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Hydrogeological Mapping of Bingham University, Karu Campus, Nasarawa State

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ABSTRACT
The hydrogeological studies of Bingham University Karu Campus to ascertain qualitative and quantitative groundwater potentials through the interpretation of 32 Vertical Electrical Soundings (VES) data of the geophysical investigation with complementary ADMT isoline maps has revealed three to five subsurface geoelectric layers and geologic sections, namely: topsoil, clay/silty followed by wet weathered basement, fractured and fresh basement rocks. The aquifer units in the study area consist of the weathered basement and fractured layers. The study area's predominant layer of a weathered basement, which ranges in resistivity from 17 Ωm to 710 Ωm, was selected as a viable aquifer zone target for groundwater exploitation. Given the thickness of the underlying aquifers, the indicated zones have a higher storage capacity and are well-suited to accommodate any potential future water demand within the university community. The prominent zones found for groundwater development are VES points A1 – A4, B2, B3, B5, C7, C8 and D5 with depth zones ranging from 15.1m to 130m. Six points failed productivity evaluation due to the shallow depth and resistive nature of the aquifers in the regions and discouraged groundwater development.

Keywords:
Vertical Electrical Sounding (VES),
Aquifer,
Weathered Basement,
Fractured layers,
Ground water.

INTRODUCTION

Bingham University community has rapidly grown owing to its proximity to Abuja, the Federal Capital of Nigeria. To maintain its role as the nation's information citadel, the institution is experiencing development. Due to this development, there is an increase in the demand for resources, including water resources. Globally, groundwater has been one of the hidden and valuable natural resources that affects all aspects of life. Everyone has the right to obtain clean, sufficient drinking water, regardless of their level of education, social class, economic standing, or development (Omeiza & Dary, 2018). Groundwater continues to be a crucial natural resource for people, with more than 1.5 billion people strongly reliant on it (Gibson et al., 2018). Continuous efforts to provide clean water and reduce pollution utilizing all available resources have not yet produced substantial results (Alao, 2023; Alao et al., 2023). Therefore, one of the global challenges for water management in the recent past and the decades to come is providing appropriate storage capacity under the current expanding water demand and unstable climate circumstances (Tuinhof et al., 2005). The demands on groundwater resources will increase, and multiple storage systems will be needed in addition to the current storage capacity, like overhead tanks, to provide enough water, particularly during dry spells (Tuinhof et al., 2005). Despite the fact that some studies have suggested using rainwater as a storage reservoir (Shah et al., 2000; Keller et al., 2000), the majority of rainwater still runs off into the ocean, and only a small number of dams (about 800,000) around the world are able to store more than one-fifth of the world's annual precipitation (Shah et al., 2000). Therefore, an effective aquifer storage support mechanism (ASSM) can act as a substitute for traditional water storage and as a way to address groundwater-related issues, particularly in light of recent changes in the global climate (Sheng & Zhao, 2015). ASSM is a technical alternative for artificial aquifer storage that is a necessary purification step for water security, sustainability, and preservation.

Poor yield of water was observed from some drilled boreholes within the campus and this necessitated the study of hydrogeological mapping of the region. The synthesis and transmission of field data across domains is a crucial function of maps in hydrogeology study and professional practice. Hydrogeological maps combine information on the container (an aquifer) and the content (groundwater) to display the composition and structure of the subsurface with the presence and flow of groundwater (Margaret and van der Gun, 2013). Additionally, hydrogeological maps address the following: i) data on groundwater dynamics and the relationship between groundwater and surface water; ii) the presentation of observed or inferred structural elements at depth, in particular, those of delineated aquifer systems which form the framework for evaluating and managing groundwater resources; and iii) data on groundwater dynamics and the relationship between groundwater and surface water and iv) Depending on the state of knowledge, further information can be added to these fundamental components about groundwater recharge through the infiltration of extra rainwater, water quality, and abstraction works (Margaret and van der Gun, 2013).

A dominant method of discovering groundwater potential in geophysical survey is Electrical resistivity which helps to image the subsurface using the differences in electric potential to identify subsurface materials. There are many applications of electric resistivity methods which include groundwater detection, mineral and oil identification, waste exploration, etc. It can be classified into two major categories. Measurement of the resistivity or conductivity of rocks is the focus of one group, while measurement of their capacitance is the focus of the other. Induction polarization techniques fall under the second group, while the galvanic, induction, magneto-telluric, and telluric techniques are under the first group (Fetter, 2001). The study of variations in resistivity with depth (depth sounding methods) or the investigation of lateral changes in resistivity (horizontal profiling methods) can both be done using any resistivity method (Aboh, 2009).

Vertical Electrical Sounding (VES) method introduced by Schlumberger since 1934 is one of the most commonly used and cost-effective resistivity survey methods. More specifically, a sandstone body's seismic signal would be the same whether its pores were filled with fresh or brackish water, but its resistivity would fluctuate in response to minute changes in the salt of the water. The low cost and this characteristic make the VES methods ideal for groundwater investigation. Currently, Schlumberger array remains the best array for depth sounding amongst others developed over the years (Jatau et al., 2013).

In basement complex, the closer new technique in subsurface fluids detection complementary to VES is the Aidu Magnetotelluric (ADMT) water detector, The ADMT-300S measures natural electromagnetic field strength, its response to changes in resistivity of the subsurface formation to help in analyzing and determining the location and depth of groundwater and other geological features (source: www.alibaba.com, 2022). It is easier to operate than the VES method and the probe depth per unit time is deeper but cannot reveal the lithological components of the subsurface like the VES.

Previous research has demonstrated that the silty, clay, worn, and fractured basement contains the primary aquifer components of the basement complex (Alao et al., 2022). Typically, laterites and sandstones cover the local rock formations. The surface of the laterite is heavily cemented, specifically, and weathered into lateritic nodules that are intermingled with silty and sandy clays (Oyawoye, 1964). However, the weathering of Precambrian rocks exposed by erosion is usually the cause of some rock outcrops of hard-resistant granite existing in the region (Oyawoye, 1964). While the streams in the area change periodically, the case study's drainage pattern is dendritic. The underlying solid geology of the Nasarawa state is a transition zone made up of a mixture of Basement and Sedimentary formations. The study area is situated within Nigeria's basement rock structure. According to McCurry (1976), the migmatite, gneiss, and granite that made up Nigeria's basement complex were reactivated old crystalline rocks that belonged to a single petrogenetic unit. According to Rahman (1973), the metamorphism of the Nigerian basement rocks was polycyclic. For the basement rocks to be reliable indicators of groundwater sources and locations for drilling tube wells for potable water supply, Abdullahi & Udensi (2008) underlined the necessity of joints and fracture sets in crystalline rocks. The basement complex rocks in some areas of the Lokoja metropolis in north central Nigeria are suggested by Obaje (2007) to be prospective groundwater supplies. According to field research conducted in the Gwarinpa-Keffi region, the rocks that make up the basement complex are migmatite, and gneiss, with intrusions of Older Granite complexes, and pegmatite dykes. In the NNE-SSW and NNW-SSE orientations, fractures are trending northward. This study is aimed at providing a subsurface information that will aid the University in citing boreholes for good and efficient ground water development in the Campus.

METHODS AND MATERIALS

Study Area

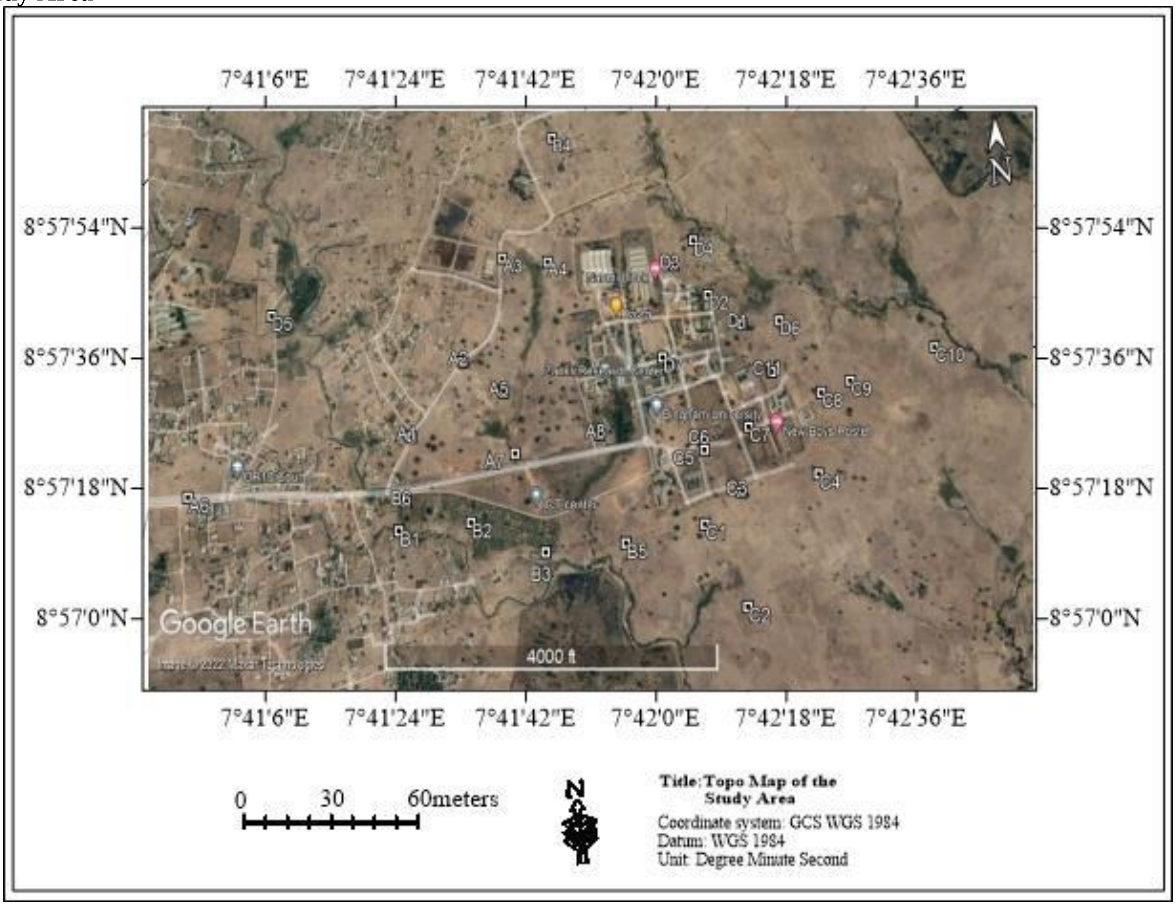


Figure 1: Map of the Study Area.

The case study lies at latitude 8.9565ºN and longitude 7.6997ºE along the Abuja-Keffi Road in Nasarawa State, Nigeria. It has a total landmass of 259 hectares (BHU-DPP&D, 2020). The study region is surrounded by seasonal streams and drained by surface water and groundwater.

Materials

Materials used for the field work includes: Ohmega Terrameter, electrodes, hammers, measuring tape, rims of conducting cable, range poles, pegs, field notepad, Global Positioning System (GPS), ADMT 300S set. Software like Res D1, suffer 11, MS Excel, ADMT automated set were used during data processing and interpretation of the results.

Method

Vertical Electrical Sounding (VES) using Schlumberger Electrode Array was used during the field work.

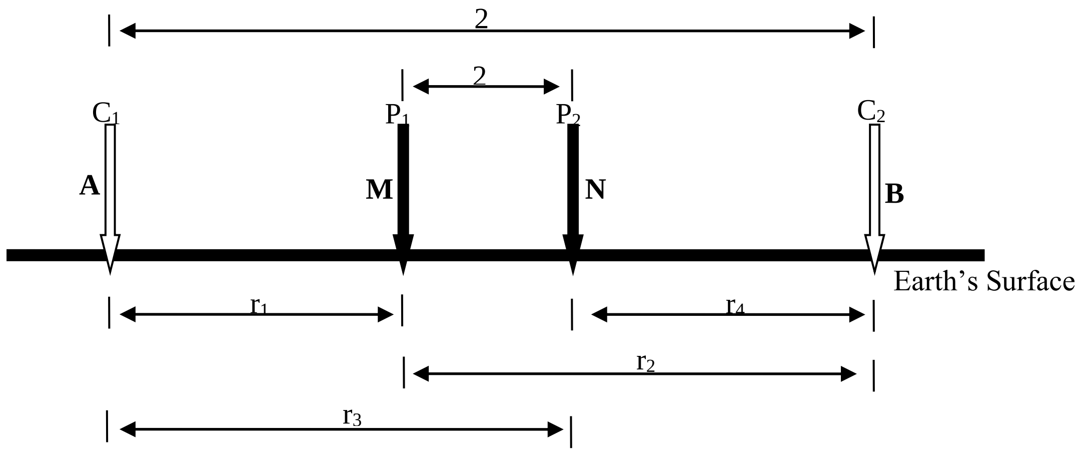


Figure 2: Schlumberger Electrode Array (Telford et al, 1990 and Dogara, 2022).

According to Ohm's law, the relationship between the current I and potential V in a metallic conductor at constant temperature is as follows:

$$V = IR \quad (1)$$

where R is the proportionality constant, expressed in ohms, known as resistance. The resistance R of a conductor is inversely proportional to its cross-sectional area A and directly proportional to the length L as given by

$$R = \frac{\rho L}{A} \quad (2)$$

Where ρ is the resistivity, a characteristic of the material under consideration. Based on (1) and (2),

$$V = \frac{I\rho L}{A} \quad (3)$$

With a central reference point established, potential electrodes MN are positioned between the current electrodes AB using the Schlumberger arrangement. At each subsequent reading, the current electrodes AB pushed symmetrically outward to allow for deeper current penetration and, thus, deeper probing. While maintaining that MN is much less than AB, the distance between the MN electrodes increases when the current electrodes AB spread apart from one another (Figure 1). This is to maintain detectable potentials and keep the voltage from decreasing below the voltmeter's reading accuracy. When current electrodes placed on the equipotential surface are semi-spherical downward into the ground at each electrode, a potential gradient is at M and N. The surface area will be $2\pi L^2$, where L is the sphere's radius. Thus,

$$V = \frac{I\rho}{2\pi L} \quad (4)$$

The potential at M (V_M), caused by the two current electrodes, is therefore deduced to be

$$V_M = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad (5)$$

The potential at electrode N (V_N) is similarly given by

$$V_N = \frac{I\rho}{2\pi}\left(\frac{1}{r_3} - \frac{1}{r_4}\right) \quad (6)$$

Figure 1 depicts r_1, r_2, r_3 and r_4

Between electrodes M and N, there is a potential difference, or $V = V_M - V_N$. (Telford et al, 1990).

$$\Delta V = V_M - V_N \quad (7)$$

$$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right] \quad (8)$$

$$\Rightarrow \rho = \frac{2\pi\Delta V}{I}\left[\frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)}\right] \quad (9)$$

For an inhomogeneous body like the study area, the apparent resistivity (ρ_a) is considered,

$$\rho_a = K\left(\frac{\Delta V}{I}\right) \quad (10)$$

where ρ_a is apparent resistivity measured in ohm-metre, and,

$$K = 2\pi\left[\frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)}\right] \quad (11)$$

K is a geometric factor whose value depends on the type of electrode array used. For the Schlumberger array, if MN = 2b and $\frac{AB}{2} = L$, then (Telford et al, 1990 and Dogara, 2022):

$$K = \pi\left(\frac{L^2}{2b} - \frac{b}{2}\right) \quad (12)$$

Field Work

Vertical Electrical Sounding (VES)

The campus was divided into four profiling zones to collect data from 32 Vertical Electrical Sounding (VES) locations. 150m interval was between the VES points. At each VES point, the maximum separation of current electrodes (AB/2) was 150m.

Figure 1 shows the Schlumberger array electrode configuration used in this work. The current went to the ground through electrodes A and B. Potential difference was across from electrodes M and N. The field approach expands the current electrodes' distribution while maintaining an approximately constant potential electrodes' range. To create a potential difference between the potential electrodes M and N for each reading, a current was discharged into the ground through A and B. The magnitude of the potential difference that developed was an indicator of the electrical resistance of the ground between the potential electrodes. This resistance depends on the electrodes' geometrical arrangement and the electrical characteristics of the ground (Dogara, 1995).

As the separation of AB increases, the potential between MN reduces and becomes negligible at some point. The potential electrodes MN are now separated further, resulting in a value greater than the value obtained earlier. Each sounding's data was recorded as resistivity and apparent resistivity was calculated by multiplying that value by a geometric constant (K). The data were recorded and processed with Res D1, suffer 11, MS Excel and IPI2WIN software.

Aidu Magnetotelluric method (ADMT)

The Aidu Magnetotelluric method ADMT-300S is the second method used. It has a mainframe working with either two electrodes or a wireless sensor. The software installed on an Android mobile phone collected, processed and store the data in the ADMT cloud. The magnetotelluric survey uses electric field associated with the earth currents at each point that the VES was carried out. As a hand-on equipment that has ease of operation and faster though not detailed in subsurface categorization (Telford et al, 1990).

RESULTS AND DISCUSSION

Schlumberger array of electrical resistivity methods was carried out at the Bingham University premises to delineate the aquifer potential for groundwater development. During the investigation, thirty-two (32) vertical electrical sounding (VES) points were established on four zones of the university premises as follows:

Zone A: Southwest - 8 VES points

Zone B: Northeast and some parts of Southwest - 6 VES points

Zone C: Central and Southeast - 11 VES points

Zone D: Cental and easthern parts - 7 VES points

Results of Zone A

The composite Geoelectric/geologic section for the eight (8) VES stations deployed in zone A is shown in Figure 3. The top layer's resistivity and thickness were found to be in the range of 118 Ωm to 1396 Ωm and 1.1 m to 4.8 m, respectively. According to studies, the weathered and fractured basement serves as the water-bearing unit for the majority of Northern Nigeria (Abdullahi and Udensi, 2008; Alao et al., 2022; Alao and Dogara, 2018; Omeiza et al., 2022). The fractured layer's resistivity and thickness range from 453 Ωm to 1473 Ωm and 25 m to 42 m, respectively, whereas the weathered layer, which is the second layer, is discovered to have resistivity values ranging from 75 Ωm to 486 Ωm. That is, zone A indicates high aquifer thickness and relatively low resistivity except in A5 with a shallow depth. The presence of fracture rocks in the preceding layer would ensure ground water security.

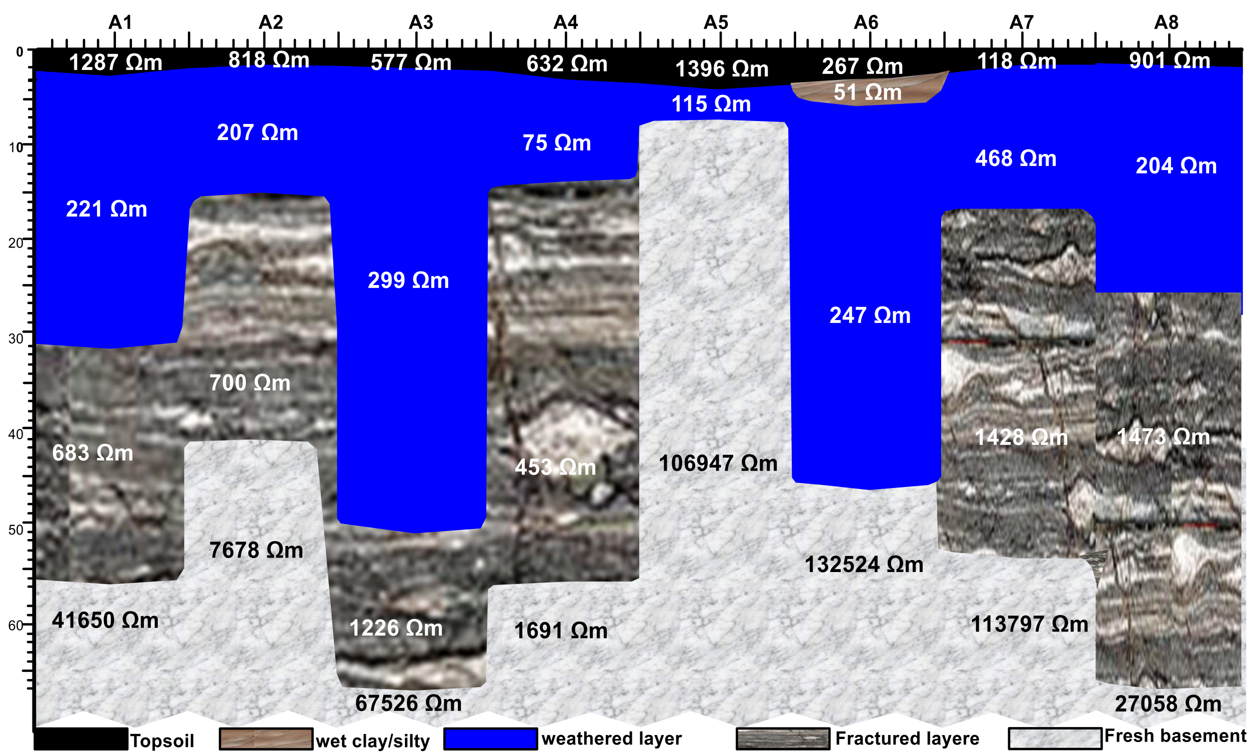


Figure 3: Hydrogeological and Lithological Parameters of Zone A

Results of Zone B

The composite Geoelectric/geologic section for the six (6) VES stations deployed in zone B is shown in Figure 4. The top layer's resistivity and thickness were found to be in the range of 178 Ωm to 700 Ωm and 1.0 m to 2.8 m, respectively. The presence of indurated laterite may be indicated by the high resistivity value reported around B1, B2, B3, B5, and B6. The study area's water-bearing unit is the cracked and worn basement. The fractured layer's resistivity and thickness range from 453 Ωm to 1473 Ωm and 5.9 m to 89.2 m, respectively, whereas the second layer, the weathered layer, has resistivity values that range from 45 Ωm to 710 Ωm and thicknesses that range from 5.0 m to 70 m. That is, zone B indicates high aquifer thickness and relatively low resistivity except in B4 and B6 with a shallow depth. According to (Aboh et al., 2016; Aweto, 2012; Bello et al., 2019; Olayinka, 1992), the quantitative and qualitative water are usually found in the subsurface porous rocks beneath the water table. Therefore, the presence of fracture rocks in the preceding layer would ensure ground water security. Figure 5 and Figure 6 in zone C and D respectively show similar trends with that of Figure 3 & 4.

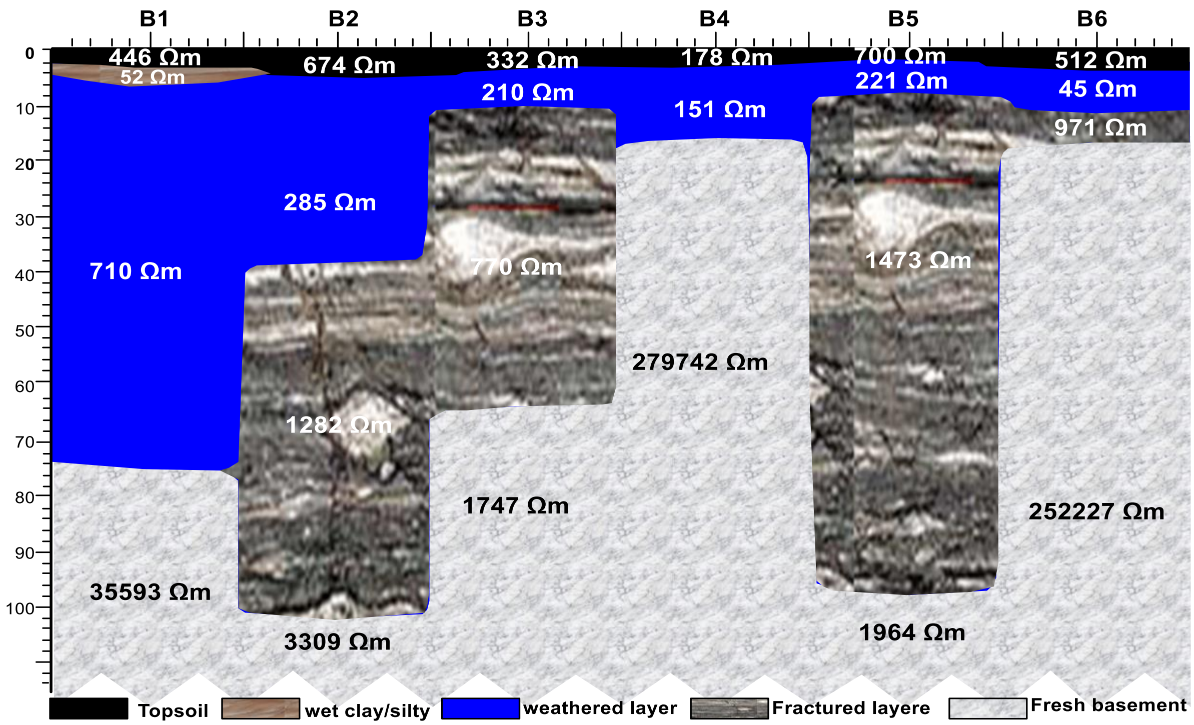


Figure 4: Hydrogeological and Lithological Parameters of Zone B

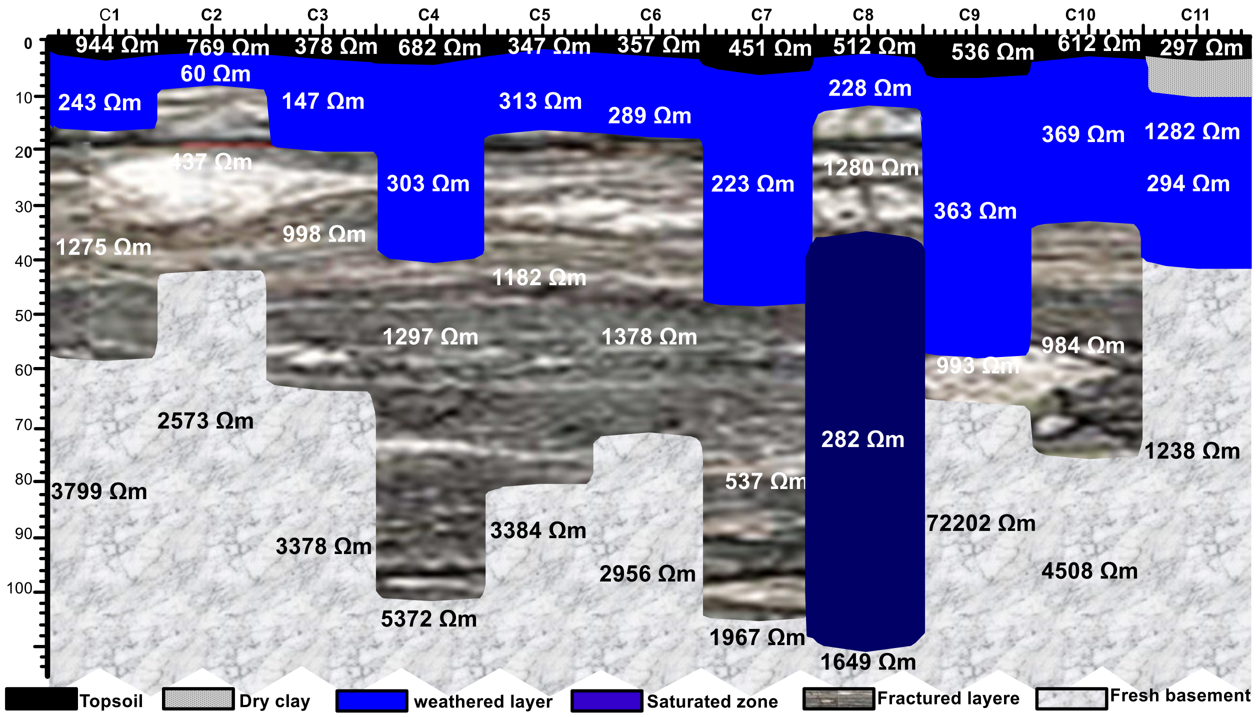


Figure 5: Hydrogeological and Lithological Parameters of Zone C

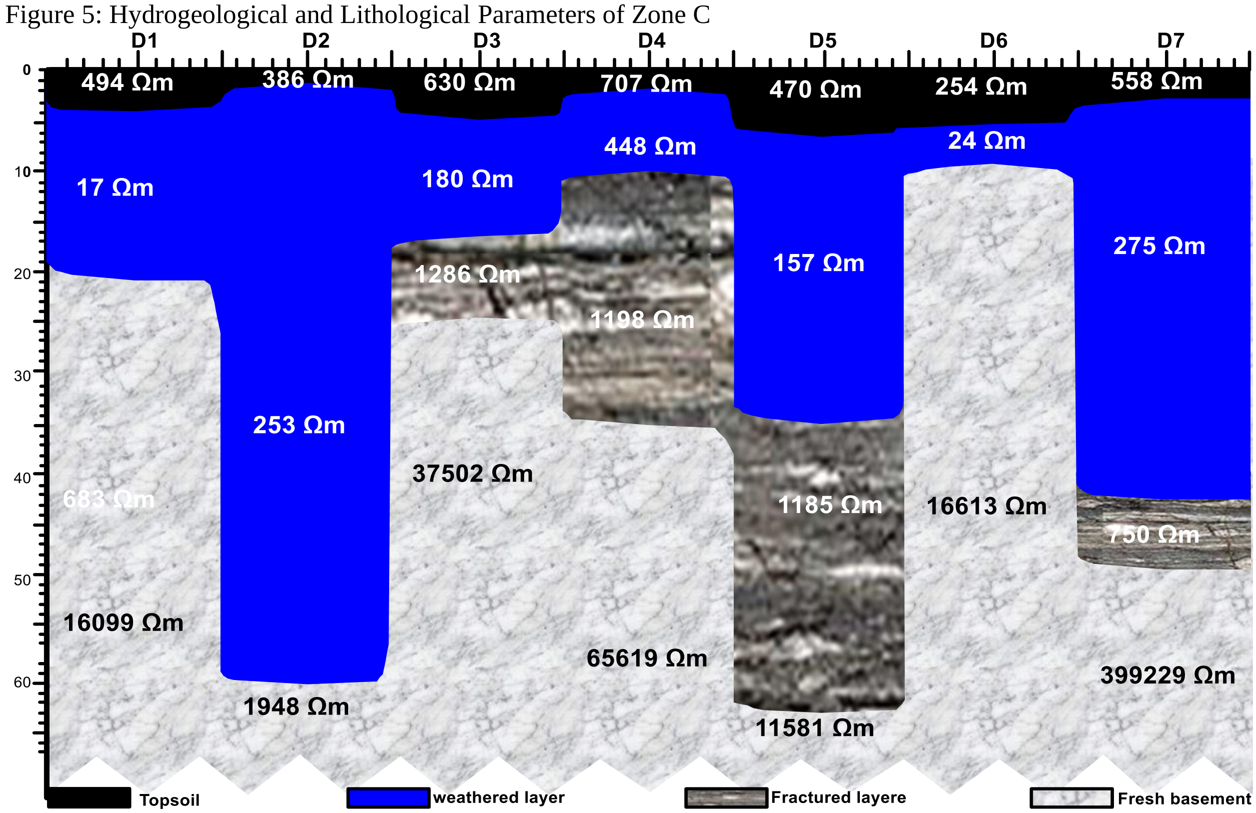
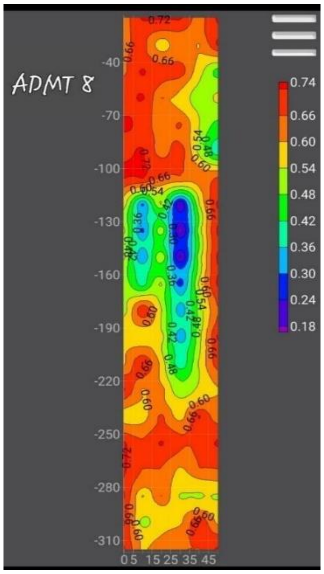


Figure 6: Hydrogeological and Lithological Parameters of Zone D



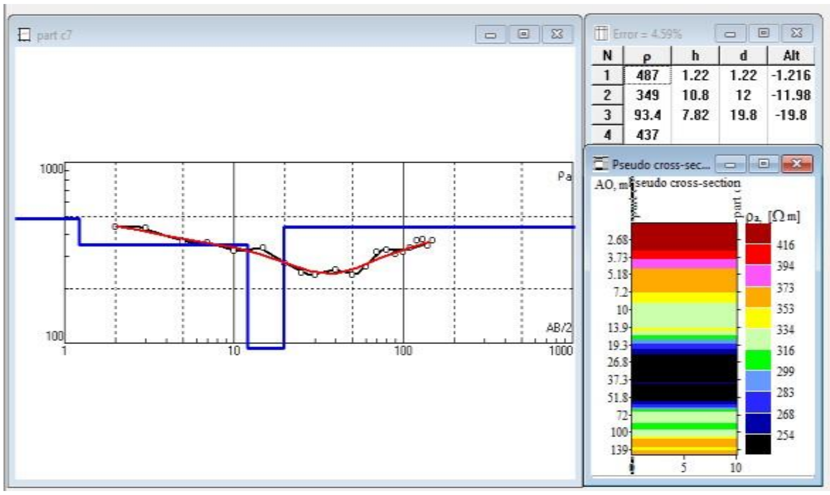


Figure 7: ADMT Map

Figure 7: shows one (1) out of the 32 ADMT isoline/raster maps which all agrees with VES data interpretation across the four (4) zones. In terms of yield per liter, it reveals the aquifers potential range of 0.009 – 0.74liters/second with an average of 0.36liters/second mostly within 15m – 55m depth which is higher than the moderate rate of 0.2liters/second (Cretons and Crust Ltd, 2022).

Discussion

Aquifers are geologically deposited materials with significant water storage, recovery, and transmission capabilities (Bello et al., 2019). The study area, except for a few places, is very productive for groundwater exploitation (the sitting of boreholes), according to the resistivity and thickness values of the aquifer unit and the overburden thickness of the study site as shown in (Figure 4 - 7). Within a studied region, aquiferous units made of overburdened materials from weathered/fractured basements constitute a significant portion of the groundwater potential. The observed thickness and makeup of the weathered layer in the research area are crucial to the growth and sustainability of the groundwater system. The water-bearing layer, which is a weathered/fractured layer that is very thick and has a low resistivity, indicates the strength of the local aquifers and points to saturation conditions, high storage, and high recovery systems. However, the VES points A5, B4, B6, C11, D1, and D6, indicate shallow aquifers and may be considered weak for groundwater development. This is because shallow aquifers are vulnerable to contaminations, low storage capacity and poor recovery system, as suggested by Aweto, (2012), that a shallow aquifer region may be susceptible to contamination brought on by human activity. Deeper aquifer regions are primarily productive for the development of groundwater in good quality and quantities and are less susceptible to contamination that may occur from human activities, according to Alao and Dogara (2018) and Alao et al. (2022). Consequently, these areas suggested for groundwater development are highly protective from the near-surface pollutants.

CONCLUSION

Water in this area is usually gotten from the weathered overburden, fractures and fissures of the rocks known as the aquifer unit. The study area has 91% highly productive zone, 6% averagely productive zone and 3% weakly/poor productive zone for groundwater exploitation.

Currently, there are five (5) poor yielding boreholes in the study area, of which two (2) are due to siting and three (3) due to non-hydrogeological factor(s)

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