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

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Authors' contributions

This work was carried out in collaboration between all authors. Author NK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AOH and JR managed the analyses of the study. Authors IHD and JOA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A geoelectrical survey was carried out in order to evaluate the groundwater potential of ABU Zaria, Nigeria. A total of four Vertical Electrical Soundings (VES) were carried out using Schlumberger electrode configuration with half current electrode spacing of maximum 100 m. The Interpreted data revealed that the study area is underlain by three to four layers. The topsoil thickness and resistivity values vary from 0.4 – 2.0 m and 186 – 833 Ωm respectively. The thickness and resistivity of the weathered basement ranges between 3.0 – 15.2 m and 109 – 360 Ωm respectively. The fresh basement layer which has resistivity values of 1603 – 49788 Ωm is of infinite depth and thickness. The areas with relatively high thickness and low resistivity values of the weathered layer and fractured bedrock have been successfully identified as potential aquifer zone targets for groundwater exploitation.

Keywords: Aquifer; Schlumberger; Zaria; weathered and fresh basement.

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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 become very imperative [1].

Useable fresh water is present within voids in soils and permeable geological formation as groundwater and over half of the world depends on the proper exploitation of the groundwater for general water supplies [2]. 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 [3], [4]. Groundwater, through the various dissolved salts it contains, is ironically 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. The study area lacks geophysical record as all available reports are on regional scale. The aim of this work is to determine the area with potential for groundwater. In this work, D.C resistivity method is considered to be the quickest and the most economical technique for groundwater exploration.

1.1 Site Description

The study area, ABU, Zaria, Kaduna State in the Northern Nigeria is located on the geographical coordinates of latitude 11° 08′ 26.36″ to 11° 09′ 21.29″ N and longitude 07° 38′ 35.92″ to 07° 39′ 11.35″ E. It lies on an average height of 658 m above the sea level. The study area is capped by laterites; the laterites are sometimes highly consolidated especially at the surface and weathered into lateritic nodules mixed with silty and sandy clays. The relief of the area is characterized by undulating plain, gentle slopes, and consists of peneplains with eroded flat tops, often capped by layers of indurate laterites [5]. The study area is a portion in the Northern sector of Nigeria Basement Complex rock (Fig. 1a), 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 [6]. On structural evolution, Nigeria Basement Complex has been subjected to at least two major orogenic cycles [7]. The early Paleozoic began folding in two successive phase, first about east-west axis and secondly about North- south axis [6]. The typical rock types underlying the entire land area of Kaduna State consists the Precambrian migmatite-gneiss complex, meta-sediments/ meta-volcanics (mostly schists, quartzites, amphibolites and banded iron formations) [8]. Most of the areas underlain by the Basement Complex rocks in northern Nigeria consists a thin discontinuous mantle of weathered rock overlying them. The average thickness of the mantle is about 15 m, although depths of about 60 m may be encountered. The unweathered bedrock is characterized by rapid grain-size variations from micro to pegmatitic regions but normal sizes are dominant [5]. The study area base map is depicted in Fig. 1b.

The components of aquifers system in Zaria have been mapped to consist weathered and fractured basement, weathered laterite (older and younger) and alluvial deposits [6,10]. However, in the Basement complex, the permeability and storability of the groundwater system are dependent on structural features such as the extent, and volume of fractures together with thickness of weathering [11].

2. MATERIALS AND METHODS

Electrical resistivity is a geophysical survey method in which an electrical current is injected into the ground to measure the electrical properties of the subsurface. It is based on the response of the subsurface material to the current flow through electrodes to the ground [12]. In this survey, a total of four (4) Vertical Electrical Sounding (VES) points were acquired at the study area with maximum spread of 100 meters with ABEM Terrameter SAS 300 along with other geophysical equipment. Generally, four electrode array, were used at the surface, one pair for introducing current into the earth and the other pair for potential difference. In resistivity method, current are driven into the ground. Any variation of subsurface resistivity (ρ) alters the current flow which in turn affects the distribution of electric potentials. The potentials established are measured at the surface. The equation which gives the potential due to a single point source of current at surface can be deduced from two basic equations; ohm's law and divergence condition [13]. And the ohm's law is given as:

$$\Delta.J = 0 \tag{1}$$

Where J is current density.

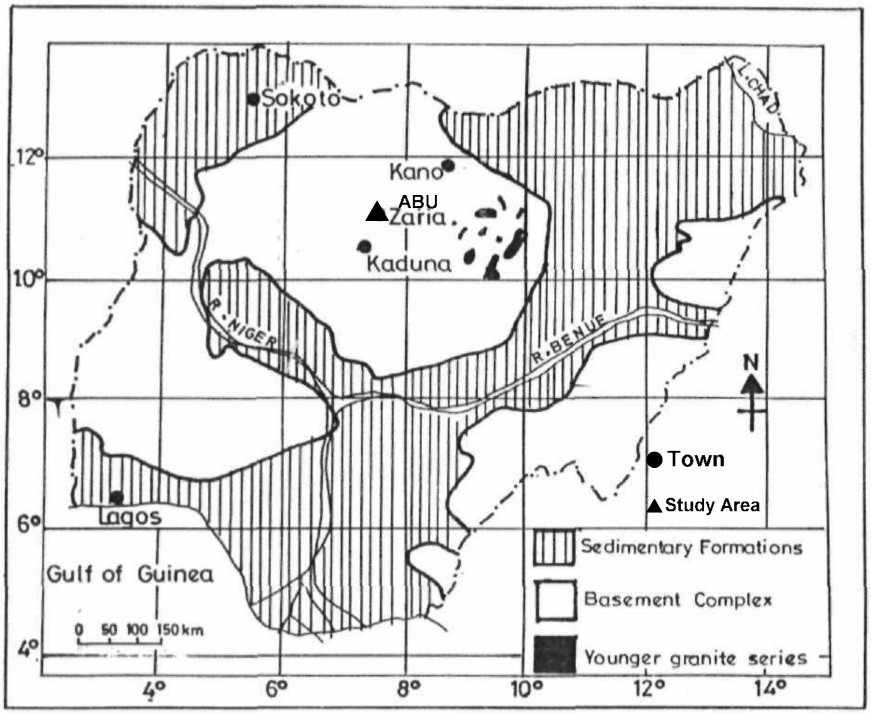

Fig. 1a. Geology Map of Nigeria (after Abdullahi et al. [9])

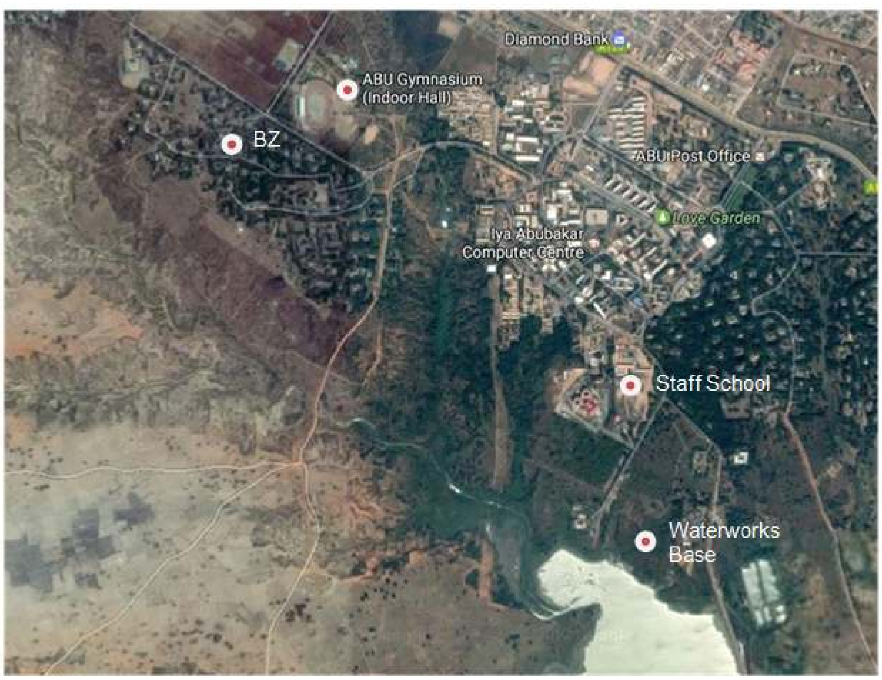

Fig. 1b. Google map of VES station 1-4 ABU Zaria, Nigeria

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

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

Where ρ is the earth density, I is current and r is Resistance; the current I, is passed through current electrode C1, C2 as shown in figure below (Fig. 2).

The potential difference at M is

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

The potential difference at N is

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

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

$$\Delta U = U_m - U_n$$

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

Hence, the resistivity is given by:

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

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 $R = \Delta u/I$

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 the choice of Schlumberger configuration. This configuration is therefore more cost effective since it saves time and manpower [11]. The Schlumberger electrode array is illustrated in Fig. 3.

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

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

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

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

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

Therefore

$$\rho a = \pi/\{a\hat{}2/2b-b/2\}\Delta u/I \quad (10)$$

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

This last expression gives the approximate relationship between the apparent resistivity ρa, and the approximate resistivity value term usually given by Terrameter during field measurement. The coefficient of Δu/I 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 geophysical equipment cables and electrodes.

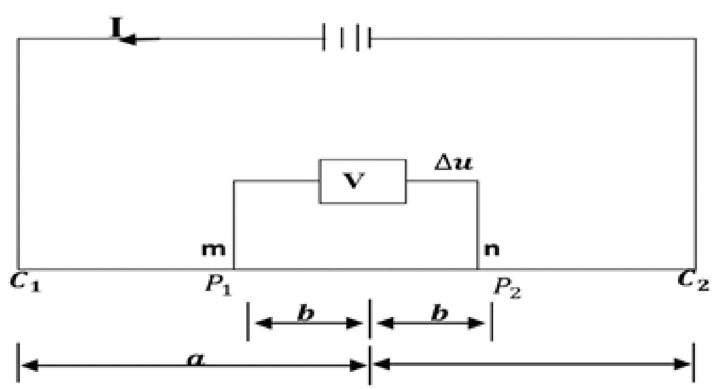

Fig. 2. General four (4) electrode configuration for resistivity measurement

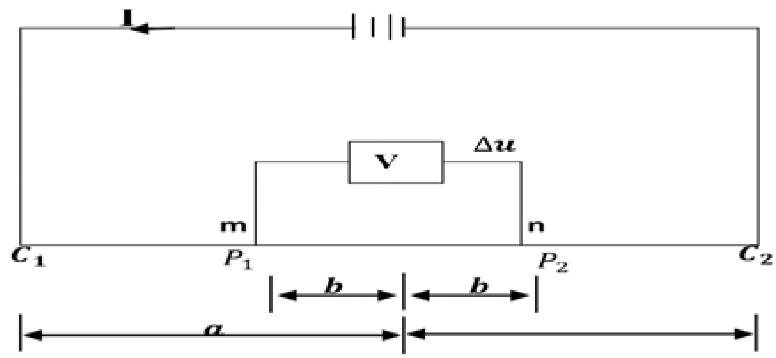

Fig. 3. Generalized Schlumberger electrode configuration resistivity measurement

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 [14].

The resulting curves and their final model parameters after quantitative interpretation were established, and the final model geoelectric parameters across the sections of the area were used for the preparation of the geoelectric sections in Figs. 4 - 7.

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

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 [12,1], and [15].

3. RESULTS AND DISCUSSION

3.1 Evaluation of Resistivity Curve of VES Station 1 (Waterworks Base)

Fig. 4 shows that the VES station is underlain by four subsurface layers. This station is characterized by KH-curve type as classified by Keller and Frischnecht [16]. 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 resistivity value of 285.6 Ωm and thickness of 12.2 m. The fourth layer, which is the bedrock shows the resistivity value of 43789 Ωm with an infinite thickness. This layer is understood to be the fresh basement. The overburden thickness of this VES station is 15.2 m.

3.2 Evaluation of Resistivity Curve of VES Station 2 (Staff School)

Fig. 5 shows that the VES station is underlain by three subsurface layers. This station is characterized by H-curve type. The resistivity and thickness of the first layer was found to be 186 Ωm and 2.0 m respectively. The resistivity value suggests lateritic clay at the top layer. The second layer resistivity and thickness are 109 Ωm and 2.5 m respectively. This parameter

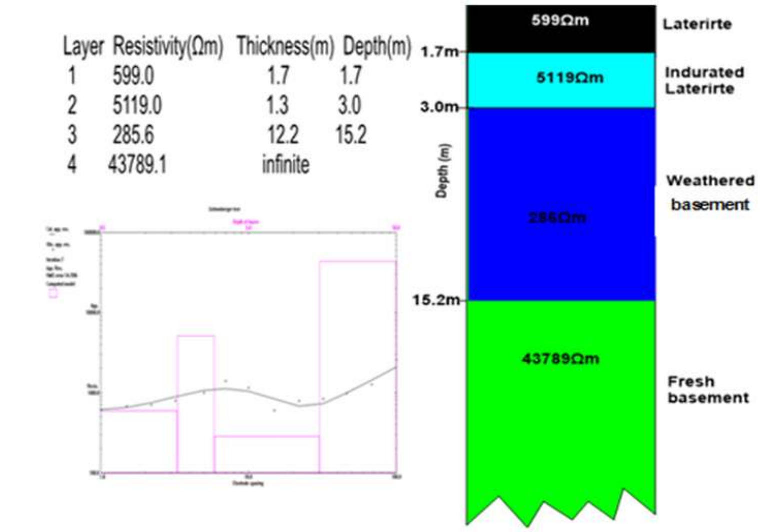

Fig. 4. Sounding Curve and Geoelectric Unit of VES 1 (Waterworks Base, Zaria)

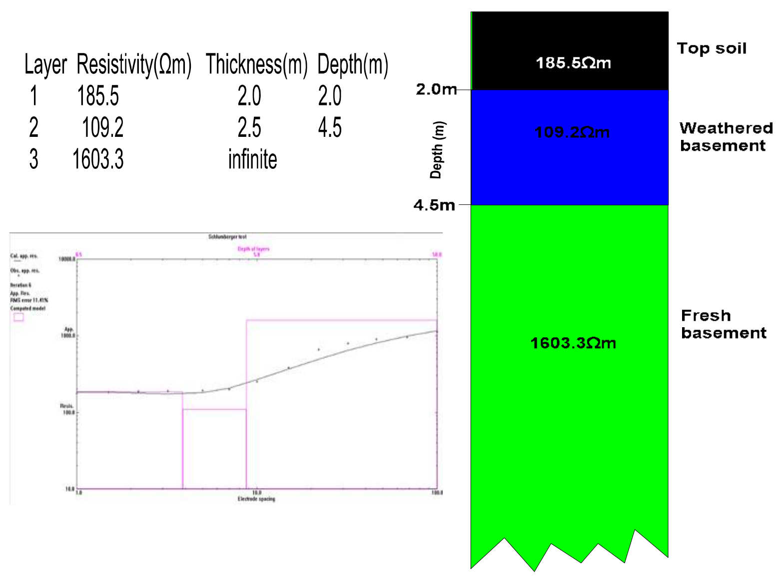

Fig. 5. Sounding Curve and Geoelectric Unit of VES 2 (Staff School, Zaria)

suggests that the layer is made up sand/ silty/clayed which constitute the aquifer unit of the area. The third layer, which is the final layer with resistivity values of 1603 Ωm with an infinite thickness, is believed to be the fresh basement.

3.3 Evaluation of Resistivity Curve of VES Station 3 (BZ)

Fig. 6 shows that the VES station is underlain by three subsurface layers. This station is characterized by H-curve type. 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 resistivity value of 360 Ωm and thickness of 6.2 m, the layer could be considered as the fracture layer which forms the main aquifer in respect to their importance in groundwater storage in Zaria [11]. The third layer, which is the final layer is characterize with high resistivity value of 41711 Ωm with an infinite thickness. This layer is understood to be the fresh basement. The overburden thickness of this VES station is 7.9 m as presented in Fig. 6.

3.4 Evaluation of Resistivity Curve of VES Station 4 (ABU Gymnasium)

Fig. 7 shows that the VES station is underlain by three subsurface layers. This station is characterized by H-curve type. 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 shows the resistivity value 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.

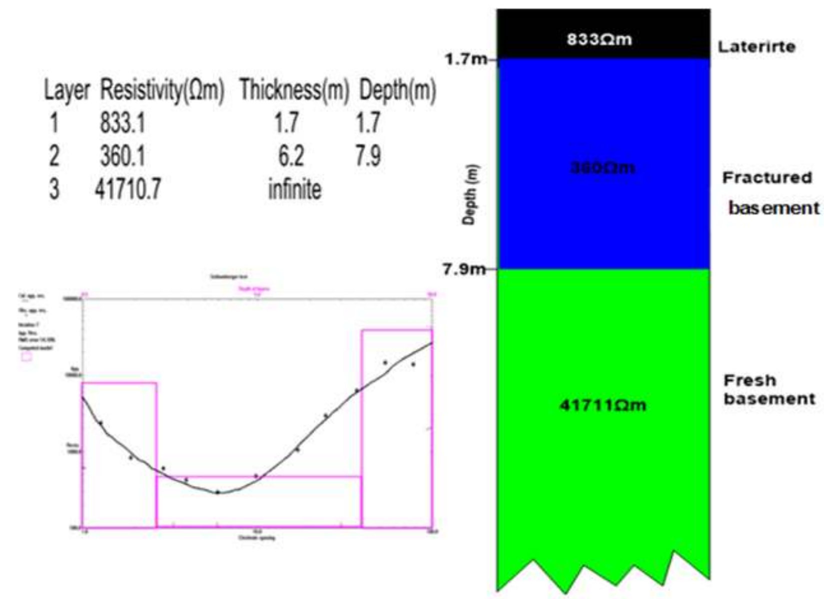

Fig. 6. Sounding Curve and Geoelectric Unit of VES 1 (BZ, Zaria)

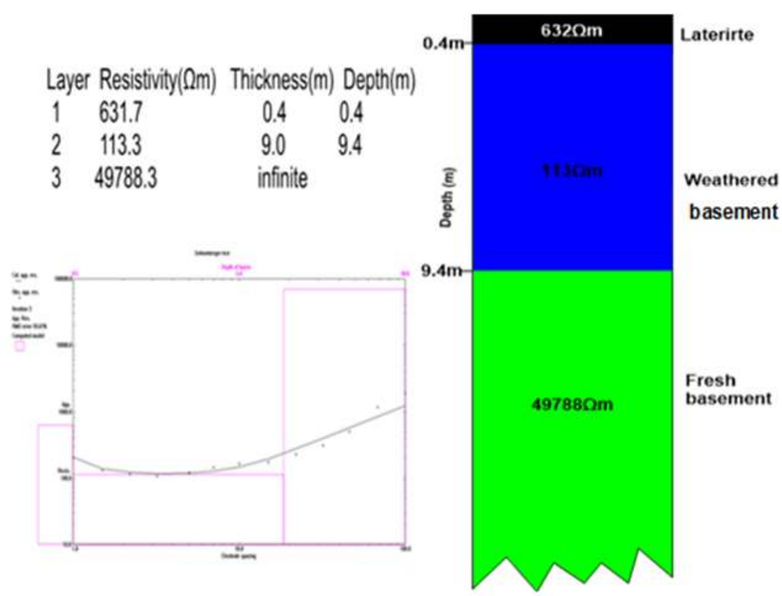

Fig. 7. Sounding Curve and Geoelectric Unit of VES 1 (ABU Gymnasium, Zaria)

3.5 Aquifer Evaluation

The high topsoil resistivity indicated 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 of weathered/fractured basement at VES 1 to VES 4 as 285 Ωm and 12.2 m, 109 Ωm and 2.5 m, 360 Ωm and 6.2 m and 113 Ωm and 9.0 m respectively, these zones constitute the aquiferous zones in the study area. This is in agreement with Aboh's report that weathered and fractured layers form the main aquifer unit in Zaria and the study area is highly productive for groundwater exploitation [11]. Aweto observed that a region with a relatively shallow (<11 m) may be vulnerable to contamination that may arise from human activities [17]. 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 unprotected 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 [10]. As presented in Figs. 4 - 7, such conditions are only met at waterworks base and ABU Gymnasium. However, location (Staff school, VES 2) indicates a very thin aquifer unit and it may not be advisable for siting borehole due to the nature of the basement present in its subsurface.

4. CONCLUSION

The geoelectric investigation of the study area has revealed three 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 which 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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