

Exploration of Shallow Basement Aquifers for Cost-Effective Groundwater Exploitation Using Electrical Resistivity Profiling and Vertical Electrical Sounding in Minna, Nigeria

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ABSTRACT

Geoscientific exploration is a prerequisite for groundwater development through borehole drilling in the Basement Complex. With advances in model drilling technologies that increase drilling depth, accompanied by uncertainties, the cost of drilling boreholes has increased, especially where shallow groundwater zones are poorly explored. Horizontal Electrical Resistivity Profiling (HERP) and Vertical Electrical Sounding (VES), employing the Schlumberger configuration, were used to investigate the lateral and vertical resistivity variation of the study area. 5 profile lines, each consisting of 5 to 7 sounding stations, were established. Low resistivity points on the profiles were selected for further prospecting employing the VES with 50 m maximum current electrode half separation ($AB/2$). The HERP reveals lateral variation of the resistivity distribution associated with the subsurface weathered and fractured Basement rock units. Relatively low resistivity values (0.12Ω to 0.17Ω and $30.0 \Omega\text{m}$ to $41.9 \Omega\text{m}$) were delineated in the north-western and south-western portions of the study area. These portions are interpreted as weathered, fractured, and water-saturated lithologies with shallow groundwater potential. In contrast to low resistivity zones, high resistivity zones, which represent relatively unfractured, fresh Basement lithology, observed along parts of profile 3 are considered unsuitable zones for shallow groundwater exploitation. VES interpretation reveals predominantly H-model curve type comprising 3 geoelectric layers ($\rho_1 > \rho_2 < \rho_3$). These layers represent the unsaturated topsoil, the weathered materials, and the fractured/fresh Basement rock units. The fractured Basement rock layer defines the shallow aquiferous zone within the depths of 30 m to 50 m.

Keywords: Shallow Aquifer; Vertical Electrical Sounding; Profiling, Resistivity; Groundwater.

1.0 INTRODUCTION

The inability of the Nigerian state to provide a dependable source of electricity has been a critical factor in the match to industrialization and civilization. Electric power is in short supply, and the cost to install alternative sources of energy seems out of reach for many (International Energy Agency, 2024; World Bank, 2023; Transmission Company of Nigeria, 2023). This results in the non-continuous supply of potable water from motorized borehole facilities, therefore creating difficulty in accessing the potable water supply on time. The supply of potable water from the state water board has proven grossly insufficient to meet the growing needs of the population, especially in public places like primary and secondary schools. The private sector is working hard to embrace appropriate mechanisms that would sustain groundwater supplies at all costs. The need to access groundwater using mechanical means, wherever possible, has been increasing, especially in schools, due to epileptic power supply and population growth.

Groundwater, as a precious natural resource, is sometimes scarce and unevenly distributed, both in space and time within geological formations of the earth's subsurface (Mandal & Saha, 2024; Amadi & Olasehinde, 2009). The occurrence and distribution of groundwater are mainly dependent on the local and

regional geology of an area, geomorphology/weathering, and precipitation (Magesh & Chandrasekar, 2024). There is a greater uncertainty in locating productive bedrock aquifers within the Basement Complex terrain (Todd, 1980). The difficulties inherent in the exploration and exploitation of prolific shallow basement aquifer zones make it desirable to employ several careful approaches for investigative purposes. The occurrence of groundwater in recoverable quantities, as well as its circulation in a Basement terrain, is controlled by the degree of weathering and fracturing within the rock (Mokgolodi & Molwalefhe, 2025). The physical and hydrogeological properties of the subsurface geological units vary widely from place to place and sometimes within the smallest area coverage (Abdulaziz, 2005; Offodile, 2002).

The choice of appropriate geophysical methods and applying these methods in a rightful manner is very critical to the success of any geophysical investigation (Abdulaziz, 2005; John, 2003). How successful a chosen geophysical technique is also dependent on several key geological and cultural factors, such as the nature of the target, the depth of burial of the target, target size, measurement station interval, and data calibration (Abubakar *et al.*, 2023). The direct-current (DC) electrical resistivity method for conducting

horizontal electrical resistivity profiling (HERP) and vertical electrical sounding (VES) of the electrical technique has been extensively used in groundwater exploration because of the correlation that often exists between electrical properties, geologic formations, and their fluid content (Rahaman *et al.*, 2025; Reinhard, 2006). In the application of electrical methods to groundwater investigations, two properties are of primary concern: the ability of rocks to conduct an electric current and the polarization that occurs when an electric current is passed through the rocks (Tiruneh *et al.*, 2026).

Horizontal Electrical Resistivity Profiling (HERP) is used to investigate the lateral variations in resistivity of subsurface lithologies, thereby detecting anomalous zones of structural deficiencies such as joints, fractures, faults, and weathered zones that may serve as groundwater conduits (Abubakar *et al.*, 2023). In crystalline basement terrains, these features are detected as anomalies with relatively low electrical resistivity values with reference to the surrounding unaltered fresh bedrock (Shuaibu, 2024; Fawale *et al.*, 2023).

Vertical Electrical Sounding (VES), used in measuring the vertical distribution of subsurface lithological layers with respect to depth to bedrock, thickness of weathered zones, and the exaggerated extent of the fractured Basement, complements the HERP (Adeyinka, 2025; Akinyemi, 2024).

Integrating HERP with VES enhances the efficiency of Basement aquifer characterization by providing defined subsurface lithologic resolution that accommodates groundwater in sufficient quantity (Jayawardana *et al.*, 2025; Adebisi *et al.*, 2023). The results of horizontal profiling and vertical electrical sounding are often affected by both horizontal and vertical variations in the electrical properties of the subsurface (Zohdy *et al.*, 1974).

2.0 STUDY AREA

The premises of Himma International School, Minna, North-Central Nigeria, constitute the study area. The area confined between longitude 39° 15'E and 39° 15'E and latitude 39° 15'N and 39° 15'N. It is defined by the tropical climate with distinct dry and rainy seasons. The climate is typically tropical, with distinct dry and rainy seasons, with the rainy season extending from April to October (NiMet, 2025).

The area is underlain by crystalline Basement Complex rocks of the Precambrian Era, consisting of igneous and metamorphic rocks of varied composition. The rocks in the study area include granite, migmatite gneisses, granite gneisses, and schist. The rocks have undergone multiple phases of deformation during the Pan-African Orogenic events, resulting in the

development of anomalous structural features such as joints, faults, and fractures (Amadi *et al.*, 2022).

3.0 MATERIALS AND METHODS

The general four-electrode arrangement of electrical resistivity investigation, consisting of a pair of current electrodes and a pair of potential electrodes using the Wenner and Schlumberger configurations (Koefoed, 1979; Reynolds, 2011), was used in this study with the aid of ABAM SAS 100 Terrameter. The current electrodes A and B act as a source and a sink, respectively, while the potential difference was measured by a voltmeter connected between potential electrodes C and D.

In the HERP, a fixed electrode spacing of 20 m AB/2 was chosen on the basis of established past study results of electrical soundings of shallow boreholes within the study area (Dan-Hassan & Olorunfemi, 1999). While maintaining constant array parameters, comprising orientation, electrode separation, and current input, there was a progressive movement of the entire array along each profile to attain the desired low resistivity values at shallow depth for delineation of the groundwater zone. A total of 5 profile lines were established based on a field reconnaissance survey. Each profile line consists of 5 to 7 sounding stations.

VES measurements were further carried out at selected low resistivity points resulting from the HERP. These points were selected to obtain detailed vertical subsurface characteristics of the underlying lithologies. For each of the VES stations, the current electrode spacing was progressively increased from 1 m to a maximum half-spacing (AB/2) of 50 m, to attain the desired depth of exploration for shallow Basement rock aquifer delineation.

The horizontal electrical resistivity profiling map was generated using the Golden Surfer software, while the VES field data were analyzed and interpreted using the computer programs Winresist (Van der Velpen and Sporry, 1992).

The HERP data were digitally processed, and a resistivity distribution contour map was generated with the aid of the Golden Surfer software, while the VES data were iterated and interpreted using WinResist software.

Potential groundwater-bearing units were delineated at the shallow Basement aquifer zones from the interpretation of the resistivity data, layer thickness, and depth of the subsurface lithologies.

4.0 RESULTS AND DISCUSSION

The HERP field layout and results from the 5 profile lines involving 32 horizontal electrical resistivity profile stations and two VES stations are presented in this section (Figure 1.0 and Table 1.1).

The HERP points are displayed on the base map as stacked resistivity profile lines (Figure 2), providing a clear distribution and representation of lateral variations in subsurface resistivity. These variations show alterations in lithology and structural conditions within the subsurface Basement Complex rocks. The interpretation of the HERP shows lateral variation in the resistivity of the underlying Basement rock from which low-resistivity zones, which reflect potential groundwater-bearing units, were delineated. The low-resistivity points reflecting the water-bearing layers were further investigated through the VES to delineate the thickness and depth of the lithologic layers.

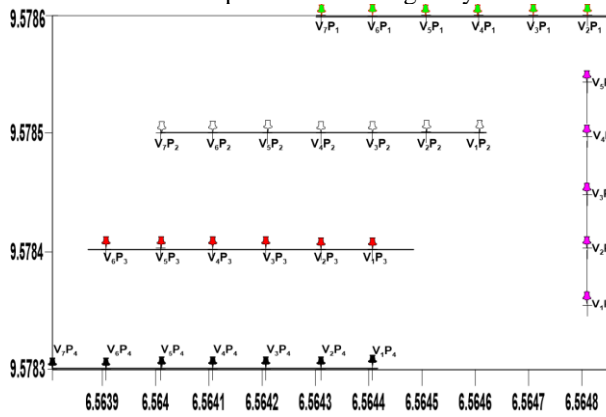


Figure 1.0. Profile Layout

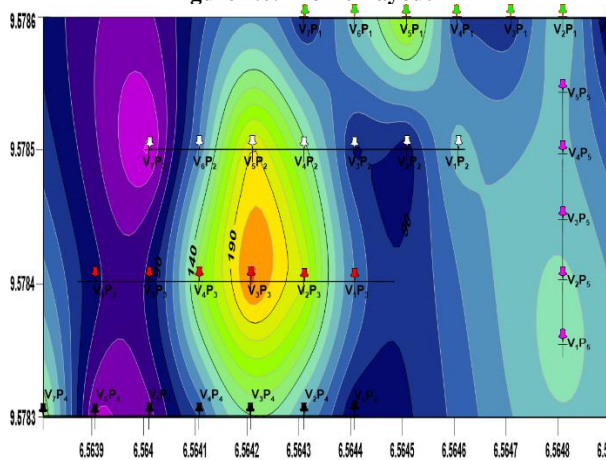


Figure 2.0: VES and HERP Profile lines

The north-western and part of the south-western portions of the studied area, which are defined by VES points, V₇P₂, V₆P₄, and V₅P₄, indicate relatively low resistivity values and are inferred to be good priority potential for further VES investigation and groundwater exploitation at shallow depths. The resistivity values range from 0.12 Ω to 0.17 Ω, while the apparent resistivity values range from 30.0 Ωm to 41.9 Ωm. These anomalous low resistivity signatures are a pointer to the occurrence of saturated weathered and fractured Basement rocks.

Points V₇P₂ (profile line 2) and V₆P₄ (profile line 4) indicate the lowest resistivity values to be subjected to further VES investigation and analysis for groundwater development. The low resistivity readings observed in the profile are attributed to the likely presence of water-saturated fractured Basement rock unit, which will serve as a shallow aquifer for groundwater exploitation.

Moderate groundwater potential is expected for HERP locations points V₁P₁, V₁P₇, V₂P₂, V₃P₂, V₆P₃, V₅P₃, and V₁P₄ (Figure 2 and Table 1). These points show intermediate resistivity values, indicating partially weathered or relatively fresh basement rock.

In contrast, HERP points V₂P₃, V₃P₃, and V₄P₃ on profile line P3 display a relatively high value of electrical resistivity, suggesting a fresh Basement rock with very low groundwater potential, which may not be recommended for further investigation and groundwater exploitation.

Table 1.1: Hydrogeophysical Field Data

DEPTH OF PROFILE =20m					GEOMETRIC CONSTANT = 247	
S/N	Profiles	LAT. (Decimal Degree)	LOG. (Decimal Degree)	Altitude (m)	R (ohm)	ℓ (Ωm)
1	V ₁ P ₁	9.578599	6.564904	257	0.30	75
2	V ₂ P ₁	9.578599	6.56481	258	0.53	131
3	V ₃ P ₁	9.578599	6.564709	257	0.25	92
4	V ₄ P ₁	9.578599	6.564606	255	0.40	99
5	V ₅ P ₁	9.578599	6.564508	252	0.69	171
6	V ₆ P ₁	9.578598	6.564407	251	0.51	127
7	V ₇ P ₁	9.578599	6.56431	258	0.35	87
8	V ₁ P ₂	9.5785	6.564607	256	0.51	125
9	V ₂ P ₂	9.578501	6.564508	258	0.34	84
10	V ₃ P ₂	9.5785	6.564407	259	0.36	88
11	V ₄ P ₂	9.5785	6.56431	259	0.58	144
12	V ₅ P ₂	9.5785	6.56421	261	0.78	192
13	V ₆ P ₂	9.5785	6.564107	260	0.45	111

14	V ₇ P ₂	9.5785	6.56401	260	0.15	48
15	V ₁ P ₃	9.578402	6.564407	260	0.45	110
16	V ₂ P ₃	9.578402	6.56431	260	0.73	181
17	V ₃ P ₃	9.578402	6.564207	262	0.86	213
18	V ₄ P ₃	9.578402	6.564107	262	0.64	158
19	V ₅ P ₃	9.578403	6.56401	261	0.34	83
20	V ₆ P ₃	9.578402	6.563907	262	0.34	84
21	V ₁ P ₄	9.578301	6.564407	260	0.32	80
22	V ₂ P ₄	9.578301	6.56431	261	0.47	117
23	V ₃ P ₄	9.578301	6.564207	259	0.56	139
24	V ₄ P ₄	9.578301	6.564107	260	0.40	100
25	V ₅ P ₄	9.578301	6.56401	261	0.27	66
26	V ₆ P ₄	9.578301	6.563907	262	0.23	58
27	V ₇ P ₄	9.578301	6.563806	262	0.61	150
28	V ₁ P ₅	9.578355	6.56481	261	0.55	136
29	V ₂ P ₅	9.578403	6.56481	261	0.53	132
30	V ₃ P ₅	9.578448	6.56481	256	0.51	127
31	V ₄ P ₅	9.578497	6.56481	258	0.49	122
32	V ₅ P ₅	9.578543	6.56481	260	0.49	122

Interpretation of the VES data shows predominantly an H-type model curve with signatures ($\rho_1 > \rho_2 < \rho_3$), indicative of a three-layer geo-electrical structure with alternating resistivity of high-low-high. The topmost geoelectric layer is made up of relatively high resistivity values ($>90 \Omega\text{m}$), indicative of unsaturated topsoil. The topmost layer is underlain by Basement rocks with a varied degree of weathering characterised by low resistivity. The third layer indicates moderate resistivity values, which are interpreted as being affiliated with fractured Basement rock with the potential of accumulating groundwater in a reasonable quantity at shallow depth.

The VES geoelectrical sections show variation in the depth to the underlying anomalous fractured basement rock units across the sounding locations within the study area. The near-surface depth range of 3.0 m to 4.5m defines the overburden material thickness. The weathered Basement thickness ranges from 3.0 m (V₆P₄) minimum to 4.5 m (V₇P₂) maximum (Figures 3 and 4).

The relatively thin overburden shown by the VES investigation suggests limited groundwater storage within the regolith/saprolite that constitutes the weathered layer, implying that groundwater occurrence and storage in the study area are primarily controlled by fracture Basement rock units underlying the area. The outcome of the investigation suggests that VES point V₇P₂ on profile line 2 is indicated as the most prominent point for shallow groundwater exploitation through hand-pump borehole development due to the presence of relatively shallow, well-developed fractured units.

Point V₆P₄ also indicates positive groundwater potential, which can serve as an alternative point for the drilling and development of a shallow aquifer within the Basement rock unit that characterises the study area.

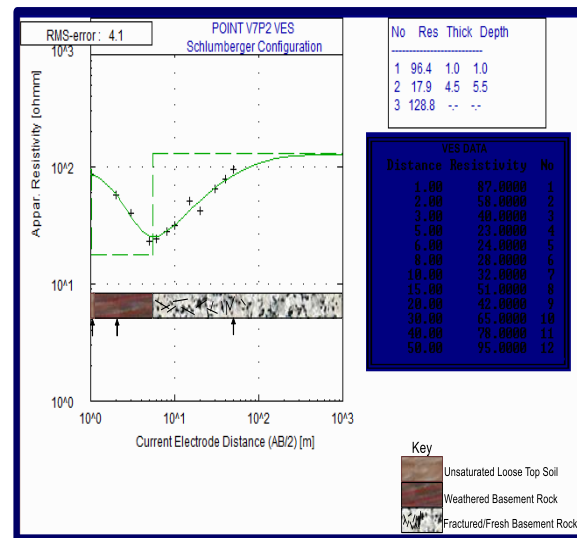


Figure 3: Model Resistivity Curve V7P2

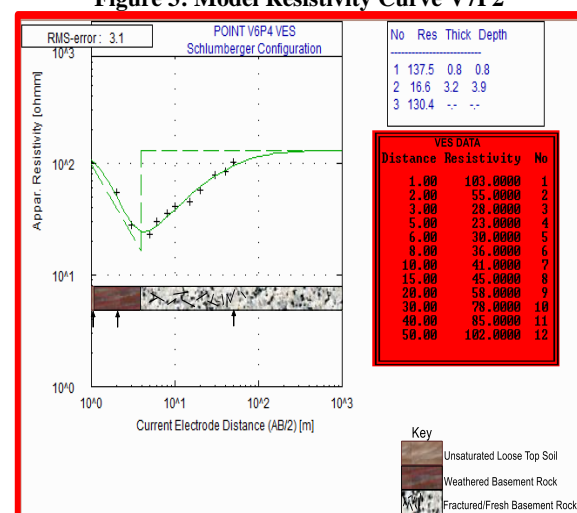


Figure 4: Model Resistivity Curve V6P4

5.0 CONCLUSION

This study has successfully shown the advantages of integrating Horizontal Electrical Resistivity Profiling

(HERP) and Vertical Electrical Sounding (VES) in prospecting for groundwater potential in shallow crystalline Basement Complex terrain. Anomalous zones of lower resistivity due to weathered basement zones and fractured crystalline rocks were identified as potential areas favourable for groundwater exploitation. The result of the study successfully revealed shallow aquiferous zones suitable for siting mechanized hand-pump boreholes capable of providing sufficient groundwater resources that would serve the population. This research outcome is particularly important in addressing the challenges posed by epileptic electric power supply, which has invariably affected the water supply system from the government or private motorized boreholes.

By the exploration and exploitation of groundwater through hand pump boreholes, independent water availability of low-cost and sustainable water supply is guaranteed. The availability of reliable potable water for the school community will enhance learning, hygiene, and health conditions of the pupils, thereby contributing to the overall education system.

In conclusion, the integration of HERP and VES in Basement Complex terrain has proven to be a reliable technique for shallow groundwater exploration, and its application in this study offers a practical pathway toward achieving sustainable water supply systems of low cost for effective functionality.

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