

Original Research Article

The Delineation of Potential Groundwater Aquifers within Basement Complex in ABU Zaria, Nigeria

ABSTRACT

Aims: This research is aimed at determining the average thickness of aquifer in units within complex basements for potential ground water exploration.

Study design: The study area Ahmadu Bello University (ABU) Zaria in Kaduna State lies approximately between latitudes 11°4'0"N and longitudes 7°42'0"E, covering an area of 563 km² (217 sq mi).

Place and Duration of Study: The study was carried out at four different locations; ABU Waterworks Base, Staff School, Gymnasium and BZ at Zaria, Nigeria between March 2005 and July 2005.

Methodology: A total of four (4) vertical electrical soundings (VES) using Schlumberger electrode array were acquired with a maximum electrode separation of AB/2=100m, using the ABEM Terrameter SAS 300.

Results: Maximum of four (4) lithologic layer were identified namely, topsoil, laterite, weathered and fractured basement and fresh basement. Qualitative analysis shows that the weathered layer and weathered/fractured basement constitutes the main aquifer units. The resistivity of the layers ranging from 113.3 Ωm to 43789.1 Ωm. The weathered and fractured basement, understood to constitute the aquifer layers of the area, has thickness ranging from 6.2 m to 12.2 m.

Conclusion: The results reveal two to four subsurface geoelectric layers and geologic sections. Aquifer component in Zaria have been classified into weathered and fractured basement area which forms the main aquifer component of the study area. From the interpreted result, the ABU gymnasium location is most suitable location for groundwater exploration based on the resistivity and thickness range of aquifer basement.

Keywords: *Aquifer, Schlumberger, Zaria, Weathered and Fresh Basement*

1. INTRODUCTION

The search for groundwater, which is basically fresh water located in the subsurface pore space of soil and rocks dates back to history; this is because water is essential to life. Its presence or lack of it determines, to great extent, the nature of the natural environment in which we live and majority of our economic activities depend on it. The development and utilization of groundwater resource therefore becomes very imperative.

According to Plummer 1999, useable fresh water is found among voids in soils and permeable geological formation as groundwater and over half the world depends on the proper exploitation of the groundwater for general water supplies [1]. The importance of geophysical exploration methods, as means of exploring the groundwater cannot be over emphasized. These methods have been used with varying degree of success. Methods including Vertical Electrical Sounding (VES), seismic refraction, horizontal profiling (Wenner) and Very Low Frequency (VLF) have been successfully used to explore for groundwater [2], [3].

Groundwater, through the various dissolved salts it contains, is ionically conductive and enables electrical current to flow into the ground. Consequently, measurement of the ground resistivity gives the possibility to identify the presence of water. In this work, D.C resistivity method is considered to be the quickest and the most economic technique. The study area is a portion in the Northern sector of Nigeria Basement Complex rock, it is underlain by gneisses, magnetite and meta-sediments of Precambrian age which have been introduced by series of granitic rocks of late Precambrian to lower Paleozoic age [4]. On structural evolution, Nigeria Basement Complex has been subjected to at least

31 two major orogenic cycles [5]. The early Paleozoic began folding in two successive phase, first about
32 east-west axis and secondly about North- south axis [4].

33 The components of aquifers system in Zaria have been mapped to consist of weathered and fractured
34 basement, weathered laterite (older and younger) and alluvial deposits [4], [6]. However, in the
35 Basement complex, the permeability and storability of the groundwater system are dependent on
36 structural features such as the extent, and volume of fractures together with thickness of weathering
37 [7]. The study area lacks geophysical record as all available reports are on regional scale. The aim of
38 this work is to determine the area with potential for ground water.

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40 2. MATERIAL AND METHODS

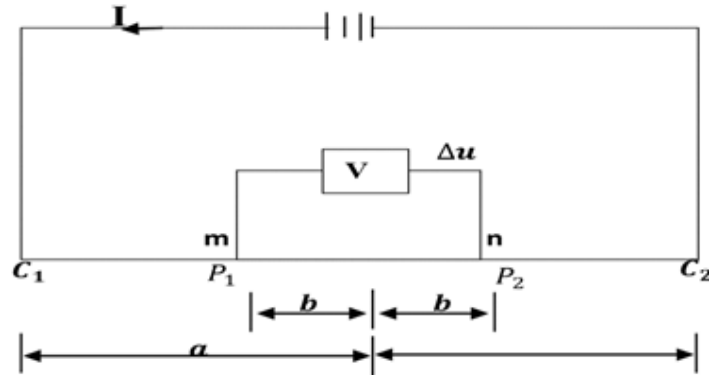
41 Large numbers of electrode arrangement have been used for resistivity exploration as in Koefoed,
42 (1979). Any of these can be used for lateral variation of resistivity or vertical variation of resistivity as a
43 function of the current depth. General, four electrode array, were used at the surface, one pair for
44 introducing current into the earth and the other pair for potential difference. In resistivity method,
45 current are driven into the ground. Any variation of subsurface resistivity (ρ) alters the current flow
46 which in turn affects the distribution of electric potentials. The potentials established are measured at
47 the surface. The equation which gives the potential due to a single point source of current at surface
48 can be deduces from two basic equations; ohm's law and divergence condition [8]. And the ohm's law
49 is given as:

$$50 \quad \Delta \cdot J = 0 \quad (1)$$

51 The potential due to a single point source of current at earth surface is given as:

$$52 \quad U = \rho I / 2\pi r \quad (2)$$

53 Where ρ is the earth density, I is current and r is Resistance; the current I , is passed through current
54 electrode C_1, C_2 as shown in figure below (Fig. 1):



55

56 **Fig. 1 General four (4) electrode configuration for resistivity measurement**

57 The potential difference at M is

$$58 \quad U_m = \rho I / 2\pi [1/r_1 - 1/r_2] \quad (3)$$

59 The potential difference at N is

60

$$61 \quad U_n = \rho I / 2\pi [1/r_3 - 1/r_4] \quad (4)$$

62 The difference in potential at M and N is given as:

$$\Delta U = U_m - U_n$$

$$\Delta U = \rho l / 2\pi [1/r_3 - 1/r_4 - 1/r_3 + 1/r_4] \quad (5)$$

Hence, the resistivity is given by:

$$\rho_a = \Delta U / l [2\pi \{1/r_3 - 1/r_4 - 1/r_3 + 1/r_4\}] \quad (6)$$

$$\text{Let } K = 2\pi \{1/r_3 - 1/r_4 - 1/r_3 + 1/r_4\}$$

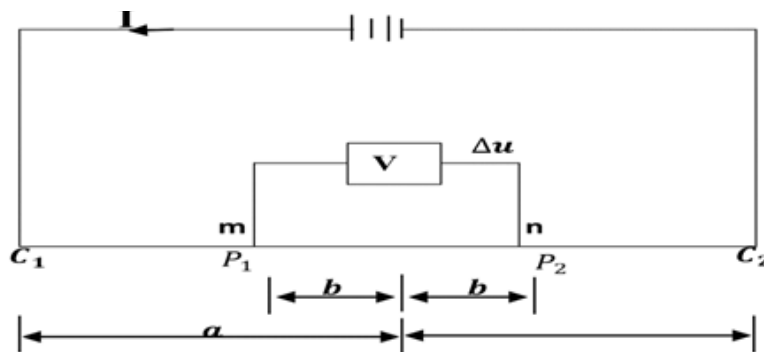
Therefore

$$\rho_a = KR \quad (7)$$

Where, K is a Geometric factor and $R = \Delta u / l$

2.1 CHOICE OF ELECTRODE CONFIGURATION

The choice of a configuration for prospecting is dependent on a number of factors amongst which are the type of investigation required, the terrain of the area of the investigation, and the position of the suspected geological structure. In vertical electrical sounding (VES) measurement, the center of the electrode spread remains fixed but the separation of electrodes is progressively increased, hence choice of Schlumberger configuration Fig. 2. This configuration is therefore more cost effective since it saves time and manpower [7]. The Schlumberger electrode array is illustrated in Fig. 2.



78

79 **Fig. 2 Generalized Schlumberger electrode configuration resistivity measurement**

80 Applying equation (5) and (6) to the above array gives:

$$K = 2\pi / \{1/(a-b) - 1/(a+b) - 1/r_{(a+b)} + 1/r_{(a-b)}\} \quad (8)$$

$$K = 2\pi / \{1/2(a-b) - 1/2(a+b)\}$$

$$K = \pi / \{1/((a-b)) - 1/((a+b))\}$$

$$K = \pi / \{a^2/2b - b/2\} \quad (9)$$

85 Therefore

$$\rho_a = \pi / \{a^2/2b - b/2\} \Delta u / l \quad (10)$$

87 Where, a, is the separation between current electrode at the center of the configuration, b, is the
88 separation between potential electrode at the center of the configuration and ρ_a the apparent
89 resistivity of the earth for a Schlumberger array.

This last expression gives the approximate relationship between the apparent resistivity ρ_a , and the approximate resistivity value term usually given by Terrameter during field measurement. The coefficient of $\Delta u/l$ is the geometric factor which is characteristics of the spread used. The electrical resistivity data was acquired with ABEM Terrameter SAS 300 along with other equipment cables and electrodes.

2.2 DATA INTERPRETATION

The interpretation of the data was done using a computer program (RES1D version 1.00.07 Beta). To interpret the data using this program, some initial value parameters were found from the observed field curve and fed into the program. The initial value parameters are taken such that each point of maxima, minima and inflection indicate the existence of layer boundaries. The program uses these values to design a model curve, comparing it with the observed field resistivity curve. Where the modelled curve and the observed field curve are not in agreement, the initial value parameters are altered until the best agreement between the modelled curve and the observed field curve is obtained. At the point when the two curves are in best agreement and minimum error, the layer resistivity and thickness are recorded [9].

Fig. 3 - 6 shows the composite geoelectric and geologic section derived for the four VES stations. The resulting curves and their final model parameters after quantitative interpretation were established. The final model geoelectric parameters across the sections of the area were used for the preparation of the geoelectric and geologic section (Fig. 3 - 6). The geoelectric sections show the average variations of resistivity and thickness values of layers within the depth penetrated in the area at the indicated sections. Generally, the sections revealed two to four subsurface layers: topsoil/laterite, indurated laterite, weathered and fresh basement layers. Table 1 shows Resistivity range of some rock types compiled from [10], [11], and [12].

Table 1 Typical Resistivity Values of Rock Materials

Rock Type	Resistivity (Ωm)
Topsoil/Clay/Silt	65 - 200
Laterite/Indurated Laterite	45 - 800
Weathered Basement	2 - 220
Fractured Basement	218 - 520
Fresh Basement	>1000

3. RESULTS AND DISCUSSION

3.1 VES Station 1 (Waterworks Base, Zaria)

Fig. 3 shows that the VES station is underlain by four subsurface layers. The resistivity and thickness of the first layer was found to be 599 Ωm and 1.7 m respectively. The resistivity value at the top layer suggests laterite. The second layer is found with high resistivity value of 5119 Ωm with thickness layer of 1.3 m, and this could indicate the presence of consolidated laterite. The weathered basement which forms the third layer indicates relatively high resistivity values of 285.6 Ωm and thickness of 12.2 m. The fourth layer, which is the final layer with resistivity values of 43789 Ωm with an infinite thickness, is understood to be the fresh basement. The overburden thickness of this VES station is 15.2 m.

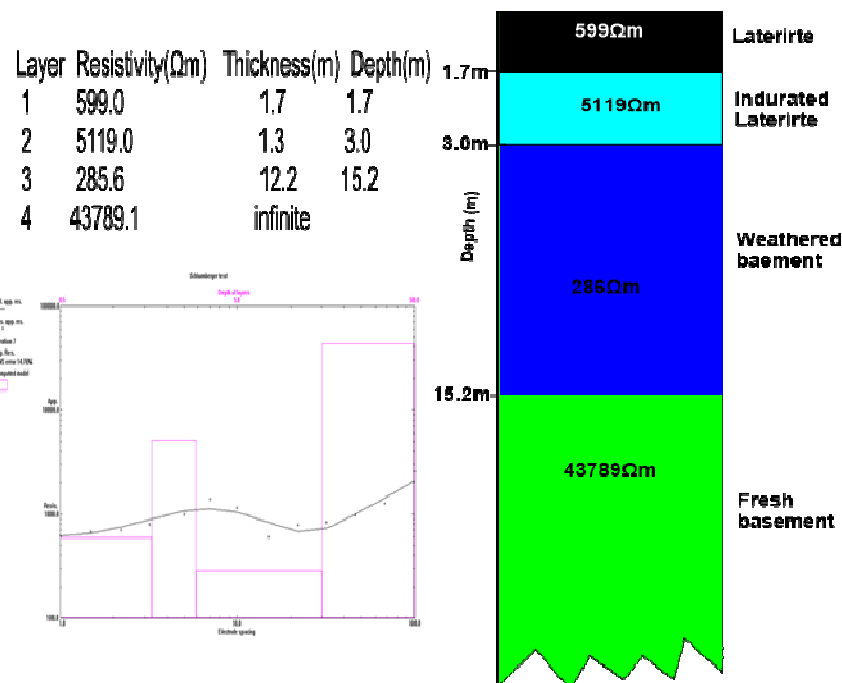


Fig. 3 Sounding Curve and Goelectric Unit of VES 1 (Waterworks Base, Zaria)

3.2 VES Station 2 (Staff School, Zaria)

Fig. 4 shows that the VES station is underlain by two subsurface layers. The resistivity and thickness of the first layer was found to be 165 Ωm and 4.3 m respectively. The resistivity value suggests clay/silty at the top layer. The second layer, which is the final layer with resistivity values of 4171.1 Ωm with an infinite thickness, is understood to be the fresh basement.

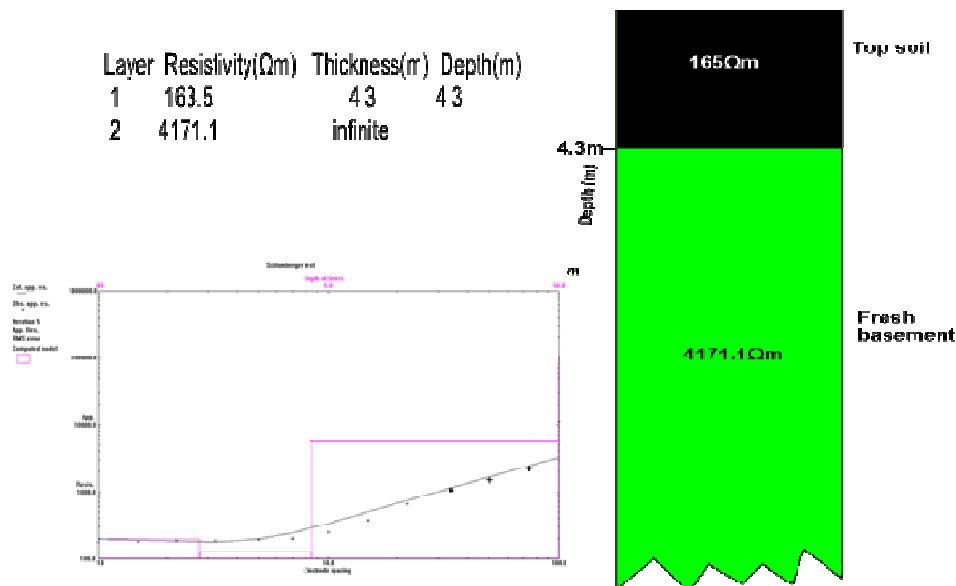


Fig. 4 Sounding Curve and Goelectric Unit of VES 2 (Staff School, Zaria)

3.3 VES Station 3 (BZ, Zaria)

Fig. 5 shows that the VES station is underlain by three subsurface layers. The resistivity and thickness of the first layer was found to be 833 Ωm and 1.7 m respectively. The resistivity value at the top layer suggests indurated laterite. The second layer is characterized with high resistivity values of 360 Ωm and thickness of 6.2 m, the relatively high resistivity could be considered fracture layer which forms the main aquifer in respect to their importance in groundwater storage in Zaria [7]. The third layer, which is the final layer is characterize with high resistivity values of 41711 Ωm with an infinite thickness is understood to be the fresh basement. The overburden thickness of this VES station is 7.9 m as presented in Fig 5.

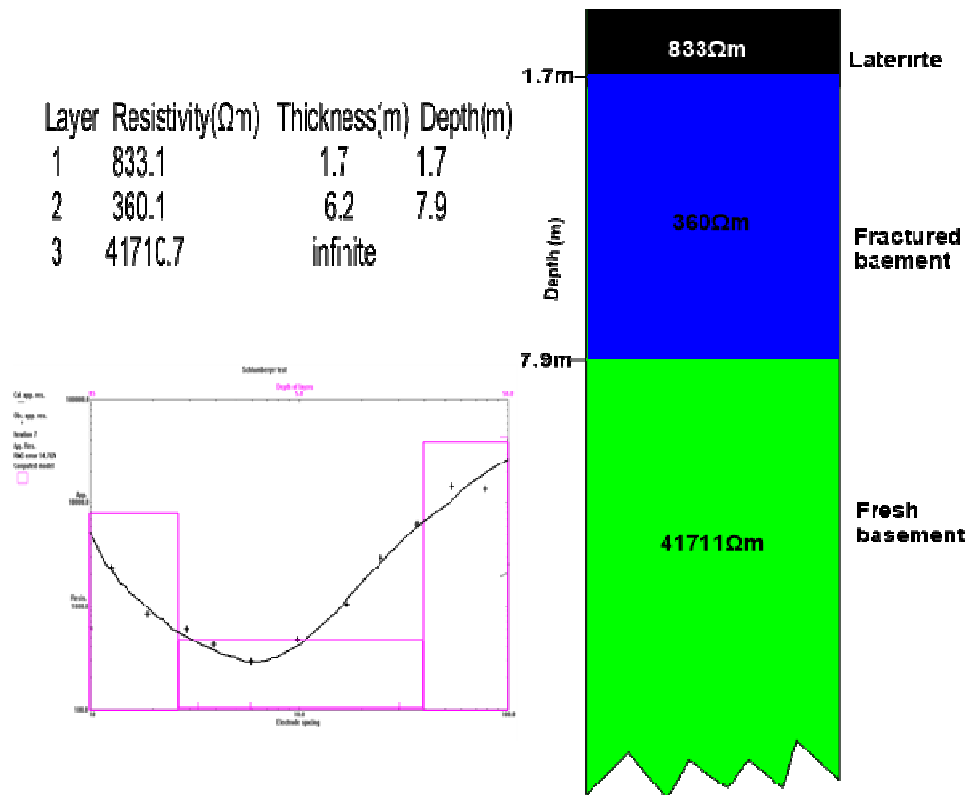


Fig. 5 Sounding Curve and Geoelectric Unit of VES 1 (BZ, Zaria)

3.4 VES Station 4 (ABU Gymnasium, Zaria)

Fig. 6 shows that the VES station is underlain by three subsurface layers. The resistivity and thickness of the first layer was found to be 632 Ωm and 0.4 m respectively. The resistivity value at the top layer suggests laterite. The weathered basement which forms the second layer indicates relatively low resistivity values of 113 Ωm and thickness of 9.0 m. With this resistivity value, the station could be considered good for groundwater exploitation. The third layer, which is the final layer with resistivity values of 49788 Ωm with an infinite thickness, is understood to be the fresh basement layer. The overburden thickness of this VES station is 9.4 m.

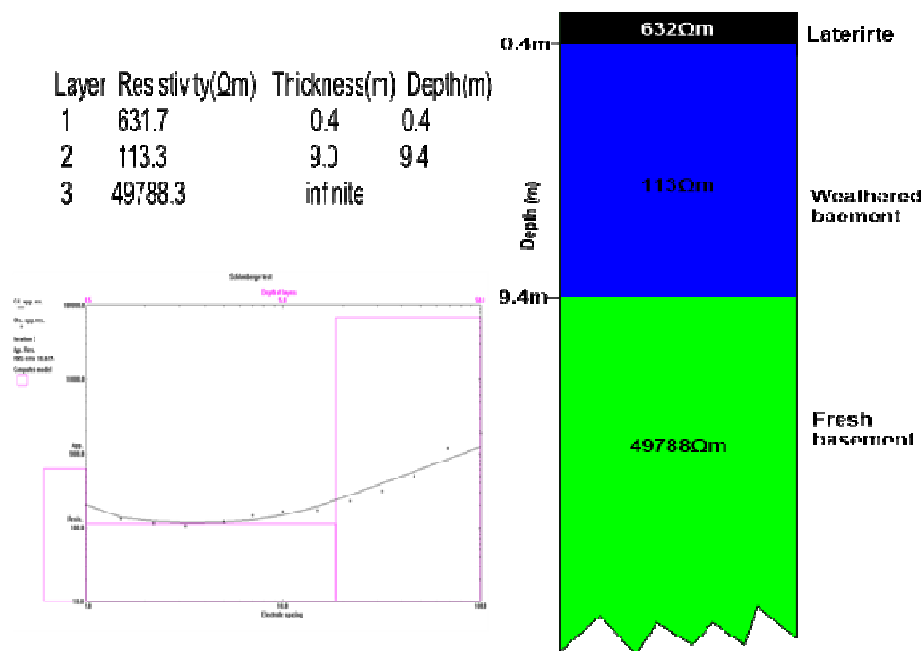


Fig. 6 Sounding Curve and Geoelectric Unit of VES 1 (ABU Gymnasium, Zaria)

3.5 AQUIFER EVALUATION

The high topsoil resistivity indicates in VES 1, 3 and 4 may not be unconnected with presence of surface indurated laterite in the first layer which may also be of great importance as it reduces surface run off and aids infiltration into the underlying aquifer. Given the resistivity and thicknesses values at VES station 1, 3 and 4 with 285 Ωm and 12.2 m, 360 Ωm and 6.2 m and 113 Ωm and 9.0 m respectively; this relatively agrees with report that weathered and fractured layer form the main aquifer unit in Zaria and the study area is highly productive for groundwater exploitation [7]. Aweto, observed that a region with a relatively shallow (<11 m) may be vulnerable to contamination that may arise from human activities [13]. Hence, the observed thickness and nature of the weathered layer in the location (Waterworks base, VES 1) layer is considered as important parameters suggested for groundwater potential development in this work. Shallow regions (<12 m) and may be relatively considered protected against contamination from near surface activities such as waste and sewage with overburden thickness extends beyond 12 m. Olayinka, observed that a borehole should be sited where it can penetrate the maximum possible thickness of the regolith, such that adequate storability and transmissivity can be guaranteed [6]. As presented in Fig. 3 - 6, such conditions are only met waterworks base and ABU Gymnasium. However, location (Staff school, VES 2) indicates two layers are not advisable for siting borehole due to the nature of the basement present.

4. CONCLUSION

The geoelectric investigation of the study area has revealed two to four subsurface geoelectric layers and geologic sections. The second layer which is presumably clay/silt/sand constituted the aquifer units in the study. Aquifer component in Zaria have been classified into weathered and fractured basement are believed to be main aquifer component of the study area. From the interpreted result, the ABU gymnasium location is most suitable location for groundwater exploration based on the nature and thickness range of aquifer basement followed by waterworks base.

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