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Hydrogeophysical Evaluation of Groundwater Potential and Aquifer Protective Capacity in Akerebiata, Ilorin, Nigeria

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Abstract: *Groundwater potential and aquifer protective capacity in Akerebiata, Ilorin, Nigeria, were assessed using Vertical Electrical Sounding (VES) at six strategically located stations. The Schlumberger array with a maximum current electrode spacing of 200 m was employed, and apparent resistivity data were interpreted through partial curve matching and iterative inversion. Three to five geoelectric layers were delineated, including topsoil (resistivity 13–405 Ωm, thickness 0.6–3.2 m), weathered basement/saprolite (20–33.5 Ωm, thickness 2.6–14.6 m), fractured basement/saprock (62.7–137.7 Ωm, thickness 1.2–5.4 m), and fresh basement (>850 Ωm). Groundwater occurrence is primarily associated with the weathered and fractured units, whereas the fresh basement is largely non-aquiferous. VES 2 and VES 3 show the highest potential, with saprolite thicknesses of 14.2 m and 14.6 m, moderate resistivity (32.7–33.5 Ωm), and underlying fractured basement, yielding total longitudinal conductance values of 0.4654 S and 0.4632 S, respectively. Stations 4 and 5 exhibit moderate potential (G ≈ 0.31 S), while VES 6 is unsuitable due to shallow bedrock (6.4 m) and minimal storage. Borehole drilling to depths exceeding 18 m is recommended, and integrating VES interpretation with longitudinal conductance analysis provides a reliable approach for evaluating aquifer potential and vulnerability in crystalline basement terrains*.

Keywords: *Groundwater Potential, VES, Aquifer Protective Capacity, Akerebiata.*

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1.0 Introduction

Water is a vital natural resource essential for human survival, economic development, and ecosystem sustainability. Rapid population growth and increasing water demand have intensified the need for reliable groundwater resources, particularly in developing regions where surface water supply is inadequate (Famiglietti & Ferguson, 2021; UNESCO, 2022). Groundwater constitutes a significant proportion of the world's accessible freshwater resources and is primarily stored within the pore spaces and fractures of subsurface geological formations (Bassey *et al*., 2023; Gleeson *et al*., 2020). Despite its importance, groundwater availability and sustainability remain highly variable in regions underlain by crystalline basement rocks, where aquifer distribution is often discontinuous and difficult to predict without detailed subsurface investigation.

In crystalline basement terrains, such as those covering approximately 50% of Nigeria's landmass, groundwater occurrence is primarily governed by the thickness of the weathered overburden (regolith) and the density of interconnected fractures within the unweathered basement rocks (Sikah *et al*., 2016; Popoola *et al*., 2020). Consequently, geophysical methods, particularly electrical resistivity techniques like Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) remain the preferred tools for groundwater exploration. These methods are favored for their cost-effectiveness and their refined ability to delineate complex subsurface lithological variations and fracture zones in Precambrian terrains (Aderemi, 2020; Sikah *et al*., 2016). Previous hydrogeophysical investigations across basement complex regions of Nigeria have demonstrated that groundwater productivity varies significantly due to spatial heterogeneity in weathering profiles and fracture connectivity. However, the success rate of borehole development remains inconsistent, largely because localized aquifer characteristics and protective capacity are not always evaluated simultaneously.

The electrical resistivity method, particularly Vertical Electrical Sounding (VES), remains a cornerstone for identifying productive aquiferous zones within basement complex environments due to its sensitivity to moisture content and clay mineralogy (Aizebeokhai *et al*., 2018; Ige *et al*., 2022). In Akerebiata and its environs, the absence of a functional municipal water distribution network has forced a heavy reliance on shallow hand-dug wells, which are often prone to seasonal failure and contamination (Ige *et al*., 2022).

Although several studies have applied electrical resistivity methods for groundwater exploration in basement terrains, detailed investigations integrating groundwater potential assessment with aquifer protective capacity evaluation remain limited in Akerebiata and its environs. As a result, the vulnerability of groundwater resources and the optimal locations for sustainable borehole development in the area are still poorly constrained. Therefore, this study aims to evaluate groundwater potential and aquifer protective capacity in Akerebiata, Ilorin, using the Vertical Electrical Sounding (VES) method to delineate productive aquifer zones suitable for sustainable groundwater development.

The study area is located within Akerebiata and its environs around Harmony Estate in Ilorin, Kwara State, Nigeria. Geologically, the site is part of the Precambrian Basement Complex of southwestern Nigeria, which is predominantly composed of migmatite–gneiss complexes and granitic rocks characteristic of the Pan-African mobile belt (Ijila *et al*., 2018; Aizebeokhai *et al*., 2018). In this crystalline environment, groundwater storage and transmission are controlled by the development of secondary porosity specifically through the weathering of the regolith and the presence of interconnected fracture systems in the bedrock (Coker *et al*., 2010). The local climate is typically tropical, featuring a bimodal rainfall pattern that plays a critical role in the seasonal recharge of these localized aquifers (Eugene-Okorie *et al*., 2020).

The outcomes of this study are expected to provide a scientific basis for groundwater resource planning and sustainable borehole siting within Akerebiata and similar crystalline basement environments. Furthermore, integrating groundwater potential evaluation with aquifer protective capacity assessment will enhance groundwater vulnerability assessment, reduce borehole failure rates, and contribute to improved water resource management in rapidly urbanizing communities lacking a reliable municipal water supply.

2. 0 Methodology

2.1 Data Acquisition

A total of six (6) Vertical Electrical Sounding (VES) stations were strategically established across the study area to provide a representative profile of the subsurface geoelectric properties. The VES locations were selected based on accessibility, surface geological observations, settlement distribution, and the need to achieve adequate spatial coverage of the study area. Data acquisition was executed using the ABEM Terrameter (SAS 1000/4000 series), a high-precision instrument favored for its digital signal processing capabilities and high signal-to-noise ratio in challenging basement terrains (Adeyeye *et al*., 2021; Alabi *et al*., 2010). The Schlumberger electrode array configuration was adopted due to its superior depth of penetration and reduced sensitivity to lateral inhomogeneities compared to the Wenner array. The half-current electrode spacing ($AB/2$) was progressively increased from 1.0 m to a maximum spread of 100 m (total $AB = 200$ m), while the potential electrode spacing ($MN/2$) was adjusted at specific intervals to maintain measurable potential differences and ensure data integrity. This configuration allowed for an effective probing depth of approximately 30 to 50 meters, which is sufficient to characterize the weathered regolith and the fractured-to-fresh bedrock interface in the region (Ige *et al*., 2022). The selected maximum current electrode spacing (AB = 200 m) ensured sufficient depth penetration to image the resistive basement layer and minimize ambiguity between partially weathered horizons and competent bedrock. The use of the ABEM Terrameter allowed for the stacking of multiple readings to minimize the effects of spontaneous potential (SP) and telluric currents often found in urbanized residential areas (Aizebeokhai *et al*., 2018). Field data quality was ensured through repeat measurements at selected electrode spacings and continuous monitoring of contact resistance. Noisy readings were re-acquired to maintain data consistency and reliability before interpretation.

2.2 Theoretical Background

In electrical resistivity surveying, an artificial direct current (or low-frequency alternating current) is introduced into the subsurface through two current electrodes (C_1 and C_2), while the resulting potential difference is measured using two potential electrodes (P_1 and P_2). Variations in the recorded subsurface resistivity reflect distinct changes in lithology, effective porosity, moisture content, and the intensity of secondary fracturing (Ogungbemi *et al*., 2013; Nwozor *et al*., 2025)

The apparent resistivity (ρ_a), expressed in ohm-meters (Ωm), is computed as:

$$\rho_a = KR \quad (1)$$

where K is the geometric factor, which is determined by the specific spatial arrangement and spacing of the electrodes. For the Schlumberger array, it is calculated as:

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

where a is half the current electrode spacing $AB/2$, and b is half the potential electrode spacing $MN/2$.

R is the measured electrical resistance (Ω), derived from Ohm's Law:

$$R = \Delta V / I \quad (3)$$

where ΔV is the potential difference in Volts and I is the injected current in Amperes).

2.3 Data Processing and Interpretation

The acquired field resistance data were converted to apparent resistivity values and processed using WinResist (Version 1.0) software. Initial model parameters were estimated via the manual method of partial curve matching using Master Curves and auxiliary point charts. These preliminary models were subsequently used as initial input parameters for iterative inversion, during which layered-earth resistivity and thickness parameters were optimized by minimizing the root-mean-square (RMS) misfit between observed and calculated curves. (Qaisar *et al*., 2020; Bassey *et al*., 2023).

Lithological interpretation of the resulting geoelectric sections was performed by correlating resistivity magnitudes and layer thicknesses with available local borehole logs and updated resistivity benchmarks for the Nigerian Basement Complex (Aizebeokhai *et al*., 2018; Sikah *et al*., 2016). Attention was paid to the saprolite (weathered) and saprock (fractured) zones, as the thickness and continuity of these layers are the primary indicators of groundwater storage and transmissivity in the crystalline rocks of the Akerebiata region (Aizebeokhai *et al*., 2018). Interpretation reliability was enhanced through consistency checks between adjacent VES stations and comparison with regional hydrogeological characteristics reported for similar basement complex terrains.

To determine the Aquifer Protective Capacity of the overburden at each VES Station, we calculate the Total Longitudinal Conductance (S). This geoelectric parameter is a measure of the ability of the overburden (layers above the aquifer) to retard and filter infiltrating contaminants from the surface. The formula for the total longitudinal conductance (G) as shown in equation 4

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

where h_i is the thickness of the i-th layer (m) and ρ_i resistivity of the i -th layer (Ωm).

The protective capacity is interpreted based on the standard classification scale for the Nigerian Basement Complex as presented in Table 1 (Oladapo and Akintorinwa, 2007).

This parameter quantifies the capacity of the overburden layers above the aquifer to attenuate and filter contaminants migrating from the surface. The aquifer protective capacity was classified using the standard longitudinal conductance rating scheme for the Nigerian Basement Complex proposed by Oladapo and Akintorinwa (2007), as summarized in Table 1.

Table 1: The protective capacity rating (Oladapo and Akintorinwa, 2007)

Longitudinal Conductance G (S)	Protective Capacity Rating
> 10	Excellent
5.0 - 10	Very Good
0.7 - 4.9	Good
0.2 - 0.69	Moderate
0.1 - 0.19	Weak
< 0.1	Poor

The integrated workflow involving data acquisition, resistivity inversion, lithological correlation, and longitudinal conductance analysis provides a comprehensive framework for evaluating groundwater potential and aquifer vulnerability in crystalline basement environments.

3.0 Results and Discussion

The geoelectric sounding at VES 1 (Fig. 1) successfully delineated four distinct subsurface layers, revealing a complex weathering profile characteristic of the Akerebiata terrain. The uppermost layer (topsoil) exhibits a relatively high resistivity of 405.5 Ωm with a thin profile of 0.8 m. This likely represents a dry, sandy-lateritic topsoil typical of the dry season in Ilorin. The second layer (weathered layer / clayey) shows a significant drop in resistivity to 20.2 Ωm, extending to a depth of 3.3 m (thickness of 2.6 m). This low resistivity is indicative of a clay-rich weathered horizon or saturated silty-clay. The third layer (partially weathered/fractured Basement)

demonstrates an increase in resistivity to 302.4 Ωm with a thickness of 5.4 m. This suggests a transitional zone of partially weathered or slightly fractured rock. The final probed layer (deep saturated zone) is characterized by an anomalously low resistivity of 9.6 Ωm. This extremely low value at depth is highly significant, and indicate a deeply weathered, water-saturated fracture zone or decomposed basement pocket with high fluid content (Aizebeokhai *et al.*, 2018). Based on the sequence of the layers resistivity values (405.5 > 20.2 < 302.4 > 9.6), this station follows a KH-curve type ($\rho_1 > \rho_2 < \rho_3 > \rho_4$). In Nigerian hydrogeology, KH-curves are often associated with high groundwater potential because they indicate a sequence of alternating porous and permeable zones. Table 2 shows geoelectric layer breakdown for VES station 1. In the four-layer model for VES 1, the overburden consists of the first three geoelectric layers overlying the highly conductive fourth layer (the probable aquifer).

The total longitudinal conductance (G) is calculated as:

Layer 1 (G_1) = 0.8 / 405.5 = 0.00197 S

Layer 2 (G_2) = 2.6 / 20.2 = 0.12871 S

Layer 3 (G_3) = 5.4 / 302.4 = 0.01786 S

$Total\ G = 0.00197 + 0.12871 + 0.01786 = 0.1485\ S$

A value of 0.1436 S indicates that the overburden at this location, indicates a weak protective capacity while the second layer (the 20.2 Ωm clay zone) provides some conductive barrier, its relatively small thickness (2.5 m) and the high resistivity of the surrounding layers mean that the underlying aquifer (Layer 4) is somewhat vulnerable to surface-derived contaminants, such as leachate from soakaways or agricultural runoff.

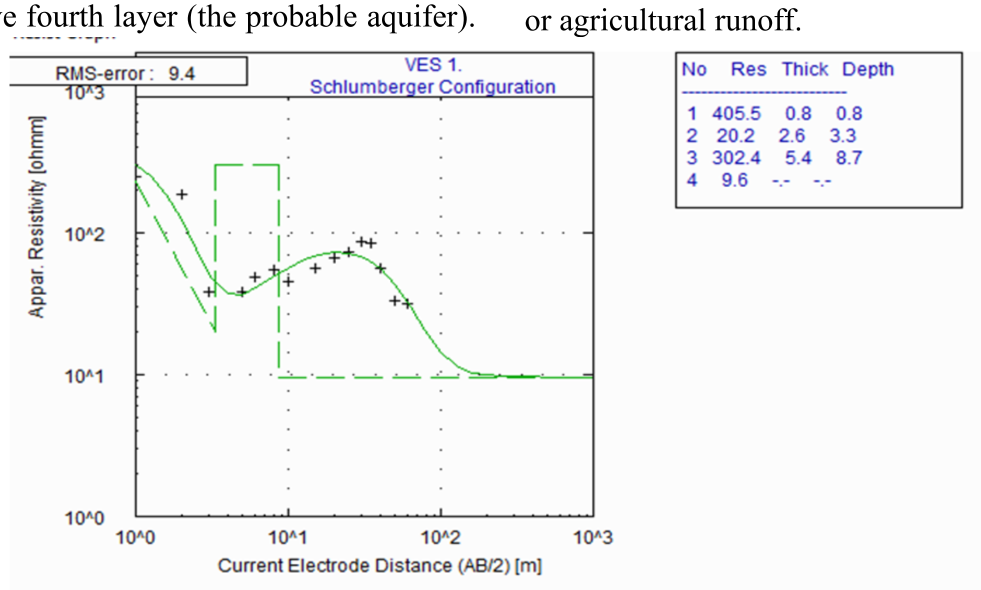

Fig.1: The digitized model of interpreted VES station 1

Table 2: Summary of Geoelectric Parameters and Inferred Lithology for VES 1

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	405.5	0.8	0.8	Topsoil (Dry/Lateritic)
2	20.2	2.6	3.3	Weathered Layer (Clayey/Saturated)
3	302.4	5.4	8.7	Partially Weathered Basement
4	9.6	∞	∞	Saturated Fracture Zone / Saprock

For VES Station 2 (Fig. 2), the geoelectric section reveals a more complex, five-layer subsurface model. This station is particularly significant because it exhibits the thickest overburden in the study area, suggesting a well-developed weathering profile. The sounding at this station follows an HKH-curve type ($\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$), which indicates an alternating sequence of resistive and conductive horizons before hitting the fresh basement. The third layer is the most hydrogeologically significant unit at this station. With a thickness of 14.2 m and a resistivity of 32.7 Ωm, it represents a substantial accumulation of weathered regolith. In the Nigerian Basement Complex, this saprolite zone often acts as the primary reservoir, providing the necessary storage capacity for groundwater (Ogungbemi *et al*., 2013). The fourth layer shows an increase in resistivity to 137.7 Ωm. This is interpreted as the fractured basement or saprock zone. While thinner than the overlying weathered layer (2.2 m), this zone is critical because fractures typically provide the secondary permeability required for high borehole yields. The combination of the thick saprolite (storage) and the underlying fractured saprock (conduit) makes VES 2 a highly favorable location for groundwater development. The total depth to the fresh basement at VES 2 is 17.7 m, the greatest depth among stations with fully resolved resistivity profiles. This is the deepest point recorded among your stations (excluding the undetermined depth at VES 1). Modern studies in the Ilorin region suggest that overburden thicknesses exceeding 15 meters in basement terrains are generally indicative of sustainable groundwater potential (Ige *et al*., 2022). While VES 1 showed a much lower resistivity at depth (suggesting higher saturation), VES 2 provides a more stable and predictable crystalline basement profile. The high resistivity of the final layer (1457.9 Ωm) confirms that the sounding successfully reached the fresh migmatite-gneiss bedrock. Table 3 shows the geoelectric layer breakdown for VES 2. The protective capacity at VES Station 2 is as follows:

- $G_1 = 0.6 / 372.9 = 0.0016\, S$
- $G_2 = 0.7 / 51.9 = 0.0135\, S$
- $G_3 = 14.2 / 32.7 = 0.4343\, S$
- $G_4 = 2.2 / 137.7 = 0.0160\, S$

$Total\ S = 0.4654\ \Omega^{-1}$

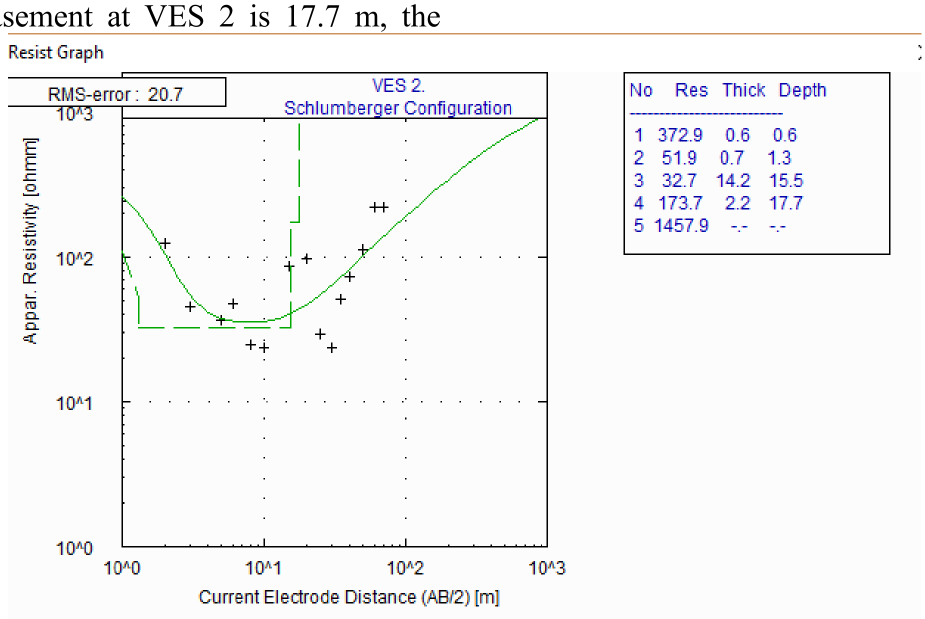

Fig.2: The digitized model of interpreted VES station 2

Table 3: Summary of Geoelectric Parameters and Inferred Lithology for VES 2

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	372.9	0.6	0.6	Topsoil (Sandy/Dry)
2	51.9	0.7	1.3	Lateritic/Clayey sand
3	32.7	14.2	15.5	Saprolite (Weathered Basement)
4	137.7	2.2	17.7	Saprock (Fractured Basement)
5	1457.9	∞	∞	Fresh Basement Rock

The results indicate a Moderate protective capacity, suggesting the overburden provides partial natural filtration against surface contaminants. According to the Oladapo and Akintorinwa (2007) classification, a value of 0.4654 S falls within the Moderate Protective Capacity range (0.2–0.69 S)S).This is a significant improvement over VES 1, suggesting that the thicker clay-rich saprolite at VES 2 provides better natural filtration against surface contaminants.

For VES Station 3 (Fig. 3), the geoelectric section reveals a four-layer subsurface model. The sounding provides a thick and productive weathered horizon. This station is characterized by an HA-type curve ($\rho_1 > \rho_2 < \rho_3 < \rho_4$), which is a very common signature in the Nigerian Basement Complex, representing a steady increase in compaction and rock freshness after an initial weathered conductive zone. The standout feature of VES 3 is the second layer. With a resistivity of 33.5 Ωm and a thickness of 14.6 m, this is the thickest single weathered unit identified in the study area. This layer serves as a massive saprolitic reservoir. Because the resistivity is relatively low (below 40 Ωm), it likely has a high clay content or is significantly saturated, which is a positive indicator for groundwater storage (Sikah *et al*., 2016). The third layer (62.7 Ωm) is a thin transitional zone of partially weathered or fractured rock. Although it is only 1.6 m thick, its position directly beneath a massive weathered reservoir is ideal. In hydrogeological terms, the saprolite (Layer 2) provides the storage, while the saprock (Layer 3) provides the transmissivity (ease of water flow) into a borehole. The fresh basement was encountered at a depth of 16.9 m with a resistivity of 1476.1 Ωm. This depth to bedrock is consistent with the findings at VES 2, suggesting that this portion of Akerebiata (near VES 2 and 3) sits on a relatively stable, moderately deep weathered trough. Table 4 shows geoelectric layer breakdown for VES 3. The protective capacity for the overburden at this station is:

- G_1 = 0.7 / 357.6 = 0.0019 S
- G_2 = 14.6 / 33.5 = 0.4358 S
- G_3 = 1.6 / 62.7 = 0.0255 S

Total $G_1 = 0.4632$ S

Similar to VES 2, the protective capacity at VES 3 is Moderate (0.4632 S). The presence of the 14.6 m thick weathered layer acts as a natural sieve, offering a moderate degree of protection for the underlying water-bearing zones against anthropogenic surface pollutants. This makes VES 3 another high-priority site for drilling, especially for community-scale water supply (Aizebeokhai *et al*., 2018).

For VES Station 4 (Fig. 4), the geoelectric section reveals a four-layer subsurface model. Similar to the previous station, this follows an HA-type curve ($\rho_1 > \rho_2 < \rho_3 < \rho_4$), but with a notably thicker topsoil layer and a shallower depth to the fresh basement compared to VES 2 and 3. The sounding at VES 4 indicates a relatively straightforward weathering profile, though the potential for high-yield groundwater is slightly lower here due to the reduced thickness of the primary weathered zone.

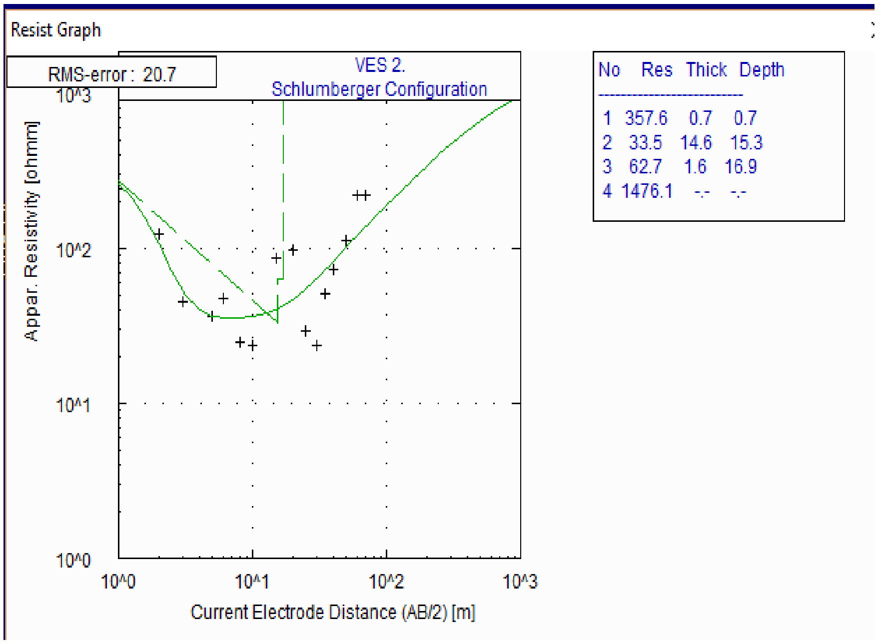

Fig. 3: The digitized model of interpreted VES station 3

Table 4: Summary of Geoelectric Parameters and Inferred Lithology for VES 3

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	357.6	0.7	0.7	Topsoil (Dry/Sandy)
2	33.5	14.6	15.3	Weathered Basement (Saprolite)
3	62.7	1.6	16.9	Fractured Basement (Saprock)
4	1476.1	∞	∞	Fresh Basement Rock

The topsoil at this station is significantly thicker (2.8 m) than at the previous stations. The second layer, with a resistivity of 20.6 Ωm, represents a highly weathered, clay-rich unit. While clayey zones are good for water storage, their low permeability can sometimes restrict the flow rate into a borehole. However, at a thickness of 5.5 m, it still contributes a modest volume to the local groundwater reservoir. The third layer (65.2 Ωm) is interpreted as the fractured basement (saprock). Its proximity to the surface (starting at 8.3 m) suggests that the weathering process has not penetrated as deeply at this location as it did at VES 2 or 3. The final layer's resistivity of 863.3 Ωm is lower than the bedrock resistivity at VES 3 (1476.1 Ωm), which may indicate that the fresh basement here is still somewhat fractured or jointed, allowing for some secondary porosity (Aizebeokhai *et al*., 2018). With the basement encountered at 10.2 m, this station sits on a relative topographic high in the subsurface bedrock compared to the deeper troughs found at VES 2 and 3. This shallow depth usually translates to lower groundwater yield, as the available bucket for storage is smaller. Table 5 shows geoelectric layer breakdown for VES 4. The longitudinal conductance (G) for VES 4 is calculated as follows:

- $G_1 = 2.8 / 187.9 = 0.0149\ S$
- $G_2 = 5.5 / 20.6 = 0.2669\ S$
- $G_3 = 1.9 / 65.2 = 0.0291\ S$

$Total\ G = 0.3109\ S$

The protective capacity at VES 4 is rated as Moderate. Although the total overburden is thinner than at VES 3, the highly conductive (clayey) nature of the second layer provides a decent electrical barrier, offering some natural protection against the infiltration of surface-borne contaminants (Bassey *et al*., 2023).

For VES Station 5 (Fig. 5), the geoelectric profile is very similar to VES 4, characterized by a four-layer HA-type curve ($\rho_1 > \rho_2 < \rho_3 < \rho_4$). This consistency suggests a degree of lateral continuity in the subsurface weathering patterns within this section of the Harmony Estate environs. The sounding at VES 5 reveals a moderately weathered profile with a slightly thicker weathered zone than VES 4, though still shallower than the major troughs identified at VES 2 and 3. The second layer, with a resistivity of 25.9 Ωm and a thickness of 7.2 m, is the primary hydrogeologic unit here. While the resistivity suggests a high clay content—which can limit permeability—the thickness is sufficient to hold a moderate amount of groundwater. According to Ijila *et al*., (2018), resistivity values between 20 and 100 Ωm in Nigerian basement terrains typically represent the saprolite zone, which acts as the main storage reservoir for the underlying fracture systems. The third layer is a thin transitional zone (1.2 m thick) with a resistivity of 69.9 Ωm.

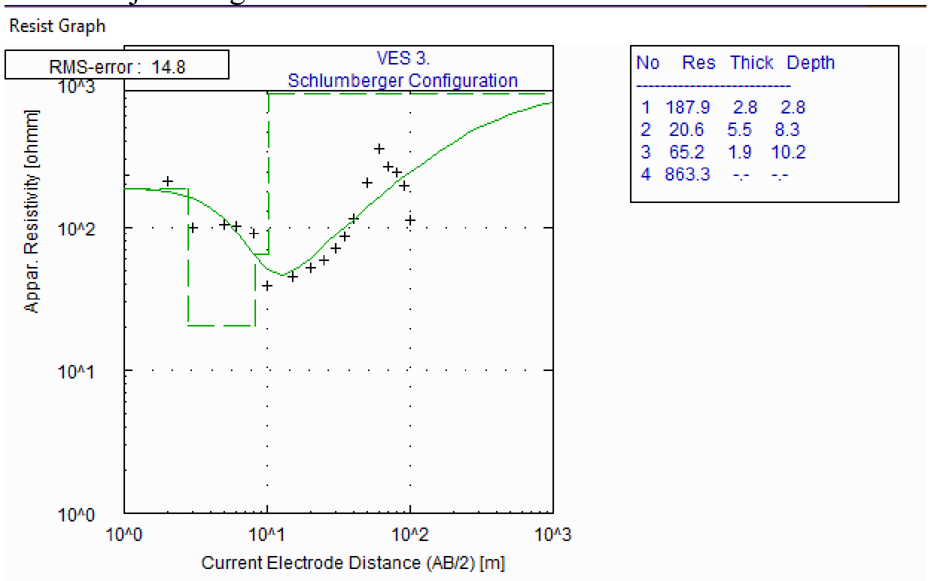

Fig. 4: The digitized model of interpreted VES station 4

Table 5: Summary of Geoelectric Parameters and Inferred Lithology for VES 4

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	187.9	2.8	2.8	Topsoil (Dry/Sandy Clay)
2	20.6	5.5	8.3	Weathered Basement (Clayey)
3	65.2	1.9	10.2	Fractured Basement (Saprock)
4	863.3	∞	∞	Partially Fresh/Fractured Basement

This observation likely represents the fractured basement or saprock. The relatively low resistivity of the final layer (874.7 Ωm) compared to the fresh bedrock at VES 6 suggests that the basement rock here is not entirely massive but may contain minor joints or fissures that could facilitate some water movement (Aizebeokhai *et al*., 2018). The fresh/partially fractured basement is encountered at a depth of 11.1 m. This places VES 5 in an intermediate category of groundwater potential better than the shallow VES 6, but less productive than the deeper weathering troughs found at VES 2 and 3.

Table 6 shows geoelectric layer breakdown for VES 5. The protective capacity for VES 5 is calculated as:

- G_1 = 2.7 / 190.3 = 0.0142 S
- G_2 = 7.2 / 25.9 = 0.2780 S
- G_3 = 1.2 / 69.9 = 0.0172 S

$Total\ G = 0.3094\ S$

The protective capacity at VES 5 is rated as Moderate. The thickness of the clayey weathered layer (7.2 m) provides a reasonably effective natural filter against surface-derived contaminants, making it a safer site for groundwater abstraction than VES 1, which had a weak rating.

For VES Station 6 (Fig. 6), the geoelectric section reveals a much simpler, three-layer subsurface model. This station follows an A-type curve ($\rho_1 < \rho_2 < \rho_3$), which indicates an ascending resistivity profile where each subsequent layer is more resistive than the one above it. This is typically the least favorable curve type for groundwater exploration in basement terrains. The sounding at VES 6 indicates a very thin overburden and a rapid transition into tight, fresh bedrock. Unlike the other stations in the Akerebiata area, VES 6 lacks a significant conductive weathered layer (saprolite).

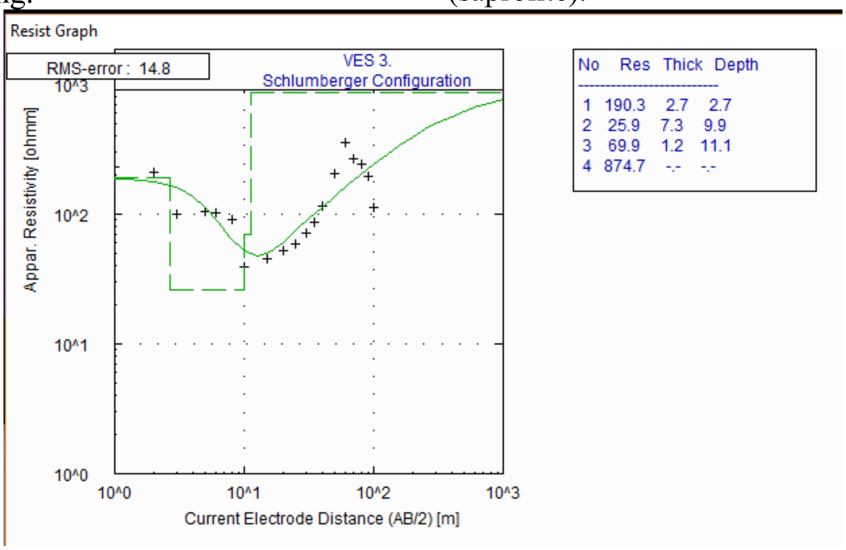

Fig. 5: The digitized model of interpreted VES station 5

Table 6: Summary of Geoelectric Parameters and Inferred Lithology for VES 5

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	190.3	2.7	2.7	Topsoil (Dry/Sandy Clay)
2	25.9	7.2	9.9	Weathered Basement (Clayey)
3	69.9	1.2	11.1	Fractured Basement (Saprock)
4	874.7	∞	∞	Partially Fresh/Fractured Basement

The second layer is relatively resistive (342.3 Ωm), suggesting it is composed of dry lateritic materials or rock fragments rather than the clayey, water-bearing regolith found at VES 2 or 3.The fresh, massive basement is encountered at a depth of only 6.4 m. This is the shallowest bedrock recorded in your study area. In the Nigerian Basement Complex, a shallow bedrock profile typically translates to a very low storage capacity for groundwater, as there is insufficient volume in the overburden to sustain a borehole through the dry season (Sikah *et al.*, 2016). The final layer resistivity of 2071 Ωm is the highest in the entire study area. This high value suggests a very fresh, tight crystalline basement with no significant secondary porosity or fracture systems (Ige *et al*., 2022). Table 7 shows the geoelectric layer breakdown for VES 6. The protective capacity assessment for VES 6 is calculated as:

- G_1 = 3.2 / 13.0 = 0.2461 S
- G_2 = 3.2 / 342.3 = 0.0093 S

$Total\ G = 0.2554$

Interpretation:

While the total G value technically falls within the Moderate protective capacity range (0.2–0.69 S), this is primarily due to the very low resistivity of the topsoil layer rather than a thick, protective weathering profile. From a hydrogeological standpoint, this protection is of little consequence because there is no viable aquifer beneath it to protect. Table 8 below shows the comparison of all stations in respect to their groundwater potentials and the key reasons.

3.1 Discussion

The geoelectrical data indicate that groundwater occurrence in the Akerebiata area is primarily controlled by the thickness and hydraulic properties of the weathered basement and underlying fractured zones, which constitute the main aquifer systems in crystalline basement terrains. The interpreted VES models reveal marked lateral variability in overburden thickness and resistivity, reflecting heterogeneous weathering and fracturing patterns typical of Precambrian basement environments. Stations VES 2 and VES 3 represent the most favorable hydrogeological settings in the study area. Both locations are characterized by thick saprolitic layers exceeding 14 m, moderate resistivity values indicative of saturated weathered materials, and underlying fractured basement zones that enhance groundwater transmissivity. This lithological configuration provides a combination of adequate storage within the weathered layer and efficient hydraulic pathways through fractures, a condition widely recognized as optimal for sustainable groundwater development in basement terrains.

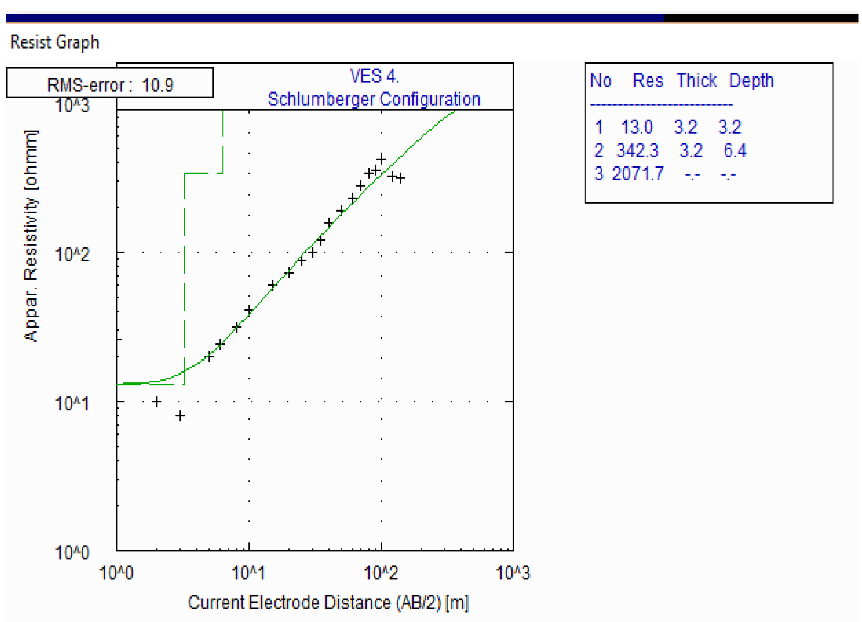

Fig. 8: The digitized model of interpreted VES station 6

Table 7: Summary of Geoelectric Parameters and Inferred Lithology for VES 6

Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	13.0	3.2	3.2	Topsoil (Wet/Clayey)
2	342.3	3.2	6.4	Laterite / Partially Weathered Rock
3	2071.7	∞	∞	Fresh Basement Rock

Table 8: Summary Comparison of All VES Stations

Station	Curve Type	Potential	Key Reason
VES 1	KH	High	Deep conductive zone (9.6 Ωm) likely representing a fracture
VES 2	HKH	High	Thickest saprolite (14.2 m) for excellent storage
VES 3	HA	High	Massive weathered zone (14.6 m) and good overburden thickness
VES 5	HA	Moderate	Decent weathered thickness (7.2 m)
VES 4	HA	Moderate	Similar to VES 5, but slightly thinner weathered layer
VES 6	A	Poor	Shallow bedrock (6.4 m) and lack of reservoir

The moderate longitudinal conductance values obtained at these stations further indicate a reasonable degree of aquifer protection against surface contamination, largely attributed to the thickness and clay content of the overburden. VES 1 also exhibits high groundwater potential based on the presence of a deep, highly conductive zone interpreted as a saturated fracture or decomposed basement pocket. However, its weak protective capacity suggests limited natural attenuation of surface-derived contaminants. This highlights the vulnerability of structurally controlled basement aquifers where protective overburden is thin or discontinuous, emphasizing the need for careful borehole siting and land-use control in such settings. In contrast, VES 4 and VES 5 display moderate groundwater potential associated with thinner weathered layers and shallower basement depths. Although these stations show moderate protective capacity due to clay-rich weathered horizons, the reduced thickness of the aquifer units implies lower groundwater storage and potentially reduced borehole yields. Such conditions are suitable for small-scale or domestic water supply but may not support high-demand abstraction. VES 6 represents an unfavorable hydrogeological condition, characterized by shallow bedrock, absence of a significant saprolitic layer, and very high basement resistivity values. Despite a calculated moderate protective capacity, the lack of a viable aquifer renders this location unsuitable for groundwater development. Overall, the study confirms that productive groundwater zones in Akerebiata are localized and structurally controlled, reinforcing the necessity of site-specific geophysical investigations prior to borehole drilling in basement complex terrains. These results emphasize the importance of site-specific geophysical surveys for borehole siting in basement terrains, as groundwater potential is highly localized and structurally controlled.

4.0 Conclusion

The Vertical Electrical Sounding (VES) investigation in Akerebiata and its environs indicates that groundwater potential is largely controlled by the thickness and resistivity of the weathered basement and the presence of fractured basement zones, which constitute the main aquifer systems. The fresh basement is generally non-aquiferous. Among the six stations studied, VES 2 and VES 3 exhibit the most favorable conditions for groundwater development due to thick saprolitic layers, an underlying fractured basement, and moderate overburden protective capacity. VES 1 also has high potential but limited protection against surface contamination, while VES 4 and VES 5 are moderately promising for domestic-scale supply. VES 6 is unsuitable due to shallow bedrock and insufficient aquifer development.

Boreholes should ideally be drilled to depths exceeding 18 m to access productive weathered and fractured zones. Wellhead protection is recommended, particularly in areas with weak overburden. Further investigations—including borehole yield tests, pumping tests, and hydrochemical analyses—are necessary to validate these geophysical interpretations and support sustainable groundwater management.

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Ahmed Kehinde Usman conceptualized the study, supervised field investigations, and prepared the manuscript. Jimoh Raimi conducted data acquisition and geophysical measurements. Mahmood Umar performed data processing, interpretation, and visualization. Mas'ud Shehu contributed to methodological validation, literature review, and manuscript editing. All authors reviewed, approved the final version, and agreed to be accountable for the research outcomes.