International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319–6378 (Online), Volume-14 Issue-5, April 2026

# Groundwater Potential Evaluation in A Basement Complex Terrain of Mubi South, Northeastern Nigeria

**Victor Vitalis, Kwaji Bitrus, Kamureyina Ezekiel, Bello Abubakar Dauda, Kasidi Simon, David John Zirra**

***Abstract:** This study evaluates groundwater potential in a basement complex terrain using Dar Zarrouk parameters derived from vertical electrical sounding (VES) data. A total of 20 VES points were acquired using the Schlumberger array configuration to determine subsurface resistivity distribution and aquifer characteristics [2]. The computed parameters include longitudinal conductance, transverse resistance, hydraulic conductivity, and transmissivity. Results reveal that approximately 80% of the study area exhibits favourable hydrogeological conditions dominated by H- and KH-type curves, indicative of weathered and fractured aquifer systems. Longitudinal conductance values range from 0.01775 to 2.316 $\Omega^{-1}$, indicating moderate aquifer protective capacity. Transverse resistance ranges from 81.17 to 2523.77 $\Omega m^2$, suggesting moderate to high aquifer saturation and thickness. Transmissivity values range from 16.68 to 1468.54 $m^2/day$, with an average of 467.46 $m^2/day$, indicating high groundwater-yield potential in 50% of locations. Hydraulic conductivity values vary from 9.50 to 36.38 m/day, reflecting moderate to high permeability. The integration of geoelectrical data with Dar Zarrouk parameters proves to be a reliable and cost-effective approach for groundwater exploration and sustainable water resource development in basement terrains.*

***Keywords**: Groundwater Potential, Dar-Zarrouk Parameters, Vertical Electrical Sounding (VES), Aquifer Characterisation, Transmissivity, Hydraulic Conductivity*

***Nomenclature:***
VES: Vertical Electrical Sounding
LoT: Longitudinal Conductance
Tr: Transverse Resistance
K: Hydraulic Conductivity
T: Transmissivity
ABEM: Applied Bentonite Electrical Method (Resistivity Meter Manufacturer)
GPS: Global Positioning System
IX1D: One-Dimensional Inversion Software (Interpex)

**Manuscript received on 01 April 2026 | First Revised Manuscript received on 06 April 2026 | Second Revised Manuscript received on 10 April 2026 | Manuscript Accepted on 15 April 2026 | Manuscript published on 30 April 2026.**

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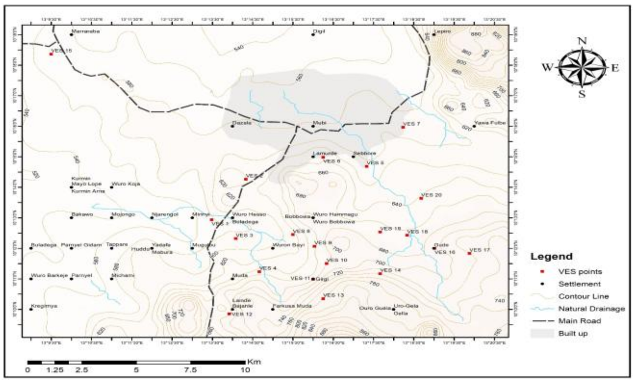
## I. INTRODUCTION

The amount of surface water available for domestic, industrial, and agricultural use is insufficient to meet current global demand. Therefore, groundwater exploration is vital. Groundwater exploration is increasingly important in Nigeria owing to the ever-increasing demand for water supplies, especially in areas with inadequate supplies, such as Mubi South. Already, ten per cent of the world's population is affected by chronic water scarcity, which is likely to rise to one-third by about 2025 (WHO, 2022). To remedy this situation, a precise and detailed geophysical study is critical to elucidate the behaviour of groundwater aquifers in the area. Aquifer Transmissivity ($m^2d^{-1}$), hydraulic conductivity ($md^{-1}$), aquifer thickness (m), Transverse Resistance ($\Omega m^2$), Longitudinal Conductance ($\Omega^{-1}$), and Storage Coefficient are the common fundamental properties usually studied. Thus, this study aims to use the Dar Zarrouk parameters, Transverse Resistance (Ωm2) and Longitudinal Conductance (Ω−1), to estimate optimal well locations in the study area (Ishola & Bukar, 2024) [6].

### A. Location and Accessibility

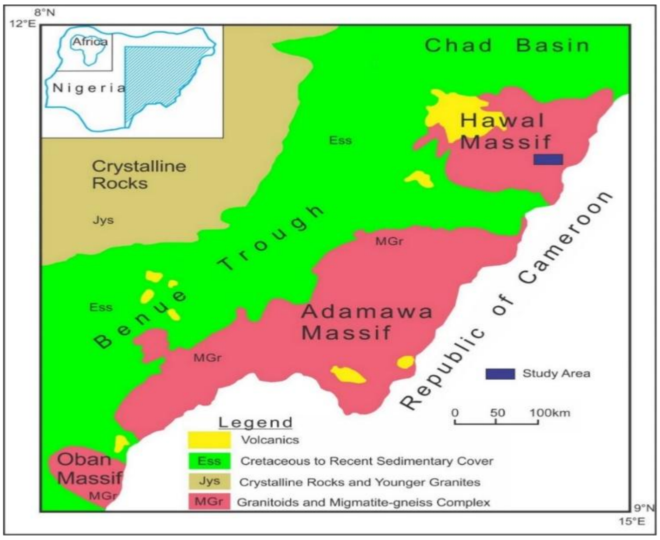
The area under study is located in Mubi South Local Government Area (Fig. 1). It is part of the sheets UBA 156 N.E and UBA 156 S.E. It is situated within latitudes 10° 11' 00" N – 10° 17' 00" N and longitudes 13° 15' 00" - 13° 21' 00" E.



**[Fig.1: Topographic Map Showing VES Points [12]]**

## II. GEOLOGY OF THE STUDY AREA

The study area lies within the Hawal Basement in the north-eastern sector of Nigeria's eastern Basement Complex (Fig. 2). Geological Survey of Nigeria (2018) [4] reported that high-grade metamorphic rocks, pervasive migmatization, and extensive granite plutonism characterise the rocks within the Hawal Basement. Most of the migmatization has been dated at 580 ± 10 Ma. It is bounded by the Tertiary–Quaternary Chad Basin northwards, the Yola arm of the Cretaceous Benue Basin southwards, and the Gongola Basin westwards. The area experienced Tertiary magmatism between 7 and 1 Ma, during which volcanic and sub-volcanic rocks were emplaced. These volcanic and sub-volcanic rocks are extensions of the Cameroun volcanic line into Nigeria. Earlier, during the Mesozoic, transitional alkali basalts were dated at 146 Ma ± 7.3 < age < 127 Ma ±, and it was reported that the gneisses and migmatites are the older rocks within the Hawal Basement, occupying mainly low-lying areas or existing as residual hills. The gneisses are generally strongly foliated and banded, and in some places are commonly dissected by quartz-feldspathic dykes and veins which impart them with migmatitic characteristics. Good examples of these can be found on Mubi. The gneisses have been subjected to a series of folding, shearing, and faulting and are extensively intruded by granitic rocks of the Pan-African orogeny (600 ± 150 Ma). The granites consist of fine to coarse-grained or porphyritic varieties with well-developed euhedral crystals. A variety exists as granite gneiss, which has well-defined foliation. Outcrops of the granite gneiss are found at Dumne, Song, Uba, and Mubi. Granites in the area have experienced extensive faulting and shearing and are commonly intruded by pegmatites. These are found in Hong, Mubi, Dumne, Song, and Pirkasa areas. (Ugbor & Ogbodo, 2023) [13].



**[Fig.2: Geologic Setting of the Study Area (Nuhu George Obaje, 2020) [10]]**

## III. METHODOLOGY

### A. Electrical Resistivity

An electrical resistivity survey involving the vertical electrical sounding (VES) method was adopted. The technique is one of the methods employed for groundwater exploration using ABEM (Signal Averaging System) SAS 4000 Terrameter with Schlumberger configuration [3]. The method used to delineate bedrock structures, determine depth to possible aquifer units, and infer the groundwater potential of the basement complex area. During a vertical electrical sounding (VES), a linear electrode array is laid out, and direct or slow alternating current is injected into the ground. In the centre, the voltage response is measured simultaneously between two electrodes. Increasing depths are achieved by enlarging the current electrodes from very small distances at the beginning to larger distances at the end of the array. In the Schlumberger array, potential electrodes remain temporally fixed, while deeper depths are probed by expanding the current electrodes symmetrically along the centre of the array (Nwozor et al., 2025) [9].

### B. Dar Zarrouk Technique for Determining Aquifer Hydraulic Characteristics from Vertical Electric Sounding Data

The continuous growth of the population and the presence of failed boreholes and dry wells pose a serious concern for the reliable supply of water. Dar-Zarrouk parameters consist of Transverse resistance and Longitudinal conductance. A geoelectric layer is described by two fundamental parameters: its resistivity ρi and its thickness, hi, where the subscript i indicates the position of the layer in the section (i = 1 for the uppermost layer). Total Transverse Unit Resistance, T (Ωm2) et Total Longitudinal Unit Conductance, S (Ω−1) (Kumar et al., 2021; Olorunfemi et al., 2020) [7].

#### *i. Transverse Resistance R*

The total transverse resistance R is given by:

$$R = \sum_{i=1}^{n} h_i \ \rho_i \qquad (1)$$

For a horizontal, homogeneous, and isotropic medium

$$\rho = (R_1 - R_2)/(h_i - h_2) \qquad (2)$$

where $h_i$ and $\rho_i$ are respectively the thickness and resistivity of the $i^{th}$ layer in the section.

**Table I: Classification of Transverse Resistance (T) Modified after Recent Studies (Abdulrahman et al., 2019) [1]**

| Transverse Resistance (Ω·m²) | Groundwater Potential |
|---|---|
| Less than 50 | Poor |
| 50 – 150 | Moderate |
| 150 – 300 | Good |
| Greater than 300 | Excellent |

**Interpretation:**

- **< 50 Ω·m²**: Suggests thin, low-resistivity layers or dry, compacted zones — **low aquifer yield potential**.
- **50–150 Ω·m²**: Indicates moderate saturation and/or thickness — **fair groundwater potential**.
- **150–300 Ω·m²**: Represents well-developed weathered/fractured zones — **good aquifer potential**.
- **> 300 Ω·m²**: Thick, resistive, and saturated layers — **very high groundwater yield**, often ideal for siting high-capacity boreholes.

#### *ii. Longitudinal Conductance S*

The total longitudinal conductance S is

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \qquad (3)$$

The longitudinal layer conductance, $S_i$, can also be expressed by

$$S_i = \frac{hi}{\rho_i} \qquad (4)$$

Where $h_i$ is the layer conductivity.

**Table II: Longitudinal Conductance Classification**

| Longitudinal Conductance (S) in Siemens (S) | Protective Capacity |
|---|---|
| > 10 | Excellent |
| 5 – 10 | Very Good |
| 0.7 – 4.9 | Good |
| 0.2 – 0.69 | Moderate |
| 0.1 – 0.19 | Weak |
| < 0.1 | Poor |

**Interpretation:**

- **> 10 S**: Thick, conductive overburden; excellent protection against contamination.
- **5–10 S**: Very good protection — suitable for shallow aquifer development.
- **0.7–4.9 S**: Good protective capacity; aquifer is fairly safe from surface contaminants.
- **0.2–0.69 S**: Moderate protection; some vulnerability exists.
- **0.1–0.19 S**: Weak protection; aquifer is highly vulnerable.
- **< 0.1 S**: Poor protection; aquifer is very prone to contamination.

### *iii. Transmissivity*

Transmissivity refers to the rate at which groundwater is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It is a major property of an aquifer that helps characterise rocks as water-conducting media. The aquifer transmissivity (T) is expressed as the product of the hydraulic conductivity and layer thickness

$$T = K \times h \qquad (5)$$

Where:

K is the hydraulic conductivity (m/day), and h is the layer thickness in (m)

Areas with high transmissivity can be attributed to having a thick aquifer and highly interconnected fractures and joints.

**Table III: Transmissivity Classification**

| Transmissivity (T) (m²/day) | Aquifer Potential |
|---|---|
| > 100 | Excellent |
| 50 – 100 | Good |
| 10 – 50 | Moderate |
| < 10 | Poor |

**Interpretation:**

- **> 100 m²/day:** Aquifer is highly productive and capable of sustaining high-yield boreholes; often found in well-developed fractured or porous media.
- **50–100 m²/day:** Aquifer has good yield, suitable for domestic, agricultural, and light industrial uses.
- **10–50 m²/day:** Aquifer has moderate yield, may support household or small-scale usage.
- **< 10 m²/day:** Low-yield aquifer, possibly due to compact formations or limited saturation; not suitable for high-demand abstraction.

### *iv. Hydraulic Conductivity*

Hydraulic Conductivity is the ability of a porous material to transmit fluid. The distribution of hydraulic properties in porous media is an important step toward understanding and predicting groundwater flow and aquifer contamination. Different approaches have been used to assess the association between aquifer hydraulic conductivity and resistivity measurements. According to Gleeson et al. (2016) [5].

Hydraulic conductivity can be determined using:

$$K = 386.40Rrw-.93283 \qquad (6)$$

Where K = hydraulic Conductivity and Rrw = Aquifer Resistivity.

**Table IV: Classification of Hydraulic Conductivity (K)**

| Hydraulic Conductivity (K) (m/s) | Aquifer Potential |
|---|---|
| $> 1 \times 10^{-3}$ | Very High (Gravel, Coarse Sand) |
| $1 \times 10^{-4} – 1 \times 10^{-3}$ | High (Medium Sand) |
| $1 \times 10^{-5} – 1 \times 10^{-4}$ | Moderate (Fine Sand, Silty Sand) |
| $1 \times 10^{-6} – 1 \times 10^{-5}$ | Low (Silt, Clayey Sand) |
| $< 1 \times 10^{-6}$ | Very Low (Clay, Massive Rock) |

**Interpretation:**

- **Very High K (> $10^{-3}$ m/s):** Excellent for high-yielding wells; typical of coarse gravelly or sandy aquifers.
- **High K ($10^{-4}$ – $10^{-3}$ m/s):** Good aquifers; medium sands often fall into this range.
- **Moderate K ($10^{-5}$ – $10^{-4}$ m/s):** Fair permeability; fine sands or silty materials.
- **Low K ($10^{-6}$ – $10^{-5}$ m/s): Poor aquifer quality; semi-confining layers.**
- **Very Low K (< $10^{-6}$ m/s):** Practically impermeable; typical of clay or massive bedrock, generally unsuitable for groundwater extraction**.**

## C. Groundwater Potential Zones Map

The principle behind the delineation of groundwater potential zones adopted in this work was based on that of Nwachukwu (2019) [8], who used aquifer thickness and aquifer resistivity, along with estimated hydraulic conductivity and Transmissivity, as indices for evaluating groundwater potential. In this work, the indices used were transmissivity and hydraulic conductivity.

# IV. RESULT

## A. Interpretation of Vertical Electrical Sounding Curves

A total of 20 Vertical Electrical Soundings (VES) were conducted across the study area, revealing a range of curve types indicative of subsurface lithological and hydrogeological conditions, as shown in Figure 3. The most dominant curve type observed was the H-type, accounting for 9 out of the 20 soundings. This curve is typically associated with a high-resistivity topsoil, underlain by a relatively low-resistivity weathered or fractured layer, and subsequently a more resistive fresh basement. Such a configuration is characteristic of productive aquifer zones, particularly within crystalline basement terrains.

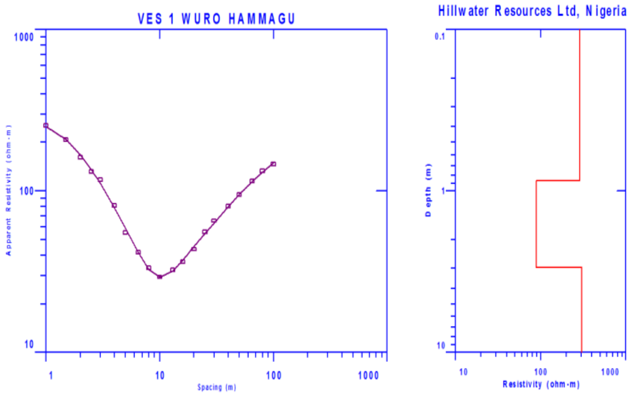
KH-type curves were identified at 3 locations, representing a resistive top layer, a conductive intermediate layer, and a high-resistivity base. These Curves are generally associated with well-developed weathered/

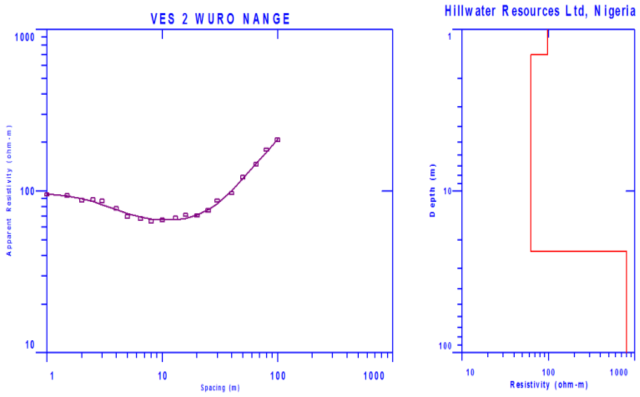
fractured aquifer systems with significant groundwater potential.

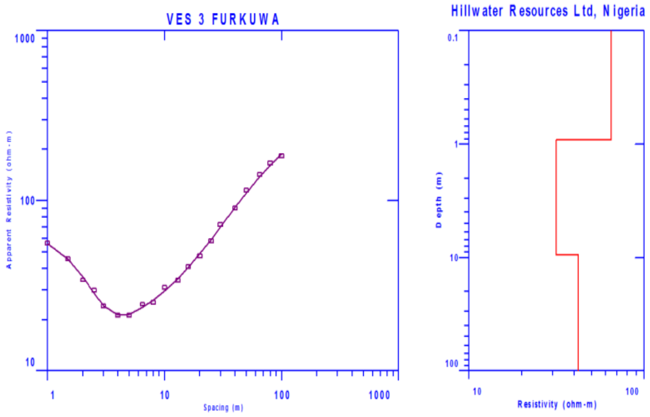
A-type curves were observed in 4 soundings and showed a continuous increase in resistivity with depth. This trend often suggests dry or compacted subsurface layers with limited porosity and permeability, thereby indicating non-aquiferous or low groundwater-potential zones.

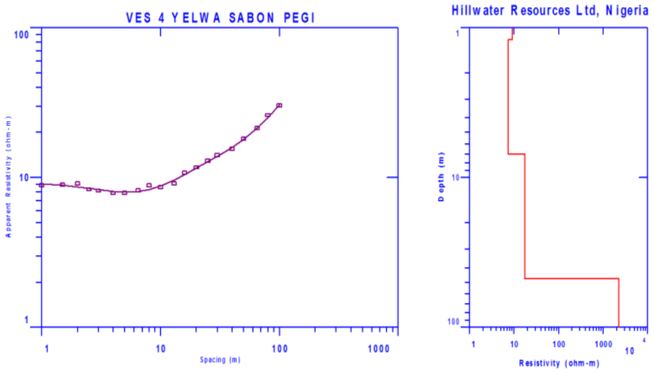
Other curve types, such as QH, AH, and K, were each observed once and are associated with more complex subsurface configurations. These were all classified as weathered/fractured aquifer systems.

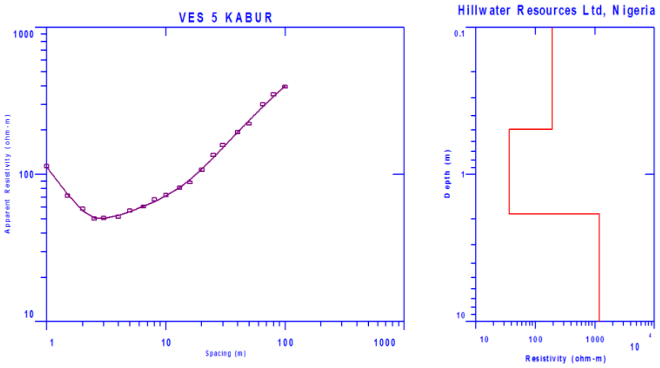
In total, 16 of the 20 VES points (80%) indicate favourable conditions for groundwater accumulation, primarily within weathered and fractured basement zones. The remaining 4 locations, characterised mostly by A-type curves, are considered less favourable for groundwater development due to their non-aquiferous nature.

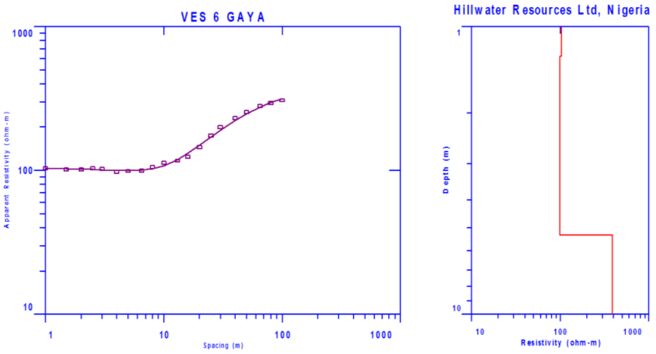


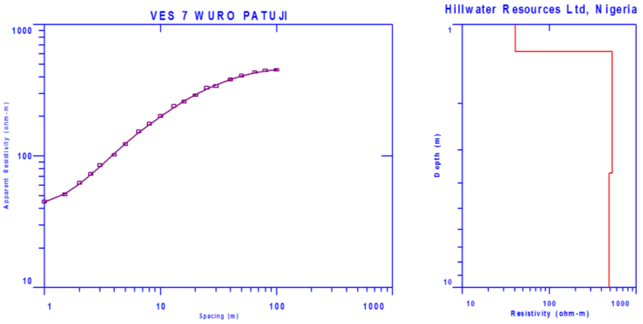


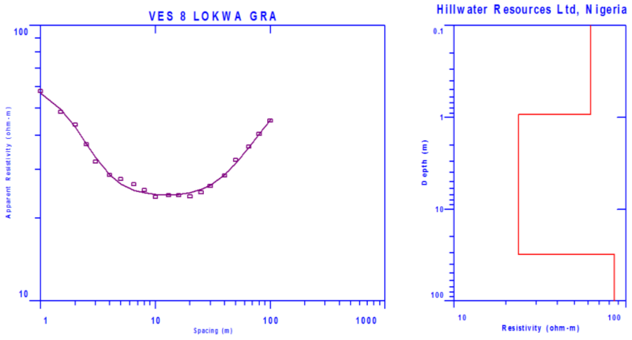












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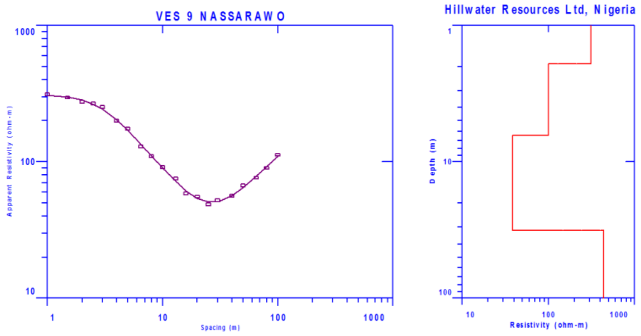
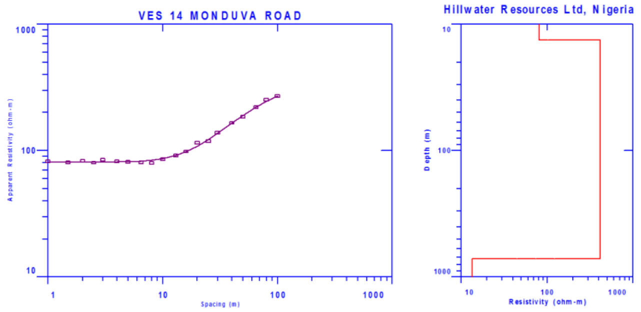
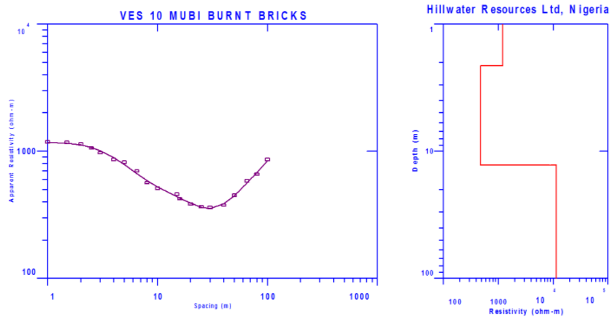
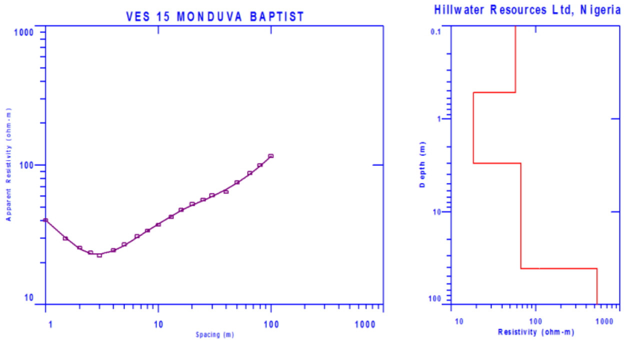
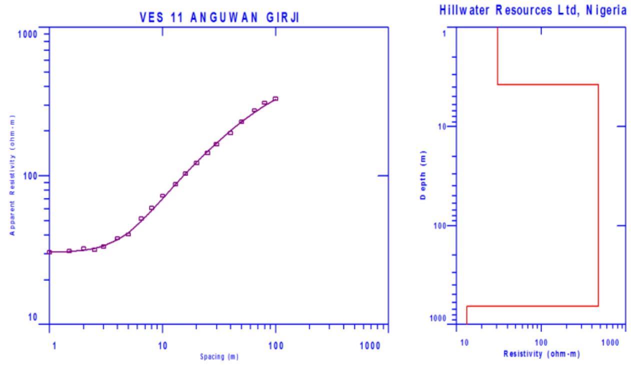
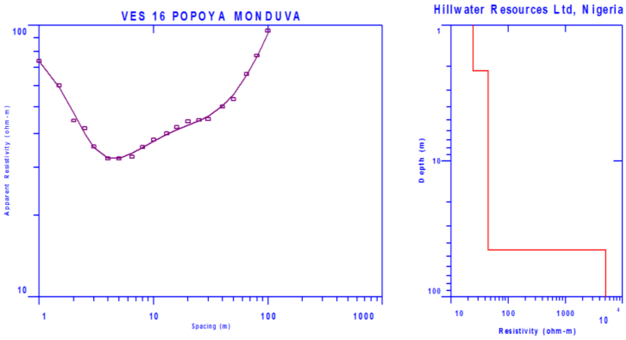

VES 9 NASSARAWO
Apparent Resistivity (ohm-m)
Spacing (m)
1000
100
10
1
10
100
1000
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)

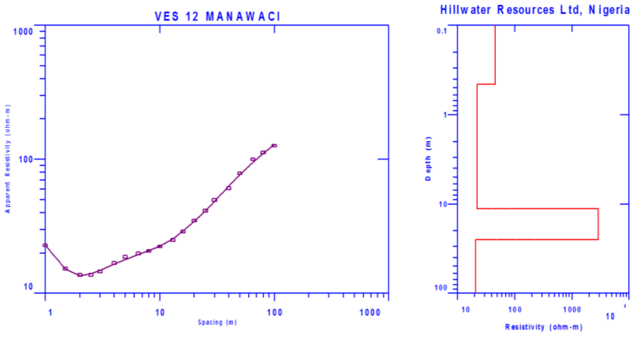

VES 14 MONDUVA ROAD
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)

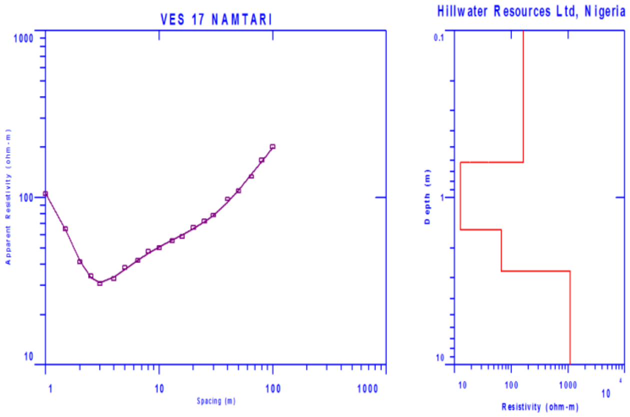

VES 10 MUBI BURNT BRICKS
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)

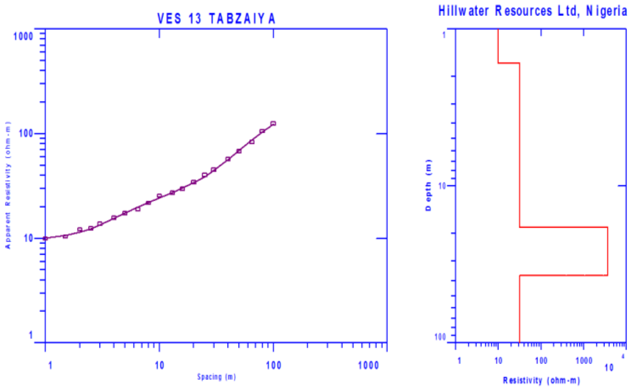

VES 15 MONDUVA BAPTIST
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)

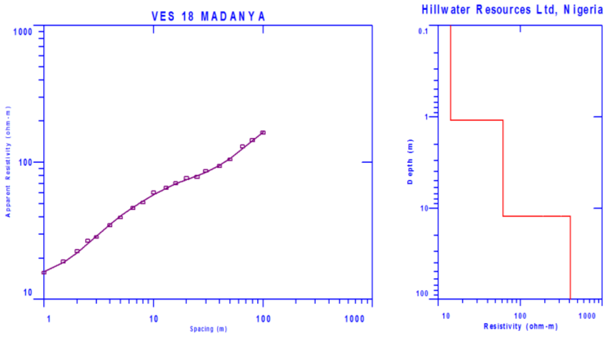

VES 11 ANGUWAN GIRJI
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)

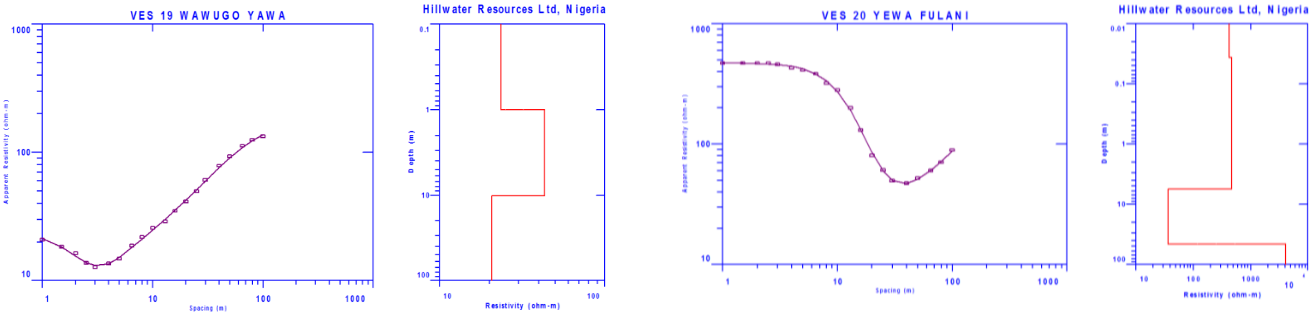

VES 16 POPOYA MONDUVA
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)


VES 12 MANAWACI
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)


VES 17 NAMTARI
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)


VES 13 TABZAIYA
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)


VES 18 MADANYA
Apparent Resistivity (ohm-m)
Spacing (m)
Hillwater Resources Ltd, Nigeria
Depth (m)
Resistivity (ohm-m)



[Fig.3: VES Curve Types]

Table V: Summary of The Results VES Data for Each Station and Its Representative Aquifer System

| VES No. | Location | Longitude | Latitude | Elevation (m.a.s.l) | Curve Type | No. of layers | Aquifer System |
|---|---|---|---|---|---|---|---|
| VES 1 | Buladega | 13°13'29"E | 10°12'56"N | 577 | KH | 4 | Weathered/fractured |
| VES 2 | Mirnyi road | 13°14'20"E | 10°14'16"N | 618 | KH | 5 | Weathered/fractured |
| VES 3 | Yaza | 13°14'05"E | 10°12'19"N | 598 | H | 4 | Weathered/fractured |
| VES 4 | Muda I | 13°14'40"E | 10°11'14"N | 610 | QH | 4 | Weathered/fractured |
| VES 5 | Sebore | 13°17'20"E | 10°14'41"N | 617 | K | 4 | Weathered/fractured |
| VES 6 | Lamurde | 13°16'15"E | 10°14'59"N | 598 | A | 3 | Non-aquiferous zone |
| VES 7 | Gipalma | 13°18'14"E | 10°15'58"N | 591 | H | 4 | Weathered/fractured |
| VES 8 | Wuro Hamagu | 13°15'30"E | 10°12'27"N | 598 | H | 4 | Weathered/fractured |
| VES 9 | Kabur | 13°16'02"E | 10°12'04"N | 612 | A | 4 | Non-aquiferous zone |
| VES 10 | Wuro Nange | 13°16'20"E | 10°11'30"N | 616 | H | 4 | Weathered/fractured |
| VES 11 | Girji | 13°16'00"E | 10°10'59"N | 654 | A | 3 | Weathered/fractured |
| VES 12 | Lainde | 13°13'55"E | 10°09'51"N | 605 | AH | 4 | Weathered/fractured |
| VES 13 | Muda II | 13°16'15"E | 10°10'21"N | 625 | H | 4 | Weathered/fractured |
| VES 14 | Gyedkwara | 13°17'40"E | 10°11'10"N | 659 | A | 3 | Non-aquiferous zone |
| VES 15 | Gella | 13°09'30"E | 10°18'22"N | 655 | H | 3 | Weathered/fractured |
| VES 16 | Gude | 13°19'01"E | 10°12'00"N | 668 | A | 3 | Non-aquiferous zone |
| VES 17 | Mawa | 13°19'53"E | 10°11'50"N | 711 | H | 4 | Weathered/fractured |
| VES 18 | Wandure | 13°18'20"E | 10°12'26"N | 602 | H | 4 | Weathered/fractured |
| VES 19 | Ngabbahi | 13°17'40"E | 10°12'32"N | 596 | KH | 4 | Weathered/fractured |
| VES 20 | Kidda | 13°18'41"E | 10°13'38"N | 610 | H | 4 | Weathered/fractured |

## B. Dar Zarrouk Parameters and Aquifer Properties

Table VI shows computed values of Dar Zarrouk parameters (transverse resistance and longitudinal conductance) and Aquifer parameters such as Transmissivity and Hydraulic conductivity from the interpreted VES result

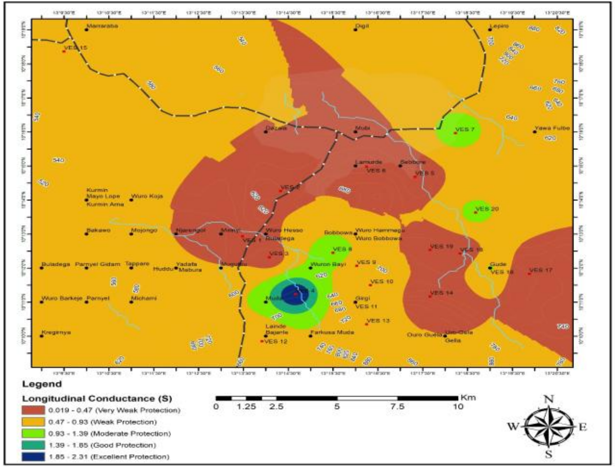
Table VI: Dar Zarrouk Parameters at Aquiferous Stations in Mubi South

| VES No. | Aquifer resistivity ρ (Ωm) | Aquifer thickness *h(m)* | Aquifer Conductivity σ = 1/ ρ | Longitudinal conductance S $\sum_{i=1}^{n} h/\rho\,(\Omega^{-1})$ | Transverse resistance T $\sum_{i=1}^{n} h\,\rho\,(\Omega m^2)$ | Hydraulic conductivity K (m/day) $K = 386.40R_{rw}^{-0.93283}$ | Transmissivity Tr = kh |
|---|---|---|---|---|---|---|---|
| 1 | 88.84 | 2.12 | 0.01126 | 0.02385 | 188.34 | 10.7 | 22.7 |
| 2 | 62.93 | 22.28 | 0.01589 | 0.3541 | 1401.74 | 14.87 | 331.29 |
| 3 | 31.49 | 8.63 | 0.03176 | 0.274 | 271.79 | 23.99 | 207.1 |
| 4 | 17.41 | 40.35 | 0.05743 | 2.316 | 702.5 | 36.38 | 1468.54 |
| 5 | 65.00 | 11.00 | 0.01538 | 0.20 | 715.00 | 17.00 | 187.00 |
| 6 | 120.00 | 3.00 | 0.00833 | 0.025 | 360.00 | 9.50 | 28.5 |
| 7 | 37.00 | 25.00 | 0.02703 | 1.10 | 925.00 | 24.00 | 600.00 |
| 8 | 23.72 | 30.15 | 0.04215 | 1.271 | 714.46 | 31.56 | 951.05 |
| 9 | 38.50 | 25.58 | 0.02597 | 0.664 | 985.83 | 27.31 | 699.15 |
| 10 | 37.00 | 30.00 | 0.02703 | 0.81 | 1110.00 | 25.00 | 750.00 |
| 11 | 45.00 | 30.00 | 0.02222 | 0.67 | 1350.00 | 20.00 | 600.00 |
| 12 | 21.95 | 10.85 | 0.04556 | 0.494 | 238.66 | 32.63 | 354.1 |
| 13 | 32.01 | 16.64 | 0.03124 | 0.52 | 532.3 | 23.76 | 395.41 |
| 14 | 110.00 | 2.50 | 0.00909 | 0.0227 | 275.00 | 10.00 | 25.0 |
| 15 | 66.64 | 37.86 | 0.01501 | 0.568 | 2523.77 | 13.99 | 529.7 |
| 16 | 45.11 | 43.12 | 0.02216 | 0.956 | 1945.97 | 19.61 | 845.42 |
| 17 | 67.64 | 1.2 | 0.01478 | 0.01775 | 81.17 | 13.9 | 16.68 |
| 18 | 62.1 | 11.16 | 0.0161 | 0.1797 | 693.44 | 15.01 | 167.49 |
| 19 | 43.12 | 9.24 | 0.02319 | 0.214 | 398.36 | 20.24 | 187.09 |
| 20 | 36.56 | 40.14 | 0.02735 | 1.097 | 1468.72 | 25.23 | 1013.7 |
| **Minimum** | 17.41 | 1.20 | 0.00833 | 0.01775 | 81.17 | 9.50 | 16.68 |
| **Maximum** | 120.00 | 43.12 | 0.05743 | 2.316 | 2523.77 | 36.38 | 1468.54 |
| **Average** | 49.88 | 20.44 | 0.02642 | 0.6397 | 809.94 | 20.46 | 467.46 |

### *i. Longitudinal Conductance S*

The longitudinal conductance of the aquiferous layer in the study area ranges from a minimum of 0.01775 Ω−1 to a maximum of 2.316 Ω−1. The average longitudinal conductance calculated is 0.6397 Ω−1. The variation in longitudinal conductance values in the study area was interpreted using the classification in Table 6.

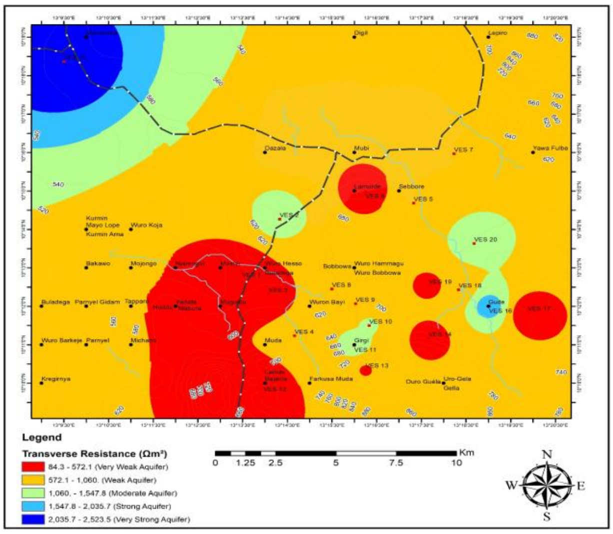
It was observed that seventy percent (70%) revealed moderate protective capacity (VES 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 15, 16, 20), ten (10%) percent revealed weak protective capacity (VES 18. 19) and twenty (20%) percent revealed poor protective capacity (VES 1, 6, 14, 17) indicating moderate groundwater protection across the study area making the area fairly susceptible to contamination as shown in Figure 4.



**[Fig.4: Longitudinal Conductance Map]**

ii. *Transverse Resistance Tr*

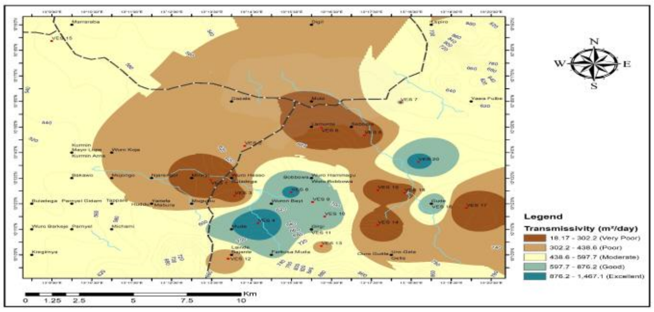
The Transverse resistance values in the study area vary significantly. The minimum observed transverse resistance is 84.30 Ωm2, while the maximum reaches 2523.5 Ωm2. The average transverse resistance calculated is 809.94 Ωm2. The variation in transverse resistance values in the study area was interpreted using the classification in Table 6 above. It was observed that thirty-five (35%) revealed weak transverse resistance (VES 1, 3, 6, 12, 14, 17, 19), forty percent (40%) revealed moderate transverse resistance (VES 4, 5, 7, 8, 9, 10, 13, 18) and twenty five (25%) revealed high trasverse resistance (VES 2, 11, 15, 16, 20) indicating moderate saturation and/or thickness revealing fair groundwater potential as shown in Figure 5.



**[Fig.5: Tranverse Resistance Map]**

iii. *Transmissivity*

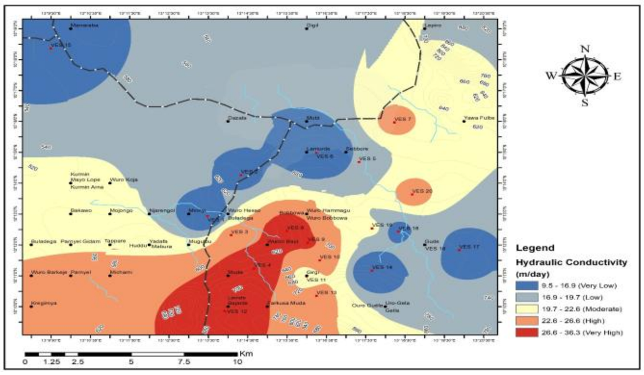
The Transmissivity values represent the rate at which water can be transmitted through a unit width of the aquifer under a unit hydraulic gradient. These values range from 16.68 m2/day to 1468.54 m2/day. The average is 467.46 m2/day [11]. It was observed that fifteen (15%) revealed Low Transmissivity (VES 1, 6, 17), thirty five percent (35%) revealed moderate transmissivity (VES 3, 5, 12, 13,14, 18, 19) and fifty percent (50%) Excellent transmissivity values (VES 2, 4, 7, 8, 9, 10, 11, 15, 16, 20) indicating Aquifer is highly productive and capable of sustaining high-yield as shown in figure 6.



**[Fig.6: Transmissivity Map]**

iv. *Hydraulic Conductivity*

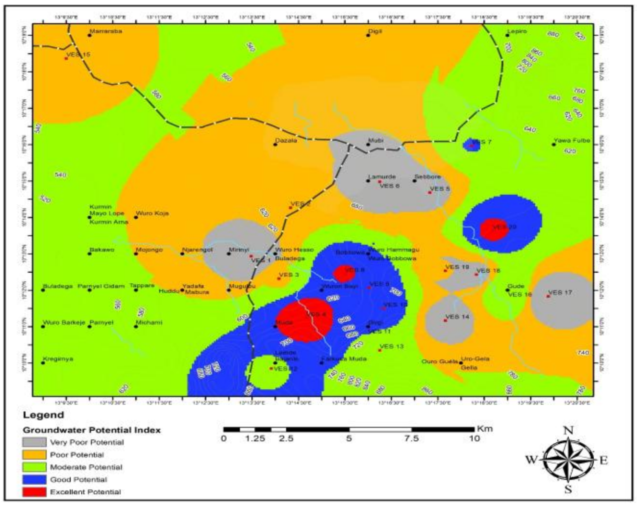
The hydraulic conductivity, which measures how easily water can pass through the aquifer material, is also detailed in Table 6—the values range from 9.50 m/day to 36.38 m/day. The average hydraulic conductivity across the aquiferous stations in the study area is 20.46 m/day. It was observed that five percent (5%) revealed low hydraulic conductivity value (VES 6), forty five percent (45%) revealed moderate hydraulic conductivity (VES 1, 2, 5, 14, 15, 16, 17, 18, 19) and fifty percent (50%) revealed high hydraulic conductivity (VES 3, 4, 7, 8, 9, 10, 11, 12, 13, 20) indicating moderate to high groundwater potential as shown in figure 7.



**[Fig.7: Hydraulic Conductivity Map]**

## C. Groundwater Potential Map

Deduced from an over-analysis using Arc GIS version 10.2 revealed that the area is classified into areas with very poor potential donated by grey colour, poor potential donated by orange colour, moderate potential donated by green colour, good potential donated by blue colour, and excellent potential donated by red colour, as shown in Figure 8.



[Fig.8: Groundwater Potential Map]

## V. DISCUSSION OF RESULTS

The analysis of geophysical and hydrogeological data from 20 VES points across Mubi South has revealed considerable variation in aquifer characteristics. The predominance of H-type and KH-type curve patterns (60%) indicates significant weathering and fracturing in the basement terrain, which is favourable for groundwater accumulation. In contrast, the A-type curves observed in VES 6, 9, 14, and 17 suggest compacted and dry subsurface materials with low porosity and permeability, making them less viable for groundwater exploitation.

The longitudinal conductance values suggest that 70% of the study area has moderate aquifer protective capacity, implying

that while groundwater development is feasible, the aquifers may be moderately susceptible to contamination from surface sources. Only 10% of locations (e.g., VES 18 and 19) exhibited weak protection, while 20% (VES 1, 6, 14, 17) showed poor protective capacity, particularly in areas with thin overburden or high resistivity layers.

Transverse resistance, a key indicator of aquifer saturation and potential yield, further confirms the groundwater viability in the area. About 40% of VES points showed moderate resistance, with 25% exhibiting high transverse resistance. These high resistance zones are likely to correspond to thick, saturated aquifers capable of yielding significant groundwater volumes.

Transmissivity values underscore the groundwater potential, with 50% of the locations falling into the high-yield category (>400 m²/day), particularly VES 4, 7, 8, 10, and 20. This reflects thick aquifers with high hydraulic conductivity, indicative of well-interconnected pore spaces or fractured zones. Low transmissivity (<100 m²/day) was observed in only 15% of locations, which could be attributed to limited aquifer thickness or to less-permeable materials.

Hydraulic conductivity analysis, computed via empirical relationships with resistivity, confirms moderate to high permeability across most stations. With an average hydraulic conductivity of 20.46 m/day, the values highlight the ease with which groundwater can move through the subsurface, enhancing the suitability of the region for groundwater abstraction.

Overall, the integration of Dar Zarrouk parameters with resistivity data has proven effective in delineating high-potential aquifer zones. The use of longitudinal conductance, transverse resistance, and transmissivity as evaluative metrics aligns with established hydro geophysical practices and supports informed groundwater resource planning.

## VI. CONCLUSION

The application of vertical electrical sounding and Dar Zarrouk parameters has provided valuable insight into the hydrogeological framework of Mubi South, Adamawa State. The results indicate that the majority of the study area exhibits favourable aquifer conditions, with high groundwater potential, as reflected in transverse resistance, hydraulic conductivity, and transmissivity values. Longitudinal conductance analysis reveals that while protective capacity is moderate in most locations, targeted wellhead protection measures are necessary in areas of weak or poor protection. The identified zones of high transmissivity and conductivity are particularly suitable for developing productive boreholes. Therefore, this study demonstrates that geoelectrical techniques coupled with the Dar Zarrouk analysis are effective tools for groundwater exploration and sustainable water resource development in basement complex terrains.

## ACKNOWLEDGEMENT

The authors acknowledge Hill Water for providing the IXD Software that was used for the data interpretation.

## DECLARATION STATEMENT

As the article's author, I confirm the accuracy of the following information based on input from all authors.

- **Conflicts of Interest/ Competing Interests:** The authors declare that they have no conflicts of interest.
- **Funding Support:** This project was supported by a Parr Grant, funded through the Parr Centre for Thriving and administered by the Office of the Vice Provost (Students) at Western University. The opinions expressed are those of the authors.
- **Ethical Approval and Consent to Participate:** This study was conducted in accordance with institutional guidelines and was exempt from research ethics board review. All data were collected as part of routine educational practice, analysed in aggregate, and contained no personally identifiable information.
- **Data Access Statement and Material Availability:** The data supporting the findings of this study are available from the corresponding author upon reasonable request through December 31, 2026.
- **Author's Contributions:** Sophia Yu and Sara Kayvani contributed equally and share first authorship. Niki Sharan served as the senior and corresponding author. All authors contributed to the study and approved the final manuscript.

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