International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Online International Journal Available at http://www.cibtech.org/jgee.htm
2013 Vol.3 (2) May-August, pp.57-67/Oluwaseun et al.
Research Article

EVALUATION OF AQUIFER PROTECTIVE CAPACITY OF GROUND WATER RESOURCES WITHIN AFE BABALOLA UNIVERSITY, ADO – EKITI, SOUTHWESTERN NIGERIA

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ABSTRACT
Many investigation techniques are commonly employed with the aim of estimating the spatial distribution of transmissivity and protective capacity of groundwater resources. Unfortunately, the conventional methods for the determination of hydraulic parameters such as pumping tests, permeameter measurements and grain size analysis are invasive and relatively expensive. A non-invasive and less-expensive geoelectric investigation involving vertical electrical sounding was carried out in some parts of the campus of Afe Babalola University, Ado Ekiti and Ekiti State, Nigeria. A total of fifty-nine (59) vertical electrical sounding (VES) data were acquired using R 50 D.C. Resistivity meter within the campus which is underlain by the Precambrian basement rock of southwestern Nigeria. Following the interpretation of the VES data, maps and 2D-sections were generated. The geoelectric sections enabled the subsurface to be characterized into five geoelectric layers namely: Topsoil, clayey/sandy-clay, weathered layer, fractured basement and basement. The assessment and analysis of the materials above the aquifers showed that longitudinal conductance (S) values ranged from 0.08438 to 0.73449 mhos; thus classifying the area into weak (0.1 – 0.19 mhos), moderate (0.2 – 0.69 mhos) and good protective capacity(> 0.7 mhos). The major aquifer delineated is the weathered/fractured basement aquifers. The aquifers are characterized by thick overburden, moderate/good protective capacity and also exhibit moderate to relatively high value coefficients of anisotropy and low transverse unit resistance which suggests that the materials above the aquifers act as seal, thus protecting the major aquiferous units, the aquifer matrix itself being relatively permeable. Areas with weak protective capacity are therefore vulnerable to infiltration of polluting fluid.

Key Words: *Basement Aquifer, Dar-Zarrouk Parameters, Aquifer Protective Capacity, Overburden, Geoelectric Section*

INTRODUCTION
Groundwater exploration within the basement complex rocks of Africa is usually carried out with the use of Vertical Electrical sounding (VES) (Palacky, 1989; Benson and Jones, 1988).
This is because the successful exploitation of basement terrain groundwater requires a scrupulous understanding of the hydrogeological characteristics of the aquifer units viz-a-viz its susceptibility to environmental pollution. This is particularly important in view of the localized nature of the basement aquifers (Satpatty and Kanugo, 1976).
Water is essential for life. It had been and will continue to be a hot topic in both the political and scientific arena for years to come (Miller, 2006). The most probable use of the electrical resistivity survey is in hydrogeological investigation in relation to aquifer delineation, lithologic boundaries and geological structures to provide subsurface information (Bose *et al.,* 1973).
The method has been used extensively in groundwater investigation in the basement complex terrains (Barongo and Palacky, 1991; Olayinka and Olorunfemi, 1992; Olorunfemi *et al.,* 1993; Omosuyi, 2000) and also in the sedimentary basins (De Beer and Blume, 1985; Mbonu *et al.,* 1991; Shemang, 1993). Hence, drilling programmes for groundwater development in areas of basement terrain are generally

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preceded by detailed geophysical investigation areas of basement terrain are generally preceded by detailed geophysical investigations.

This discontinuous nature of the basement aquifer system makes detailed knowledge of the subsurface geology, its weathering depth and structural disposition through geologic and geophysical investigations inevitable (Adiat *et al.*, 2009).

The study area is underlain by Precambrian basement complex rocks. These rocks are inherently characterized by low porosity and near negligible permeability. The highest groundwater yield in basement terrains is found in areas where thick overburden overlies fractured zones.

Afe Babalola University, Ado-Ekiti (ABUAD) is a fast growing private University in Nigeria. The continuous increase in population and the progressive infrastructural development within the campus daily emphasize the need for the development of a sustainable water supply network. The University has spent fortunes in purchasing water to ensure that the daily demand for potable water on the campus is met. ABUAD is underlain by the Basement Complex Rocks of Southwestern Nigeria.

Study Location and Geology

The study area is located within Latitude 840700 and 841710 and Longitude 753800 and 755080 in Universal Traverse Mercator (UTM). It is situated directly opposite the Federal Polytechnic Ado-Ekiti, along Ijan-Ekiti road. The topography is approximately flat with elevation ranging from 1167 to 1230 ft above sea level. Part of the Campus is drained by River Ogbese. The geology of the study area can be explained within the context of the geology of the Precambrian basement Complex of southwestern Nigeria which form a part of the basement complex of Nigeria (Rahaman, 1976). The major rock type within the area is typically Migmatite-gneiss comprising of undifferentiated granite, charnockitic rocks, medium to coarse granite and migmatite gneiss rocks (Figure 1). The vegetation in the area is of rainforest type, characterized by short dry season and long wet season, with high annual rainfall of about 1,300 mm. Annual mean temperature is between 180^{o}C and 330^{o}C with relatively high humidity (NIMET, 2007).

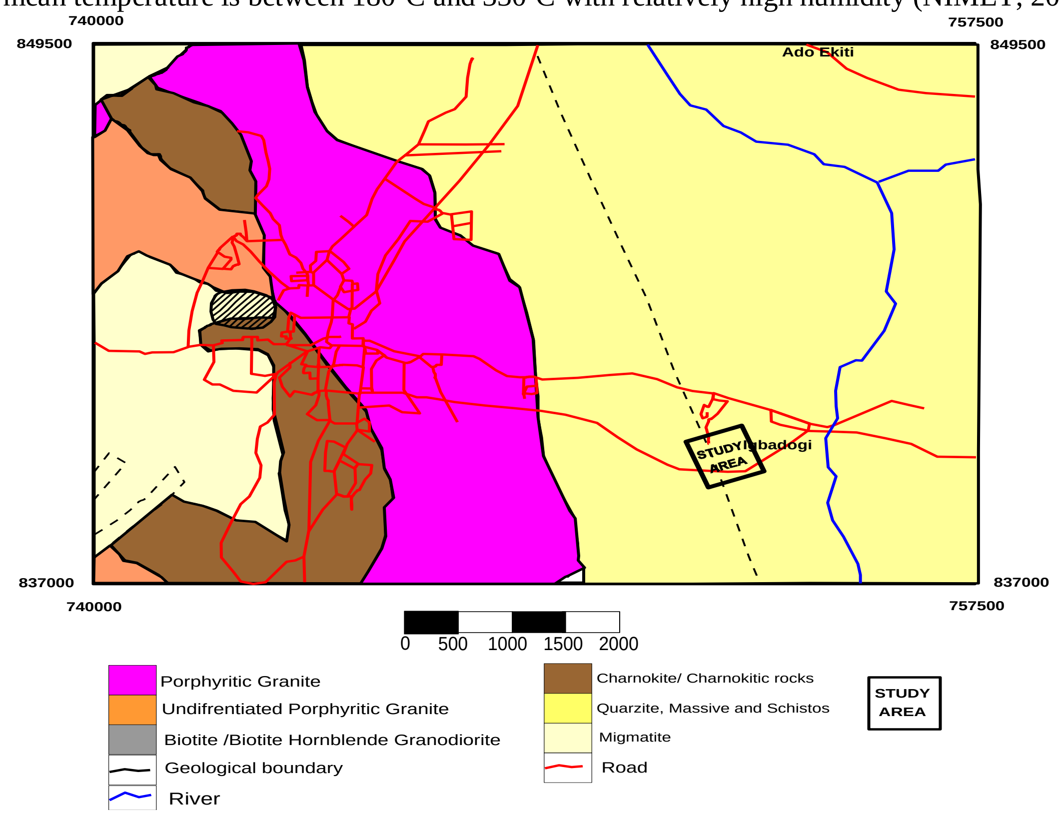


Figure 1: Geological map of Ado Ekiti showing the study area

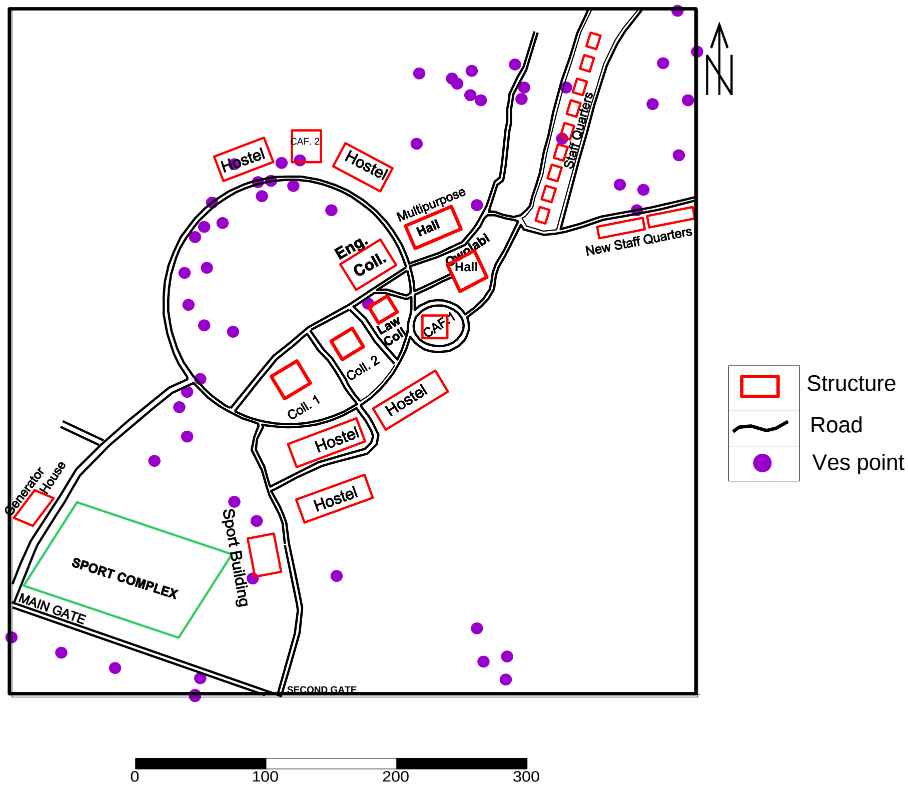


Figure 2: Base map of the study area showing VES points

MATERIALS AND METHODS

The geophysical data was acquired with the R-50 D.C. resistivity meter which contains both the transmitter unit, through which current enters the ground and the receiver unit, through which the resultant potential difference is recorded. Other materials include: two metallic current and two potential electrodes, two black coloured connecting cable for current and two red coloured cable for potential electrodes, two reels of calibrated rope, hammer for driving the electrodes in the ground, compass for finding the orientation of the traverses, cutlass for cutting traverses and data sheet for recording the field data. The Schlumberger array was adopted. The electrode spread of AB/2 was varied from 1 to a maximum of 150 m. The expected depth of investigation was (D) = 0.125 L, where L = AB/2 and AB the current electrode separation. Sounding data were presented as sounding curves, by plotting apparent resistivity against AB/2 or half the spread length on a bi-log paper.

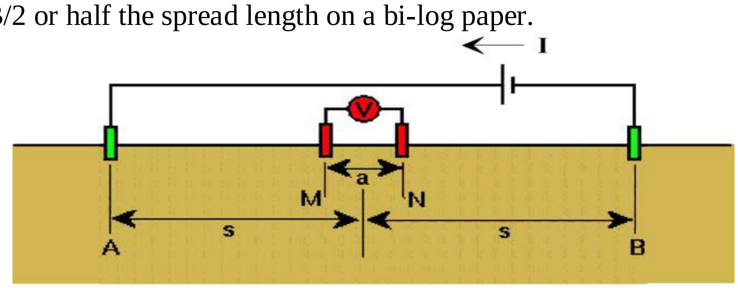


Figure 3: Sketch diagram of Schlumberger array

The models obtained from the manual curve matching interpretations were used for computer iteration to obtain the true resisitivity and thickness of the layers. Computer-generated curves were compared with corresponding field curves by using a computer program "Resist" version 1.0. The software was further used for both computer iteration and modeling. Computer iteration of between 1to29 were carried out to reduce errors to a desired limit and to improve the goodness of fit.

The Dar-Zarrouk parameters are obtained from the first order geoelectric parameters (layer resistivities and thicknesses) these include the Total longitudinal unit conductance (S), Total transverse unit resistance (T), and coefficient of anisotropy (λ). These secondary geoelectric parameters are particularly important when they are used to describe a geoelectric section consisting of several layers (Zhody *et al.*, 1974). For n layers, the total longitudinal unit conductance is:

$$S = \sum_{i=1}^{n} \left(\frac{h_i}{\rho_i}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$T = \sum_{i=1}^{n} \rho_i h_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\lambda = \left(\frac{\rho_T}{\rho_L}\right)^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where ***hi*** is the layer thickness, $\boldsymbol{\rho_i}$ is layer resistivity while the number of layers from the surface to the top of aquifer, (*i)* varies from 1 to n. Electrical anisotropy is a measure of the degree of inhomogeneity (Billings, 1972; Maliek *et al.*, 1973) in a basement terrain; which arises from near surface effects, variable degree of weathering and structural features such as faults, fractures, joints, foliations, and beddings. These in turn are responsible for creating secondary porosity (Φs) and hence effective porosity (Φe).

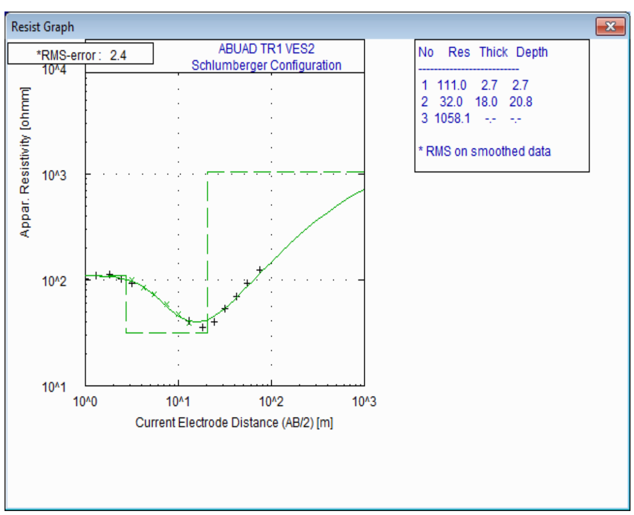
Table 1: Modified longitudinal conductance/protective capacity rating

Longitudinal conductance(mhos)	Protective capacity rating
>10	Excellent
5 - 10	Very good
0.7 - 4.9	Good
0.2 - 0.69	Moderate
0.1 - 0.19	Weak
<0.1	Poor

RESULTS AND DISCUSSION

Sounding Curves and Aquifer Types

(a)



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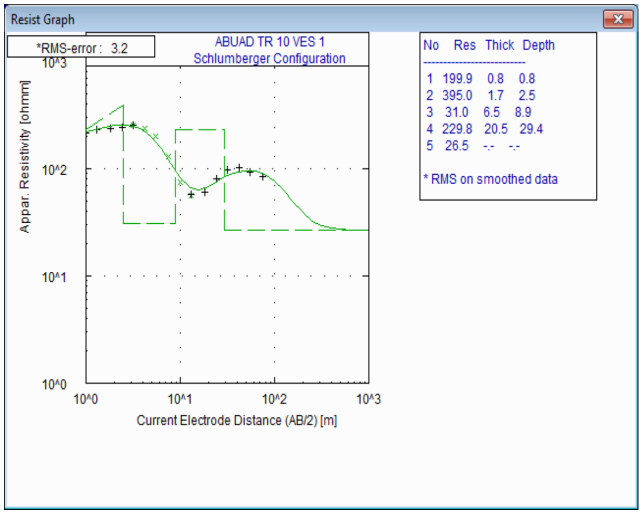
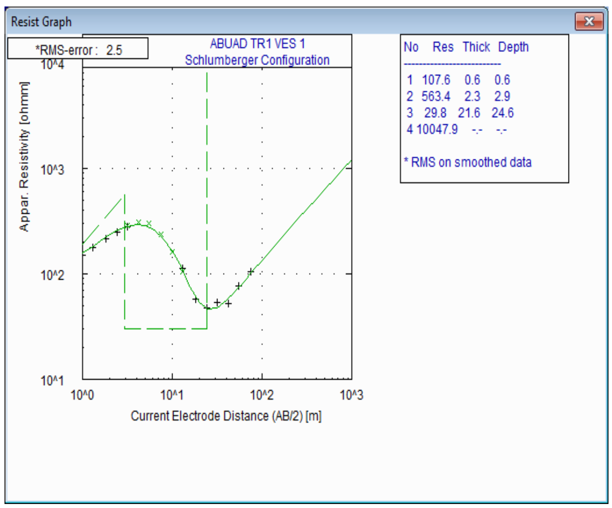
(b)



(c)



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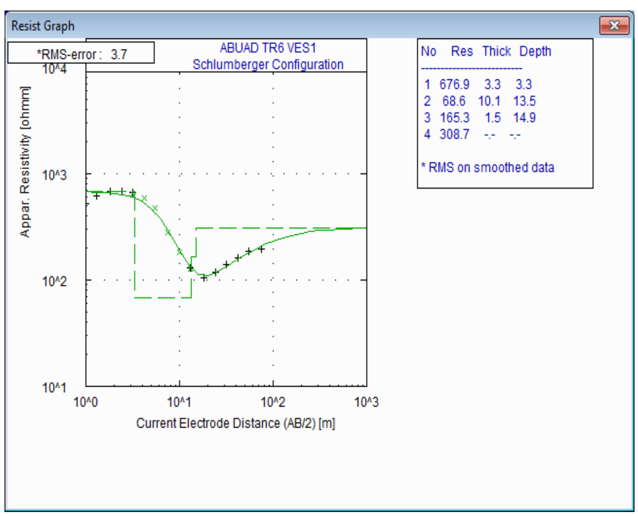

Figure 4 (a-d): Typical sounding curves

Aquifer Protective Capacity Evaluation

The nature of the materials that overlain the mapped aquifers were evaluated using the layer parameters (i.e. resistivity and thickness), the longitudinal unit conductance (S), the transverse unit resistance (T) and the coefficient of anisotropy (λ) to determine its capacity to prevent infiltration of unwanted fluids into the aquifer. It should be noted that the earth materials act as a natural filter to percolating fluids; therefore its ability to retard and filter percolating ground surface polluting fluids is a measure of its protective capacity (Olorunfemi *et al.,* 1999). That is to say that the geologic materials overlying an aquifer could act as seal in preventing the fluid from percolating into it.

The longitudinal unit conductance map (Figure 5), derived from equation 1 for all the VES locations, was used for the overburden protective capacity rating of the study area. The highly impervious clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer (Abiola *et al.*, 2009).

The longitudinal unit conductance (S) values obtained from the study area, ranges from 0.08438 to 0.73449 mhos. Clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer. According to the classification of Oladapo and Akintorinwa, (2007) in Table 1, the longitudinal unit conductance values from the study area enabled us to classify the area into weak, moderate and good protective capacity zones. Where the conductance is greater than 0.7 mhos are considered zones of good protective capacity. The portion having conductance values ranging from 0.2 to 0.69 mhos was classified as zone of moderate protective capacity; and area with values ranging from 0.1 to 0.19 mhos were classified as exhibiting weak protective capacity while the zones where the conductance value is less than 0.1 mhos were considered to have poor protective capacity. This work has revealed that the overburden materials in the area around the south-western and north-eastern portions of the study area have good to moderate protective capacity and are relatively thick (between 19 to 33 m thick). The central and western portions have moderate protective capacity materials with thin overburden (between 6 to 17 m thick), while the northern, southern, eastern and part of the central region exhibit weak to poor overburden protective capacity and thin overburden thickness. Figure 5 further reveals that about 60% of the area falls within the poor/weak overburden protective capacity, while about 40% constitutes the moderate/good protective capacity rating.

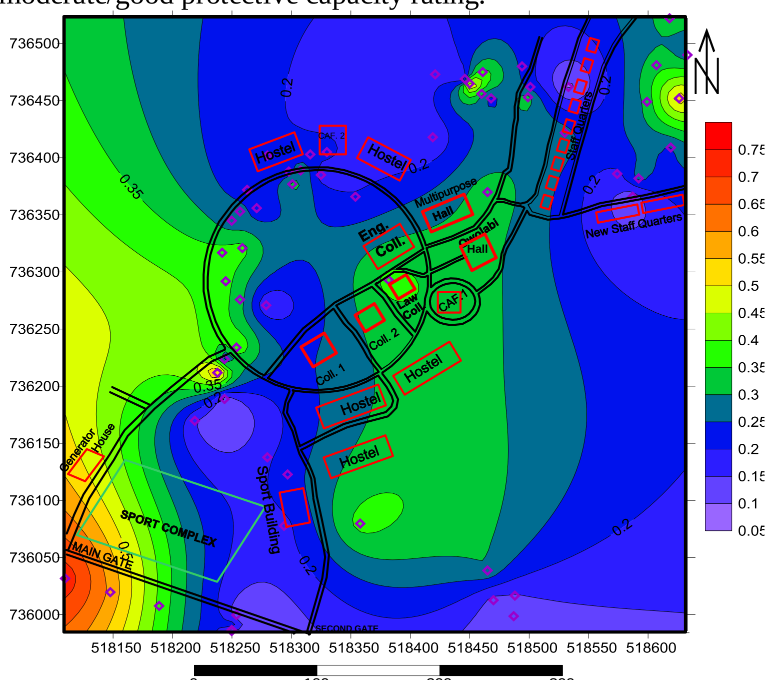

Figure 5: Longitudinal Conductance map of the study area

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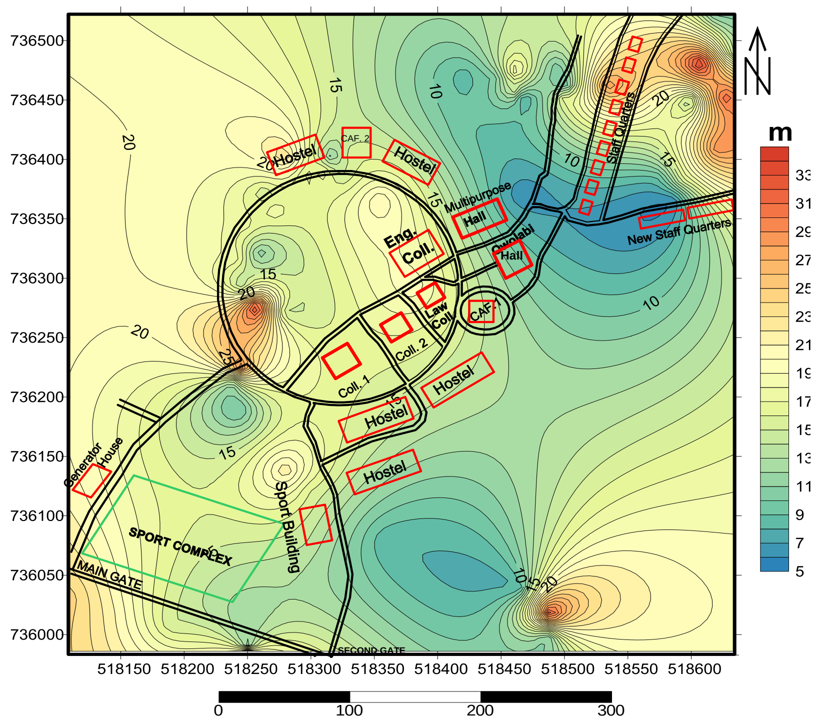

Figure 6: Overburden thickness map of the study area

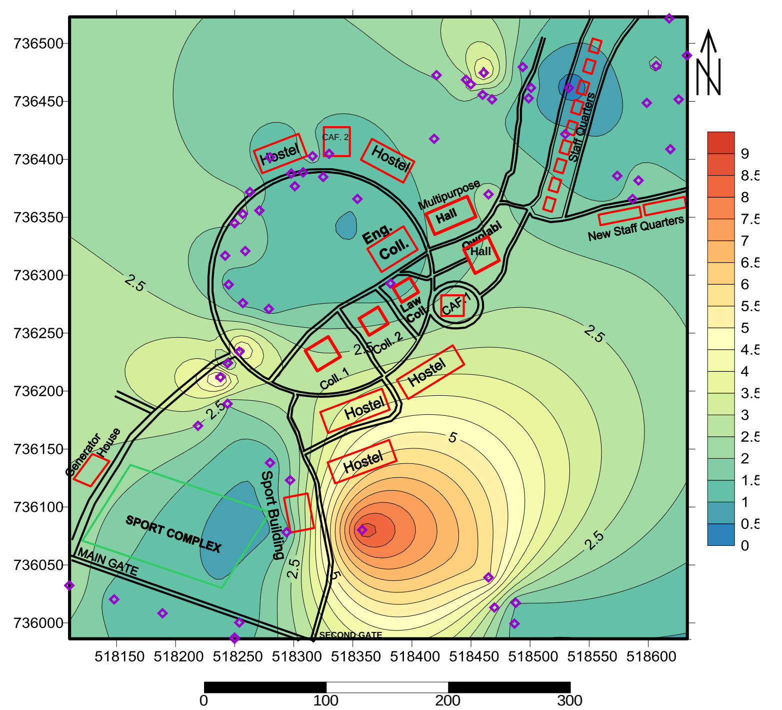

Figure 7: Coefficient of Anisotropy map of the study area

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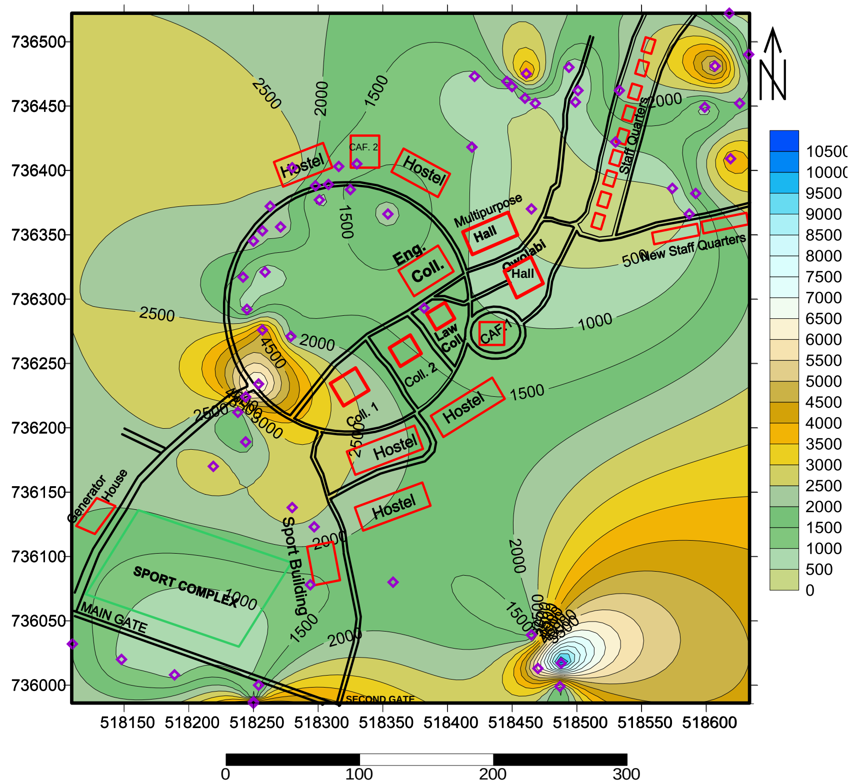

Figure 8: Transverse unit resistance map of the study area

GEO-ELECTRIC SECTIONS

The 2-D geoelectric sections (9a - c) were drawn in N-S and NW-SE directions. Figure 9a has varying topsoil resistivity of 77 - 256.1 ohm-m and thickness of 0.5 to 2.0 m. The second lithologic layer corresponds to clayey-sand with layer resistivities of 227 to 699 ohm-m and thickness of 1.0 to 1.5 m. The third layer is the weathered layer having resistivities of 26.8 to 58.9 ohm-m and thickness of 5.6 to 14.6 m.

There is the presence of fractured basement with resistivities of about 303.5 to 963.6 ohm-m and infinite thicknesses. The structural variation showed thickening of the overburden under the VES-Points WC38 and TR25/1, the depth to bedrock is deep towards the south-eastern side, while the basement is dipping towards the south-eastern side. The down dip side has the highest depth to bedrock, which is controlled by structural features relevant for groundwater development.

In Figure 9b the topsoil resistivities range from 100.7to134 Ω-m with thickness of about 0.5 to 2.7 m. The second layer has resistivities of 111 to 563.4 Ω-m and thicknesses range of 1.6 to 2.6 m, which correspond to clay materials. Under TR1/1 the clayey topsoil layer with resistivity of 111to563.4 Ω-m. There is the presence of weathered layer with resistivity of 29.8 to 33.9 Ω-m and thickness of 8.0 to 21.6 m. It is relatively thick under TR1/1 and the area is suspected to have harboured abstractable amount of portable groundwater. Structurally, the basement is depressed towards the NW part and is assumed to be groundwater flow direction. There is the presence of a fractured basement under TR2/1 which is also trending towards the north-western direction.

In Figure 9c the topsoil resistivities range from 96.6to496 Ω-m with thicknesses of about 0.6to1.8 m. The second layer, which is the sandy-clay, has resistivities of 233.8to466.6 Ω-m and thicknesses of 1.5 to 2.6 m. The clayey layer underlay the Topsoil only under TR8/1 and TR14/2 across the section. There is the presence of weathered layer with resistivities between 25.3 and 83 Ω-m and thicknesses ranging from 0.7 to 16 m. It is thickest under TR11/1 and TR16/2 and the area is favourable to groundwater accumulation

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and abstraction. Structurally, the basement is depressed towards the NW part and is assumed to be groundwater flow direction. There is the presence of a fractured basement under TR2/1 which is also trending towards the north-western direction. The aquifer mapped in the study area is the weathered/fractured layer (unconfined) and the fractured layer (confined) types.

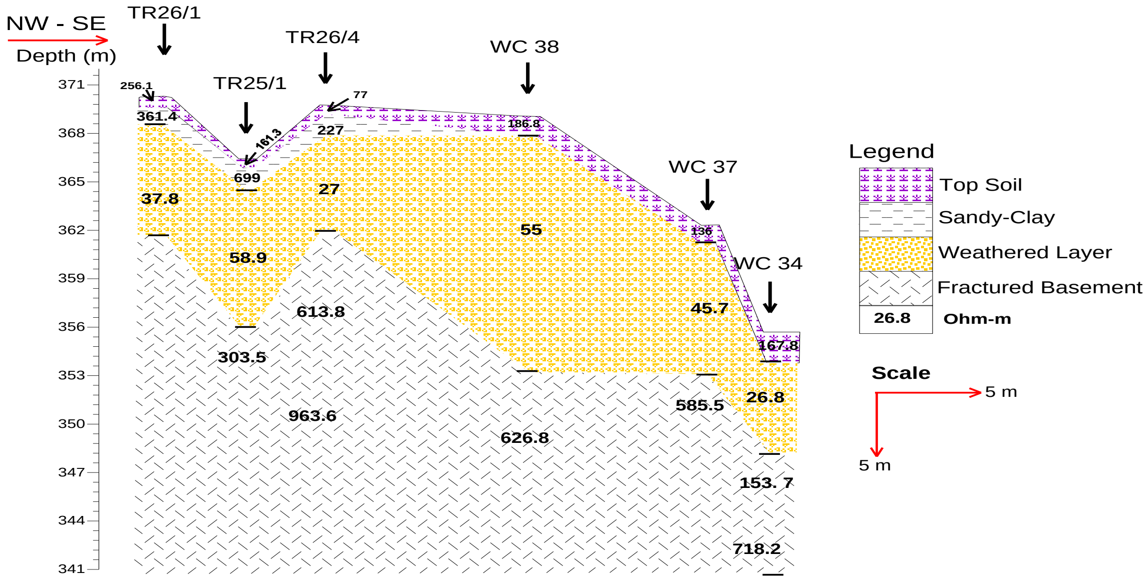

Figure 9a: Geo-electric section cutting across TR25/1, TR26/1, TR26/4, WC38, WC37 and WC34

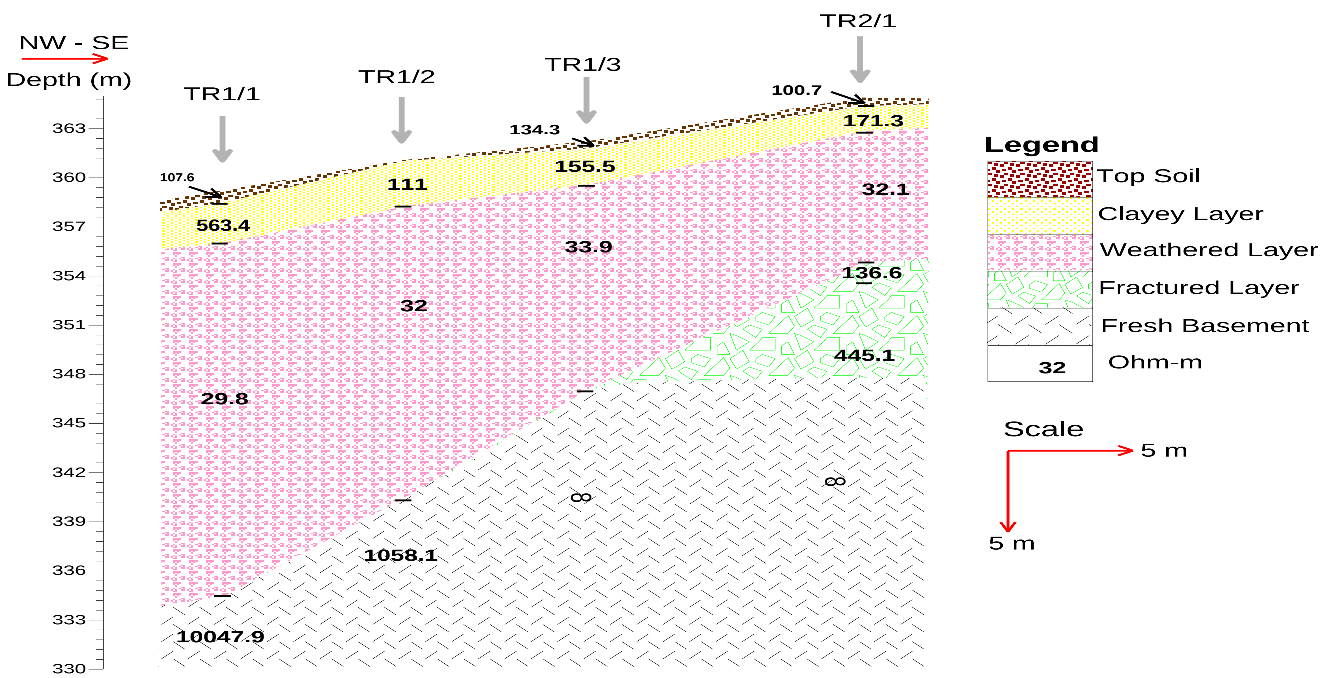

Figure 9b: Geo-electric section along traverse 1 (NW-SE) cutting across TR1/1, TR1/2, TR1/3 and TR2/1

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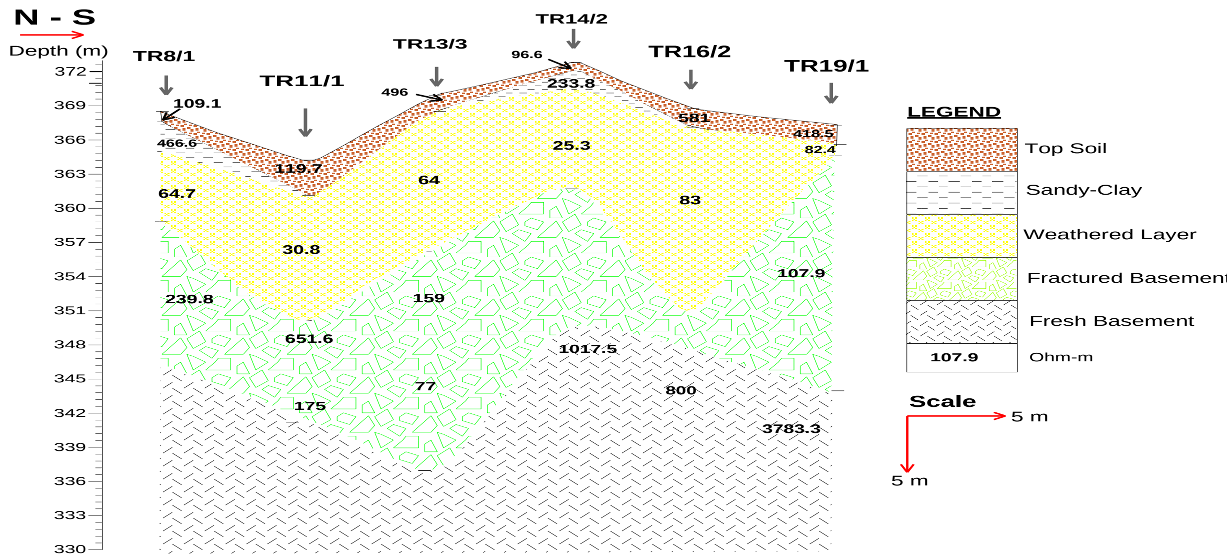

Figure 9c: Geo-electric section cutting across TR8/1, TR11/1, TR13/3, TR14/2, TR16/2 and TR19/1

Conclusion

In this study, the groundwater transmissivity and protective capacity evaluation of the rock units within Afe Babalola University, Ado-Ekiti and southwestern Nigeria were undertaken using 59 Schlumberger vertical electrical soundings (VES). The VES data interpretation involved quantitative partial curve matching and computer assisted 1-D forward modeling using resist 1.0 software. The curve types obtained include (A, H, HA, HK, HKH, KH, KHA, KHK and QH types. The subsurface sequence comprise of the topsoil with limited hydrologic appeal, sandy-clay layer, weathered/fractured basement and the fresh basement. The weathered/fractured layer constituted the sole aquifer unit in the area. The geoelectric parameters (layer resisitivity and thickness) at each sounding station were used to produce the overburden thickness map and the geoelectric sections and to also generate the secondary order parameters (Dar Zarrouk parameters) i.e. the longitudinal unit conductance (S), the transverse unit resistance (R) and the coefficient of anisotropy (λ) values of the area. The geoelectric sections show the variations of resistivities and thicknesses values of layers within the depth penetrated in the study area at the indicated VES stations. The profiles were taken along the N-S and NW-SE directions. Generally, the profiles revealed four to five subsurface layers: the top-soil, sandy-clay/clayey layer, the weathered layer, partially weathered/fractured basement and the fresh basement. The study also revealed that most parts of the area are underlain by materials of weak to moderate protective capacity. The central, the southwestern and the western portions of the area are underlain by materials of moderate to good protective capacity. The areas with good to moderate protective capacity coincide with zones of appreciable overburden thickness with clayey columns thick enough to protect the aquifer in the area from the surface polluting fluid. The area with thin overburden also coincided with weak protective capacity thereby exposing the groundwater in the area to pollution. If for example, there is leakage of buried underground storage tanks; this may constitute a serious environmental hazard. Therefore vulnerable zones include the southern, southeastern, eastern and northern region. The area with high values of coefficient of anisotropy and low values of transverse unit resistance which is a reflection of the transmissivity profile of rocks also coincide with relatively thin overburden thickness making the groundwater in the area vulnerable to polluting fluid.The results of this study have provided reliable information for an elaborate groundwater protection and environmental factors to be considered for planning, development and siting of academic, residential and commercial facilities within the central academic and residential area of the campus of Afe

Babalola University, Ado Ekiti. For effective groundwater development programmes in the study area, it is recommended that pre-drilling geophysical investigations be carefully conducted for economic and environmental purposes. Future groundwater development in the study area by the management should be concentrated within the zones of moderate/good groundwater protective capacity with appreciably thick overburden. Also, siting of underground petroleum storage tanks, sewage septic tanks and waste dump within the campus should be confined to zones of moderate/good ground water protective capacity.

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