ELECTRICAL RESISTIVITY INVESTIGATION OF SUB-SURFACE TOPOGRAPHY OF RAFIN-BAREDA AS A TOOL FOR GROUNDWATER EXPLORATION IN DUTSEN-WAI, NIGERIA

Supported by tetfund TERTIARY EDUCATION TRUST FUND

M. Umar[1]*, A. L. Ahmed[1], B. Balarabe[1] and A. Adamu[2]

[1]Department of Physics Ahmadu Bello University Zaria, Nigeria

[2]Department of Applied Geophysics, Federal University BirninKebbi, Nigeria

Corresponding author: umardk06@yahoo.com

Received: June 11, 2017 **Accepted:** October 02, 2017

Abstract: Geohydrological investigations are performed to assess the groundwater parameters for locating suitable sites for groundwater exploration and resource management in Rafin-Bareda of Dutsen-wai. Thirty-six vertical electrical soundings (VES) using Schlumberger configurations were carried out at selected locations in the area. The interpretation of sounding data has been accomplished using the software ipi2win. On basis of interpreted sounding results, eight geoelectrical cross sections have been generated along the profiles. The interpretation of data revealed four layers, generally one top thin layer overlying the other three thick layers. Base on the qualitative interpretation of the VES data, it was deducted that VES point 15, 25, 27, and 31 are potential positions for siting boreholes with appreciable thickness of weathered basement (aquiferrous zone) ranging from 7.61 to 28.10 m characterized by structural features that enhance groundwater permeability and storage. Interpreted results are corroborated with the borehole data. The results depict proper hydrological conditions for existence of good aquifers suggesting continued supply of groundwater in the area for extended period.

Keywords: Borehole, groundwater, geoelectrical cross section, vertical electrical sounding

Introduction

Groundwater is very important natural resources for sustainable development of a region (Kumar *et al*., 2014). It is the only viable source of water in many areas where development of surface water is not economically viable (Kumar *et al*., 2014). Water as renewable resource occurs in three forms; liquid, solid and gaseous (Ahilan, 2011). Water is essential for irrigation, industry and domestic purpose. Groundwater is the main source for potable water supply for domestic, industrial and agricultural uses (Ahilan, 2011). The scarcity of groundwater increases day by day due to rapid population, urbanization, industrial and agricultural related activities. The impact of trio on soil and groundwater is alarming with years of devastating effects on humans and the ecosystem (Ehirim, 2010). Study of groundwater geology is much useful for all the activities of human life. Groundwater is more advantageous than the surface water. Water scarcity problem affects the human chain and other living things. To meet out the demand of water, people are depending more on aquifers. Groundwater in alluvial and sedimentary rocks occurs in pore spaces between grains, while in hard rocks, it is largely due to secondary porosity and permeability resulting from weathering, fracturing, jointing and faulting activities (Kumar *et al*., 2014).

The area of investigation is Rafin-Bareda of Dutsen-wai. Therefore, with the aim of examining the groundwater level and locating the potential aquifers for their management, we have performed hydrological investigations at suitably chosen sites in the area. In this study, we have carried out 36 vertical electrical sounding (VES) in the area of study and the result was interpreted to estimate the parameters which may be useful for management of groundwater aquifers in the area.

Location of the study area

The area of the study Rafin-Bareda located near Dutsen-wai Complex (Fig. 1), in Kubau local government of Kaduna State and is located about 64 km NSE of Zaria. It lies between latitude $10^0$51'N to $10^0$55'N and longitude $8^0$13'E to 8^0 15' E on sheet 125 NW of Northern Nigeria survey ordinate map 1966. The Dutsen-wai Complex rises to about 120 m above the surrounding plains (Ahmed, 2006).

Climate and vegetation

The Dutsen-wai area is located on a plateau at a height between 120 and 150 m above sea-level and has a tropical continental climate (Ologe, 1971). The area is characterized by two seasons: wet and dry. The wet season lasts between April and October, with August having the highest precipitation while the dry season extents from November to March.

The mean annual surface temperature varies from about 25 to 35^0C. The temperatures generally fall in July and August periods of the year corresponding to the peak of rainy season, as well as in December and January periods corresponding to the peak of harmattan in the area (Ahmed, 2006). The vegetation here is that of Sudan Savannah characterized by grasses, shrubs, thorns and scattered trees.

Geology of the area

The Dutsen-Wai complex is intruded into an undifferentiated amphibolite grade basement composed of migmatites and granitic gneisses (Ajakaiye, 1974). Three major igneous units common to the younger granite suite make up the exposure and exhibit sharp mutual contacts (Raeburn *et al*., 1927; Turner, 1972; Jacobson and MacLeod, 1977). In chronological order these are volcanics, biotite granite and albiteriebeckite granite. Remnants of an initial volcanic phase are preserved as a narrow outcrop of explosion breccia 600 m long and up to 60 m wide composed entirely of basement rock fragments up to 0.3 m in diameter along the southern flank of the complex (Jacobson and MacLeod, 1977). The main intrusive forms 80% of the exposed complex (Fig. 1) and is nonporphyritic fine to medium-grained biotite granite which has a homogeneous macroscopic texture and composition (Jacobson and MacLeod, 1977). Its well-developed north-northwest joint system controls drainage in the immediate vicinity of its outcrop (Ajakaiye, 1974). The most prominent of these lineations occurs as a broad steep-sided flat-bottomed valley up to 1 km wide containing an underfit stream which drains to the northwest from the central part of the biotite granite exposure (Fig. 1). The biotite granite is the main source of the tin deposits mined on a very small scale in the area although (Raeburn *et al*., 1927) noted that the complex exhibited excessive tin mineralization for its outcrop size. Tin deposits are typically associated with biotite granite throughout the Younger Granite Province. A later intrusion of albiteriebeckite granite, which is poorly exposed, flanks the biotite granite on its east side (Fig. 1). It is extremely variable in texture but is compositionally homogeneous except in the degree of late stage albitization (Jacobson and MacLeod, 1977).

Contacts with the basement rocks to the east are poorly defined. Remnants of aegerine commonly form the cores of riebeckite grains. Several felsitic dikes (mostly biotitemicrogranites) associated with the biotite granite (Jacobson and MacLeod, 1977) cut the granite as well as basement rocks adjacent to the southern and eastern margins of the complex. The sequence of extrusive and intrusive igneous events in the province is well documented (Turner, 1963; 1972) and consists of an initial predominantly acidic volcanic phase accompanied or immediately followed by the formation of a peripheral vertical-sided ring fracture which broke the surface and which was filled, in most cases, with granite porphyry upon subsidence of the rocks interior to the ring fracture. A long waning felsic intrusive phase followed. In the case of the Dutsen-Wai complex, the present outcrop limits give the probable extent of the associated initial ring fracture (Fig. 1). Ring fracture followed by cauldron subsidence is considered to be the major mode of intrusive emplacement for the younger granites and is thought to give rise to plutons roughly circular in plan with generally steeply dipping contacts (Turner, 1963, 1972; Black and Girod, 1973; Jacobson and MacLeod, 1977).

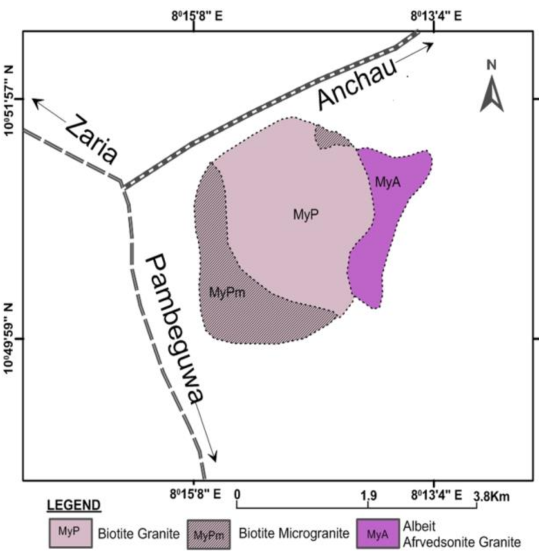

Fig. 1: Geologic map of the study area (Turner *et al*., 1978)

Materials and Method

The geophysical investigation involves the use of vertical electric sounding (VES) method. Vertical electric sounding furnishes information concerning the vertical succession of different conducting zones and resistivities (Ekwe*et al*., 2010). By measuring the electrical resistance to a direct current applied at the surface, this geophysical method can be used to locate fracture zones, faults and other preferred groundwater/contaminant pathways; locate clay, sand channels and locate perched water zones and depth to the bedrock (Sultan, 2012). Thirty-six (36) vertical electric sounding (VES) were carried out in grid point in the village. The schlumberger electrode configuration was utilized. The quantitative interpretation involved partial curve marching technique (Zohdy, 1965) using the *ipi2win* software. The principal instrument used for this survey is the omega terrameter. The resistance readings are displaced on the digital readout screen and then written down on the field report book.

Resistivity measurement

The resistivity method is based on measuring the potentials between one electrode pair while transmitting direct current (DC) between another electrode pair. Resistivity measurements separate the subsurface into different layers base on their resistivity values (Ekwe*et al*., 2010). The depth of penetration is proportional to the separation between the electrodes, in homogeneous ground, and varying the electrode separation provides information about the stratification of the ground.

Figure 2 shows the current and potential difference distribution within a homogeneous isotropic ground in a vertical plane through the current electrodes C1 and C2 and potential electrode $P_1$and P_2. When an external voltage is applied across them, there will be a flow of current through the earth from one electrode C1 to the other, C2. The resistivity method is based on measuring the potential between one electrode pair (P1 and P2, called potential electrodes) while transmitting DC between another electrode pair (C1 and C2) and r_1, r_2, r_3 and r_4 are the electrode separations. The rheostat varies the current I which is measured by the ammeter (A) while the voltmeter (V) measures the potential difference ΔU (Telford *et al*., 1990).

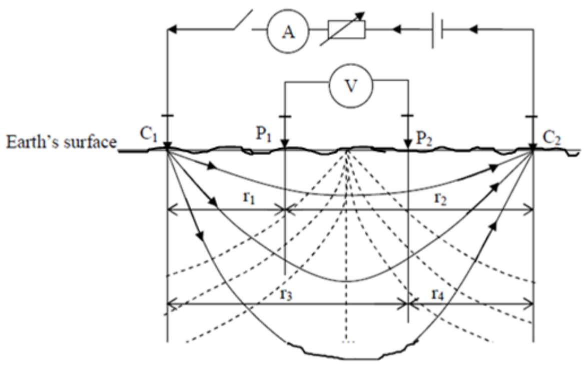

Fig. 2: Current and potential distributions within homogeneous isotropic ground (Telford *et al*., 1990).

Theory for resistivity data acquisition

Schlumberger array was used for the survey. C_1 and C_2 are point current electrodes through which current was driven into the ground while P_1 and P_2 are two potential electrodes to record the potential distribution in the subsurface within the two current electrodes (Fig.2). From Ohm's law, the current I and electric potential U in a metal conductor at constant temperature is related as follows:

$$U = IR \quad (2.1)$$

where R is the constant of proportionality termed resistance and it is measured in ohms. The resistance R, of a conductor is related to its length L and cross sectional area A by;

$$R = \rho L/A \quad (2.2)$$

where ρ is the resistivity and it is a property of the material considered. From equations (2.1) and (2.2),

$$U = I\rho L/A \quad (2.3)$$

The principle underlying the resistivity method is embodied in Ohm's law, which states that the current density at a given point is proportional to the electric field intensity at that point (Telford *et al*., 1990). Thus, Ohm's law gives the relationship between current density J (amperes/m^2) and electric field intensity E (volts/m) as:

$$J = \sigma E \quad (2.4)$$

Where σ is the conductivity of the medium; E is the gradient of a scalar potential U (volts) (Telford *et al*., 1990), i.e.,

$$E = \nabla U \quad (2.5)$$

Putting equation (2.5) into equation (2.4)

$$J = \sigma\nabla U \quad (2.6)$$

From divergence condition,

$$\nabla . J = 0 \quad (2.7)$$

Thus, from equation (2.6)

$$\nabla . J = -\nabla . (\sigma \nabla U) \qquad (2.8)$$

Or

$$\nabla \sigma . \nabla U + \sigma \nabla^2 U = 0 \qquad (2.9)$$

For a homogeneous earth, σ is a constant and since the derivative of a constant is equal to zero, then the first term in equation (2.9) vanishes hence,

$$\nabla^2 U = 0 \qquad (2.10)$$

Vertical electrical sounding (VES)

This is also known as electrical drilling or expanding probe. It is used mainly in the study of horizontal or near horizontal interfaces. In this method the current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed central point. Consequently, readings are taken as the current reaches progressively greater depth.

The measured apparent resistivity values were plotted against electrode spacing values on a log–log graph paper. To interpret the data from such a survey, it was assumed that the subsurface consists of horizontal layers. In this case, the subsurface resistivity changes only with depth, but does not change in the horizontal direction.

Results and Discussion

In many engineering and environmental studies, the subsurface geology is very complex where the resistivity can change rapidly over short distances. The resistivity sounding method might not be sufficiently accurate for such situations. However, the technique is extensively used in geotechnical surveys to determine overburden thickness and also in hydrogeology to define horizontal zones of porous strata.

For better understanding, the results of investigation are usually presented in the form of geoelectrical cross-sections. However, the topsoil and the weathered basement are regarded as the overburden while the bedrock consists of the fracture and the fresh basement rocks (Oladapo, 2013). Therefore, in accordance with above fact, eight geoelectrical cross-sections (Figs. 3 – 10) were performed along a Profile (1 – 8) and will be interpreted as follow:

Profile 1

The geoelectric section of Profile 1 is shown in the Fig. 3. The section indicates a maximum of three geoelectric layers. The profile is 60 m long and has four VES points. The first layer is generally thin and having an average thickness of 1.20 m. Its resistivity value varies from 80 to 155 Ωm. This layer is the top soil which consists of clay and laterite which is similar to that of Shemang, 1990. Underlying this is the second having resistivity value ranging from 254 to 553 Ωm. The resistivity of this layer is lower than that of the second layer. This layer is regarded as the weathered basement. Finally, the third layer on the profile has resistivity value within the range of 397 to 1121 Ωm. From characteristic resistivity of earth materials, the rocks within this area may constitute the fresh basement (Telford *et al.*, 1976).

Profile 2

In this Profile 2 (Fig. 4) the geoelectrical section indicates a maximum of four geoelectric layers. The length of the profile is 60 m with four VES points. The first layer is thin having an average thickness of 1.63 m. Its resistivity value varies from 217 to 1525 Ωm. This layer is the top soil which consists of laterite. Underlying this is the second layer which is thicker than the first layer. Its thickness varies from 1.08 m under VES7 to 7.64 m under VES5. The resistivity of this layer varies from 58 to 1325 Ωm. However, this layer has resistivity value lower than the first. It indicate that the layer consist of sandy clay, and silt sand. Underneath this layer is the third layer with resistivity value ranging from 155 to 285 Ωm. The resistivity of this layer is lower than that of the first and second layer. This layer is regarded as the weathered basement. Finally, the fourth layer on that profile has a resistivity value within the range of 461 to 1724 Ωm. From the resistivity of earth materials, the rocks within this area may constitute the fresh basement (Telford *et al.*, 1976). These results are in agreement with of Saminu (1999).

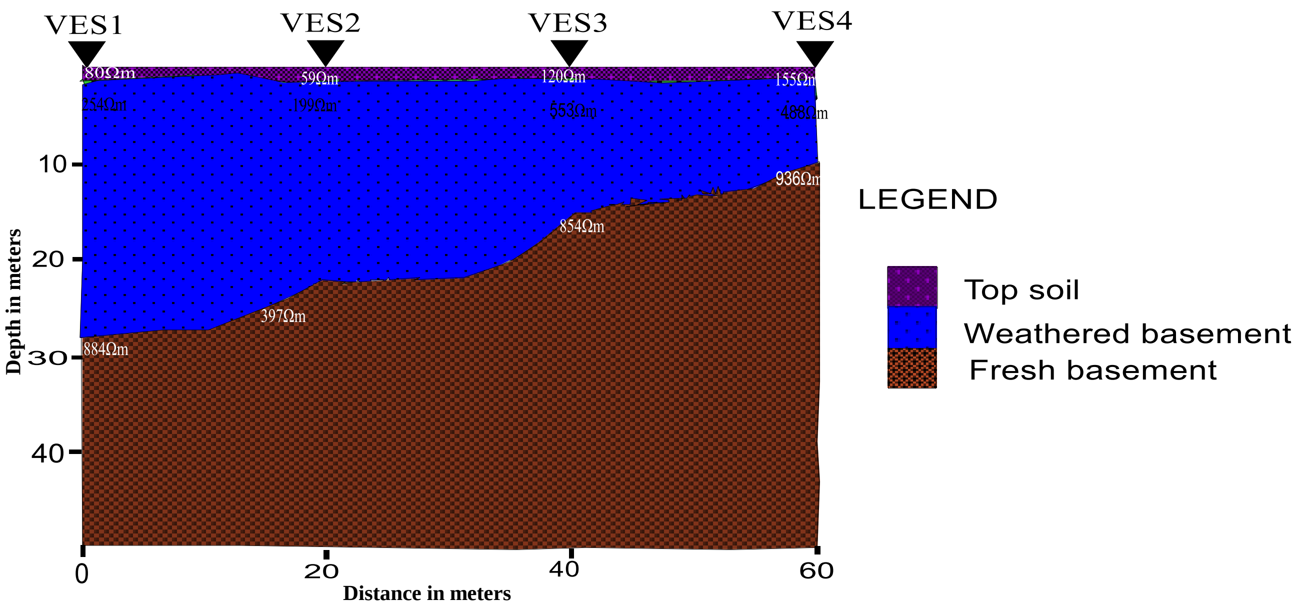

Fig. 3: Geoelectrical cross-section along Profile 1

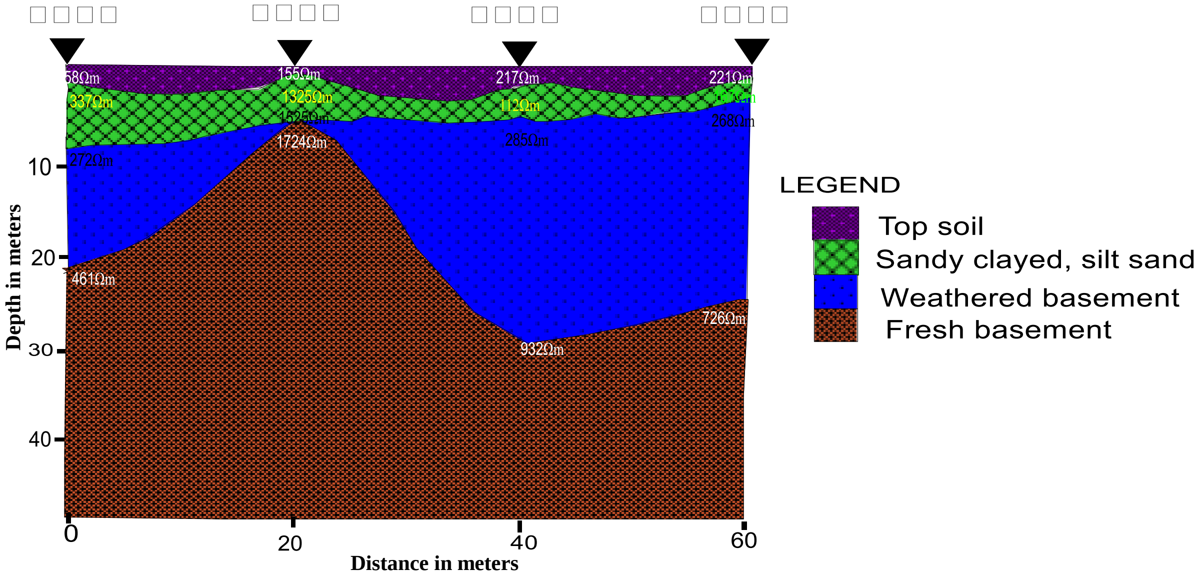

Fig 4: Geoelectrical cross-section along Profile 2

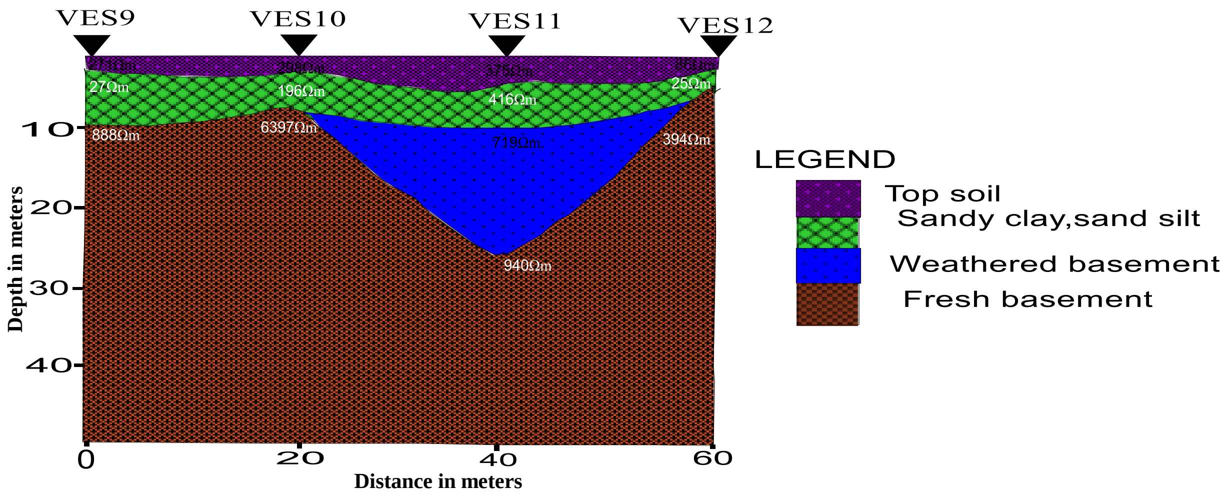

Fig. 5: Geoelectrical cross-section along Profile 3

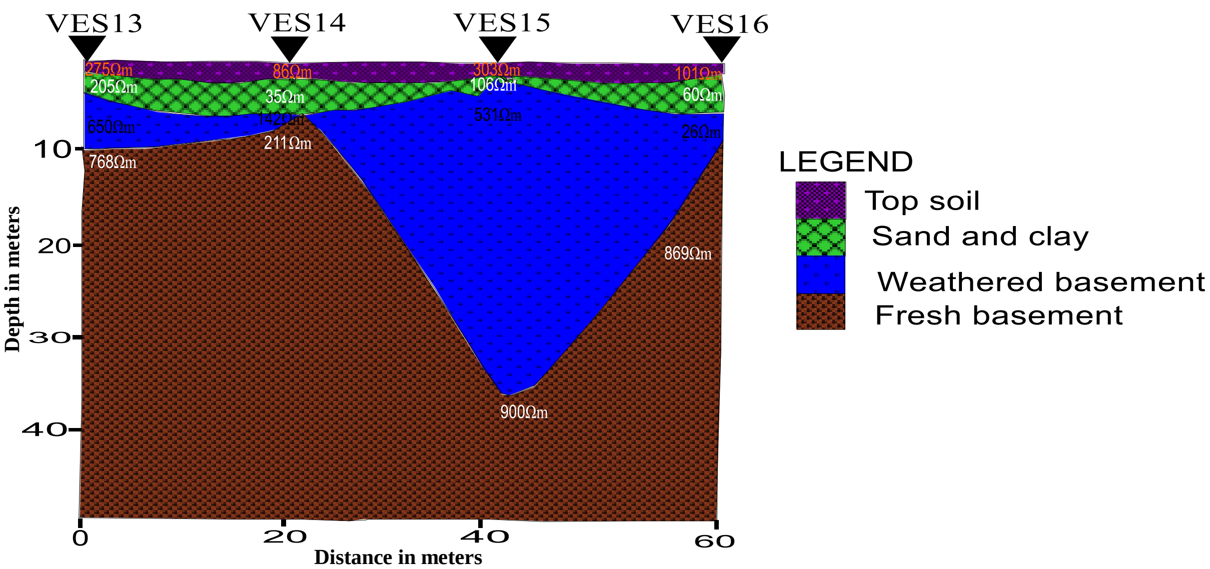

Fig. 6: Geoelectrical cross-section along Profile 4.

Profile 3
A maximum of four geoelectric layers are delineated in this Profile 3 (Fig. 5). The first layer has average thickness of about 2.10 m. Its resistivity value varies from 85 to 375 Ωm. This layer is the top soil which consists of sandy clay and silt sand. The second layer has average thickness of 6.10 m. It has resistivity value ranging from 25 to 416 Ωm. The layer is clay, sand and silt. Underneath this layer, is the third layer having resistivity value of 416 to 719 Ωm as obtained by Saminu (1999). However, this layer is not present under VES9, VES10 and VES12. This layer is the weathered basement. Finally, the fourth layer is the fresh basement from characteristic resistivity values of earth material and has a resistivity value ranging from 394 to 6397 Ωm (Telford *et al.,* 1976).

Profile 4
The Profile 4 (Fig. 6) is a combination of different layers ranging from a minimum of two to a maximum of four. The first layer has an average thickness of about 1.20 m. Its resistivity value range from 85 to 303 Ωm. This layer is the top soil which consists of sandy clay and silt sand. The second layer has a thickness of 0.79 m under VES15 to 3.94 m under VES16. It has resistivity value ranging from 35 to 205 Ωm. This value of resistivity is within the range of resistivity of clay and silt. Underneath this layer, is the third layer having resistivity value ranging from 25 to 650 Ωm. This layer is regarded as the weathered basement which identified the aquiferrous zone with characteristic low resistivity value and thick overburden. Finally, the fourth layer is the fresh basement and has a resistivity value ranging from 211 Ωm to 900 Ωm (Telford *et al.,* 1976).

Profile 5
The results of geoelectric section of Profile 5 shown in Fig.7 indicate a maximum of three geoelectric layers. The profile consists of five VES point with 80 m length. The first layer is generally thin having an average thickness of 1.40 m. Its resistivity value varies from 402 to 788 Ωm. This layer is the top soil which consists of laterite. Underlying this is the second layer which is thicker than the first, this layer having resistivity value ranging from 107 Ωm to 913 Ωm. This layer is regarded as the weathered basement. Finally, the third layer on the profile has resistivity value within the range of 560 to 949 Ωm. And from characteristics resistivity of earth materials, the rocks within this area may constitute the fresh basement (Telford *et al.,* 1976).

Profile 6
The length of Profile 6 (Fig. 8) is 80 m of five VES points with four geoelectric layers. The first layer is generally thin having an average thickness of 1.80 m. Its resistivity value varies from 102 to 679 Ωm. This layer is the top soil which consists of laterite. Underlying this is the second layer which is thicker than the first. Its thickness varies from 1.45 m under VES24 to 4.59 m under VES25. The resistivity of the layer varies from 24 to 704 Ωm. This layer consists of sand silt and laterite. Underneath this layer is the third layer having resistivity value ranging from 27 to 769 Ωm. This layer is regarded as the weathered basement which identified the aquiferrous zone with characteristic low resistivity value and thick overburden. Finally, the fourth layer on the profile has resistivity value within the range of 796 to 965 Ωm. This result is in conformity with the work of Saminu (1999). And from characteristic resistivity of earth materials, the rocks within this area may constitute the fresh basement (Telford *et al.,* 1976).

Profile 7
The Profile is 80 m long and having five VES point. The first out of four layers in profile 7 (Fig.8) is generally thin having an average thickness of 1.83 m. Its resistivity value varies from 80 to 632 Ωm. This layer is the top soil which consists of sand, silt and laterite. Underlying this is the second layer which is thicker than the first. Its thickness varies from 0.64 m under VES30 to 2.91 m under VES29. The resistivity of the layer varies from 19 to 748 Ωm. This layer consists of clay and gravel. Underneath this layer is the third layer having resistivity value ranging from 27 to 769 Ωm. This layer is regarded as the weathered basemen which identified the aquiferrous zone with characteristic low resistivity value and thick overburden t. Finally, the fourth layer on the profile has resistivity value within the range of 704 to 989 Ωm (Shemang, 1990). From characteristic resistivity of earth materials, the rocks within this area may constitute the fresh basement (Telford *et al*., 1976).

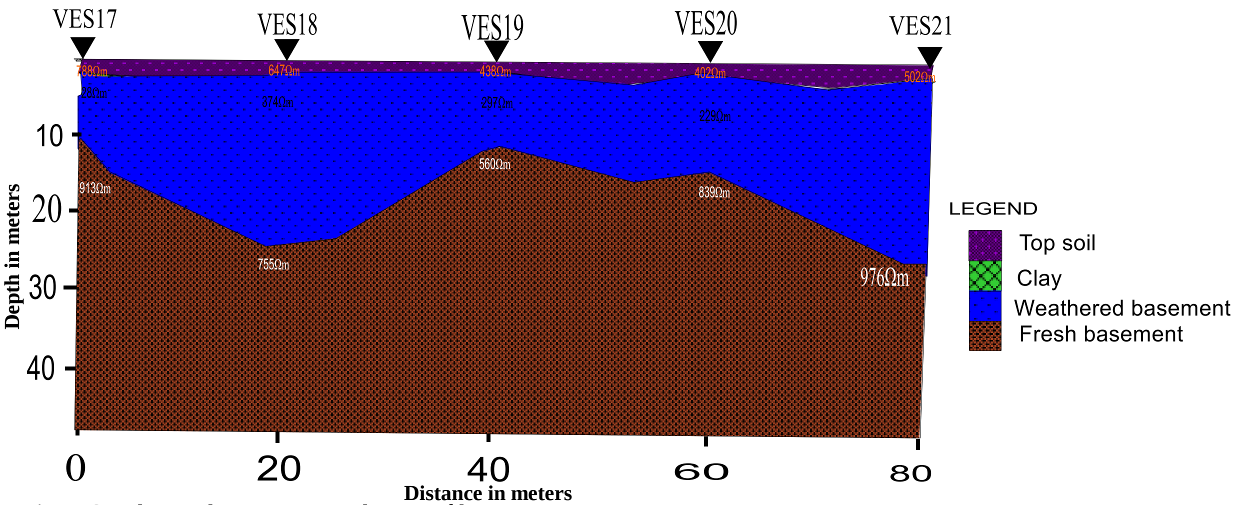

Fig. 7: Geoelectrical cross-section along Profile 5

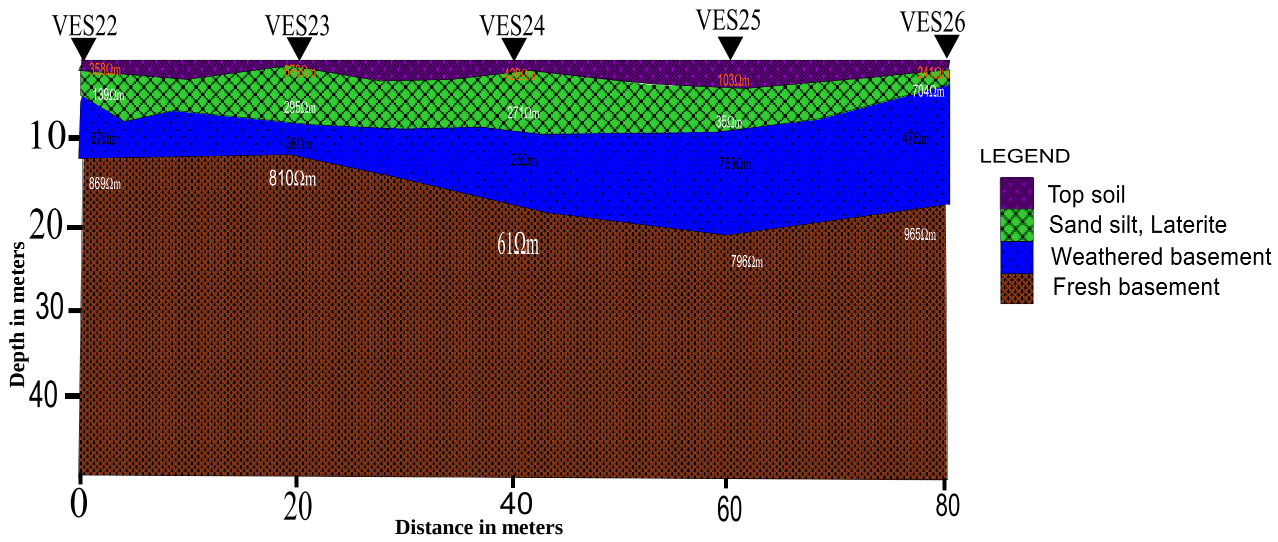

Fig. 8: Geoelectrical cross-section along Profile 6.

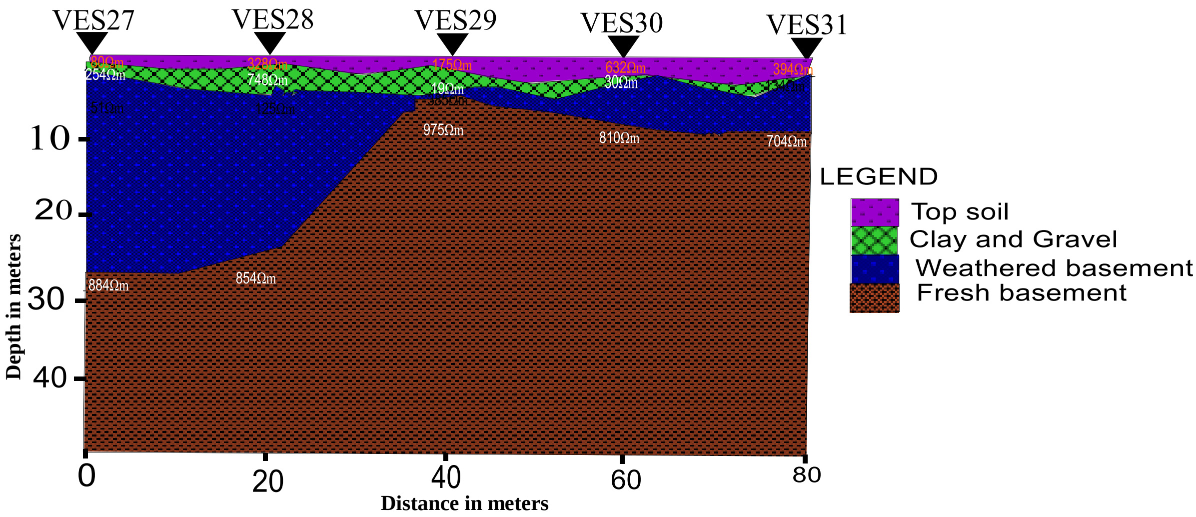

Fig. 9: Geoelectrical cross-section along Profile 7

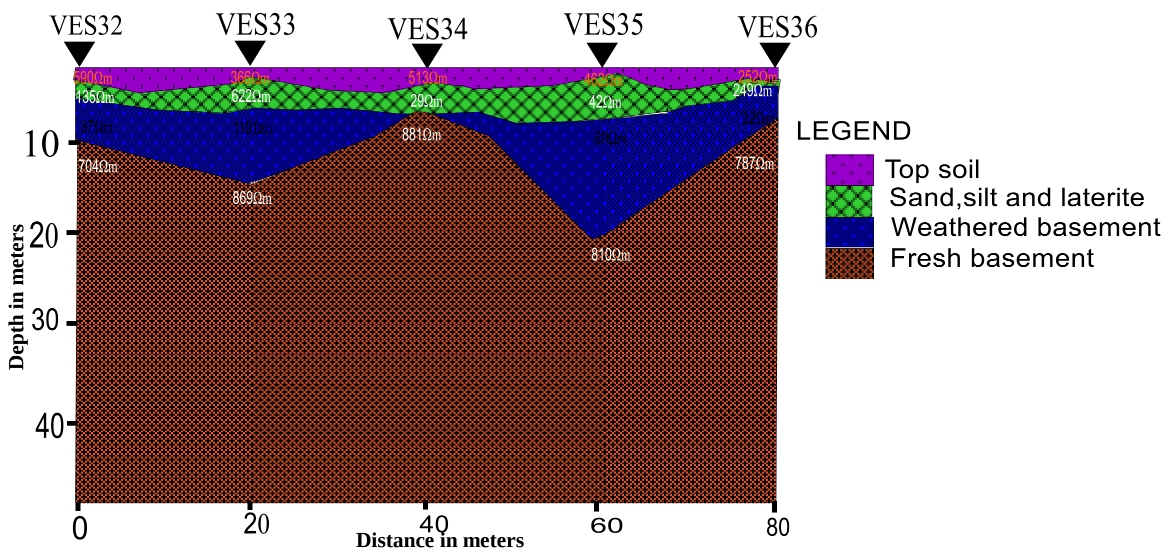

Fig. 10: Geoelectrical cross-section along Profile 8.

Profile 8

The geoelectric section of Profile 8 shown in Fig. 10 indicates a maximum of four geoelectric layers. The profile is 80 m long and having five VES point. The first layer is generally thin having an average thickness of 1.45 m. Its resistivity value varies from 252 to 590 Ωm. This layer is the top soil which consists of laterite. Underlying this is the second layer which is thicker than the first. Its thickness varies from 1.37 m under VES36 to 4.06 m under VES34. The resistivity of the layer varies from 29 to 622 Ωm. This layer consists of sand, silt and laterite. Underneath this layer is the third layer having resistivity value ranging from 22 to 881 Ωm. This layer is regarded as the weathered basement which identified the aquiferrous zone with characteristic low resistivity value and thick overburden. Finally, the fourth layer on the profile has resistivity value within the range of 704 to 869 Ωm. From characteristic resistivity of earth materials, the rocks within this area may constitute the fresh basement (Telford *et al.*, 1976).

Conclusion

The use of surface geoelectric measurements provides a method to study groundwater conditions of an area. Four geoelectric units commonly identified in the environment namely the topsoil, sandy/clayed layer, weathered basement and fresh basement has also been delineated. The zones of basement depressions with resultant significant overburden thickness constitute target areas for groundwater development in town. Thus, the weathered basement constitutes aquifer units in some areas; the fracture basement rocks constitute aquifer units in few others while combination of the weathered and fractured basement constitutes aquifer units in some others. The types of aquifer units observed from this research work represent deep groundwater. The resistivity of these layers varies due to variation in the moisture content and type of soil layer. Below the top layer, the clayed formation is present with varying thickness in some part of the area.

Base on the qualitative interpretation of the VES data, it is deducted that VES point 15, 25, 27, and 31 are potential positions for siting boreholes with appreciable thickness of weathered basement (aquiferrous zone) ranging from 7.61 m to 28.10 m characterized by structural feactures that enhance groundwater permeability and storage.

These results can be used as preliminary information for further potential assessment and management of groundwater for sustainable development in the area.

References

Ahilan J &Senthil Kumar GR 2011. Identification of aquifer zones by VES method: A case study from Mangalore block, Tamail Nadu, S. India, *Archives of Appl. Sci. Res*., 3: 414- 421.

Ahmed AL 2006. Detailed Radiometric survey of the AlbiteRiebeckite granites of Dutsen-wai ring Complex. Unpublished Ph.D. Thesis, Department of Physics, Ahmadu Bello University, Zaria.

Ajakaiye DE & Sweeny JF 1974. Three dimensional gravity interpretation of the Dutsen-wai complex. Nigerian younger granite province. *Tectonophysics, Elsevier Scientific Publishing Company, Amsterdam*, 24: 331-341.

Black R &Girod M 1973. Late Paleozoic to Recent igneous activity in West Africa and its relationship to basement structure. In: TN Clifford and IGGass (Editors), African Magmatism and Tectonics. Oliver and Boyd, Edinburgh, pp. 185-210.

EhirimCN&NwakwoCN 2010. Archves of physics Research. Vol. 2: pp. 396-403.

Ekwe AC, Nnodu IN, Ugwumbah KI &Onwuk OS 2010. Estimation of aquifer hydraulic characteristics of low permeability formation from geosounding data: A case study of Oduma town, Enugu State Nigeria.*Medwell Journals*, 4: 19-26.

Jacobson, R. R. E. and Macleod, W. N. (1977). Geology of Liruei, Banke and adjacent Younger granite ring complexes. Geological Survey of Nigeria Bulleting 33: 1-117.

Kumar R, Tiwari AK, YadavGS& Singh NP 2014. Geohydrological Investigation using vertical Electrical Sounding at Banaras Hindu University Campus, Varansi, UP India. *Int. J. Res. Engr. &Techn.*, 3: 252-256.

Oladapo MI 2013. Hydro-geoelectric study of Ijare town Southwestern Nigeria. *Int.J. Water Reso. &Envtal. Engr.*, 5: 687-696.

Ologe M 1971. Geomorphology of Zaria and its region, Department of Geography occasional paper, Ahmadu Bello University, Zaria.

Raeburn C, Bain ADN& Russ W 1927. The tinfields of Zaria and Kano provinces. *Geol. Surv. Niger. Bull*., 11.

Saminu O 1999. Geophysical Investigation of Federal College of Education, Zaria. Unpublished M.Sc. Thesis. Department of Physics, Ahmadu Bello University, Zaria.

ShemangEM 1990. Electric Depth Sounding at selected Well Sites within Kubani River Basin Zaria. Unpublished M.Sc. Thesis. Department of physics, Ahmadu Bello University, Zaria.

Sultan ASA 2012. Groundwater Management by Using Hydro- Geophysical Investigation: Case Study: An Area Located at North Abu Zabal City, Hydrogeology - A Global Perspective, Dr. Gholam A. Kazemi (Ed.), ISBN: 978-953-51 0048-5, InTech, Available from:http://www.intechopen.com/books/hydrogeology a global- perspective/groundwater-management-by-using-hydro-geophysical- investigation-case-study-an-arealocated-at-north.

Telford WM, Geldart LP, Sheriff RE & Keys DE 1976. *Applied Geophysics* London: Cambridge University Press.

Telford WM, Geldart LP & Sheriff RE 1990. *Applied Geophysics* second edition Cambridge University Press London, pp. 522-525.

Turner DC 1963. Ring structures in the Sara-Fier younger granite complex, northern Nigeria. *Q. J. Geol. Sot., London*, 119: 345-366.

Turner DC 1972. Structure and tectonic setting of the younger granite ring complexes of Nigeria and southern Niger, Part I: ring complexes and their component units. *Savanna*, 1: 223-236.

Turner DC, Bowden P, BagnettJN, Ike EC, Abaa SI, Kinnaird JA, Abernethy CA, Badejoko TA &Moyes AB 1978. The northern Nigeria Ring Complexes. St. Andrews University Younger Granite Research Group (1973-1978).

Zohdy A 1965. The auxiliary point method of electrical sounding interpretation, and its relationship to the Dar Zarrouk parameters. *Geophysics*, 30(4): 644-660.