Research Article *http://dx.doi.org/10.4314/mejs.v18i2.9* *Open Access*

Geophysical Investigation of Termite Mounds as Indicators of Groundwater in University of Education and Entrepreneurship and Adjoining Villages in Akamkpa, Nigeria

Abong, A. A[1*] and Nkom, P. Y[2]

[1]Department of Physics, University of Cross River State, P.M.B 1123, Calabar, Nigeria (*abongaustine@unicross.edu.ng; https://orcid.org/0000-0002-8300-3762).

[2]Department of Chemistry, University of Cross River State, P.M.B 1123, Calabar, Nigeria (patiencenkom@unicross.edu.ng; https://orcid.org/0000-0002-2681-0015).

ABSTRACT

This study assessed the suitability of termite mounds as indicators of groundwater occurrence in Akamkpa, Nigeria, using geoelectrical methods. Eight Vertical Electrical Soundings (VES) were conducted with a maximum electrode spread of 400 m using the Schlumberger array. Six VES stations were located near termite mounds, while two control stations were established away from the mounds for comparison. Data were acquired using Resistivity meter Model SSR-MP-ATS IGIS (India) that measures resistance to an accuracy of 1μΩ and its accessories, and interpreted using Dar Zarrouk parameters to evaluate groundwater potential. The results showed that the weathered basement layer, or aquifer layer, lies between resistivity 261.90Ωm and 573.80Ωm and this corresponds to saturated weathered gneiss, which forms the main aquifer in the area. Among the surveyed locations, VES 7, situated near a termite mound, recorded the lowest resistivity values and exhibited the highest groundwater potential. Aquifer thickness generally increased from the southwestern to the eastern part of the study area, with VES 8 indicating particularly favourable groundwater prospects. Similarly, overburden thickness increased toward the southeastern region, where VES 3, VES 4, VES 7, and VES 8 recorded the greatest thicknesses. High total transverse resistance values, particularly at VES 8 located near a termite mound, further confirmed favourable groundwater conditions. Total longitudinal conductance values indicated weak to poor aquifer protective capacity across the study area, suggesting that the groundwater is susceptible to contamination, especially in the southwestern zone. In addition, the low anisotropy value (1.10) observed at the termite mound location VES 8 indicated groundwater potential. Overall, the findings demonstrate that termite mounds can serve as reliable hydrogeological indicators for groundwater exploration in the study area.

Keywords: Termite mounds, Groundwater, Aquifer, Oban Massif, Dar Zarrouk parameters.

1. INTRODUCTION

The importance of water to man, animals and plants across the globe especially where surface water is scarce cannot be overemphasized. Its importance over sources of water is that it cannot easily be contaminated or polluted where the aquifer thickness is large. It is not visible to the eyes but is found beneath the earth's surface and moves at a slow speed. The characteristics of groundwater are influenced by the geological formations present within the region as well as the patterns of land utilisation.

Groundwater serves as a significant resource across the globe. In densely populated countries such as the United States, China, and India, more than fifty percent of the agricultural land

Submitted: 23rd November 2025 Accepted: 26th August 2026 Published: 29th October 2026

© CNCS Mekelle University. This article is licensed under a Creative Commons Attribution 4.0 International License. This license enables re-users to distribute, remix, adapt, and build upon the material in any medium or format, so long as attribution is given to the creator. The license allows for commercial use. To view the details of this license, visit http:// creativecommons.org/ licenses/ by/4. 0/. CC: Creative Commons; BY: credit must be given to the creator.

is irrigated utilising groundwater (Sharma et al., 2021). Throughout history, humanity has managed and harnessed water, an essential natural resource, to ensure the sustenance of life. Nevertheless, a mere fraction of the earth's water resources is appropriate for human consumption as fresh water. More than fifty percent of the fresh water required for everyday activities, including hydration, culinary preparation, and personal sanitation, is derived from groundwater (Sikakwe, 2020).

Approximately, two-thirds of the global populace encounters water scarcity at least once within a given year (Mekonnen and Hoekstra, 2016). Of the 3.6 billion people who lack access to basic sanitary facilities, 55.6% lack access to clean drinking water (United Nations World Water Development Report (UNWWDR, 2023). For example, 60 million citizens of Nigeria are deprived of access to potable drinking water within their residences, notwithstanding numerous initiatives by the government and the River Basin Authority (The World Bank, 2021). In densely populated and economically advanced nations such as China, India, and various African nations including Nigeria, the escalating demand for water for domestic, agricultural, and industrial utilisation has emerged as a critical issue (Ojo et al., 2024). The quantity and quality of groundwater resources are profoundly influenced by an array of factors, including urban expansion, industrial development, and deforestation (Olusola et al., 2017; Ijioma, 2021). As reported by Ojo et al. (2024), residential, agricultural, and industrial sectors account for 36%, 42%, and 22% of groundwater resource utilisation, respectively.

Additionally, groundwater supports the aquatic ecology and improves the flow of wetlands, streams, and springs, which serve as homes for fish, plants, and wildlife. It recharges surface water bodies, filters pollutants, and aids in maintaining the quality of the water. However, statistics show that over 1.8billion people worldwide use untreated drinking water, which raises their risk of catching cholera, polio, diarrhoea, typhoid, dysentery, and other water-borne illnesses. According to 2015 research by the World Health Organisation (WHO) and the United Nations Children's Emergency Fund, poor access to water sanitation (WASH) facilities has been linked to 10% of the total sickness burden and 94% of the prevalence of diarrhoea. The Nigeria Health Demographic Survey (NDHS) (2019) found that 46.4% of people in Cross River State continue to get their drinking water from unimproved sources. Given the rise in water-related illnesses in recent years, this number appears concerning.

Access to safe and enough water remains a big challenge in University of Education and Entrepreneurship and adjoining in Akamkpa despite groundwater potential identified in the area. Because of the operations of quarrying businesses, water sources are susceptible to pollution and degradation. Local residents, employees, and students compete for water, particularly during the

dry season. It can be challenging to prospect for groundwater in this basement complex. According to reports, termite mounds can identify groundwater (Ahmed et al., 2020).

People who reside in tropical or subtropical regions of the world, where termite activity is more prevalent, are also among the poorest. This is primarily due to water shortages, which have an impact on their social inclusion, income, education, and health (Liu et al., 2018). The rationale for using termite mounds as indicators of groundwater stems from the fact that termites need a relatively moist environment for survival and construction of their colonies. Areas where termite colonies exist may therefore reflect subsurface conditions that provide sufficient moisture. Also, termites excavate and transport soil from below the ground surface during mound construction. The materials that come to the surface originate from deeper soil horizons and may indirectly reveal variations in the underlying geology. These variations can be associated with zones of weathering, fractures, or permeable formations that influence groundwater occurrence.

The objective of this study is to investigate termite mounds as indicators of groundwater using vertical electrical sounding method. Also, to evaluate the Dar Zarrouk parameters close and far away from termite mounds in University of Education and Entrepreneurship and adjoining villages in Akamkpa Nigeria

2. MATERIALS AND METHODS

2.1. Location, Hydrogeolgy and Geology

The study area is Awi situated in Cross River State in Akamkpa Local Government Area and includes the University of Education and Entrepreneurship (UEE) and nearby villages. Awi is located between latitude $5^0$15’ 15” N to $5^0$20’50” N and longitude $8^0$20’55” E to $8^0$21’ 25” E (Fig 1). The University is about 40km North of Calabar and can be accessed from the Calabar – Ikom highway through a vehicle, motor cycle or foot path. The undulating topography and the points of lowest elevation (the troughs) constitute the drainage channels and serve as water channels (Streams) for surface run offs. The streams which are perennial empty into the River Iyako which flows into the Great Qua River.

The hydrogeology of the study area is controlled by geology, structure and weathering of the Precambrian Basement Complex of southeastern Nigeria. Groundwater occurrence in basement terrain is not as a result of primary porosity but due to secondary porosity from weathering and fracturing (Oladapo and Akintorinwa, 2007). Two major aquifer systems exist in the study area and they include weathered zone/regolith aquifer and fractured basement aquifer. The weathered zone aquifer stores water in pore spaces between weathered materials. Studies in nearby Calabar and Oban Massif indicate that this layer is the main source of shallow groundwater (Ekwok et al., 2020).

The fractured basement aquifer consists of fractured gneiss underlying the weathered zone and groundwater is stored and transmitted through faults, joints and fractures (Offordile, 2014; Oladapo and Akintorinwa, 2007; Yohanna et al., 2022).

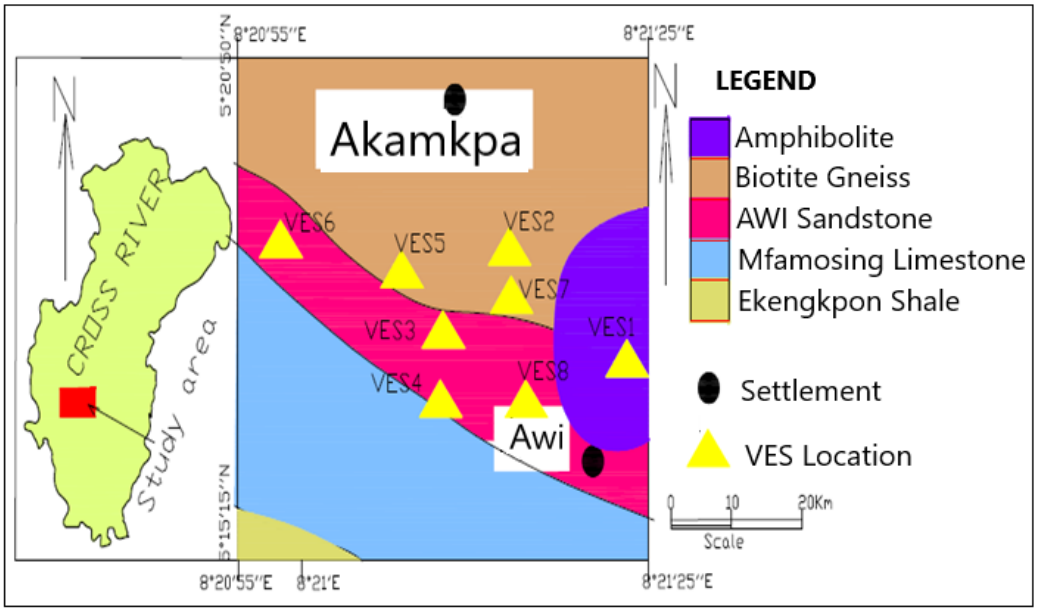


Figure 1. Geological map of the study area.

The geology of Awi is underlain by rocks of the Oban Massif within the Basement Complex and is situated in the southeast of Nigeria and stretches into Cameroon, a neighbouring country. The Calabar Flank's Cretaceous–Tertiary sediments cover it. Phyllites, schists, gneisses, and amphibolites are among the mappable rock units that make up this 10,000km^2 area. Pegmatite, quartz vein, granite, granodiorite, diorite, tonalite, monzonite, and dolerites are among the intrusive rocks in the area (Ekwueme et al, 1993). Charnokites are found as enclaves in granodiorites and gneisses. Oban Massif's rock outcrops are highly weathered and making it difficult to get fresh samples for geological research (Oyewole et al., 2017).

2.3. Field Procedure

Vertical electric sounding (VES) was conducted in the study area. The survey was carried out using Schlumberger electrode spread with current electrode spacing ranging from 1 - 200m (AB/2). This was enough to delineate the major rock boundaries to the fresh rocks. The distance between potential electrodes was increased at intervals of 0.25m - 10.00m in order to maintain a measurable potential difference across the current electrodes. Resistivity meter Model SSR-MP-ATS IGIS(India) which can measure to an accuracy of 1μΩ and the complete accessories for current and potential electrodes, a measuring tape, a hammer and umbrella. such as cables and reels were employed for data acquisition. Also, the Global Positioning System (GPS) Garmin 72 was used to take the coordinates and elevations of sounding locations (Table 1).

Table 1. Midpoint coordinates in the University of Education and Entrepreneurship (UEE) and adjoining villages in Akamkpa.

S/N	***Sampled points***	***Label***	***Latitude***	***Longitude***	***Elevation(m)***
1	In front of the Catholic Church, UEE	VES 1	N05^0 15’17.4’’	E008^{0}21’25.6’’	121.0
2	Behind Provost Office, UEE	VES 2	N05^{0}15’18.9’’	E008^{0}21’15.5’’	122.0
3	Across Staff Demonstration Nursery/primary School to Provost Office Block, UEE	VES 3	N05^0 15’20.2’’	E008^{0}21’11.5’’	129.0
4	In front of Exams and Records Block to the Demonstration school field, UEE	VES 4	N05^0 15’26.0”	E008^0 21’11.8’’	124.0
5	Female hostel Road junction staff quarters Road (Control), UEE	VES 5	N05^0 15’36.0’’	E008^{0}21’08.9.”	117.0
6	Staff quarters Road (Control), UEE	VES 6	N05^0 15’45.4’’	E008^0 20’57.8’’	123.0
7	In front of female hostel, UEE	VES7	N05^0 15’36.9’’	E008^{0}21’15.9’’	122.0
8	In front of Chapel of Glory,UEE	VES 8	N05^0 15’26.6’’	E008^{0}21’18.0’’	124.0

Using the Schlumberger array, eight (8) vertical electrical soundings (VES) with a 400m spread length were carried out. In order to ensure that AB is equal to or larger than (i.e., AB ≥5MN), the potential electrodes were placed inside, while the current electrodes were placed outside. When the distance between the current and potential electrodes was suitably adjusted, the Terrameter measured the resistance of the subsurface soil.

The measured resistance was multiplied by the geometric factor to obtain apparent resistivity. Then this was plotted on the bi-logarithm graph with the aid of Microsoft Excel. Then a Win Resit software version 2.0 was employed to invert evaluated apparent resistivity. Apparent resistivity employed in this study can be expressed as:

$$\rho_a = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] R \qquad (1)$$

Where, AB = distance in metres between current electrodes

MN = distance in metres between potential electrodes

R = resistance of the subsurface materials and is given by $R = \frac{\Delta V}{I}$ (2)

ΔV = change in potential differences measured in volts

I = current in Amperes; $\pi = \frac{22}{7}$

The termite mounds were chosen based on size, activity level and space that could accommodate 400m spread length of the VES survey. The measurements of the VES points were taken 0.50m close to the termite mounds. After analysis of the resistivity curves, a borehole lithological log was used to validate and infer lithology of the different layers for the eight (8)

vertical electrical sounding in the study area. The study was restricted to eight (8) because of space constraints that could accommodate 400.0m spread length.

Despite the usefulness of results obtained from vertical electrical sounding survey in the University of Education and Entrepreneurship and adjoining villages in Awi, Akamkpa, certain limitations were encountered. The survey was conducted within the same season and weather condition. Variations in rainfall and temperature affect moisture content of the near-surface layers. During the dry season, the topsoil becomes highly resistive due to moisture loss, while during the rainy season, infiltration reduces resistivity. This seasonal variation may cause differences in the apparent resistivity. Also, the study area is associated with undulating terrain typical of the basement complex region. The VES method assumes horizontally layered earth. However, slopes, lateral variations, and nearness to streams or roads can introduce 3D effects and distort current flow. This may lead to errors in layer thickness and evaluation of resistivity. In this study, slopes and nearness to streams and roads were avoided.

2.4. Geoelectric Parameters

The following equations were employed to evaluate the geoelectric parameters.

2.4.1. Total Longitudinal Conductance (S)

According to Ahmed et al. (2020), the total longitudinal conductance is as follows (Table 2):

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \cdots + \frac{h_n}{\rho_n} \quad (3)$$

Where, the layer resistivity parameters are ρ_1, ρ_2, ρ_3, and ρ_n, and
the layer thicknesses are h_1, h_2, h_3, and h_n.

Table 2. Overburden thickness protective capacity rating based on longitudinal unit conductance values (Oladapo and Akintorinwa, 2007).

S/N	*Total longitudinal unit conductance*	*Overburden thickness protective capacity*
1	<0.10	Poor
2	0.1 – 0.19	Weak
3	0.20 – 0.79	Moderate
4	0.8 – 4.9	Good
5	5.0 – 10.0	Very good
6	>10.0	Excellent

2.4.2. Total Transverse Resistance (T)

The following represents the overall transverse resistance (Table 3):

$$T = \sum_{i=1}^{n} h_i \rho_i = h_1\rho_1 + h_2\rho_2 + h_3\rho_3 + \cdots h_n\rho_n \quad (4)$$

Where, the layer resistivity parameters are ρ_1, ρ_2, ρ_3, and ρ_n, and
the layer thicknesses are h_1, h_2, h_3, and h_n.

Table 3. Classification of transverse resistance for aquifer (Keller, 1966; Olayinka, 1992; Laouini et al., 2017).

S/N	***Transverse resistance (Ωm²)***	***Aquifer Class***
1	<2,000	Poor
2	2,000 – 5,000	Fair
3	5,000 – 10,000	Good
4	10,000 – 20,000	Very Good
5	>20,000	Excellent

2.4.2. Coefficient of Anisotropy (λ)

The coefficient of anisotropy is represented by the following (Table 4):

$$\lambda = \left(\frac{\rho_t}{\rho_L}\right)^{\frac{1}{2}} = \left(\frac{TS}{H^2}\right)^{\frac{1}{2}} \quad (5)$$

Where, the average transverse resistivity, or ρ_t, is determined by

$$\rho_t = \frac{T}{H} = \left(\frac{\sum h_i \rho_i}{\sum h_i}\right) \quad (6)$$

The average longitudinal resistivity, or ρ_L, is determined by:

$$\rho_L = \frac{H}{S} = \frac{\sum h_i}{\left(\frac{\sum h_i}{\rho_i}\right)} \quad (7)$$

Where, h is the thickness of the layer and ρ is the resistivity of the layer.

Table 4. Classification of coefficient of anisotropy (Telford et al., 1990; Olayinka, 1992; Reynolds, 2011).

Coefficient of anisotropy	***Degree of anisotropy***	***Hydrological implication***
1.00 - 1.10	Isotropic	Uniform groundwater flow in all directions; excellent for borehole development homogeneous aquifer.
1.11 – 1.30	Slightly anisotropic	Predominantly horizontal flow. Good aquifer potential. Uniform drawdown.
1.31 – 1.50	Moderately anisotropic	Flow is more horizontal than vertical. Fair aquifer potential. Possible preferential flow paths.
1.51 – 2.00	Highly anisotropic	Strong directional control of groundwater. Poor to fair aquifer. Fractures control flow.
>2.00	Extremely anisotropic	Groundwater flow highly restricted. Poor aquifer potential. Requires careful borehole sitting.

3. RESULTS

The qualitative interpretation of the VES model curves in the study area (Figs 2-9) indicates four to five geoelectric layer conditions. HKH and KH are the most common curve types, followed by KHK and KQH (Fig 10). The summary of geoelectric parameters is given in table 5.

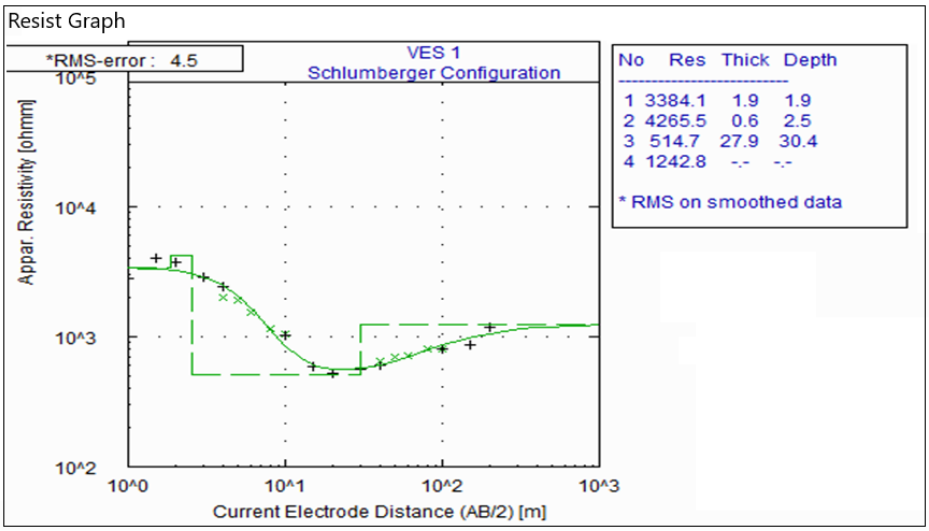


Figure 2. KH VES curve in front of the Catholic Church in University of Education and Entrepreneurship, Akamkpa.

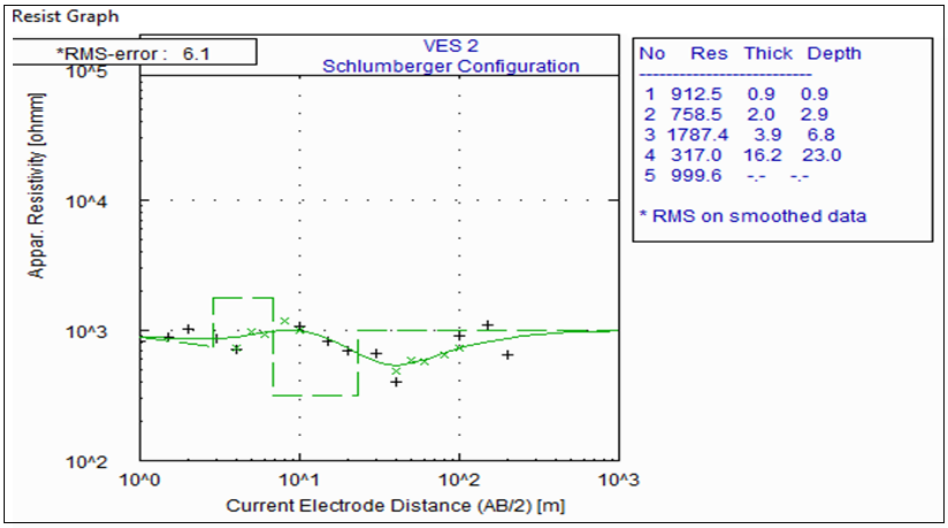


Figure 3. HKH VES curve behind Provost Office., University of Education and Entrepreneurship, Akamkpa.

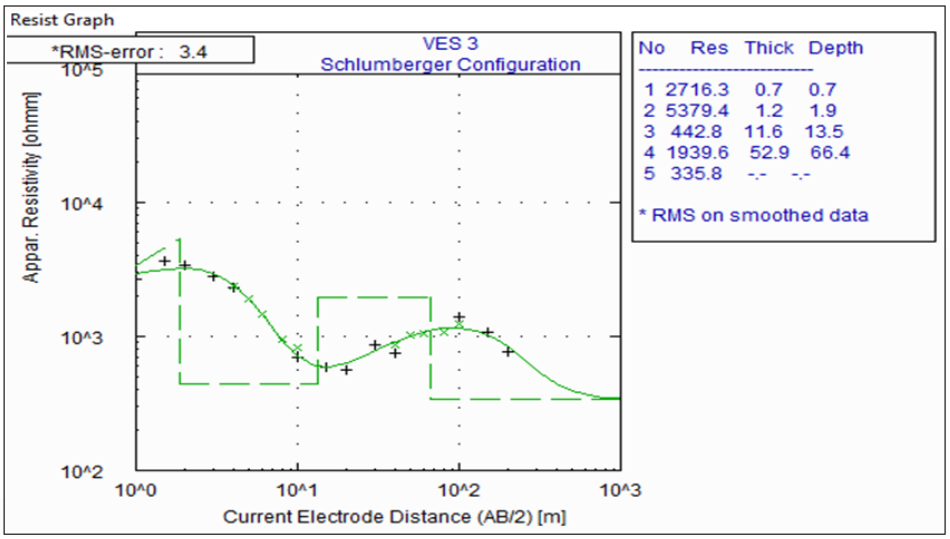


Figure 4. KHK VES curve across Staff Demonstration Nursery/primary School to Provost Office Block in the University of Education and Entrepreneurship, Akamkpa.

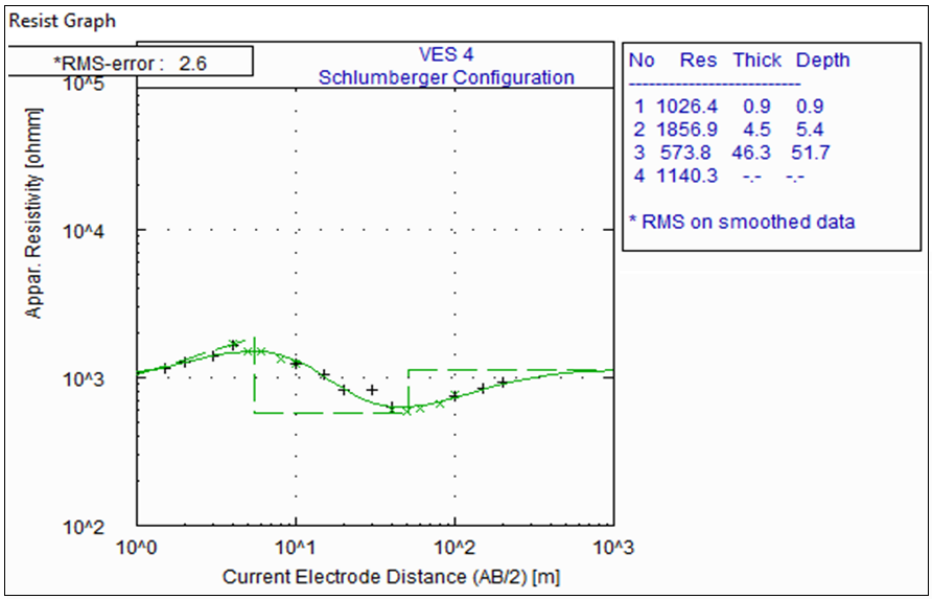


Figure 5. KH VES curve in front of Exams and Records Block to the Demonstration school field in the University of Education and Entrepreneurship, Akamkpa.

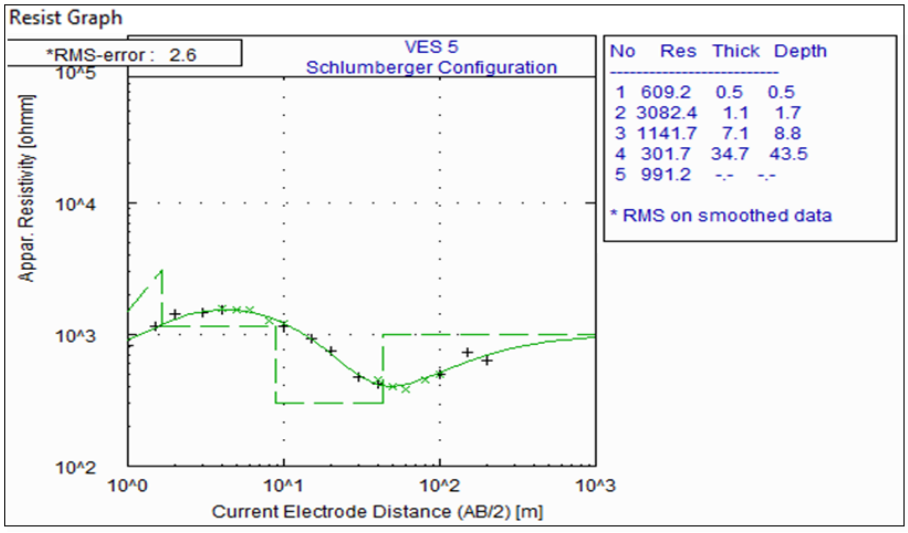


Figure 6. KQH VES curve at female hostel Road junction staff quarters road (Control) in the University of Education and Entrepreneurship, Akamkpa.

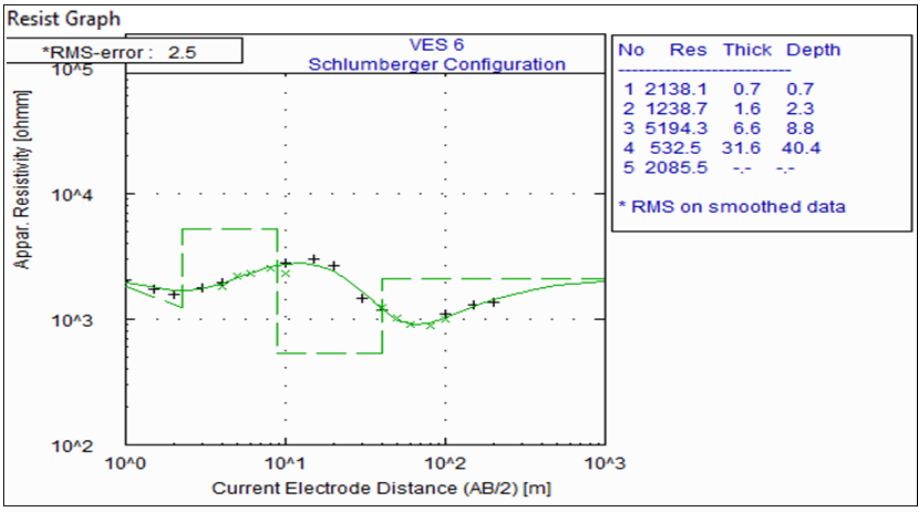


Figure 7. HKH VES curve at Staff quarters (Control) in the University of Education and Entrepreneurship, Akamkpa.

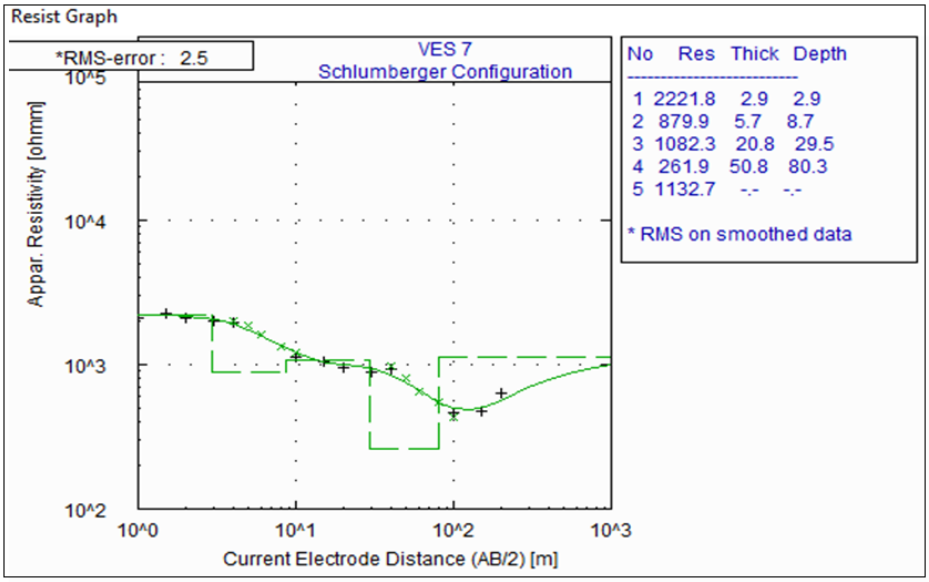


Figure 8. HKH VES curve at in front of female hostel University of Education and Entrepreneurship, Akamkpa.

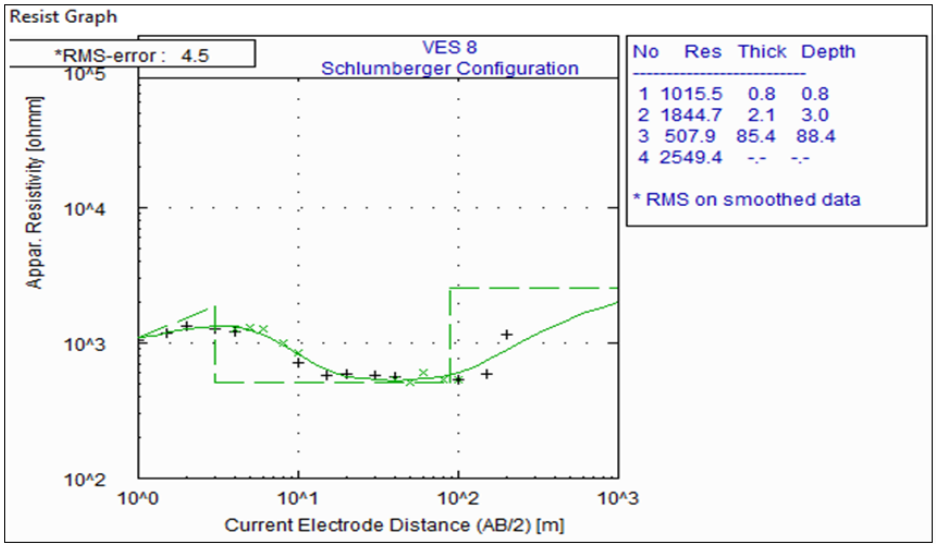


Figure 9. KH VES curve in front of Chapel of Glory University of Education and Entrepreneurship, Akamkpa.

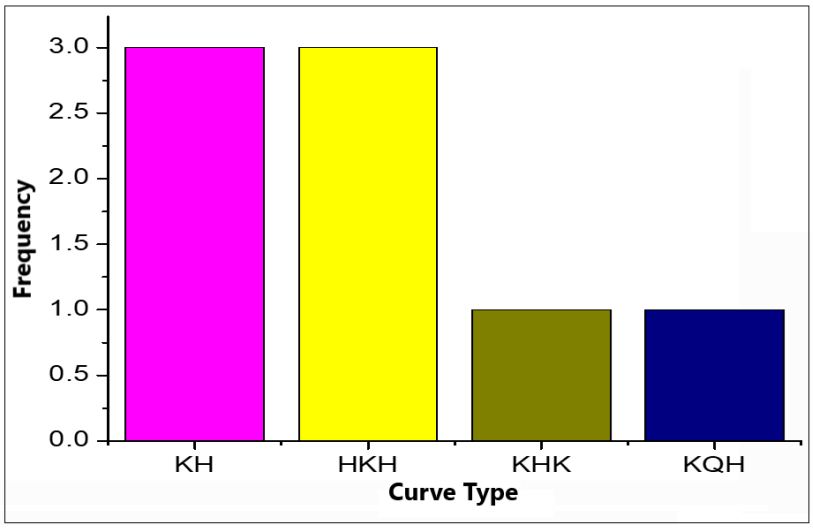


Figure 10. Bar chart displaying the varieties of VES curves in the study area.

Table 5. Summary of geoelectric parameters.

VES points	***ρ_1(Ωm)***	***ρ_2(Ωm)***	***ρ_3(Ωm)***	***ρ_4(Ωm)***	***ρ_5(Ωm)***	***h_1(m)***	***h_2(m)***	***h_3(m)***	***h_4(m)***	***$\sum h_i$(m)***	***Curve type***
VES 1	3384.10	4265.50	514.70	1242.80	-	1.90	0.60	27.90	-	30.40	KH
VES 2	912.50	758.50	1787.40	317.00	999.60	0.90	2.00	3.90	16.20	23.00	HKH
VES 3	2839.40	4483.20	416.30	1776.90	425.40	0.70	1.40	10.20	45.00	57.30	KHK
VES 4	1026.40	1856.90	573.80	1140.30	-	0.90	4.50	46.30	-	51.70	KH
VES 5	609.20	3082.40	1141.70	301.70	991.20	0.50	1.10	7.10	34.70	43.40	KQH
VES 6	2138.10	1238.70	5194.30	532.50	2085.50	0.70	1.60	6.60	31.60	40.50	HKH
VES 7	2221.80	879.90	1082.30	261.90	1132.70	2.90	5.70	20.80	50.80	80.20	HKH
VES 8	1015.50	1844.70	507.90	2549.40	-	0.80	2.10	85.40	-	88.30	KH

***Note*:** Layer resistivity is represented by ρ, layer thickness by h, overburden thickness by ∑hi.

4. DISCUSSION

VES 1 is a four-layer curve and the aquifer zone is in layer 3 with resistivity value of 514.7 Ωm and depth of 2.50m – 30.40m. In comparison with the borehole lithological log in the area, the four layers consist of laterite topsoil, shallow fresh gneiss/hard pan, weathered gneiss + Clayey sand and fractured gneiss.

VES 2 is a five -layer curve and the aquifer zone is in layer 4 with resistivity value of 517.00 Ωm and depth of 6.80m – 23.00m. Based on borehole lithological log in the study, the lithology is made up of lateritic topsoil, partly weathered gneiss, fresh gneiss boulder/outcrop, completely weathered gneiss and fractured gneiss.

VES 3 is also a five – layer curve with dual aquifer one in layer 4 with resistivity value of 442.80 Ωm with depth between 1.90m and 13.50m and the second aquifer in layer 5 with resistivity value of 335.80 Ωm and depth of 66.40m above. The subsurface layers consist of lateritic topsoil, fresh gneiss/boulder, completely weathered gneiss, fresh massive gneiss, and highly fractured gneiss.

VES 4 is a four-layer curve with aquifer in layer 3 with resistivity value of 573.8 Ωm and depth of 5.40m – 51.70m. The lithology in the light of borehole lithological log comprises lateritic topsoil, slightly weathered gneiss, completely weathered gneiss + clayey sand and fractured gneiss.

VES 5 is a five – layer curve with aquifer in layer 4 with resistivity value of 301.70 Ωm and thickness 8.80m – 43.50m. The subsurface layers are sandy topsoil, fresh gneiss/boulder, slightly weathered gneiss + clayey sand, completely weathered gneiss + clayey sand and fractured gneiss.

VES 6 is also a five-layer curve with aquifer zone in layer 4 with resistivity value of 532.50 Ωm and depth of 8.80m – 40.40m. The lithological units are lateritic topsoil, partly weathered gneiss, fresh gneiss boulder/outcrop, completely weathered gneiss + clayey sand and Fresh slightly fractured gneiss.

VES 7 is a five – layer curve with aquifer zone at layer 4 with resistivity value of 261.90 Ωm and depth of 29.50m – 80.30m. The lithological units are lateritic topsoil, partly weathered gneiss, slightly weathered gneiss, completely weathered gneiss + clayey sand and fractured gneiss.

VES 8 is a four-layer curve with aquifer in layer 3 with resistivity value of 507.90 Ωm and depth of 3.00m – 88.40m. The lithology is composed of lateritic topsoil, slightly weathered gneiss, completely weathered gneiss + Clayey sand and Fresh massive gneiss.

Summary of resistivity values with depth and lithology in the study area is given in table 6.

Table 6. Summary of resistivity, depth and lithology in the study area.

No.	***Layer***	***Resistivity (Ωm)***	***Depth(m)***	***Lithology***
VES 1	1	3384.10	0.00 – 1.90	Lateritic topsoil
	2	4265.50	1.90 – 2.50	Shallow fresh gneiss/Hardpan
	3	514.70	2.50– 30.40	Weathered Gneiss + Clayey sand
	4	1242.80	30.4 -	Fractured Gneiss
VES 2	1	912.50	0.00 – 0.90	Lateritic topsoil
	2	758.50	0.90 – 2.90	Partly weathered gneiss
	3	1787.40	2.90 – 6.80	Fresh gneiss boulder/outcrop
	4	517.00	6.80– 23.00	Completely weathered gneiss
	5	999.60	23.00	Fractured gneiss
VES 3	1	2716.30	0.0 – 0.70	Lateritic topsoil
	2	5379.40	0.70 – 1.90	Fresh gneiss/boulder
	3	442.80	1.90 – 13.50	Completely weathered gneiss
	4	1939.60	13.50 – 66.40	Fresh massive gneiss
	5	335.80	66.4+	Highly fractured gneiss
VES 4	1	1026.40	0.00 – 0.90	Lateritic topsoil
	2	1856.90	0.90 – 5.40	Slightly weathered gneiss
	3	573.80	5.40– 51.70	Completely weathered gneiss + clayey sand
	4	1140.30	51.70+	Fractured gneiss
VES 5	1	609.20	0.00 – 0.50	Sandy topsoil
	2	3082.40	0.50 – 1.70	Fresh gneiss boulder
	3	1141.70	1.70 – 8.80	Slightly weathered gneiss + Clayey sand
	4	301.70	8.80 – 43.50	Completely weathered gneiss + Clayey sand
	5	991.20	43.50	Fractured Gneiss
VES 6	1	2138.10	0.0 0– 0.70	Lateritic topsoil
	2	1238.70	0.70 – 2.30	Partly weathered gneiss
	3	5194.30	2.30 – 8.80	Fresh gneiss boulder/outcrop
	4	532.50	8.80 – 40.40	Completely weathered gneiss + Clayey sand
	5	2085.50	40.4 0+	Fresh slightly fractured gneiss
VES 7	1	2221.80	0.00 – 2.90	Lateritic topsoil
	2	879.90	2.90 – 8.70	Partly weathered gneiss
	3	1082.30	8.70 – 29.50	Slightly weathered gneiss
	4	261.90	29.50 – 80.30	Completely weathered gneiss + Clayey sand
	5	1132.70	80.30 +	Fractured gneiss
VES 8	1	1015.50	0.00 – 0.80	Lateritic topsoil
	2	1844.70	0.80 – 3.00	Slightly weathered gneiss
	3	507.90	3.0 – 88.40	Completely weathered gneiss + Clayey sand
	4	2549.40	88.4 +	Fresh massive gneiss

4.1. Aquifer Layer Resistivity

In the study area, the resistivity values of the aquifer were VES 1(514.70 Ωm) in layer 3; VES 2 (517.90 Ωm) in layer 4; VES 3 (442.80 Ωm) in layer 3; VES 4 (573.80 Ωm) in layer 3; VES 5(301.70 Ωm) in layer 4; VES 6 (532.50 Ωm) in layer 4; VES 7 (261.7 Ωm) in layer 4 and VES 8 (507.9 Ωm) in layer 3. Hence, the weathered basement layer, or aquifer layer, lies between resistivity 261.90Ωm and 573.80Ωm (Table 7). The low resistivity zone of 261.90Ωm - 573.80Ωm corresponds to saturated weathered gneiss which forms the main aquifer in the area. The contour map shows a sharp rise from the research area's southern to northern regions (Fig 11).

Table 7. Typical borehole lithological log in the University of Education and Entrepreneurship, Awi Akamkpa (Elevation: 180m asl; Total Depth: 100m; Terrain: Basement Complex).

S/N	***Depth(m)***	***Thickness (m)***	***Lithology description***	***Hydrological significance***
1	0.0 - 0.5	0.5	Topsoil: Brown, sandy clay with organic matter	No aquifer
2	0.5 – 4.0	3.5	Lateritic clay: Reddish brown, compact, low permeability	Protective layer
3	4.0 – 18.0	14.0	Weathered Basement/Regolith: sandy clay, gravelly, brown to yellow, partly saturated	Shallow aquifer
4	18.0 – 35.0	17.0	Clayey Sand: Light brown, medium grained, with quartz fragments	Transition zone. Poor aquifer
5	35.0 – 48.0	13.0	Completely weathered Gneiss: Silty clay, micaceous, low plasticity	Main Weathered Aquifer: Moderate yield 1 – 3m^3/hr
6	48.0 – 62.0	14.0	Fractured Gneiss: Hard, grey. Moderately fractured. Water strike at 52m and 58m	Fractured Aquifer 1. Good yield 2 – 5 m^3/hr
7	62.0 – 78.0	16.0	Fresh Gneiss: Very hard, grey, massive, no fracture	Aquiclude
8	78.0 – 88.0	10.0	Fractured Geiss: Hard, grey, highly fractured, jointed. Major water strike at 82m	Fractured Aquifer 2. Best aquifer. Yield 3 – 8 m^3/hr
9	88.0 – 100.0	12.0	Fresh Granitic Geiss: Very hard, grey, massive. No fracture.	Basement. End of borehole.

Note: 1. Aquifer type: Dual aquifer system, (a) Weathered Layer Aquifer: 4.0m – 48.0m. unconfined); (b) Fractured Basement Aquifer: 48.0m – 62.0m and 78.0m – 88.0m. semi – confined to confined.
2.Water strikes: Most common at 50.0m – 60.0m and 80.0m – 90.0m. these are major fracture zones in the gneiss.
3. Borehole Success: Drilling to 80.0m – 100.0m gives 70 – 80% success rate in Awi area.
4. Water Quality: Usually fresh, pH 6.5 – 7.5, low TDS. But can have high Fe/Mn due to weathering of biotite gneiss.
(**Source:** Rural Water Supply Agency (RUWASSA). Cross River State. Borehole Completion Reports. Akamkpa LGA. 2018 – 2023).

The amount of linked pore spaces and the quantity of conducting fluids present determine the resistivity of the aquifer layer (Adeyemo et al., 2017). Also, according to the studies by Barker et al. (1992); Olayinka et al. (2004); Adeyemo et al. (2017); and Yohanna et al. (2022) where

resistivity values ranging between 250 Ωm – 600 Ωm were attributed to water- bearing weathered basement are similar to the groundwater yielding boreholes in the basement complex in the present study with resistivities ranging from 100Ωm to 600Ωm. The results of this study indicate that the aquifer unit with a lower resistivity value has a better chance of absorbing groundwater. Because of its lower resistivity value, termitarium location VES 7 offers very good groundwater potential.

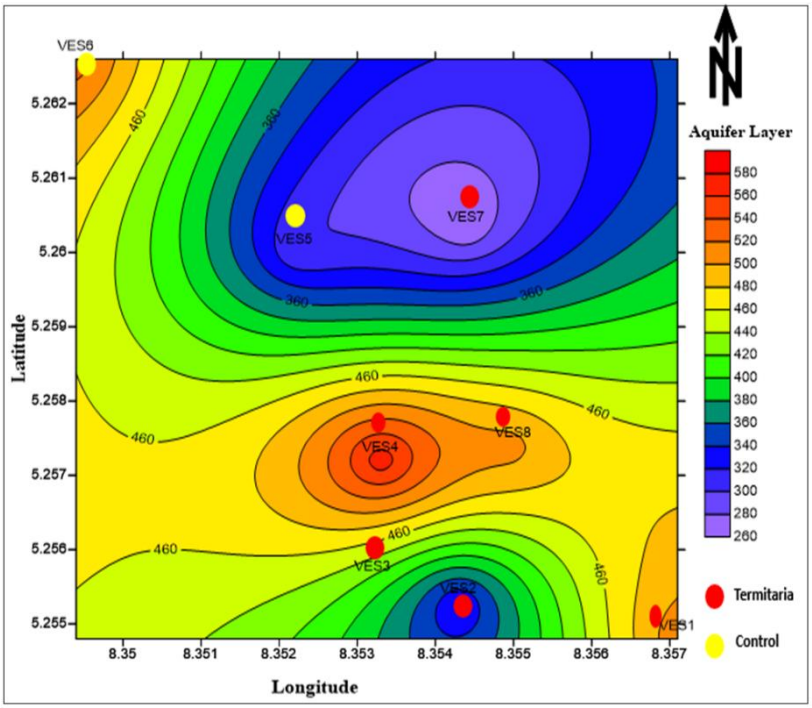


Figure 11. Contour map of the research area's aquifer layer, University of Education and Entrepreneurship, Awi, Akamkpa.

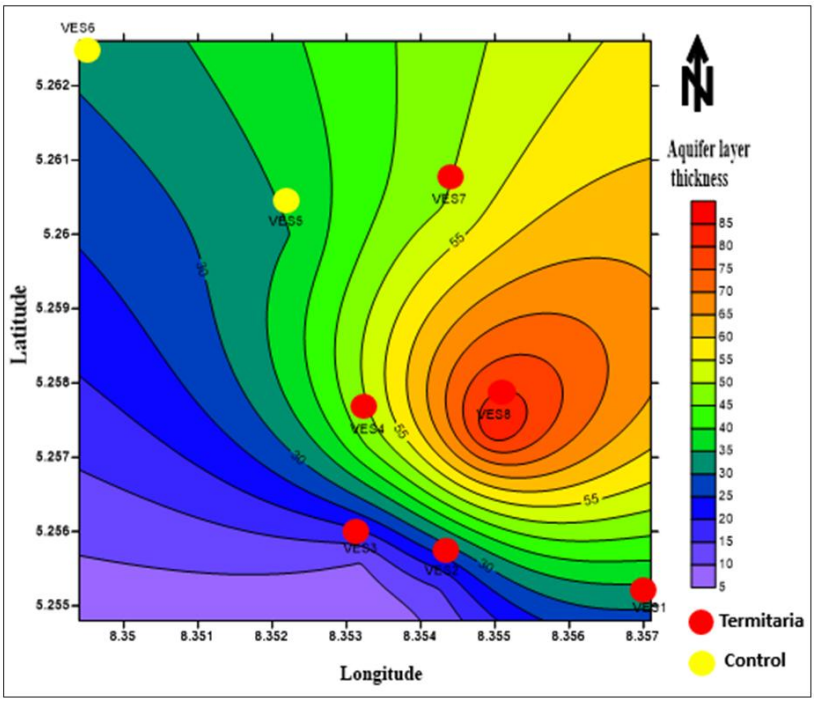


Figure 12. Contour map aquifer unit layer thickness in University of Education and Entrepreneurship, Awi, Akamkpa.

4.2. Aquifer Unit Layer Thickness

The thickness of the aquifer layer (weathered layer) in the research area ranged from 16.20m to 85.40m, with VES 8 having the highest value and VES 2 having the lowest. The contour map of the aquifer unit layer (Fig 12) shows that the thickness of the aquifer layer increases from the southwest to the eastern portion of the research area. The thickest aquifer unit layer is found in VES 8, followed by VES 7, VES 4 and VES 3 which are where the termitaria are located.

According to Amigun et al. (2015), aquifer layer thickness is considered a critical parameter for evaluating groundwater potential using geophysical sounding. Additionally, Adeyemo et al. (2017) stressed that aquifer layer thickness is one of the three most important indices, following geology and aquifer layer resistivity. Because it provides a larger water column, the thickness of the aquifer layer increases the possibility of groundwater accumulation (Adabanija et al., 2014; Adeyemo et al., 2017; Kayode et al., 2016).

From the southwest to the eastern part of the research area, the aquifer thickness increases. The study's findings indicate that all VES have good potentials for groundwater in the study area, but the termitarium locations, VES 8, VES 7, VES 4, VES 3 have more groundwater potential as compared to the controls taken away from the termitaria. This agrees with the driller's ranking based on aquifer thickness (Table 8) (RUWATSSA 2018 – 2023 Report).

Table 8. Ranking of VES for groundwater based on overburden thickness.

S/N	***NO***	***Location***	***Aquifer thickness(m)***	***Rank***
1	VES 1	Termitarium	27.1	7th
2	VES 2	Termitarium	16.2	8th
3	VES 3	Termitarium	45.0	4th
4	VES 4	Termitarium	46.3	3rd
5	VES 5	Control	34.7	5th
6	VES 6	Control	31.6	6th
7	VES 7	Termitarium	50.8	2nd
8	VES 8	Termitarium	85.4	1st

4.3. Overburden Thickness

The overburden thickness is the sum of the weathered and subsurface rocks that cover a fresh basement rock. The study area's overburden thickness ranged from 23.00m to 88.30m. The thicknesses are presented in the contour map increase from southwestern part to the southeastern part (Fig 13). VES 3, VES 8, VES 7, and VES 4 display the regions with the highest overburden thicknesses (termitaria location). As compared to the VES5 and VES 6 without termite activity. Numerous studies have connected overburden thickness to groundwater potential or the actual output of boreholes (Adabanija et al., 2014; Kinwumiju et al., 2016; Kayode et al., 2016). Because the thickness of the overburden cannot be consolidated due to weathering and fracturing, there is

more pore space available for groundwater accumulation. This leads to an adequate column for groundwater storage and a thicker aquifer layer (Ahmed et al., 2020).

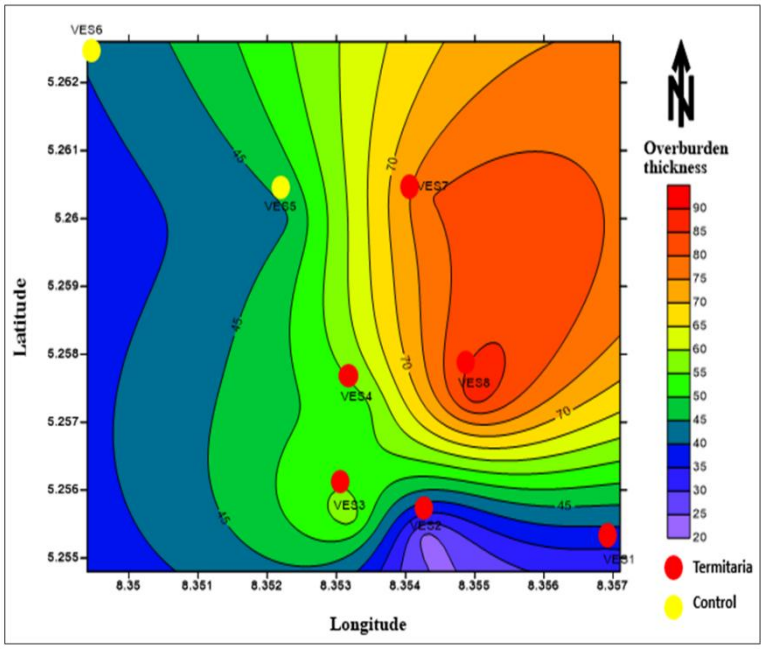


Figure 13. A Contour map showing overburden thickness in the in University of Education and Entrepreneurship, Awi, Akamkpa.

According to this study, the overburden thickness increases from the southwest to the southeast, with the largest overburden thicknesses found in VES 8, VES 7, VES 4, and VES 3 (termitaria locations). This finding is supported by Ahmed et al. (2020), who proposed that termites are probably weathering agents that aid in the weathering process through bioturbation and networking of in-situ soils.

4.4.Total Transverse Resistance (T)

Within the study region, transverse resistance of aquifer ranged from 5,135Ωm^2 to 43,373Ωm^2 indicating Fair to Excellent (Table 9) with VES 8 exhibiting the greatest value and VES 2 the lowest. According to the contour map, the northern region VES 8 (termitarium location) and central region VES 4 (termitarium location) have the highest transverse resistances indicating excellent groundwater potential (Fig 14).

Table 9. Aquifer protective capacity in the study area.

S/N	*NO*	*Location*	*Transverse resistance (Ωm^2)*	*Aquifer class*
1	VES 1	Termitarium	14360.13	Very good
2	VES 2	Termitarium	5135.40	Fair
3	VES 3	Termitarium	5136.48	Fair
4	VES 4	Termitarium	26566.94	Excellent
5	VES 5	Control	10469.00	Very good
6	VES 6	Control	16817.52	Very good
7	VES 7	Termitarium	13304.52	Very good
8	VES 8	Termitarium	43374.66	Excellent

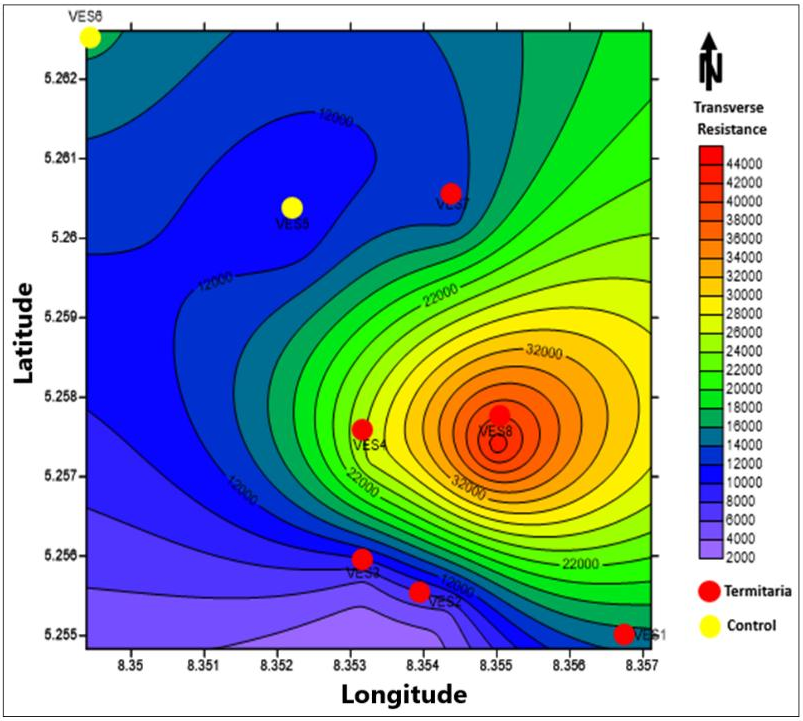


Figure 14. A contour map showing transverse resistance in the in University of Education and Entrepreneurship, Awi, Akamkpa.

A region's transmissivity is measured by its total transverse resistance (T); high T values indicate high groundwater potential and transmittivity, and vice versa (Jayeoba and Olagundoye, 2013; Suneetha and Gupta, 2018). According to Mogaji and Lim (2017), transverse resistance and true borehole transmissivity are related, and areas without transmissivity data or boreholes can be readily assessed using the geophysical data that is now accessible. The termitaria locations in the southwest portion of the study area exhibited the highest total resistance (VES 4 and VES 8 termitaria locations), indicating excellent groundwater potential. Transverse resistance correlated well with the termitarium location such that high values of transverse resistance 43,373Ωm^2 and aquifer thickness of 85.40m indicate excellent groundwater potential. Apart from geophysical parameters, biological factors such as termite activity may also enhanced aquifer characteristics observed in this location. Also, the thick overburden of 85.40m at VES 8 suggests intense weathering. Field observation during survey observed the presence of old termitaria within 20m of VES 8. This supports the view that termites may have contributed to deep weathering and increased porosity at this point.

4.5. Total Longitudinal Conductance(S)

The longitudinal conductance of aquifer of the examined area varied from 0.0542Ω^{-1} to 0.194Ω^{-1} indicating poor to low protective capacity (Table 10). The contour map showed a significant increase in total longitudinal conductance values from the southwest to the northeastern part of the research site, with low values VES 1 and VES 3 near the termitarium position (Fig 15).

Table 10. Aquifer protective capacity in the study area.

S/N	***NO***	***Location***	***Longitudinal conductance (mhos)***	***Aquifer protective capacity***
1	VES 1	Termitarium	0.0542	Poor
2	VES 2	Termitarium	0.0511	Poor
3	VES 3	Termitarium	0.0262	Poor
4	VES 4	Termitarium	0.0807	Poor
5	VES 5	Control	0.1150	Low
6	VES 6	Control	0.0594	Poor
7	VES 7	Termitarium	0.1940	Low
8	VES 8	Termitarium	0.1681	Low

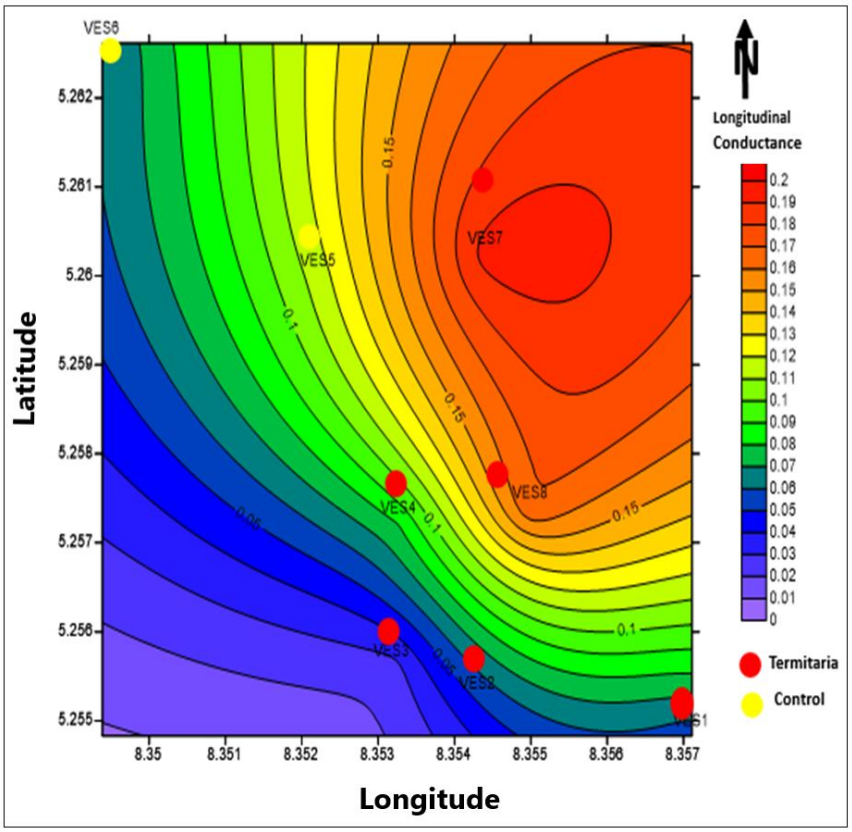


Figure 15. A contour map of longitudinal conductance in the in University of Education and Entrepreneurship, Awi, Akamkpa.

The total longitudinal conductance on top of basement rocks is used to assess the protective capacity of overburden, which serves as a natural sieve for entering fluid (Bayewu et al., 2018). It is not enough to have a high groundwater production or potential; it is also crucial to consider how susceptible it is to pollution. Atakpo and Ayolabi (2009) stated that longitudinal conductance is categorised as weak when S is between 0.1 and 0.19, moderate when S is between 0.2 and 0.69, and good when S is larger than 0.7. The study's findings indicate that groundwater is vulnerable to contamination, with the southwestern region being most at danger, and that the overburden's protective ability is inadequate over the whole study area in both termitaria locations and locations without termitaria.

4.6. Coefficient of Anisotropy (λ)

The coefficient of anisotropy on top of the basement rock varied from 1.10 to 1.22, with the highest value around VES 3 and the lowest value around VES 7 (Termitarium site) (Table 11). The research area's contour map shows that the coefficient of anisotropy abruptly rises from the southeast to the northeast (Fig 16). This demonstrates that the sub surface's anisotropic and heterogeneous character is primarily in SE-NW directions. The values of coefficient of anisotropy in different geological settings are not greater than 2 (Zohdy et al., 1974) and are regarded as important tools in prospecting for groundwater when the values range from 1 to 1.5 (Suneetha et al., 2017). According to Suneetha et al. (2017), low anisotropy values signify modest fluctuations in the water table and thus, strong groundwater potential. With values ranging from 1.10 to 1.22, the termitarium location (VES 7) located in the extremely low anisotropy region. According to Ahmed et al. (2020), the termitarium location had the highest groundwater potential since it had the lowest anisotropy value. Also, the coefficient of anisotropy value of 1.10 which is <1.3 indicates that it is very homogeneous, vertical and lateral groundwater flow (Telford et al, 1990; Olayinka, 1992; Reynolds, 2011).

Table 11. Coefficient of anisotropy in the study area.

S/N	***NO***	***Location***	***Coefficient of anisotropy***	***Interpretation***
1	VES 1	Termitarium	1.18	Isotropic
2	VES 2	Termitarium	1.21	Slightly anisotropic
3	VES 3	Termitarium	1.22	Slightly anisotropic
4	VES 4	Termitarium	1.15	Slightly anisotropic
5	VES 5	Control	1.12	Slightly anisotropic
6	VES 6	Control	1.19	Slightly anisotropic
7	VES 7	Termitarium	1.10	Isotropic
8	VES 8	Termitarium	1.13	Slightly anisotropic

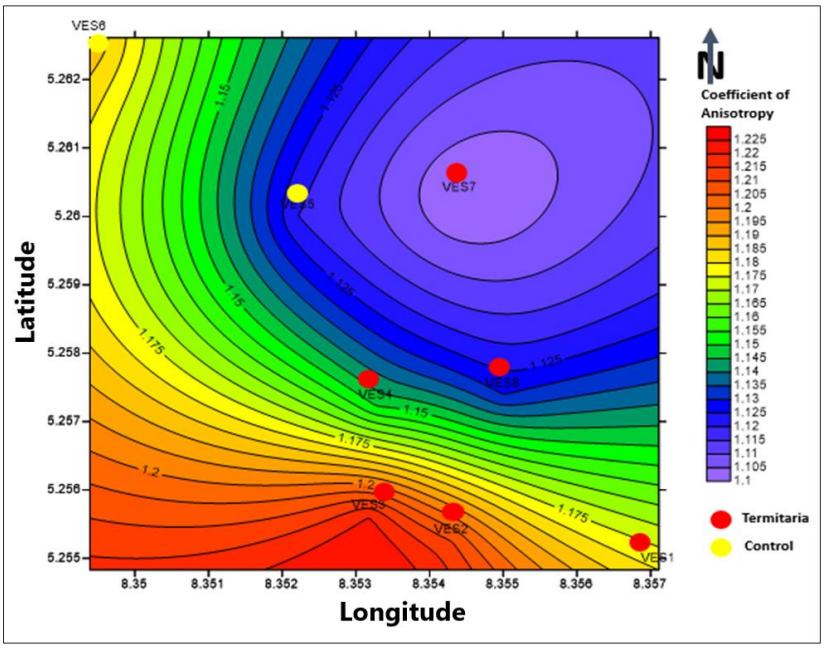


Figure 16. A contour map showing anisotropy in the in University of Education and Entrepreneurship, Awi, Akamkpa.

Generally, seasonal variation in water table levels significantly affects the geophysical response of termite mounds used as groundwater indicators. Electrical resistivity, the primary parameter in vertical electrical sounding (VES) is controlled by pore spaces and fluid availability. As such, during wet seasons when the water table rises, resistivity beneath and around termite mounds decreases due to increased saturation. On the other hand, during dry seasons, falling water tables cause resistivity to increase. Studies on basement complex terrain by Turner (2006); Ige et al. (2015); and Ahmed et al. (2019) showed that the water table in some locations can rise to first layer during wet seasons but falls drastically during dry season, while in others it does not dry up even during long dry periods. Also, termites actively modify soil moisture. Soil moisture within mounds increases through the rainy season as termites pass moist soil upward from deeper horizons. Mounds also show significantly higher rates of surface water infiltration, which enhances seasonal recharge beneath mounds.

Therefore, geophysical surveys over termitaria must take into consideration timing, Dry season VES data are more preferable for estimating sustainable aquifer thickness, while wet season may reflect temporary saturation. Despite seasonal effects, the fundamental relationship is that termite mounds tend to overlie deeper weathered zones and thus remain valid, though seasonally – modulated, indicators of groundwater.

5. CONCLUSION

Groundwater prospecting in basement complex terrains is often challenging due to lateral and vertical inhomogeneities within the subsurface. However, analysis of resistivity values validated by borehole lithological log, curve types, and Dar Zarrouk parameters in this study indicate that termite mounds are indicators of groundwater occurrence in the research area. Compared with nearby locations lacking termite activity, termitaria sites exhibited greater groundwater potential, characterised by thicker overburden, lower aquifer resistivity, and more favourable hydrogeological conditions. Hence, termite mounds represent valuable landscape features that hydrogeologists can utilise as natural biomarkers in groundwater exploration, particularly within basement terrains.

6. ACKNOWLEDGEMENTS

Authors are grateful to Tertiary Education Trust Fund (TETF) for providing funding for this work.

7. CONFLICT OF INTEREST

There is no conflict of interest.

8. REFERENCE

Adabanija, M. A., Afolabi, A. O., Olatunbosun, A. T & Kolawole, L. L. 2014. Integrated Approach to Investigation of Occurrence and Quality of Groundwater in Ogbomoso North, Southwestern Nigeria. *Environmental Earth Science*, **73**: 139-162, https://doi.org/10.1007/s12665-014-3401-8.

Adeyemo, I. A., Omosuyi, G. O., Ojo, B. T & Adekunle, A. 2017. Groundwater Potential Evaluation in a Typical Basement Complex Environment Using GRT Index - A Case Study of Ipinsa-Okeodu Area, near Akure, Nigeria. *Journal Geosciences. Environment Protection*, **5**: 240 – 251, https://doi.org/10.4236/gep.2017.53017.

Ahmed, I. I., Pradhan, B., Mansor, S., Yusoff, Z. M & Ekpo, S. A. 2019. Aquifer Potential Assessment in Termites Manifested Locales Using Geo-Electrical and Surface Hydraulic Measurement Parameters. Sensor, **19(9)**: 2107, https://doi.org/10.3390/s19092107.

Ahmed II, J. B., Salisu, A., Pradhan, B., Mansor, S., Yusoff, Z. M & Ekpo, S. A. 2020. Do termitaria indicate the presence of groundwater? A case study of hydrogeophysical investigation on a land parcel with termite activity. *Insects*, **11**(11): Article 728, https://doi.org/10.3390/insects11110728

Ahmed II, J. B., Salisu, A., Pradhan, B & Alamri, A. M. 2020. Do termitaria indicate the presence of groundwater? A case study of hydrogeophysical investigation on a land parcel with termite activity. *Insects*, **11**(11): Article 728, https://doi.org/10.3390/insects111107

Amigun, J. O., Faruwa, R. A & Komolafe, A. A. 2015. Integrated Landsat Imagery and Geophysical Exploration for Groundwater Potential Evaluation of Okene and its Environs, Southwestern Nigeria. *International J. Geosciences*, **6(3)**: 209-229, http://dx.doi.org/10.4236/ijg.2015.63015.

Atakpo, E. A & Ayolabi, E. A. 2009. Evaluation of aquifer vulnerability and the protective capacity in some oil producing communities of western Niger Delta. *The Environmentalist*, **29**: 310–317, https://doi.org/10.1007/s10669-008-9191-3

Barker, R. D., White, C & Houston, J. F. T.1992. Borehole siting in an African Accelerated Drought Relief Project. *Geological Society, London, Special Publications*, **66**: 183-201, https://doi.org/10.1144/GSL.SP.1992.066.01.09.

Bayewu, O. O., Oloruntola, M. O., Mosuro, G. O., Laniyan, T. A., Ariyo, S. O & Fatoba, J. O. 2018. Assessment of Groundwater Prospect and Aquifer Protective Capacity using Resistivity Method in Olabisi Onabanjo University campus, Ago-Iwoye, Southwestern Nigeria. *NRIAG J. Astronomy and Geophysics*, **7(2)**: 347-360, https://doi.org/10.1016/j.nrjag.2018.05.002.

Ekwok, S. E., Akpan, A. E., Kudamnya, E. A & Ebong, E. D. 2020. Assessment of groundwater potential using geophysical data: A case study in parts of Cross River State, south-eastern Nigeria. *Applied Water Science,* **10**: Article 144, https://doi.org/10.1007/s13201-020-01224-0.

Ekwueme, B. N., Nyong, E. E & Petters, S. W. 1995. Geological Excursion Guidebook to Oban Massif, Calabar Flank, Ikom-Mamfe Embayment and Southeastern Nigeria. Calabar: Dec-Ford Publishers.

Ijioma, U. D. 2021. Delineating the Impact of Urbanization on the Hydrochemistry and Quality of Groundwater Wells in Aba, Nigeria. *Journal of Contaminant Hydrology*, **240**: 103792, https://doi.org/10.1016/j.jconhyd.2021.103792.

Ige, O. O., Oredipe, I. M & Ogunsanwo, O. 2015. Effect of seasonal variation on physicochemical properties of shallow groundwater in a typical basement complex terrain of Nigeria. *Al-Hikmah Journal of Pure & Applied Sciences*, **1**: 8–17.

Jayeoba, A & Oladunjoye, M. A. 2013. Hydro-geophysical evaluation of groundwater potential in hard rock terrain of southwestern Nigeria. *RMZ–Materials and Geoenvironment,* **60(4)**:271–285, https://www.dlib.si/details/URN:NBN:SI:doc-NIE2ACFO.

Kayode, J., Adelusi, A., Nawawi, M., Bawallah, M & Olowolafe, T. 2016. Geo-electrical Investigation of Near Surface Conductive Structures Suitable for Groundwater Accumulation in a Resistive Crystalline Basement Environment: A Case Study of Isuada, southwestern Nigeria. *Journal of African Earth Science*, **119**: 289-302, https://doi.org/10.1016/j.jafrearsci.2016.04.009.

Keller, G. V. 1966. Electrical resistivity studies of the groundwater of the Tucson Basin. Arizona (U.S. Geological Survey Water Supply Paper 1819-E). U.S. Government Printing Office.

Kinwumiju, A. S. A., Olorunfemi, M. O & Afolabi, O. 2016. GIS-Based Integrated Groundwater Potential Assessment of Osun Drainage Basin, Southwestern Nigeria. *Ife Journal of Science*, **18**: 147-168.

Laouini, G., Etuk, S. E & Agbasi, O. E. 2017. Delineation of aquifers using Dar Zarrouk parameters in parts of Akwa Ibom, Niger Delta, Nigeria. J*ournal of Hydrogeology & Hydrologic Engineering*, **6**(1): Article 1000151, https://doi.org/10.4172/2325-9647.1000151.

Liu, W., Zhao, M & Xu, T. 2018. Water Poverty in Rural Communities of Arid Areas in China. *Water*, **10**: 505, https://doi.org/10.3390/w10040505.

Mekonnen, M. M & Hoekstra, A. Y. 2016. Four Billion People Facing Severe Water Scarcity. *Science Advances*, **2(2)**: e1500323, https://doi.org/10.1126/sciadv.1500323.

Mogaji, K. A & Lim, H. S .2017. Groundwater Potentiality Mapping using Geoelectrical-based Aquifer Hydraulic Parameters: A GIS-based multi-criteria Decision Analysis Modelling

Approach. *Terrestrial Atmosphere and Oceanic Science*, **28**: 479-500, https://doi.org/10.3319/TAO.2016.11.01.02

Offordile, M. E. 2014. Hydrogeology: Groundwater Study and Development in Nigeria. *Mecon Geology and Engineering Services Ltd*, Jos, Nigeria.

Ojo, O. T., Ike, J. C & Nwokeabia, C. N. 2024. Integrated Geophysical and GIS Approaches for Groundwater Potential Assessment: A case Study of Aladja, Delta State, Nigeria. *Water Practice & Technology*, **19(10)**: 4282-4302, https://doi.org/10.2166/wpt.2024.254.

Oladapo, M. I & Akintorinwa, O. J. 2007. Hydrogeophysical study of Ogbese, Southwestern Nigeria. *Global Journal of Pure and Applied Sciences*, **13(1)**: 55–6, https://doi.org/10.4314/gjpas.v13i1.16669.

Olayinka, A., Amidu, S & Oladunioye, M. 2004. Use of Electromagnetic Profiling and Resistivity Sounding for Groundwater Exploration in the Crystalline Basement Area of Igbeti, Southwestern Nigeria. *Global Journal of Geological Sciences*, **2(2)**: 243-253, https://doi.org/10.4314/gjgs.v2i2.18701.

Olayinka, A. I. 1992. Geophysical siting of boreholes in crystalline basement areas of Africa. *Journal of African Earth Sciences*, **14(2)**: 197–207, https://doi.org/10.1016/0899-5362(92)90097.

Olusola, A., Adeyeye, O & Durowoju O. 2017. Groundwater: Quality Levels and Human Exposure, SW Nigeria. *Journal of Environmental Geography*, **10(1–2)**: 23–29, https://doi.org/10.1515/jengeo-2017-0003.

Oyewole, A. M., Omoboriowo, A. O & Adiela, U. P. 2017. A Geologic Field Report on the Geology of Part of the Oban Massif and Calabar Flank, South Eastern Nigeria. *International Journal of Scientific Engineering and Science*, **1(5)**: 29-34, http://ijses.com/.

Reynolds, J. M. 2011. An introduction to applied and environmental geophysics. 2nd edition, ISBN-13: 978-0471485360, Wiley – Blacwell, 712p.

RUWATSSA (Cross River State Rural Water Supply and Sanitation Agency). 2023. Annual reports, 2018–2023. Cross River State Government, Nigeria.

Sharma, R., Kumar, R., Agrawal, P. R., Ittishree, C & Gupta, G. 2021. Groundwater Extractions and Climate Change. In: Binota Thokchom, Pengpeng Qiu, Parameswar K. Iyer (Eds.), *Water Conservation in the Era of Global Climate Change*, 23-45, https://doi.org/10.1016/B978-0-12-820200-5.00016-6.

Sikakwe, G. U. 2020. Geospatial applications in delineating groundwater prospect zones in a hard rock terrain: an integrated approach. *Environmental Earth Sciences*, **79**: 487, https://doi.org/10.1007/s12665-020-09235-5.

Suneetha, N & Gupta, G. 2018. Evaluation of groundwater potential and saline water intrusion using secondary geophysical parameters: A case study from western Maharashtra, India. *E3S Web of Conferences*, 54: Article 00033, https://doi.org/10.1051/e3sconf/20185400033.

Telford, W. M., Geldart, L. P & Sheriff, R. E. 1990. Applied geophysics. 2nd edition, ISBN: 9781139642927, Cambridge University Press.

Turner, J. S. 2006. Termites as mediators of the water economy of arid savanna ecosystems. In: J. F. Weltzin & G. R. McPherson (Eds.), *Ecology and biomechanics of water balance in plants and animals* (pp. 303 – 339), Cambridge University Press.

UNWWDR - United Nations World Water Development Report. 2023. Billions of people lack access to clean drinking water. United Nations.

World Bank. 2021, May 26. Nigeria: Ensuring water, sanitation and hygiene for all. https://www.worldbank.org/en/news/feature/2021/05/26/nigeria-ensuring-water-sanitation-and hygiene-for-all

Yohanna, A., Musa, N., Balogun, F. O., Jabbo, J. N., Adamu, A & Galumje. S. S. 2022. Assessment of groundwater potentials of crystalline basement complex aquifers using hydraulic properties in the ussa area of Taraba State, North-east Nigeria. FUDMA Journal of Sciences, **6(3)**: 88-94, https://doi.org/10.33003/fjs-2022-0603-974.

Zohdy, A. A., Eaton, G. P & Mabey, D. R. 1974. Application of Surface Geophysics to Ground-Water Investigations- Techniques of Water-Resources Investigations 02-D1. USGS, https://doi.org/10.3133/twri02D1.