

## ORIGINAL RESEARCH ARTICLE

## Integrated 1-D Resistivity and GIS Analysis for Groundwater Potential Mapping at Umaru Musa Yar'adua University, Katsina (Nigeria)

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### ABSTRACT

Groundwater exploration is essential for a sustainable water supply in Katsina, northwestern Nigeria, where surface water is scarce and unreliable. This study developed a groundwater potential map for Umaru Musa Yar'adua University using Vertical Electrical Sounding (VES) with the Schlumberger array. Twenty (20) VES stations were surveyed with a maximum current electrode spacing (AB/2) of 100 m and potential electrode spacing (MN/2) of 20 m. The data were processed in IPI2Win and integrated into ArcGIS for spatial analysis. Results revealed three to five subsurface layers with resistivity values ranging from 8.9–92,400  $\Omega \cdot m$  and thicknesses up to 44.4 m. Productive aquiferous zones were mainly identified in saturated sandstone and lateritic formations. Aquifers occurred at depths between 10–96 m, with resistivity values of 28.9–950  $\Omega \cdot m$  for saturated sandstone (VES 18) and 76.7–14,903  $\Omega \cdot m$  for weathered basement (VES 10). The thickest aquiferous layer (44.4 m) was observed at VES 11 with resistivity values of 40–69,213  $\Omega \cdot m$ , while shallow promising layers were detected at VES 2–4 (13–15 m depth, 593–12,989  $\Omega \cdot m$ ). Groundwater potential mapping categorized the study area into good, moderate, and poor zones, with the most favorable zones located along P1 (stations 2–5), P2 (station 6), and P3–P4 (stations 12, 16, 18, and 20). Conversely, stations near the ASSU Secretariat (e.g., S7–S8, S15) showed poor groundwater potential. The study demonstrates that combining VES interpretation with GIS enhances delineation of groundwater zones and provides a reliable basis for siting productive boreholes within the university community.

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### INTRODUCTION

Groundwater is a crucial natural resource that supports both human life and ecosystems (Shaikh & Birajdar, 2024). It plays a key role in agriculture, industry, and domestic water supply, especially in areas where surface water is unavailable or unreliable (Akpan et al, 2018). In recent years, population growth and rapid urbanization have increased the challenge of meeting the rising demand for clean and safe water (Akor et al 2017). Groundwater is stored in pores, cracks, and fractures within rocks and soils beneath the Earth's surface. To locate and evaluate this hidden resource, geophysical techniques are often used. Among these, the electrical resistivity method, particularly the Vertical Electrical Sounding (VES), has proven to be one of the most reliable and commonly used tools (Ibrahim et al, 2023). Due to growing industrialisation and population growth, it is becoming increasingly difficult to obtain a sufficient quantity of high-quality surface water. Since water supplies are not consistent throughout the year, it is necessary to find additional sources of surface water to replace them (Akor et al., 2017). Akpan et al. (2018) estimated that 53% of the

world's population gets their drinking water from groundwater. Water that is found in lithological formations, fractures, and soil pore spaces below the Earth's surface is known as groundwater. In order to maximize the potential of available water, geophysical field measurements are conducted to evaluate groundwater supply and pinpoint the ideal borehole locations for groundwater after extraction (Aluko et al., 2017). Most of the excess rainfall flows on the ground's surface, but some seeps below and produces groundwater, which creates lakes, wells, and springs (Aluko et al., 2017).

In many instances, boreholes are drilled at deeper depths but do not yield enough groundwater for domestic use. This is due to the lack of available geophysical surveys and data on the UMYU 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. Lawal and Usman (2022) conducted a VES study at

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Umaru Musa Yar'adua University but did not integrate GIS in their analysis.

As student and staff populations continue to grow, there is increasing demand for safe and reliable water sources, especially groundwater. Previous attempts at groundwater exploration in this area yielded limited success, mainly due to the use of techniques that provided limited subsurface information in only one direction. This study attempts to overcome that limitation using a more detailed and spatially extensive resistivity approach. The groundwater potential map of the study and zones was developed in the research.

**METHODOLOGY AND INSTRUMENTATION**

The survey was conducted between the Academic Staff Union of Universities (ASUU) Secretariat and the Faculty of Agriculture Annexe Building of Umaru Musa Yar'adua University Katsina, within geographic coordinates N 12°53'55.2" and E 7°34'49.8".

**Instrumentation**

The Vertical Electrical Sounding (VES) survey employed the following equipment: resistivity meter (digital ohmmeter), non-polarizable steel electrodes (current and potential), insulated connecting cables, a Garmin GPS device, 12 V car battery (power source), measuring tape,

hammer, digger, and cutlass for electrode installation. IPI2Win software was used for resistivity data processing and inversion, while ArcGIS was used for spatial analysis and map production.

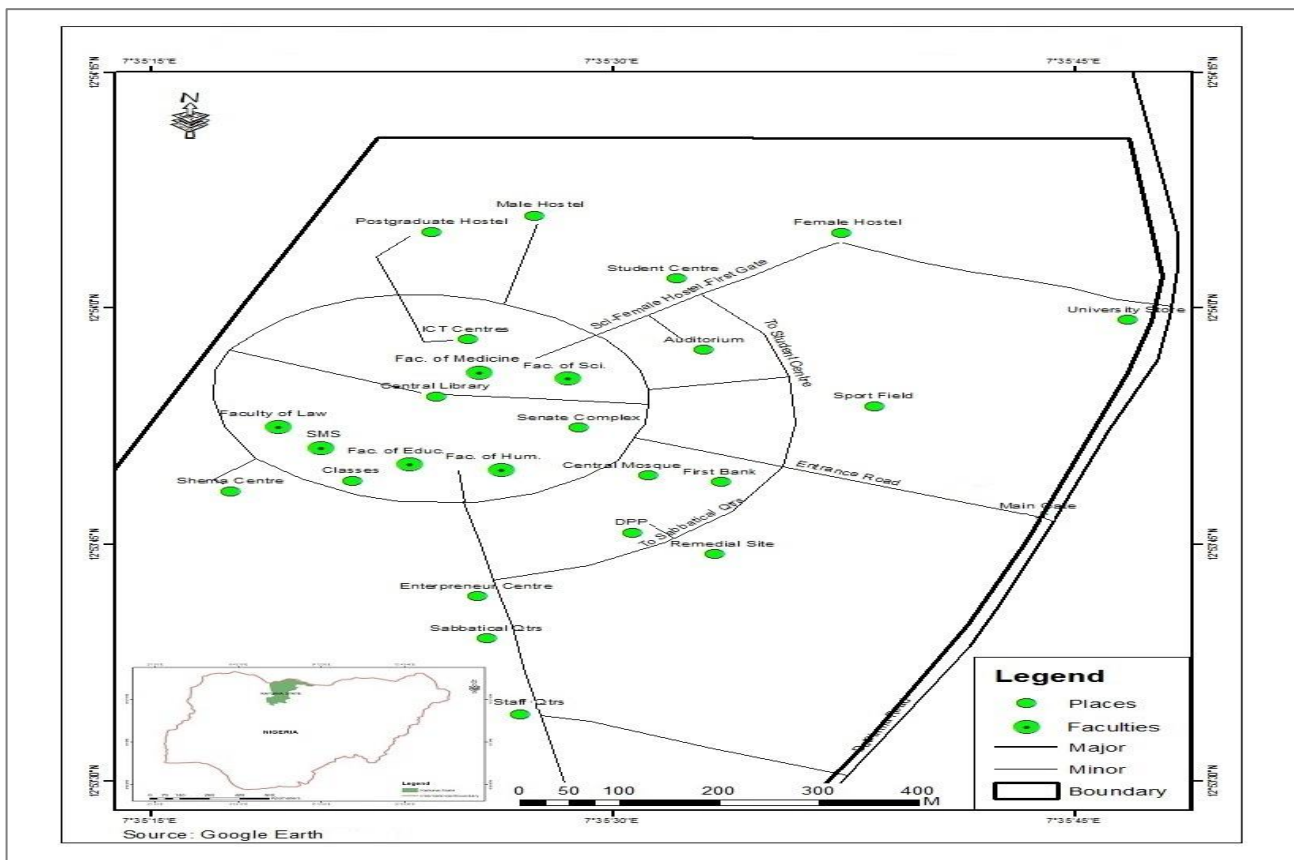
To ensure reliable contact between electrodes and the ground, contact resistance was checked at each station. High-resistance points were mitigated by pouring water mixed with salt around the electrodes or by driving them deeper into the ground.

**Environmental Conditions**

The field survey was carried out in the dry season (June 2024), under stable weather conditions (average temperature ~35 °C, no rainfall), which reduced surface soil moisture variability. Measurements were taken during the daytime (08:00–16:00) to maintain consistent environmental conditions and avoid temperature-related instrument drift.

**Map of UMYUK**

Umaru Musa Yar'adua University is located in the Batagarawa Local Government Area, about 10 km from Katsina City and 1.9 km from Batagarawa Low-Cost Housing Estate. The study area lies between latitudes 12°53'25"N to 12°53'42"N and longitudes 7°34'48"E to 7°35'26"E.



**Figure 1: Map of UMYUK**

The Basement Complex in this region comprises diverse rock types, including sandstone, rhyolite, migmatite, porphyritic gneiss, granite gneiss, coarse and fine-grained biotite-hornblende granite, and silicified sheared rocks.

The specific geology underlying UMYUK consists mainly of coarse biotite-hornblende granite and sandstone, both of which influence groundwater occurrence and resistivity signatures in the area (Lawal & Usman, 2022).

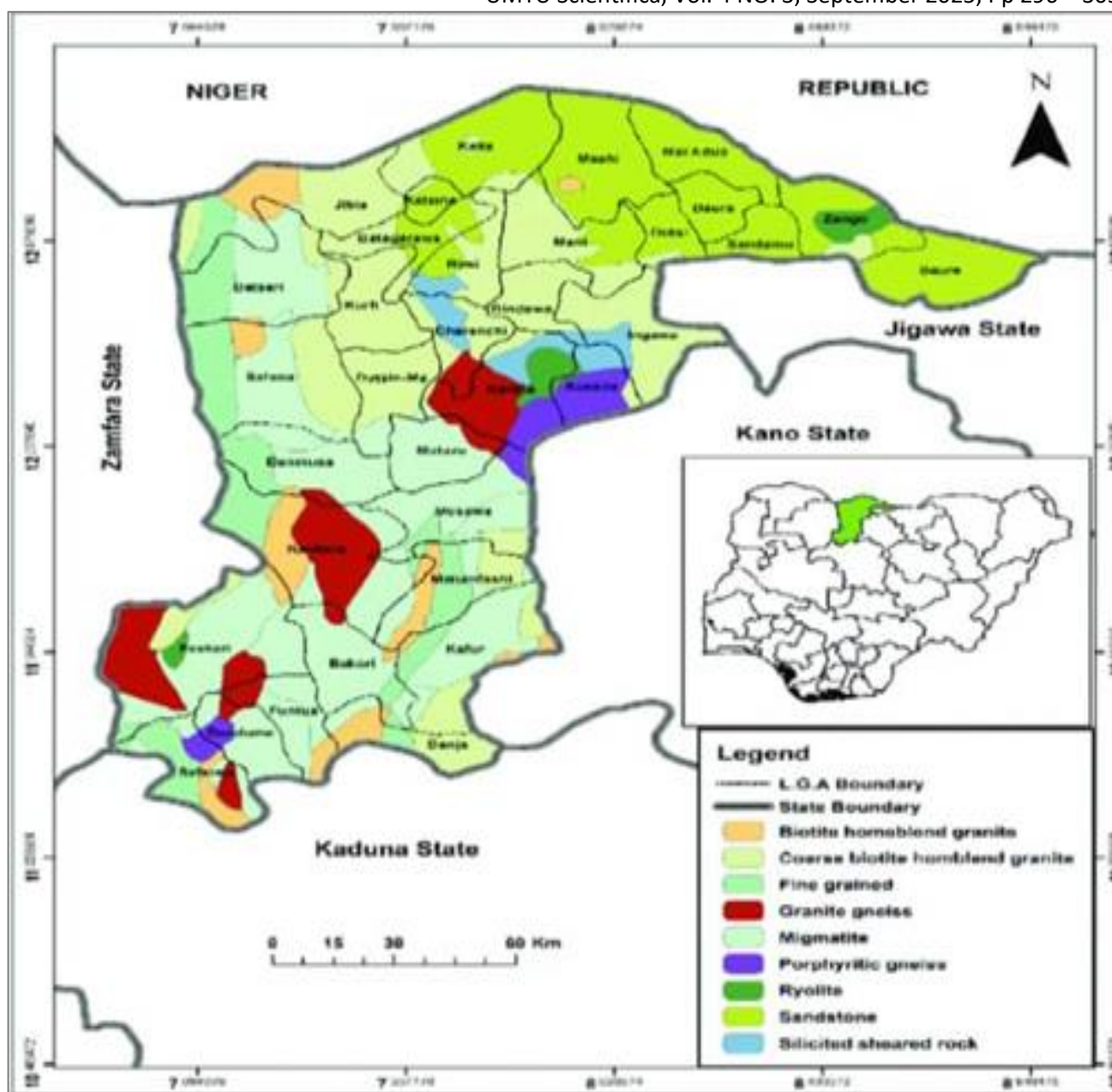


Figure 2: Geology of Katsina State (Mukhtar et al., 2021 in Lawal & Usman 2022)

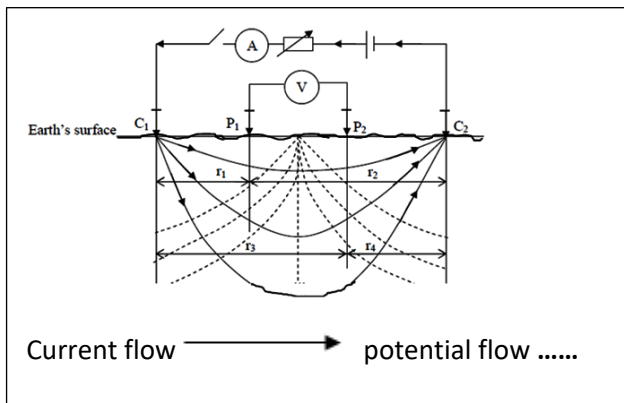
**Method**

A 1D resistivity sounding survey was chosen for this study due to the following reason: the 1D Resistivity method is a commonly important technique in groundwater exploration. It has been shown that this method has been successfully used for delineating of geo-electrical layers in the subsurface that steer exploration of groundwater resources (Anudu, et al., 2008; Porsani, et al., 2005).

Resistivity sounding is a survey designed to determine resistivity variations with depth below a fixed surface point. During this survey, current was injected into the Earth through a pair of current electrodes, and the potential difference was measured between a pair of potential electrodes. The current and potential electrodes are generally arranged in a linear array. Although, electrode spacing varies for each measurement, the center of the electrode array where the electrical potential is measured remains the same. The two potential electrodes and the

two current electrodes are aligned in a straight line. The current electrodes are placed at equal distances from the centre of the sounding ( $AB/2=1$  m at the initial measurement). The potential electrodes were also positioned at equal distances from the center; however, this distance ( $MN/2=0.5$  m at the initial measurement) is much less than the distance  $AB/2$ . Most interpretation software assumes that the spacing of the potential electrodes is negligible compared to that of the current electrodes. When the distance between the current electrodes increases, the space between the potential electrodes is also increased to produce a measurable potential difference, and electrode configurations can be set up in various ways, with spacing up to  $AB/2=100$  m. The instruments were then moved to the next VES point along the same line, and the process was repeated. At each VES station, current magnitudes ranged between 50 mA and 200 mA depending on subsurface resistance, with measurement intervals determined by electrode expansion steps. Each profile consisted of five VES stations spaced

at 94.4 m intervals. Four profiles (P1–P4) formed a rectangular grid measuring 377.6 m × 283.3 m, resulting in a total of 20 VES stations.



**Figure 3: General four-electrode arrangement**

**Data processing and inversion**

The computer inversion program IPI2WIN was used in conversion VES data in this study while computing the geo-electrical parameters of the study area through the following steps:

1. Data input and quality control (removal of noisy or spurious readings).
2. Error correction and curve matching.
3. Initial 1D forward modeling using a layered-earth starting model.
4. Automatic inversion with model constraints guided by the local geology.
5. Iterative adjustment until the root mean square (RMS) misfit fell below 10%, which was set as the acceptance criterion.

**Groundwater Potential Mapping**

The ArcGIS software was used in developed map of the study area as well as that of groundwater potential map through the following steps: Conversion of latitude and longitude (degree minute second) to decimal degree, Converting the data into comma separated value, Transporting the data to ArcGIS software, Matching the data to geographic location, Adding the data in layers, Customization and sharing of the data (map).

**Determination of the Resistivity Value associated with the Groundwater**

The resistivity value associated with groundwater can be lower in the areas with high saline water and high in areas with less conductivity water or dry soil. Therefore, the resistivity value associated with groundwater in the area indicates low resistivity values within the VES interpreted result, supported by the geology of the study area.

**Characterization of the available Water Aquifers as well as Lithology**

The lithology of the study area was determined from the VES results, where the resistivity values of the sounding points change with layers, using the borehole log and geologic information of the study area as a guide.

**Mapping the Prosperous Zones of the Groundwater Potential in the Study Area**

The ArcGIS software was used to map the prosperous zones of the groundwater potential in the study area. After transporting the data, it was matched to the geographic location, where the data was added in layers.

**RESULTS**

**Table 1: Consolidated Geoelectric Parameters of the 20 VES Stations in the Study Area**

VES No.	Layer No.	Resistivity ( $\Omega$ m)	Thickness (m)	Depth (m)	Lithology
1	1	351	0.5	0.5	Topsoil
	2	2,573	0.34	0.84	Sandstone
	3	111	1.76	2.6	Saturated Sandstone
	4	3,640	—	—	Weathered Basement
2	1	1,321	0.53	0.53	Laterite
	2	593	12.6	13.2	Lateritic Soil
	3	2,075	—	—	Sandstone
3	1	888	0.5	0.5	Saturated Sandstone
	2	343	2.86	3.36	Sandstone + Laterite
	3	122	2.65	6	Lateritic Soil
	4	12,989	8.88	14.9	Laterite
	5	866	—	—	Sandstone
4	1	794	0.87	0.87	Topsoil
	2	1,612	1.38	2.24	Laterite
	3	240	4.63	6.87	Sandstone + Laterite
	4	41,375	4.99	11.9	Laterite
	5	92.4	—	—	Saturated Laterite
5	1	578	0.5	0.5	Lateritic Soil
	2	889	2.01	2.51	Laterite
	3	375	7.45	9.96	Saturated Laterite
	4	6,276	—	—	Weathered Basement

*To be continued next page*

Table 1 continued

VES No.	Layer No.	Resistivity ( $\Omega$ m)	Thickness (m)	Depth (m)	Lithology
6	1	185	3.21	3.21	Sandstone + Laterite
	2	80.9	3.26	6.47	Sandstone
	3	625	26.5	33	Sandstone + Gravel
	4	74,033	—	—	Weathered Basement
7	1	754	0.61	0.61	Sandstone
	2	4,890	0.65	1.26	Weathered Basement
	3	129	1.7	2.96	Saturated Sandstone
	4	2,858	—	—	Weathered Basement
8	1	2,951	0.51	0.51	Laterite
	2	449	7.89	8.4	Lateritic Soil
	3	23,437	9.52	17.9	Sandstone
	4	40.4	—	—	Saturated Sandstone
9	1	1,017	0.67	0.67	Topsoil
	2	368	0.71	1.38	Sandstone + Laterite
	3	1,614	1.09	2.47	Sandstone
	4	174	3.13	5.6	Saturated Sandstone
	5	8,668	12.9	18.5	Weathered Basement
	6	582	—	—	Weathered Basement
10	1	964	1.23	1.23	Laterite + Gravel
	2	185	1.06	2.3	Lateritic Soil
	3	4,515	1.95	4.25	Weathered Basement
	4	278	6.11	10.4	Lateritic Soil
	5	14,903	11.1	21.5	Weathered Basement
	6	76.7	—	—	Saturated Laterite
11	1	140	0.5	0.5	Lateritic Soil
	2	788	0.31	0.81	Sandstone
	3	40	1.06	1.87	Saturated Sandstone
	4	648	44.4	46.3	Aquiferous Layer
	5	69,213	—	—	Weathered Basement
12	1	257	0.5	0.5	Clayed Sand + Gravel
	2	1,133	0.33	0.83	Sandy Soil
	3	53.7	0.49	1.32	Clayed Sand
	4	413	35.6	36.9	Saturated Sandy Soil
	5	200,000	—	—	Weathered Sandstone
13	1	123	0.56	0.56	Lateritic Soil
	2	442	0.77	1.33	Sandstone + Laterite
	3	126	6.56	7.88	Lateritic Soil
	4	22.3	7.67	15.6	Saturated Laterite
	5	14,680	—	—	Weathered Basement
14	1	1,632	0.5	0.5	Topsoil
	2	739	1.46	1.96	Laterite
	3	194	2.66	4.62	Lateritic Soil
	4	1,090	38.1	42.7	Sandstone + Lateritic Soil
	5	59,196	—	—	Weathered Basement
15	1	854	1.36	1.36	Dry Sandy Soil
	2	101	2.31	3.67	Lateritic Soil
	3	11,384	5.97	9.64	Weathered Basement
	4	8.88	—	—	Saturated Laterite
16	1	331	0.86	0.86	Sandstone + Laterite
	2	659	26.8	27.7	Sandstone
	3	3,391	15.6	43.3	Weathered Sandstone
	4	7.49	—	—	Saturated Sandstone
17	1	1,017	0.67	0.67	Topsoil
	2	368	0.71	1.38	Sandstone + Laterite
	3	1,614	1.09	2.47	Laterite
	4	174	3.13	16.6	Saturated Laterite
	5	8,668	—	—	Weathered Laterite
18	1	227	1.24	1.24	Sandstone + Laterite
	2	950	95.2	96.4	Saturated Sandstone

To be continued next page

Table 1 continued

VES No.	Layer No.	Resistivity ( $\Omega$ m)	Thickness (m)	Depth (m)	Lithology
19	3	28.9	—	—	Fresh Basement
	1	571	0.78	0.78	Lateritic Soil
	2	3,469	0.95	1.73	Sandstone
	3	230	4.96	6.69	Sandstone + Laterite
	4	15,368	9.63	16.3	Weathered Basement
20	5	26.2	—	—	Saturated Sandstone
	1	176	1.79	1.79	Topsoil
	2	40.1	1.03	2.82	Dry Sandy Soil
	3	547	33.9	36.7	Sandstone
	4	5,899	—	—	Weathered Basement

Table 2: Groundwater potential zones for all VES/stations

VES/Layer No.	Depth (m)	Resistivity ( $\Omega$ m)	Thickness (m)	Lithology
VES 1	2.6	111 – 3640	1.76	Saturated Sandstone
VES 2	13.2	593 – 2075	12.6	Lateritic soil
VES 3	14.9	122 – 12989	8.88	Laterite
VES 4	11.9	92.4 – 41355	4.99	Laterite
VES 5	9.96	375 – 2676	7.45	Saturated Laterite Sandstone + Gravel
VES 6	33.0	80.9 – 74033	26.5	Saturated Laterite Sandstone + Gravel
VES 7	2.96	129 – 2858	1.70	Saturated Sandstone
VES 8	17.9	40.4 – 23437	9.52	Sandstone
VES 9	18.5	174 – 8668	12.9	Weathered Basement
VES 10	21.5	76.7 – 14903	11.1	Weathered Basement
VES 11	46.3	40 – 69213	44.4	Aquiferous Layer
VES 12	36.9	53.7 – 2.0E+5	3.6	Saturated Sandy Soil
VES 13	15.6	22.3 – 14680	7.67	Saturated Laterite
VES 14	42.7	194 – 59196	38.1	Sandstone + Laterite Soil
VES 15	9.64	8.88 – 11384	5.97	Weathered Basement – Weathered Sandstone
VES 16	43.3	7.49 – 3391	15.6	Weathered Basement – Weathered Sandstone
VES 17	16.6	174 – 8668	3.13	Saturated Laterite
VES 18	96.4	28.9 – 950	95.2	Saturated Sandstone
VES 19	16.3	26.2 – 15368	9.63	Weathered Basement
VES 20	36.7	40.1 – 5899	33.9	Sandstone

The spatial analysis and groundwater potential mapping were conducted using ArcGIS 10.8. The interpreted resistivity and layer thickness data from the 20 VES stations were spatially interpolated to delineate groundwater potential zones. The Inverse Distance Weighted (IDW) interpolation method was selected due to its simplicity and suitability for sparse geoelectrical datasets, where sample points exert local influence on the surrounding area. The interpolation was performed with a cell size of 30 m × 30 m, and a power parameter of 2, ensuring balanced smoothing between high and low resistivity zones.

Groundwater potential typically divides an area into different zones, each with a different level of potential. The zones are usually categorized as follows:

**Good Potential Zone:** This was indicated along P1 from station 2 to station 5 (laterally about 300 m). Along P2, only station 6 is having good potential. Also, station 11 and S12 on P3 shows good potential. Finally, stations 16, S18, S19 and S20 along P4 revealed good groundwater potential.

**Moderate to Poor Potential Zone:** Areas with a moderate to poor groundwater potential. This also indicates station 10 on P2. Along P3, only stations 13 and S14 shows moderate to poor potential. Finally, station 17 along P4 revealed moderate to poor potential.

**Poor potential Zone:** Areas with low groundwater potential. This was indicated at station 9 along P2 and station 15 along P3, which have poor potential zones.

**Very Poor Potential Zone:** Areas with a very low groundwater potential, often with no groundwater present or very low yields. This was indicated along P1 from station 1, along P2 at stations 7 and S8, revealing a very poor potential zone.

### 3.1 Data Quality and Error Control

To ensure data reliability, repeat VES measurements were performed at two stations (approximately 10% of the total), representing typical geological variations across the study area. The repeat soundings showed less than 5% variation in apparent resistivity values, confirming good instrument stability and consistent field procedures.

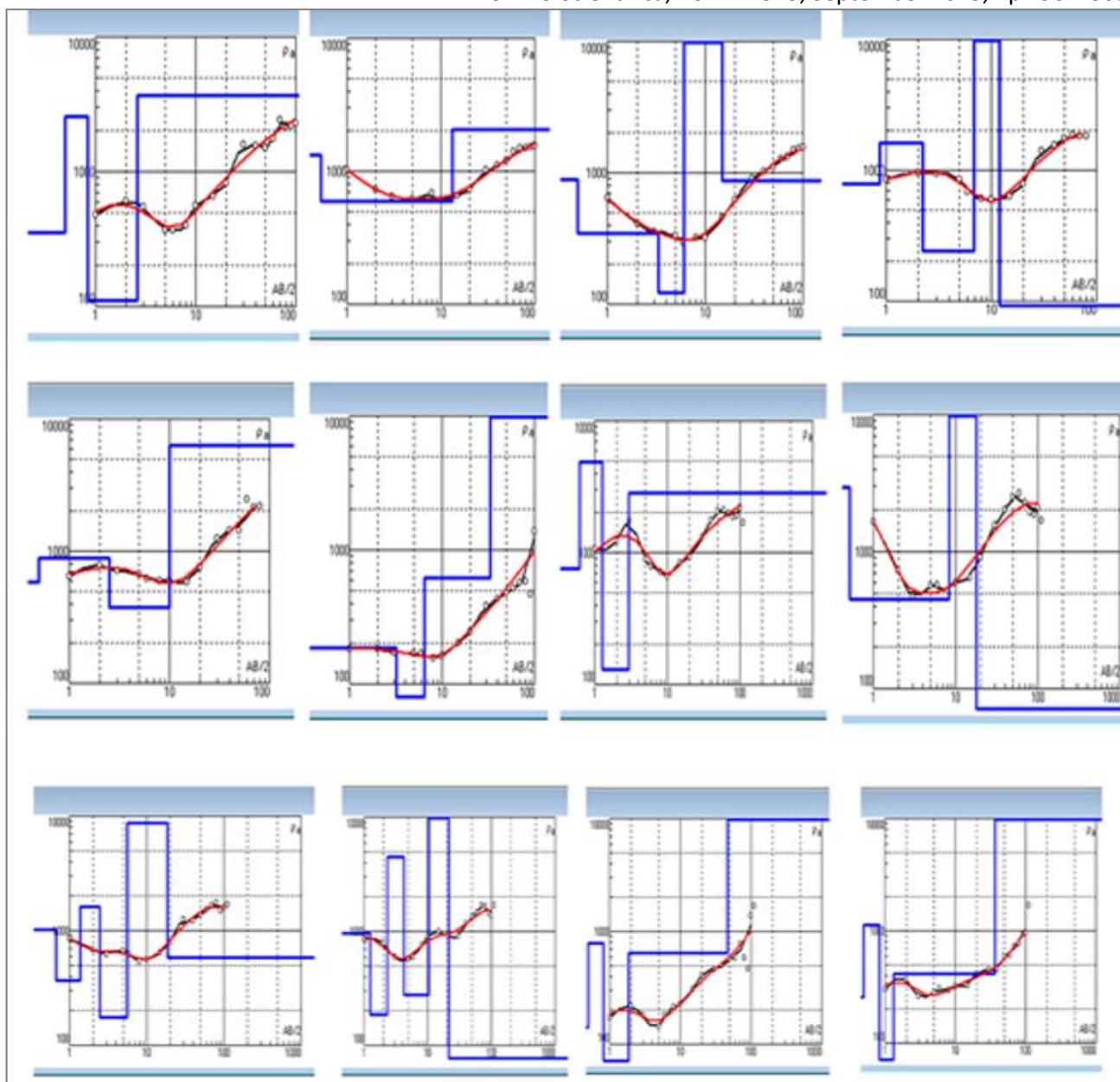


Figure 4: IPI2WIN Computer Software iterated curve of VES 1 – VES 12

During data acquisition, contact resistance was carefully monitored and maintained below 2 k $\Omega$  at all stations by applying saltwater around the electrodes when necessary. The RMS misfit values obtained from the IPI2Win inversion ranged from 3.8% to 9.6%, with an average of 6.2%, indicating that the modeled curves closely matched the observed data.

For spatial interpolation and mapping in ArcGIS, the Inverse Distance Weighting (IDW) method was used with a power parameter of 2. To evaluate map reliability, a five-fold cross-validation (K=5) was performed, yielding a mean absolute error (MAE) of 0.08 and a correlation coefficient (R<sup>2</sup>) of 0.92, confirming high spatial prediction accuracy.

## DISCUSSION

The electrical resistivity values recorded across the study area ranged from 7.49  $\Omega$ m to approximately 200,000  $\Omega$ m,

revealing the presence of three to five geoelectric layers. These layers were interpreted based on resistivity variation, lithological correlation, and groundwater saturation characteristics.

### Top Layer

The first layer generally consists of topsoil, laterite, and lateritic soil, with resistivity values ranging from 123  $\Omega$ m to 2951  $\Omega$ m, as correlated with the findings by Lawal and Usman (2022). This layer has a relatively shallow depth, extending to about 3.21 meters below the surface. The variation in resistivity suggests a mix of dry and moist surface materials.

### Second Layer

Beneath the topsoil lies the second layer, characterized by sandy soil, laterite, lateritic soil, and sandstone. This layer displays variable thicknesses ranging from 0.31 m to 95.2 m, with resistivity values between 40  $\Omega$ m and 4890  $\Omega$ m.

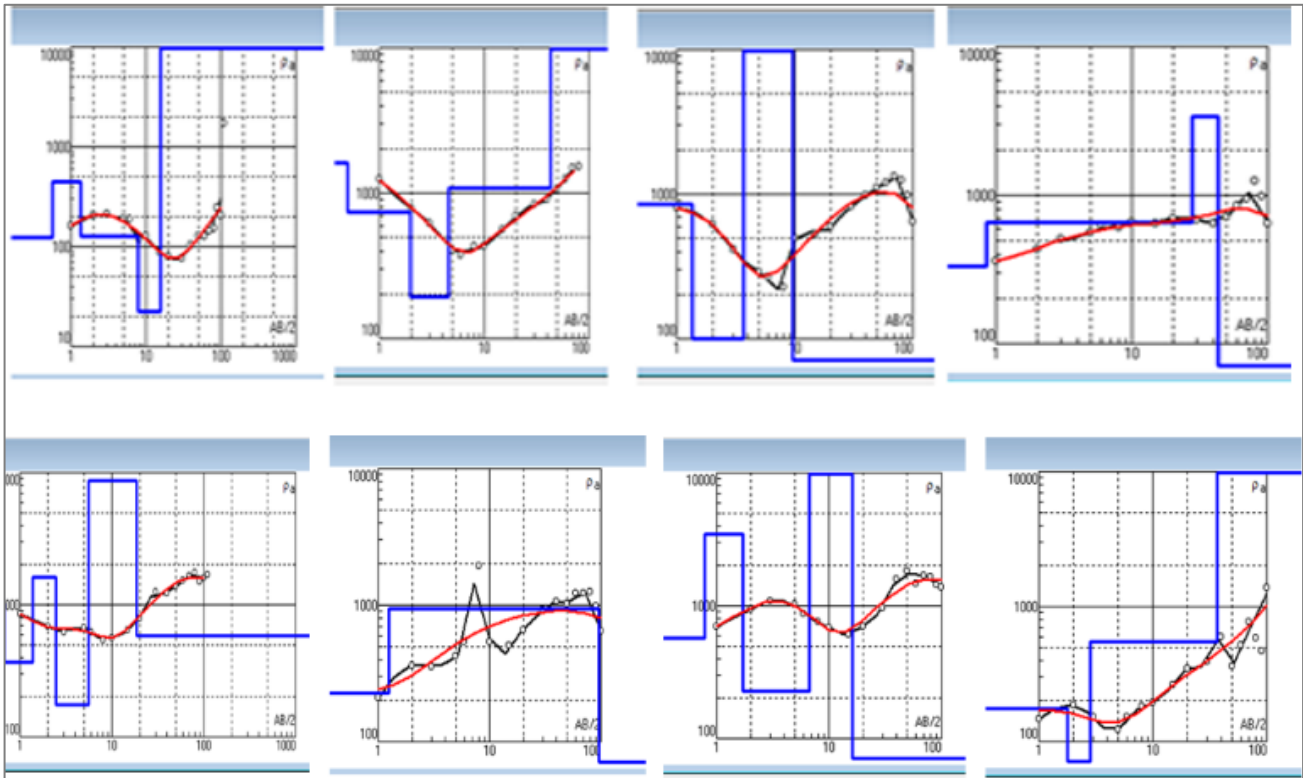


Figure 5: IPI2WIN Computer Software iterated curve of VES 13 – VES 20

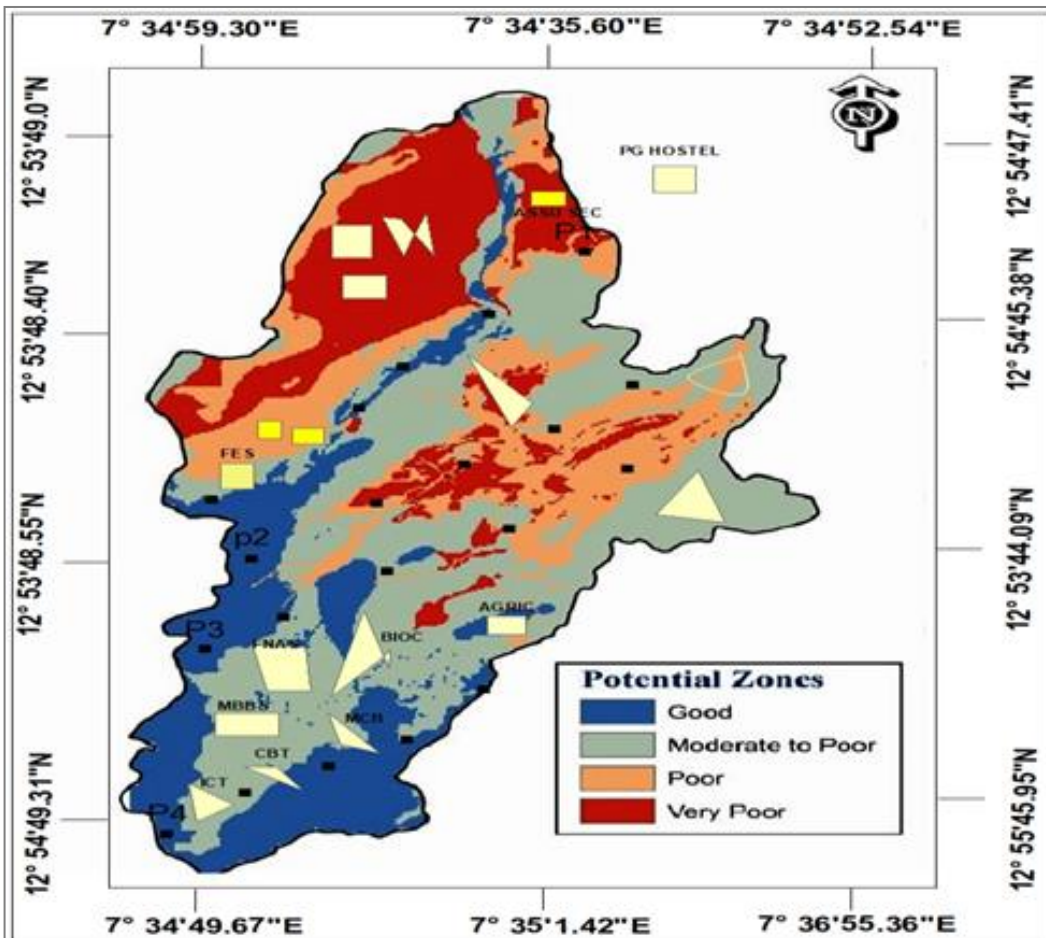


Fig 6: Groundwater Potential Map for the Study Area

It extends to depths of approximately 0.81 m to 96.4 m, depending on the station, and is indicative of heterogeneous materials that could support moderate groundwater accumulation (Akor et al, 2017).

**Third Layer**

The third layer shows a more complex and varied structure across different VES stations. For instance:

- Stations 6, S8, S9, S10, S15, S16, S17, and S20 revealed increased resistivity values, typically associated with laterite, weathered basement, and, in some cases, weathered basement rock.
- Stations 2, S3, S4, S5, S7, S11, S12, S13, S14, S18, and S19, on the other hand, indicated the presence of saturated sandstone with traces of laterite.

This third layer has resistivity values ranging from 29  $\Omega\text{m}$  to 23,430  $\Omega\text{m}$ , with a maximum thickness of about 33 meters, reaching depths of up to 43 meters. The presence of saturated sandstone in several stations suggests potential aquifer zones (Lawal and Usman, 2022).

#### Fourth Layer

The fourth layer is saturated in several locations, including stations 8, S9, S12, S13, S14, S15, S16, and 17, where it is composed mainly of sandstone with occasional laterite. Station 4 shows an aquiferous layer, while stations 2 and 18 terminate at the third layer, suggesting shallower bedrock (Suleiman et al, 2018). Resistivity values here range from as low as 2  $\Omega\text{m}$  to about 74,000  $\Omega\text{m}$ , and the layer reaches a maximum thickness of 44 meters, extending to depths of about 46 meters. The low resistivity in some stations indicates groundwater saturation, while the higher values suggest either dry bedrock or low porosity formations.

#### Fifth Layer

This deepest layer appears at only a few stations, notably station 4 and station 19, where it shows signs of groundwater saturation. In contrast, stations 9, S10, S11, S12, S13, S14, and S17 reflect the presence of basement rock, with resistivity values ranging from 26  $\Omega\text{m}$  to about 200,000  $\Omega\text{m}$  (recorded at station 12). These high resistivity values are typical of compact, crystalline basement material with minimal water content (Ubaidullah et al, 2021). Resistivity Interpretation and Groundwater Implication generally, low resistivity values are associated with saturated zones, especially in clayey or saline environments, while high resistivity values indicate dry or resistive formations like granite or dry sandstone. Thus, the interpreted resistivity signatures, when combined with borehole and geological data enabled accurate identification of aquiferous zones in the study area.

The spatial variation in resistivity across the study area is primarily governed by lithological composition, degree of weathering, and groundwater saturation. Low to moderate resistivity values (8.88–950  $\Omega\text{m}$ ) are associated with saturated sandstone and weathered basement units, indicating zones of high groundwater potential, whereas higher resistivity values (>10,000  $\Omega\text{m}$ ) correspond to compact, dry basement rocks with limited water content. These interpretations align with the established hydrogeological framework of Batagarawa and the broader Katsina region, where groundwater occurrence is predominantly controlled by weathered and fractured basement systems as well as sandstone formations. The observed aquifer depths (15–110 m) and resistivity

characteristics correlate well with existing borehole yield data, reinforcing the validity of the geophysical interpretation. Consequently, the identified high-yielding zones—particularly around VES 6, 11, 12, 18, and 19—are considered the most suitable for future borehole development and sustainable campus water supply planning.

## CONCLUSION

This study employed 1D Vertical Electrical Sounding (VES) using the Schlumberger array to evaluate groundwater potential within Umaru Musa Yar'adua University, Katsina. Twenty VES points were investigated and analyzed using IPI2Win and ArcGIS software, delineating three to five subsurface layers with resistivity values ranging from 7.49  $\Omega\text{m}$  to 200,000  $\Omega\text{m}$ . The interpreted layers—comprising topsoil, sandy soil, lateritic soil, sandstone, and weathered basement—reflect variable groundwater potential across the study area.

The integrated geophysical and GIS analysis identified high-yield groundwater zones at stations 6, 11, 12, and 16–20, which are suitable targets for borehole development at depths between 40 m and 100 m. Moderate potential zones were observed at stations 10, 13, 14, and 17, while low to very low potential zones occurred at stations 1, 7, 8, 9, and 15. The derived groundwater potential map provides a reliable decision-support tool for optimizing borehole siting and water resource planning within the university and its surroundings.

Future work should include 2D or 3D resistivity surveys to evaluate lateral continuity of the aquifer units and improve hydrogeological modeling accuracy for sustainable groundwater management.

## ACKNOWLEDGEMENT

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