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ORIGINAL RESEARCH ARTICLE

Investigation of Groundwater Potential at Fatima Shema Housing Estate Katsina Northern Nigeria

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ABSTRACT

Groundwater exploration in Fatima Shema Housing Estate Katsina (FSHEK) has faced challenges due to inconsistent results and limited academic research. To address this, a geophysical survey using Vertical Electrical Sounding (VES) was conducted at 8 locations using Schlumberger array with the maximum current electron (AB/2) of 120 m. This study aims to optimize borehole locations by assessing the electrical resistivity characteristics of subsurface layers. To achieve this, the Schlumberger array was employed in a (VES) survey. The data were analysed using IPI2Win software, the software was used for interpreting the VES data through automatic curve matching and inversion, allowing estimation of subsurface layer resistivities and thicknesses. IPI2Win software reveal the subsurface structures and groundwater potentials. The subsurface consists of 4 layers overburden, weathered zones, fractured zones and consolidated bedrock. The Aquifer found in the third layer exhibits resistivity values between 68.7 Ωm and 391 Ωm with a thickness of up to 37.1 m indicating good groundwater storage. Analysis shows that VES 1 to VES 5 have favourable conditions for groundwater at depths of 12 m to 50 m. Conversely, VES 6 to VES 8 indicate poor groundwater potential due to high resistivity and limited aquifer thickness. This study identifies VES 1 to VES 5 as promising sites for groundwater development and provides valuable insights for sustainable water resource management in the area.

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INTRODUCTION

Water, like air and land, is essential to human survival. Over time, groundwater has been increasingly utilized for domestic purposes, livestock, and irrigation needs (Ozegin & Okolie, 2018). Groundwater refers to water stored within saturated pathways underground, including natural springs that surface the Earth. This resource is especially crucial in regions lacking rivers, streams, or regular rainfall, as it can support community development depending on its quality and availability (Rolia and Sutjiningsih, 2018). Typically found in soil pores and fractures within geological formations, groundwater becomes accessible when rock units or loose deposits, known as aquifers, yield usable quantities of water. The water table marks the depth where all rock fractures and soil pores are saturated (Alabi et al., 2010).

Groundwater is extracted through wells for agricultural, municipal, and industrial purposes and serves as a major source for drinking water and irrigation in food production. About 53% of the population globally relies on groundwater as a drinking water source, with even higher dependence in rural areas (Alabi et al., 2010). While surface water sources such as rivers and lakes are prone to contamination, groundwater remains a widely accessible and affordable source, making up over 90% of Earth's accessible freshwater stored in geologic pore spaces and fracture zones (Kolawole & Olawale, 2021). Geophysical techniques are commonly used for groundwater and geotechnical assessments. Vertical electrical sounding (VES), electrical resistivity tomography (ERT), and ground-penetrating radar (GPR) are some of the effective methods adopted for identifying aquifers under varied hydrogeological conditions and mapping groundwater resources (Haque et al., 2020). Several types of electrode array configurations have also been adopted, including Schlumberger, Wenner, and Dipole sounding, which vary based on electrode configurations. Among these, the Schlumberger method is frequently applied in groundwater studies, especially in alluvial and hard rock settings (Rolia and Sutjiningsih, 2018).

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In spite of the general groundwater residue beneath the earth's geologic pore spaces and fracture zones, FSHEK is experiencing difficulty with drilling groundwater boreholes. In many instances, boreholes are drills at deeper depths but without sufficient enough groundwater for domestic usage. This owes to the lack of available geophysical survey and data information of the FSHEK's subsurface structures for potential groundwater drilling. Ahmad et al. (2021) examined groundwater potential at the Federal University Dutsin-Ma Faculty of Medicine and Engineering by employing nine VES points. Their study identified five layers, with the weathered and fractured layers acting as aquifers. Albaba and Nuraddeen (2022) conducted a VES study at Umaru Musa Yar'adua University, using a Schlumberger Array to assess lithology and groundwater potential. The study identified multiple layers, with certain VES points demonstrating low resistivity and a high potential for groundwater extraction, making them suitable for drilling certain VES points exhibited low to moderate resistivity, indicating high groundwater potential. Therefore, to the best of our knowledge VES method is less explored at FSHEK for groundwater potential. FSHEK shares **similar geological characteristics** with FUDMA and UMYUK. It lies within the **basement complex terrain**, which consists of **hard crystalline rocks** that only store water in their **weathered or fractured zones.** These geological factors directly affect groundwater availability. Since the VES method has successfully identified aquifers in similar locations, applying it at FSHEK is expected to provide valuable data for better borehole placement. This work presents a geophysical survey investigation for groundwater potential at FSHEK. VES method using Schlumberger array has been adopted for the study of some selected locations. Electrode spacing of 240 meters has been maintained. The data were analysed using IPI2Win software. IPI2Win software revealed the subsurface structures and points with groundwater potentials at FSHEK. The research aims to optimize borehole locations by assessing the electrical resistivity properties of the subsurface layers of the study area.

MATERIALS AND METHOD

The study area is FSHEK, Nigeria. FSHEK is between latitude 12°56'50.55" N and longitude 7°37'20.16" E to latitude 12°57'5.36" N and longitude 7°37'11.72" E.

2.1 Instrumentation

List of Instruments used: 1. Electrodes, 2. Multi-core resistivity cables, 3. Ohmmeter, 4. Computer and IPI2WIN software

2.2 The Study area

Katsina State is primarily underlain by three major geological formations: the Chad Formation, the Illo-Gundumi Formation of the Sokoto Basin, and the Nigerian Bedrock Complex (Figure 1). The Chad and Illo-Gundumi Formations cover about 20% of Katsina State, while the bedrock complex underlies the remaining 80%. The bedrock complex in this region includes nine distinctive geological formations: biotite-hornblende granite, coarse biotite-hornblende granite, fine-grained granite, granite gneiss, migmatite, porphyritic gneiss, rhyolite, sandstone, and silicified sheared rock (Mukhtar et al., 2021).

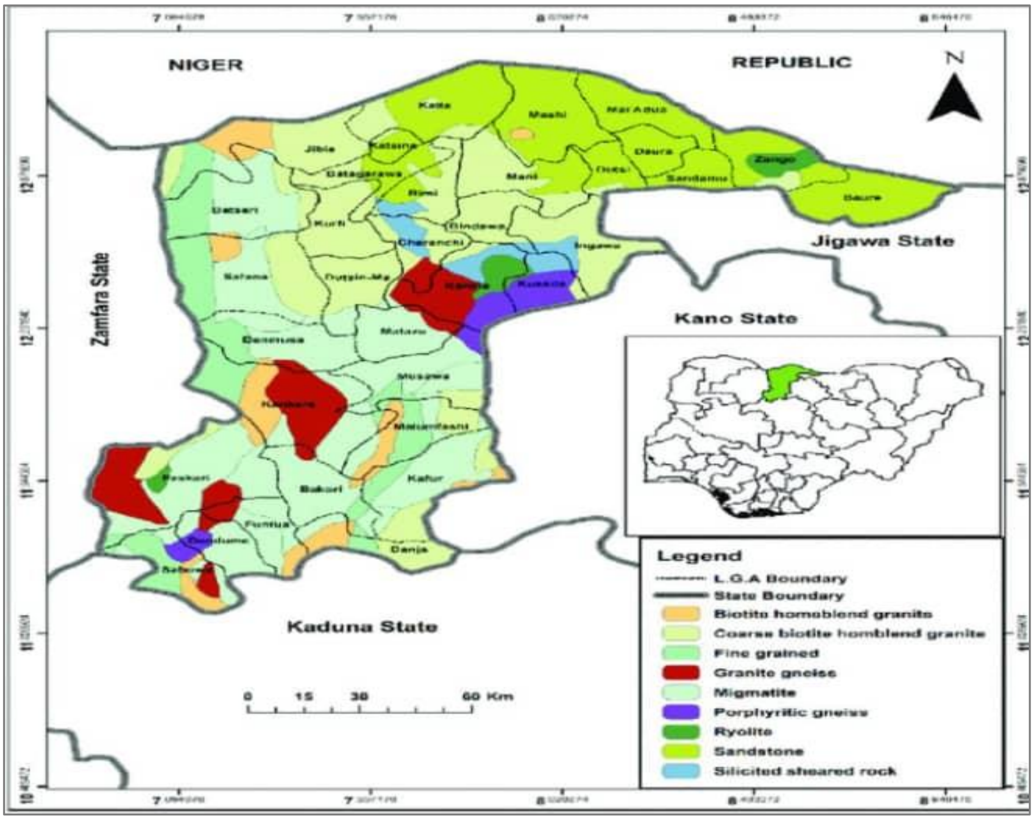

Figure 1: The Geology of Katsina State (Mukhtar et al., 2021).

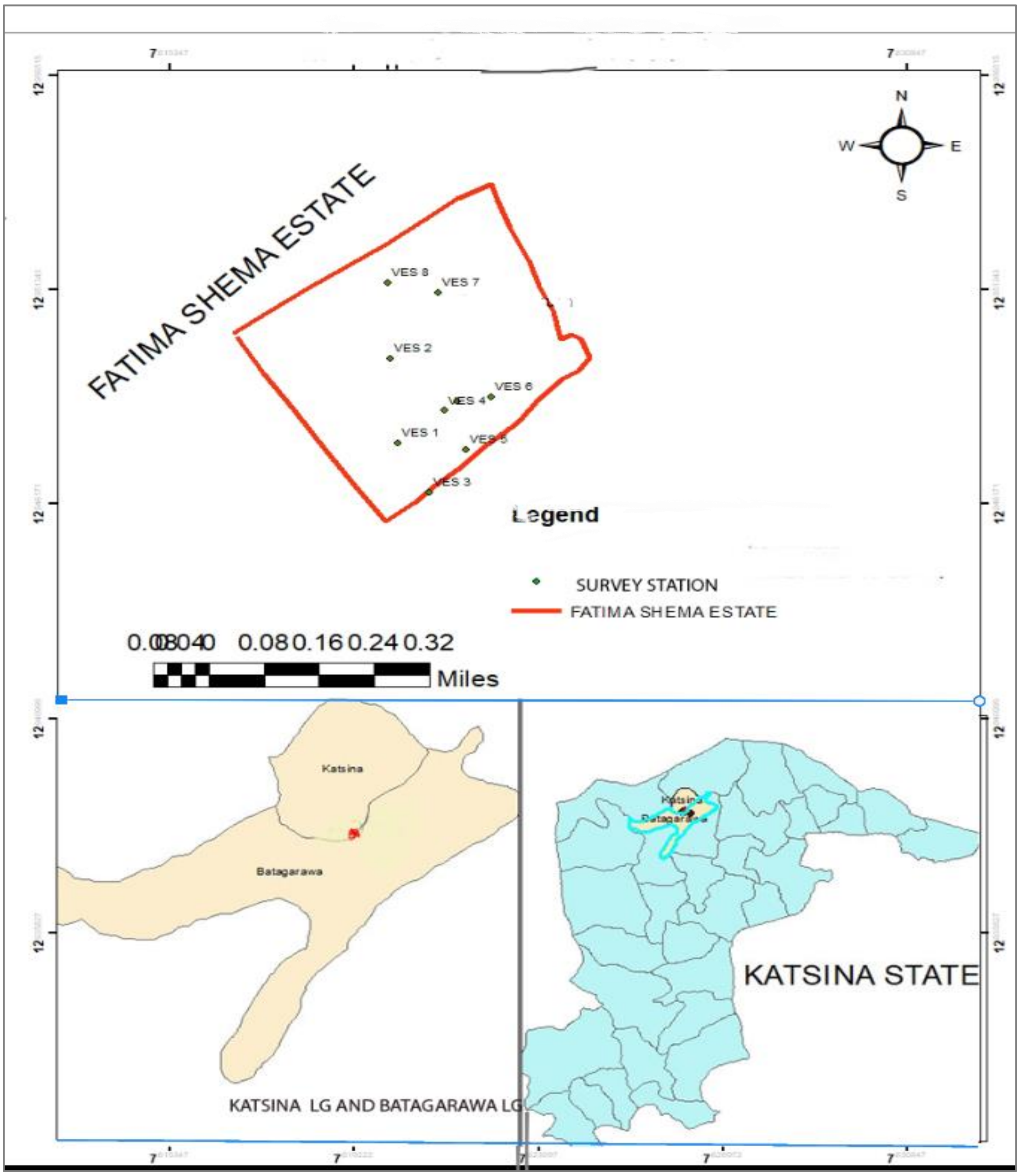

Figure 2: Map of the study area

Figure 2 shows the study area, FSHEK, in Katsina city, Katsina State. The map includes three key sections: the estate boundary with VES locations, a map of Katsina LGA, and a state-level map for regional context. The VES points were carefully selected based on geological variations, topography, and drainage patterns to identify potential groundwater zones. Locations were also chosen considering future borehole placement for water supply. The southern and central VES points cover areas with possible weathered bedrock zones, while the northern points assess lithological changes. This map helps visualize the study area and ensures proper distribution of VES locations for assessing groundwater potential effectively.

2.3. Method

The Vertical Electrical Sounding (VES) survey was carried out using the Schlumberger array, a widely used method for groundwater exploration due to its ability to probe deeper subsurface layers. Eight VES stations were strategically selected to cover the study area and provide reliable data on subsurface resistivity variations.

Field Data Collection

An Ohmmetre was used to measure resistivity, along with other essential equipment such as four steel electrodes, field hammers, measuring tape, reels of wire, and a GPS device for precise location tracking. At each VES station, an electrical current was introduced into the ground through two current electrodes (C1 and C2), while the resulting voltage difference was recorded between two potential electrodes (P1 and P2). The electrodes were arranged in a straight line, with the midpoint as a measurement reference (Figure3). The survey began with:

- Initial current electrode spacing (AB/2) is set at 2 m and potential electrode spacing (MN/2) at 0.5 m.

- As AB was progressively increased, MN was adjusted proportionally to maintain accurate potential measurements.
- The maximum AB/2 reached 120 m, allowing deeper subsurface investigation.
- Multiple readings were taken at each station to improve accuracy and minimize errors caused by environmental factors or electrode contact resistance.

After completing measurements at one VES point, the equipment was moved to the next location, and the process was repeated across all survey stations.

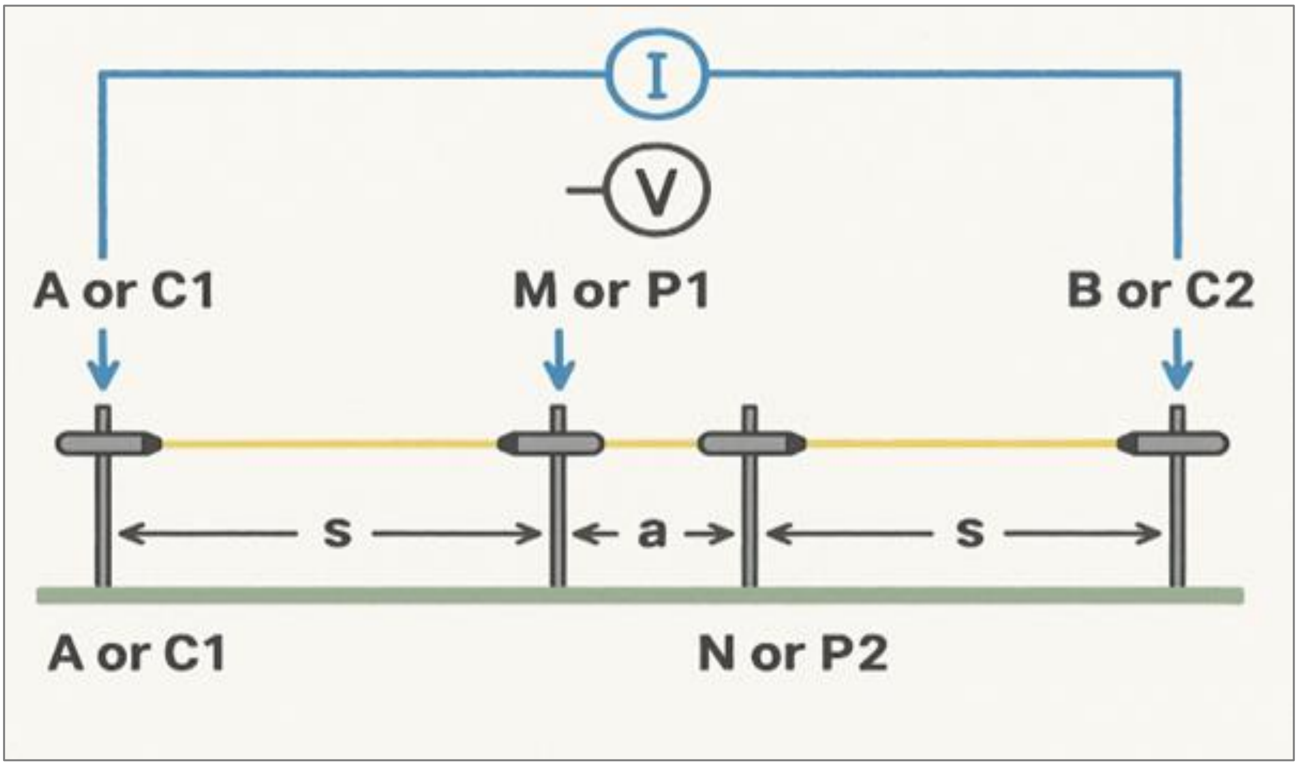

Figure 3: Schlumberger Array setup showing the configuration of current and potential electrodes.

Data Processing and Interpretation

The field data was analysed using IP2Win software, which applies curve-matching techniques to estimate true resistivity values and layer thicknesses.

The interpretation involved:

1. Examining the raw field curves to identify resistivity variations.
2. Fitting the data to standard geo-electric models to determine subsurface layers and their properties.
3. Comparing results with known geological formations to correlate resistivity values with aquifer potential.

Validation and Integration

To ensure accuracy and reliability, the interpreted resistivity model is validated using independent data sources, such as: Borehole logs (Table 1).

RESULTS AND DISCUSSION

The geophysical investigation conducted in the study area using VES revealed variations in subsurface resistivity and layer thickness, indicating different lithological formations and groundwater potential. The resistivity values range from 3.7 Ωm to 34,015 Ωm, corresponding to five distinct subsurface layers.

First Layer (Topsoil and Lateritic Cover)

The topsoil layer across all VES points (i.e., VES 1 - 8) exhibits varying resistivity values, ranging from 114 Ωm to 1.1×10^7 Ωm, with thicknesses between 0.103 m and 1.11 m. The resistivity range varies widely, from 114 Ωm at VES 3 to 1.1×10^7 Ωm at VES 6. This variation indicates diverse material compositions: sandy or weathered material with limited water storage at VES1 and sandy loam at VES 2, clayey soil at VES 3, compacted lateritic layers at VES 5 and VES 6, gravelly topsoil at VES 4, and dry sandy/clayey material at VES 7 and VES 8. The thinness of this layer and its relatively high resistivity in some areas suggest poor water retention, making it unsuitable for groundwater storage.

Second Layer (Weathered and Fractured Zones)

The second layer has resistivity values ranging from 65.3 Ωm to 2962 Ωm and thicknesses between 0.512 m and 2.46 m. VES 1 (0.79 m) and VES 5 (1.12 m) indicate compacted, low-permeability materials, while VES 2 (1.04 m) VES 8 (1.12 m) have sandy clay or weathered granite with moderate water retention. VES 4 (34.5 m) stands out as a thick fractured zone with strong groundwater potential. In contrast, VES 3 (0.512 m), VES 6 (2.46 m), and VES 7 (0.856 m) show limited water retention due to relatively higher resistivity values, suggesting drier conditions.

Table 1: Borehole Data Log for Batagarawa Local Government Area, Katsina State (Source: RUWASSA (2021) Geological Well Log).

Depth (m)	Lithology Description
0 – 5 m	Sandstone, laterite, lateritic soil, and granite
5 – 22 m	Weathered sandstone, sandy clay, dry sandy soil; some portions contain lateritic sand
22 – 40 m	Saturated laterite, sandy soil, and sandy clay (potential aquifer zone)
40 – 100 m	Fresh bedrock rock (transition zone)

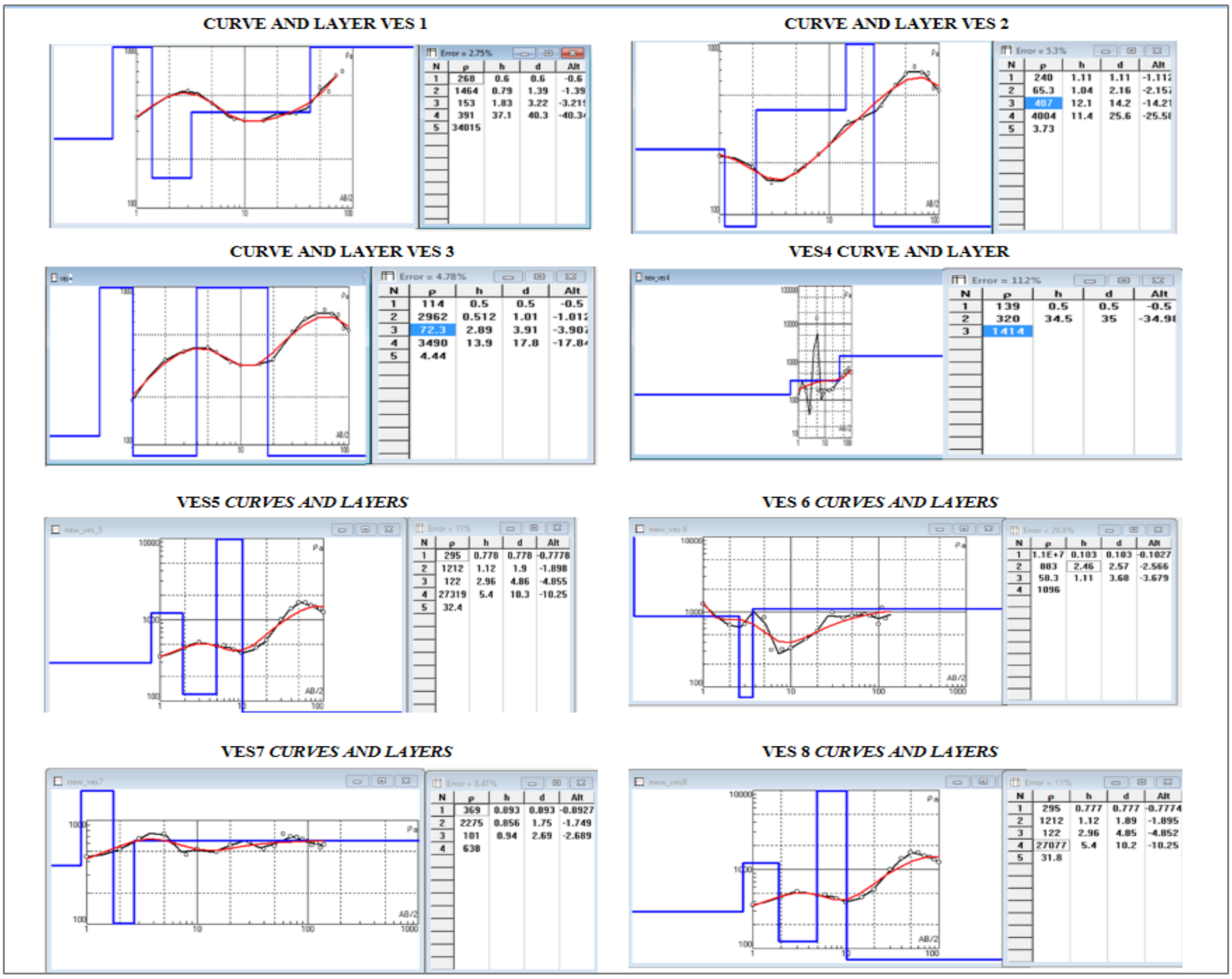

Figure 4: IPI2WIN Computer Software iterated curve of VES 1 – VES 8

Figure 4 shows the results of Ipi2win software from VES 1 to VES 8.

Third Layer (Fractured Bedrock and Saturated Zones)

This layer is the primary water-bearing zone in most VES locations. The resistivity values range from 68.7 Ωm to 407 Ωm, with thickness varying from 0.94 m to 37.1 m. At VES1 shows a resistivity of 153 Ωm, thickness 1.83 m suggest moderate groundwater potential. At VES 2, the fractured bedrock (resistivity: 407 Ωm, thickness: 12.1 m) suggests moderate groundwater storage potential. VES 3 has a weathered or fractured bedrock (72.3 Ωm, thickness: 2.89) suggests groundwater storage and flow based on its relatively low resistivity. VES 4 shows a high resistivity of 1414 Ωm, making it dry. VES 5 has a weathered zone of 4.86 m and a resistivity of 122 Ωm, indicating moderate groundwater potential. VES 6 (1.11 m) and VES 7 (0.94 m) show lower groundwater potential due to thin saturated zones. VES 8, with a 2.96 m fractured/saturated zone, suggests limited but possible groundwater storage.

Fourth Layer (Fresh Bedrock Rock and Deep Saturated Zones)

Fresh bedrock rock, encountered at most VES locations, is marked by high resistivity values, ranging from 391 Ωm (VES 1) to 27,319 Ωm (VES 5). This layer is largely impermeable, marking the lower boundary for groundwater movement. At VES 8 also shows a high resistivity. VES 6 and VES 7, however have relatively shallow bedrock rock, limiting water storage potential.

VES 3 and VES 4 also show high resistivity, indicating minimal groundwater movement.

Fifth Layer (Deep Fresh Bedrock)

The final layer represents the fresh bedrock rock with extremely high resistivity values (up to 34,015 Ωm). This layer is observed at VES 1, VES 2, VES 3, VES 5, and VES 8, confirming fresh bedrock rock with high resistivity values and an impermeable nature. However, the survey did not reach this depth at VES 4, VES 6, and VES 7 due to factors such as the presence of buildings and other environmental constraints. The fifth layer is generally impermeable, some of the overlying layers in VES 1, VES 2, and other points exhibited moderate resistivity values and thicknesses that suggest favourable conditions for groundwater occurrence.

Groundwater Potential and Suitability

- Highly Suitable Areas: VES 1, VES 2, and VES 4 have significant fractured zones and relatively low resistivity, making them ideal for groundwater exploration.
- Moderately Suitable Areas: VES 3 and VES 5 show some potential for groundwater storage, though deeper drilling may be required.
- Unsuitable Areas: VES 6, VES 7, and VES 8 have limited groundwater potential due to thin weathered layers and high resistivity bedrock rock.

Table 2: Interpreted Data for VES 1 to VES 8

Layers	R (Ω·m)	T (m)	Interpretation
VES 1: 12°56'51.5" N, 7°37'12.5"E			
Topsoil	268	0.6	Sandy/slightly weathered material with limited water storage.
Second Layer	1464	0.79	Compacted dry granite or sandstone, low permeability.
Shallow Weathered Zone	153	1.83	Sandyclay weathered granite; not for substantial groundwater.
Fractured Zone	391	37.1	Bedrock rock fractures may store some water.
Fresh Bedrock Rock	34,015	Infinite	Impermeable granite bedrock.
VES 2: 12°56'58.8"N, 7°37'11.9"E			
Topsoil	240	1.11	Sandy loam with low water retention.
Weathered Zone	65.3	1.04	Clay or moist weathered granite, limited storage.
Fractured Bedrock	407	12.1	Groundwater storage possible.
Fresh Bedrock Rock	4004	11.4	Dense, impermeable granite.
Deep Fresh Bedrock	3.7	Infinite	Unfractured rock, no water storage.
VES 3: 12°56'47.2" N, 7°37'14.9" E			
Topsoil	114	0.5	Sandy/clayey material, negligible groundwater potential.
High Resistivity Layer	2962	0.512	Compacted, dry granite.
Weathered Bedrock	72.3	2.89	Potential for groundwater storage and flow.
Fresh Bedrock Rock	3490	13.9	Impermeable solid rock.
Deeper Layer	4.44	Infinite	Low permeability.
VES 4: 12°56'54.3" N, 7°37'16.0" E			
Topsoil	139	0.5	Thin sandy/clayey material, low storage.
Weathered Bedrock	320	34.5	Significant aquifer zone.
Fresh Bedrock Rock	1414	Infinite	Impermeable granite.
VES 5: 12°56'50.93" N, 7°37'17.67" E			
Topsoil	295	0.78	Dry sandy/clayey material, minimal storage.
Lateritic Zone	1212	1.12	Compact, slightly permeable layer.
Weathered Zone/Aquifer	122	2.96	Good groundwater potential.
Bedrock Rock	27,319	5.4	Solid granite, lower boundary of storage.
Deep Saturated Zone	32.4	Infinite	Possible deep saturated zone.
VES 6: 12°56'55.46" N, 7°37'19.57" E			
Topsoil	1.1×10^7	0.103	Extremely dry, compact material.
Weathered Zone	882	2.46	Poorly saturated, low potential.
Shallow Saturated Zone	68.7	1.11	Limited water presence.
Bedrock Rock	1096	Infinite	Impermeable, prevents infiltration.
VES 7: 12°57'4.56" N, 7°37'15.58" E			
Topsoil	369	0.893	Dry sandy/clayey soil, minimal water potential.
Weathered Zone	2275	0.856	Dry lateritic or compacted material.
Fractured Zone	101	0.94	Possible groundwater, unreliable.
Bedrock Rock	638	Infinite	Impermeable, semi-fresh bedrock.
VES 8: 12°57'5.36" N, 7°37'11.72" E			
Topsoil	295	0.777	Sandy/lateritic soil, minimal potential.
Weathered Zone	1212	1.12	Dry lateritic or compacted material.
Fractured/Saturated Zone	122	2.96	Possible groundwater, limited storage.
Bedrock Rock	27,077	5.4	Fresh, impermeable granite.
Deep Saturated Zone	31.8	Infinite	Possible deep saturated zone.

R = Resistivity and T = Thickness

Table 3: Summary of Groundwater Potential

VES Point	Fractured/Weathered Zone Thickness (m)	Resistivity (Ω·m)	Groundwater Potential	Suitability
VES 1	1.83 m (Shallow Weathered Zone) + 37.1 m (Fractured Zone)	153 Ω·m, 391 Ω·m	Moderate to high	Suitable
VES 2	1.04 m (Weathered Zone) + 12.1 m (Fractured Bedrock)	65.3 Ω·m, 407 Ω·m	High	Good
VES 3	2.89 m (Weathered/Fractured Bedrock)	72.3 Ω·m	Moderate	Fairly suitable
VES 4	34.5 m (Weathered Bedrock/Fractured Zone)	320 Ω·m	Very high	Highly suitable
VES 5	4.86 m (Weathered Zone)	122 Ω·m	High	Good
VES 6	1.11 m (Shallow Saturated Zone)	68.7 Ω·m	Low	Unsuitable
VES 7	0.94 m (Fractured Zone)	101 Ω·m	Very low	Not suitable
VES 8	2.96 m (Fractured/Saturated Zone)	122 Ω·m	Moderate	May require deeper drilling

The investigation confirms that VES 1, VES 2 are the most promising sites for groundwater development, with thick, weathered, and fractured bedrock layers supporting substantial storage. Conversely, VES 6, VES 7, and VES 8 have low water retention capacities, making them less favourable for borehole drilling. The findings provide a solid basis for site selection in future groundwater development projects in the study area.

Table 2 comprehensively summarizes resistivity, thickness, and subsurface interpretations, guiding groundwater exploration in the study area.

- **Best Groundwater Potential:** VES 4 (34.5 m thick Aquifer, 320 Ω·m) and VES 5 (weathered zone at 4.86 m, 122 Ω·m).
- **Moderate Potential:** VES 1, VES 2, and VES 3, showing fractured bedrock with limited storage.
- **Low Potential:** VES 6 and VES 7, where shallow water zones are unreliable due to depth and contamination risks.
- **Recommended Borehole Locations:** VES 4 and VES 5, due to significant aquifer zones and weathered bedrock.

This analysis provides a clear overview of subsurface conditions for groundwater assessment.

The VES results (Table 3) reveal significant variations in the groundwater potential across the study area. The interpretation of the fractured and weathered zones provides insight into the suitability of each location for groundwater exploration.

1. High Groundwater Potential Zones
    - The VES 4 and VES 2 locations exhibit the most promising groundwater conditions, with substantial fractured/weathered zone thicknesses of 34.5 m and 12.1 m, respectively. Their moderate resistivity values suggest sufficient porosity and permeability, making them highly suitable for borehole development. The thickness of these layers enhances their capacity to serve as aquifers, supporting long-term water extraction.
    - VES 1 and VES 5 also indicate considerable groundwater potential, with moderate fractured/weathered zone thicknesses. Although these zones may not have the same storage capacity as VES 4 and VES 2, they still present viable options for groundwater exploration, particularly in areas with moderate water demand.
2. Moderate Groundwater Potential Zones
    - VES 3 and VES 8 exhibit moderately thick fractured/weathered zones of 2.89 m and 2.96 m, respectively. These layers suggest some potential for groundwater storage, though the limited thickness

may result in lower borehole yields. While these sites may support small-scale groundwater extraction, additional hydrogeological investigations are necessary to determine their long-term sustainability.

3. Low Groundwater Potential Zones

   - VES 6 and VES 7 display thin weathered/fractured layers, measuring 1.11 m and 0.94 m, respectively. These shallow, low-capacity zones suggest minimal groundwater storage, making them unsuitable for sustained water extraction. The presence of high-resistivity bedrock rock at shallow depths further limits their hydrogeological significance. Consequently, these locations are not recommended for borehole drilling.

The findings from the VES survey highlight the most suitable locations for groundwater development, with VES 4 and VES 2 emerging as the best candidates for borehole siting. These locations possess thick fractured/weathered zones that enhance water storage and transmission. In contrast, VES 6 and VES 7 are not viable for groundwater exploration due to their limited water-bearing capacity. Further hydrogeological assessments, including pumping tests and groundwater recharge analysis, are recommended before final borehole placement to optimize groundwater extraction and ensure sustainable water supply.

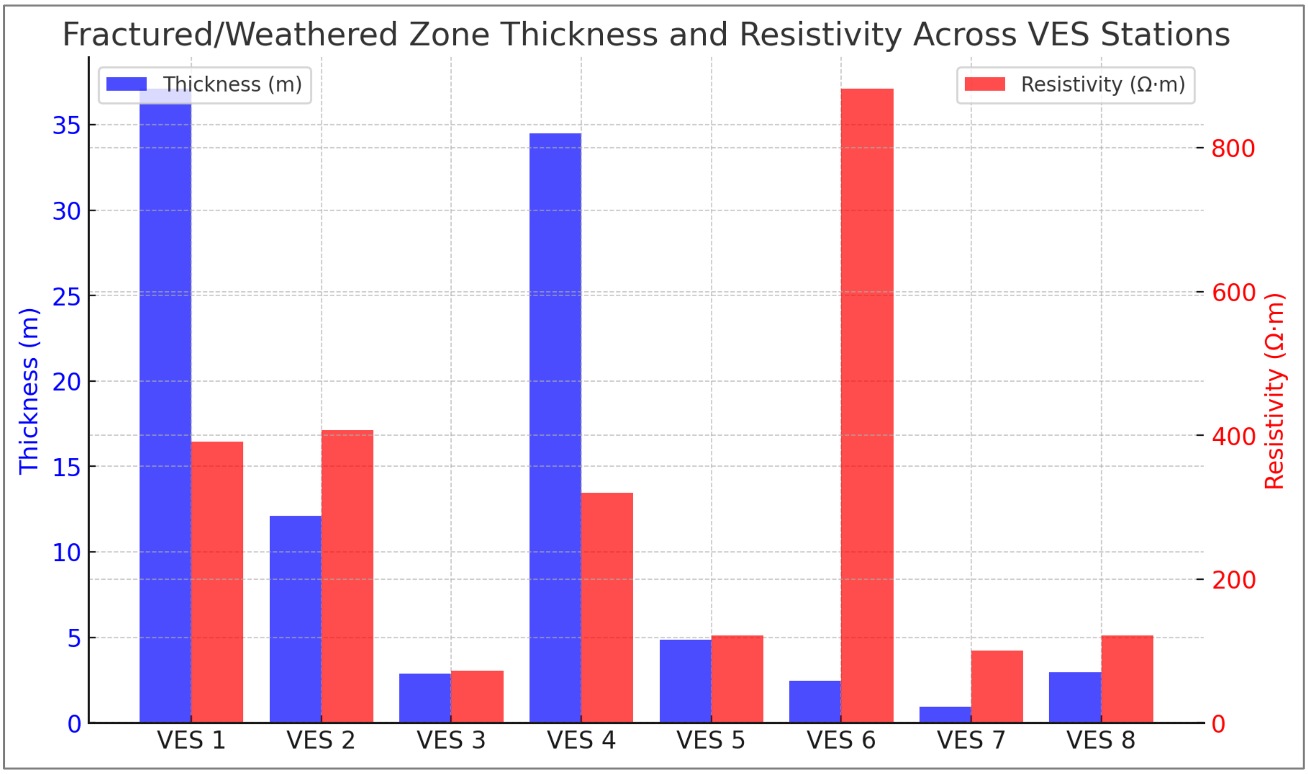

Figure 5: Bar Chart Representation of VES Data

The bar chart (Figure 5) presents the resistivity (Ω·m) and thickness (m) of various subsurface layers at different VES stations within the study area. The resistivity values indicate the nature and composition of the subsurface materials, while the thickness values highlight the depth of each layer.

- Higher resistivity values suggest compacted, less permeable materials such as fresh bedrock rock or lateritic zones.
- Lower resistivity values are associated with weathered or fractured zones, which often contain groundwater.
- The variations across VES stations help in identifying zones with higher groundwater potential.

CONCLUSION

The geophysical survey across eight VES stations revealed distinct subsurface layers, including topsoil, lateritic horizons, weathered zones, fractured zones, and fresh bedrock rock. The interpretation of resistivity data indicated considerable variation in subsurface composition across the study area. Shallow water-saturated zones were observed primarily within the weathered or fractured layers. However, due to their relatively thin profiles (generally less than 3 meters in thickness), these zones present limited groundwater potential for sustainable abstraction. In contrast, semi-fractured zones, particularly those with moderate resistivity values and greater thicknesses, were consistently identified in several VES points (notably VES 3, VES 4, and VES 5) as the most promising aquifer units. These layers, typically found between 30 m and 100 m depths, are considered optimal targets for groundwater exploration and borehole drilling. The deeper layers, dominated by high resistivity bedrock (with values reaching up to 34,015 Ω·m), confirm the presence of impermeable granite. Nevertheless, some groundwater potential still exists in localized zones where the bedrock is fractured or weathered as seen in VES 1, VES 2, and VES 8. While shallow zones (less than 30 m) are generally insufficient for long-term water supply, the 30 – 100 m depth range holds favorable conditions due to thicker weathered/fractured zones and moderate resistivity values. Beyond 100 m, the subsurface is largely fresh bedrock, which limits water storage and flow. Therefore, boreholes drilled to depths greater than 100 m are recommended when targeting confirmed fractured zones to intercept deeper aquifers. This strategy enhances the likelihood of achieving sustainable groundwater yields, particularly in areas with complex or poorly understood subsurface conditions.

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REFERENCES

Alabi, A. A., Bello, R., Ogungbe, A. S., & Oyerinde, H. O. (2010). Determination of groundwater potential in Lagos State University, Ojo; using geo-electric methods (vertical electrical sounding and horizontal profiling). *Report and Opinion, 2*(5), 68–75.

Albaba, A. L., & Nuraddeen, U. (2022). Application of vertical electrical sounding for the investigation of groundwater potentials at Umaru Musa Yar'adua University, Katsina. *UMYU Scientifica, 1*(1), 292–302. [Crossref]

Ahmad, U., Francis, A. A., & Francis, W. K. (2021). Assessment of groundwater potential using vertical electric sounding technique at Faculty of Medicine and Engineering, Federal University Dutsin-ma Katsina State, Nigeria. *Global Journal of Earth and Environmental Science, 6*(4), 98–105. [Crossref]

Haque, S., Kannaujiya, S., Taloor, A. K., Keshri, D., Bhunia, R. K., Ray, P. K. C., & Chauhan, P. (2020). Identification of groundwater resource zone in the active tectonic region of Himalaya through earth observatory techniques. *Groundwater for Sustainable Development, 10*, 100337. [Crossref]

Hamzah, U., Samsudin, A. R., & Malim, E. P. (2007). Groundwater investigation in Kuala Selangor using vertical electrical sounding (VES) surveys. *Environmental Geology, 51*, 1349–1359. [Crossref]

Idiahi, E., Adiat, K. A. N., Ozegin, K. O., Salufu, S. O., Adebayo, S., & Akinlalu, A. A. (2023). The assessment of groundwater availability in sedimentary environments using the electrical resistivity method: A case of Ekpoma and its environs, Southern Nigeria. *Indonesian Journal of Earth Sciences, 3*(2), A784–A784. [Crossref]

Kolawole, A. T., & Olawale, F. M., (2021). Investigation of the thermo-physical and mechanical properties of coir and sugarcane bagasse for low temperature insulation. International Journal of Engineering Materials and Manufacture, 6(4), 340-356. [Crossref]

Mukhtar, A., Nuraddeen, N. G., Rabiu, N., Muneer, A. S., Suleiman, B., & Mayeen, U. K. (2023). Statistical analysis of terrestrial gamma radiation dose rates in relation to different geological formations and soil types of Katsina State, Nigeria. *International Journal of Environmental Analytical Chemistry, 103*(14), 3251–3163. [Crossref]

Ozegin, K. O., & Okolie, E. C. (2018). Application of combined electrical resistivity techniques for subsurface characterisation and groundwater resource development in Okpella, Edo State Nigeria. *Nigerian Journal of Physics, 27*(S), 69–82.

Rolia, E., & Sutjiningsih, D. (2018, June). Application of geo-electric method for groundwater exploration from surface (A literature study). In *AIP Conference Proceedings* (Vol. 1977, No. 1). AIP Publishing. [Crossref]

RUWASSA. (2021). *Geological well-log of Batagarawa Local Government Area, Katsina State, Nigeria*. Rural Water Supply and Sanitation Agency (RUWASSA), Katsina State

Suleiman, B. A., Idris, M. C., & Ibrahim, S. G. (2018). Geo-electric investigation of aquifer characteristics and ground water potential in Kafin Hausa, Jigawa State, Nigeria. *Dutse Journal of Pure and Applied Sciences, 4*(2), 434–443.