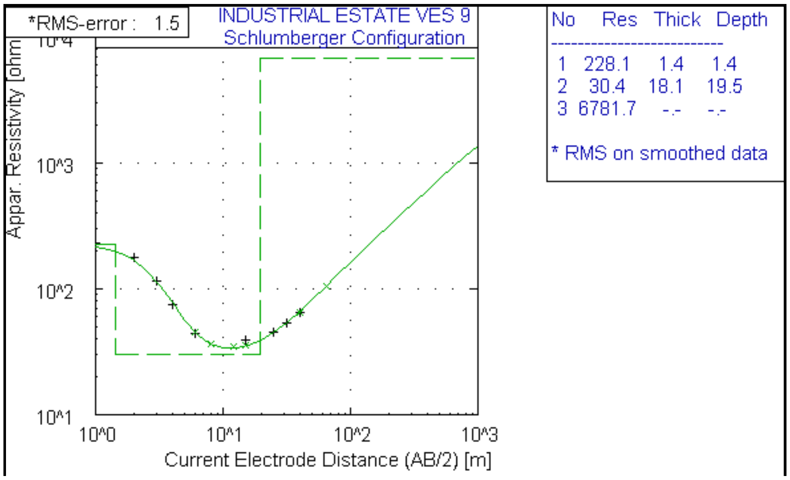
(f) The modeled curve for VES 6



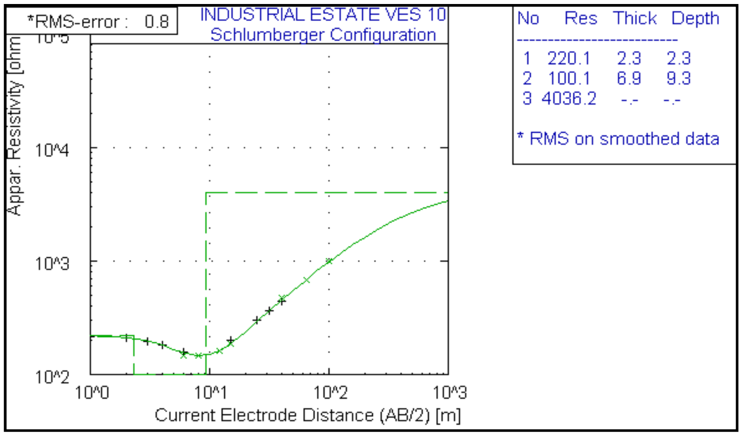
(g) The modeled curve for VES 7



(h) The modeled curve for VES 8



(i) The modeled curve for VES 9



(j) The modeled curve for VES 10

Fig. 3: The modeled curves for VES 1-10

VES 8 and 9) while the remaining 20% of the VES stations have thick overburden and fractured basement rocks (i.e., VES 2 and 6).

From the results, VES 2 and 6 are the best location for groundwater prospect because of the thick overburden and fracture in the basement (Wright, 1990; Meju *et al*., 1999). VES 8 and 9 could be considered as another location for groundwater exploration because Benson and Jones (1988) and Lenkey *et al*. (2005) reported that boreholes should be sited where the regolith is thickest.

Geoelectric sections: From Fig. 2, the 10 VES stations were grouped into 4 profiles (A, B, C and D) according to how convenient they can be located on a straight line to see an image representation of the subsurface. The results of the interpreted VES curves were used to draw 2D geoelectric sections (Fig. 4a to d) along profiles A, B, C and D to show the vertical distribution of resistivity's within the volume of the earth in the investigated area. The sections consist of sequence of uniform horizontal (or slightly inclined) layers (horizons). Each layer (horizon) in a geo-electrical section may completely be characterized by its thickness and true resistivity. The geoelectric sections show both vertical and lateral variations in layer resistivity. One of the importance's of 2D geoelectric sections is that it helps someone to see clearly where there is thin overburden as well as thick overburden within the sounding locations.

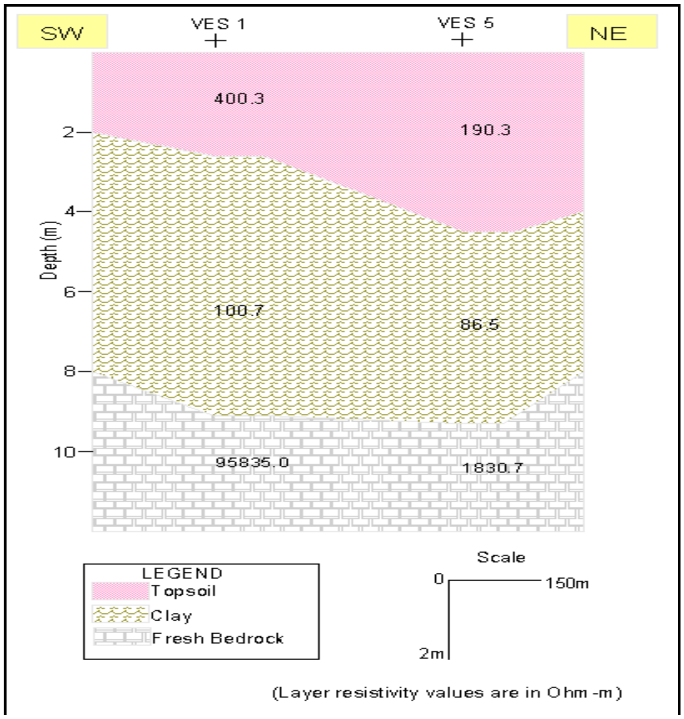
Profile A: A maximum of three subsurface geoelectric units were delineated beneath this profile (Fig. 4a). These include the topsoil which lies above the water table, the clay/partially weathered rock with resistivities of 100.7 and 86.5 Ωm and the fresh bedrock which is highly resistive. Because of the fresh bedrock and thin overburden present in this profile, it is considered as absolutely bad for groundwater prospect.

Profile B: Geoelectric section of profile B showed that it is divided into three regions (Fig. 4b); the topsoil, the clayey layer and the fractured bedrock. The fractured bedrock and thick overburden present in this profile will be helpful in drilling to the aquifer in order to have a sustainable water supply in the industrial estate. Hence, this profile is the best profile to choose for groundwater prospect in industrial estate Ogbomosho.

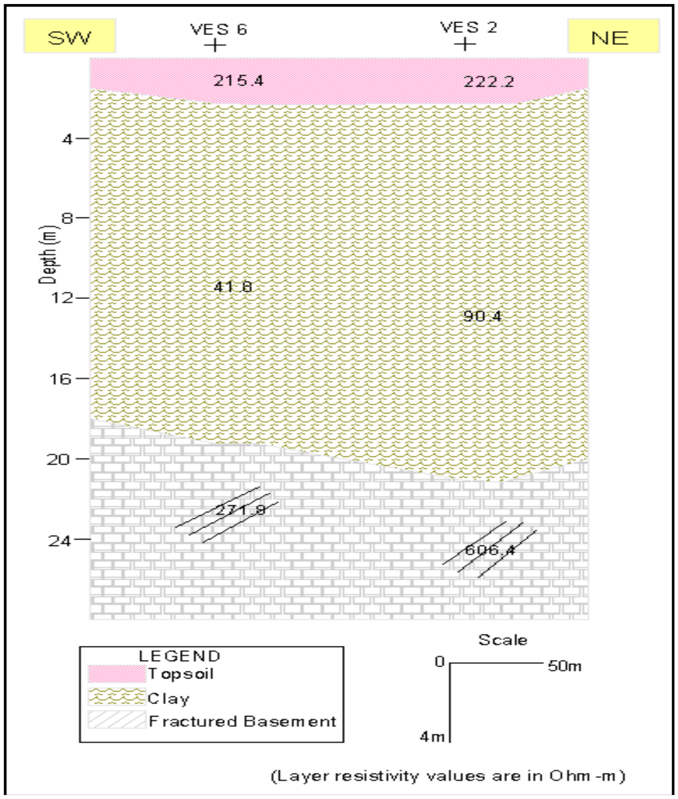
Profile C: Geoelectric sections of profile C resemble that of profile A in that it is divided into three geoelectric units as that of profile A, it has highly resistive bedrock and thin overburden (Fig. 4c). Therefore, the profile is considered as bad for groundwater prospect in industrial estate Ogbomosho.

Profile D: A maximum of three-to-four subsurface geoelectric units were delineated beneath this profile (Fig. 4d). These include the topsoil, the lateritic layer, the clay/partially weathered rock and the fresh bedrock. The bedrock of this profile is highly resistive but possesses thick overburden towards the Northeastern side of the industrial estate, Ogbomosho (i.e., VES 8 and 9). This area could be considered as another favorable zone for groundwater prospect because of its thick overburden (Benson and Jones, 1988; Lenkey *et al*., 2005).

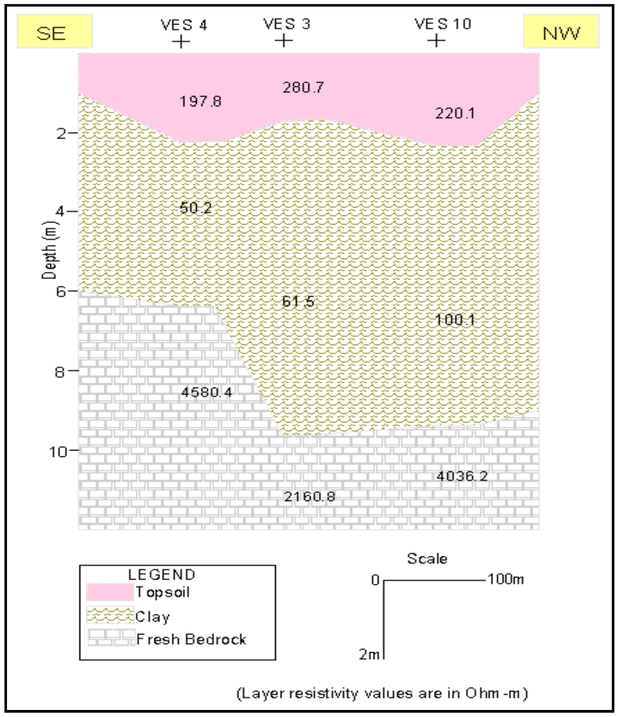
Flow net: From the flow net (Fig. 5), Western, Southwestern and Southeastern part of the industrial estate (i.e., VES 1, 3, 4, 5 and 7, respectively) are found to be discharge zones while Southern and Northeastern


SW
VES 1
VES 5
NE
400.3
190.3
100.7
86.5
95835.0
1830.7
Depth (m)
2
4
6
8
10
LEGEND
Topsoil
Clay
Fresh Bedrock
Scale
0
150m
2m
(Layer resistivity values are in Ohm-m)

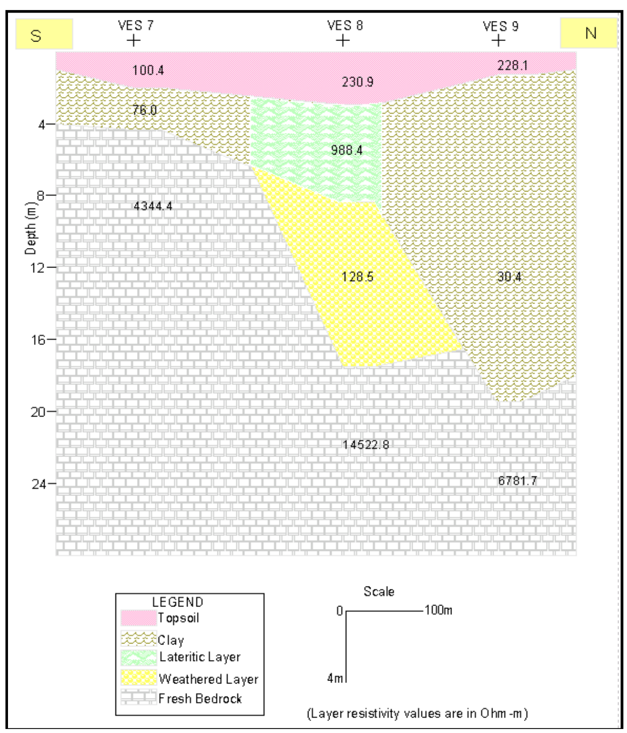
(a)


SW
VES 6
VES 2
NE
215.4
222.2
41.8
90.4
271.9
606.4
Depth (m)
4
8
12
16
20
24
LEGEND
Topsoil
Clay
Fractured Basement
Scale
0
50m
4m
(Layer resistivity values are in Ohm-m)

(b)



(c)



(d)

Fig. 4: (a) Geoelectric section along profile A, SW-NE direction (b) geoelectric section along profile B, SW-NE direction (c) geoelectric section along profile C, SE-NW direction (d) geoelectric section along profile D, S-N direction

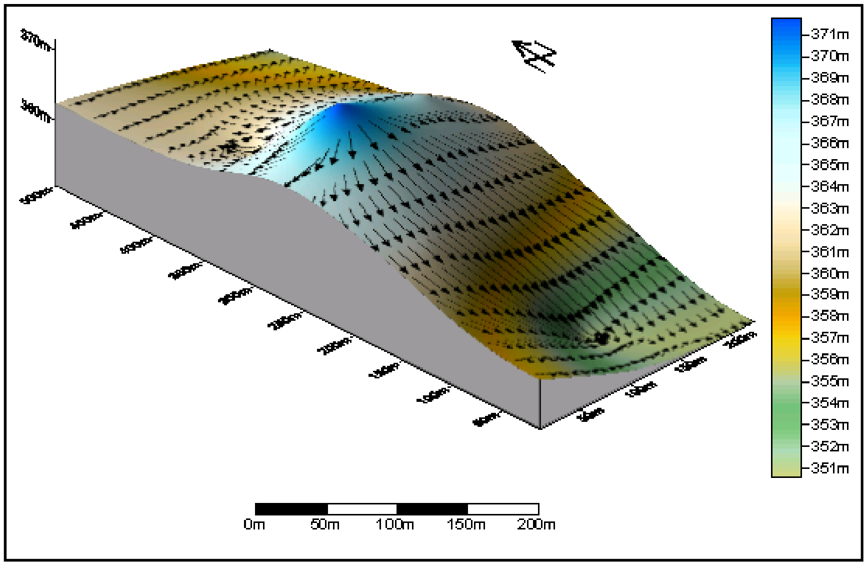


Fig. 5: Flow net of Oyo state industrial estate Ogbomosho

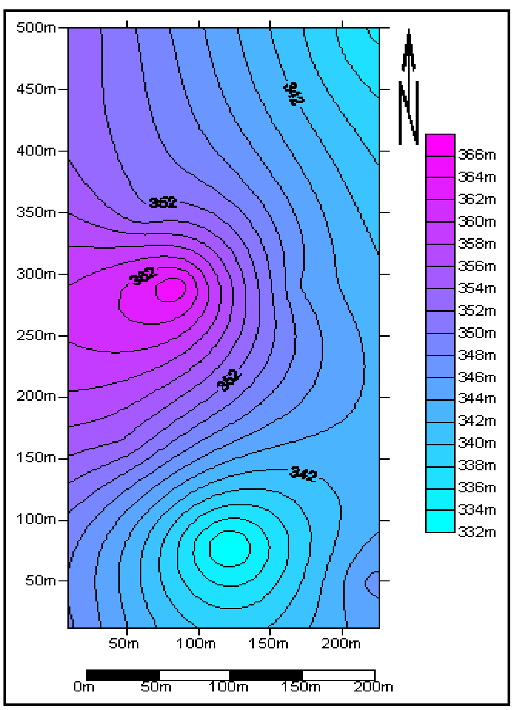


Fig. 6: 2D bedrock relief map

part of the industrial estate (i.e., VES 2, 6, 8 and 9, respectively) are recharge zones. The base of Northwestern part of the estate (VES 10) also showed to be recharge zone. Though, Acworth (1987) reported successful completion of boreholes in shallow weathered zones in a typical basement terrain, in the time of prolonged dry season, there might be insufficient supply of water from this region. Alagbe (2005) reported that some boreholes that were no more yielding in Ladoke Akintola University of Technology Ogbomosho environs were due to drilling of such boreholes in shallow weathered zones.

Bedrock relief map: The bedrock relief map is a contoured map of the bedrock elevations beneath all the VES stations. Figure 6 is 2D plot while Fig. 7 is 3D of the bedrock, respectively. These elevations were obtained by subtracting the overburden thicknesses from the surface elevations at the VES stations. The bedrock relief map generated for the locations shows the subsurface topography of the bedrock across the surveyed area. The hydro geologic significance of bedrock relief has been recognized by Okhue and Olorunfemi (1991), Olorunfemi and Okhue (1992), Olorunfemi *et al.* (1999) and Bala and Ike (2001).

Figure 6 shows low bedrock relief at Southern and Northeastern part while high bedrock relief is shown at Western region of the study area but Fig. 7 shows 3-dimensional image of the bedrock. The map (Fig. 7) shows series of basement lows/depressions and basement highs/ridges. Southern and Northeastern part (i.e., VES 2, 6, 8 and 9, respectively) are the designated areas for the depressions while Western, Southwestern and Southeastern part (i.e., VES 1, 3, 4, 5 and 7, respectively) are ridges zones. The depression zones are noted for thick overburden cover while the basement high/ridge zones are noted for thin overburden cover. Omosuyi and Enikanselu (1999) findings revealed that depressions zone in the basement terrain serves as

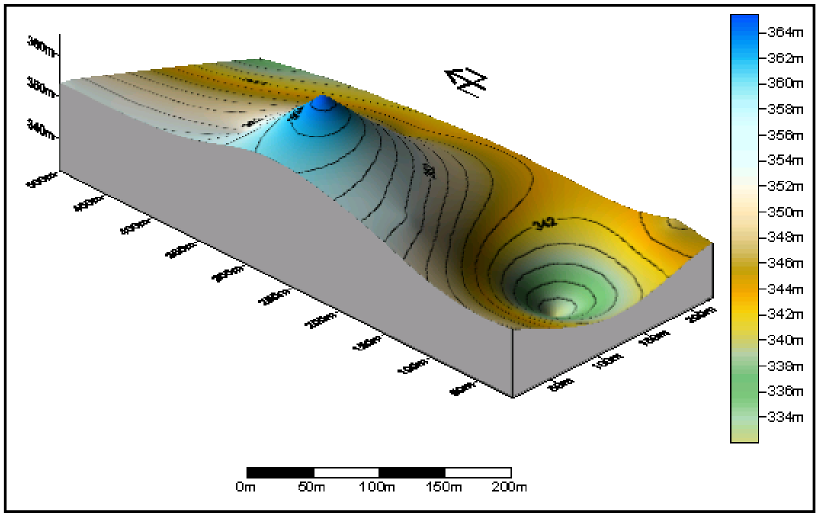


Fig. 7: 3D bedrock relief map

groundwater collecting trough especially water dispersed from the bedrock crests. Thus, the zones with basement depressions are priority areas for groundwater development in the study locations. Though the base of the Northwestern part of the estate (i.e., VES 10) showed a little depression but due to the thin overburden present beneath the station, the water present there might not be able to serve the industrial purposes in the time of prolonged dry season.

CONCLUSION

The study has been able to highlight the importance of resistivity method in effective hydro geologic characterization and groundwater exploration. This study has proved to be quite successful for mapping out rock types, structural formations and fractures which would not have been observed at the surface. The presence of weathered layer and fractured basement are key components of aquifer system and zone of groundwater accumulation in industrial estate, Ogbomosho. A multidimensional approach to the studies (that is modeled curves, geoelectric sections, flow net and bedrock relief maps) has made the study both very qualitative and quantitative as information missed by any of the methods is revealed by the other and thereby necessitating justifiable conclusions.

It can be concluded that the low resistivity and significantly thick weathered rock/clay and the fractured basement constitute the aquifer in this area. Results from this study have revealed that the Southern and Northeastern directions of the study area are good for borehole development. However, the Northwestern region can be considered as fair for borehole development.

It is recommended that detailed work be done in this industrial estate using other relevant geophysical methods so as to confirm the fractures predicted and to elucidate the patterns of the fractures.

ACKNOWLEDGMENT

The authors are grateful to God for the success of this study. Also, two out of the authors (Mr. T.A. Adagunodo and Mr. E.R. Olafisoye) are grateful to the Board of Post Graduate School, Ladoke Akintola University of Technology and Ogbomosho, Nigeria for the financial support to carry out this research.

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