Bima Journal of Science and Technology, Vol. 9(2A) Jun, 2025 ISSN: 2536-6041

DOI: 10.64290/bimagombe.v9i2A.1060

Evaluation of Groundwater Potential in Bakarare Village Using Electrical Method

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ABSTRACT

This study assesses the groundwater potential of Bakarare village in Minjibir Local Government Area (LGA), Kano State, Nigeria, using electrical resistivity methods. Geographically, the village lies between latitudes 12°10′0″N to 12°13′30″N and longitudes 8°32′30″E to 8°36′0″E. A total of 46 Vertical Electrical Soundings (VES) were conducted using the Schlumberger array configuration. The collected data were processed, modeled, and interpreted to delineate subsurface layers, evaluate aquifer thicknesses, and identify recharge zones. The findings revealed promising groundwater potential zones at depths ranging from 60.7 m to 72 m, with aquifer thicknesses between 56 m and 67.54 m. Laterite layers with thicknesses ranging from 1.54 m to 2.1 m (thin) and 2.25 m to 2.98 m (moderate) were identified as suitable for water infiltration and recharge to deeper aquifers. These results underscore the effectiveness of electrical resistivity methods for groundwater exploration and provide a scientific basis for addressing the village's critical water scarcity challenges.

Keywords: Aquifer, Electrical Resistivity, Geophysics, Laterite and Overburden.

INTRODUCTION

Water is one of the most vital natural resources for sustaining human life and ecological balance. Groundwater, in particular, serves as a reliable and cost-effective source, especially in areas where surface water is limited or absent. It can be accessed through boreholes and hand-dug wells, which are more affordable than surface water systems that require large-scale infrastructure such as dams and pipelines [1].

In regions experiencing increasing water scarcity particularly arid and semi-arid zones geophysical methods have become essential tools for groundwater exploration. Techniques such as Vertical Electrical Sounding (VES), Induced Polarization (IP), and Self-Potential (SP) offer non-invasive means of assessing subsurface conditions, identifying aquifer zones, and minimizing the risk associated with borehole drilling [2]. VES, in particular, is widely used due to its capability to detect resistivity variations with depth, enabling the identification of aquifer structures and lithological stratification.

Previous studies in Kano State have demonstrated the successful application of these methods. For example, [3] applied VES in Tudun Wada LGA to delineate productive aquifers. Similarly, studies by [2] utilized SP, VLF, and resistivity techniques to assess groundwater potential and kaolin deposits near Minjibir. These studies identified distinct subsurface layers and proposed sites suitable for borehole development. Meanwhile, [4] investigated rainfall trends and groundwater dynamics in the Kano basement complex and found that although rainfall had increased since the late 1990s, groundwater levels declined due to over-extraction.

Despite these efforts, Bakarare village continues to face severe water shortages, particularly during the dry season. The village depends on a single surface water

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source that dries up seasonally, and its only borehole and well have both failed due to excessive extraction. Consequently, residents are forced to travel long distances to access potable water.

Given this context, the present study focuses on evaluating the groundwater potential of Bakarare village using a geophysical approach centered on VES. The objective is to identify aquifer zones, assess recharge potential, and provide data to support sustainable groundwater development in the area.

Location of the Study Area

Bakarare village is situated in the Minjibir Local Government Area of Kano State, Nigeria . It is bounded by Latitude 12°10'0"N to 12°13'30"N and Latitude 8°32'30"E to 8°36'0"E, covering an area of approximately 16 km² with a population of 794 as of the 2006 census. The village is surrounded by about six other villages: Sabon Gari Mallam to the north, Gorrike Garfe to the northeast, Goda and Kabuge to the northwest, and Kantama to the southeast as shown in Figure 1. Nature of Bakarare village's geology were characterized by a basement complex (as shown by legend in Figure 2) interplay of metamorphic and igneous process. The soil characteristics reflect the weathering of this of these rocks, resulting in soils suitable for various agricultural activities.

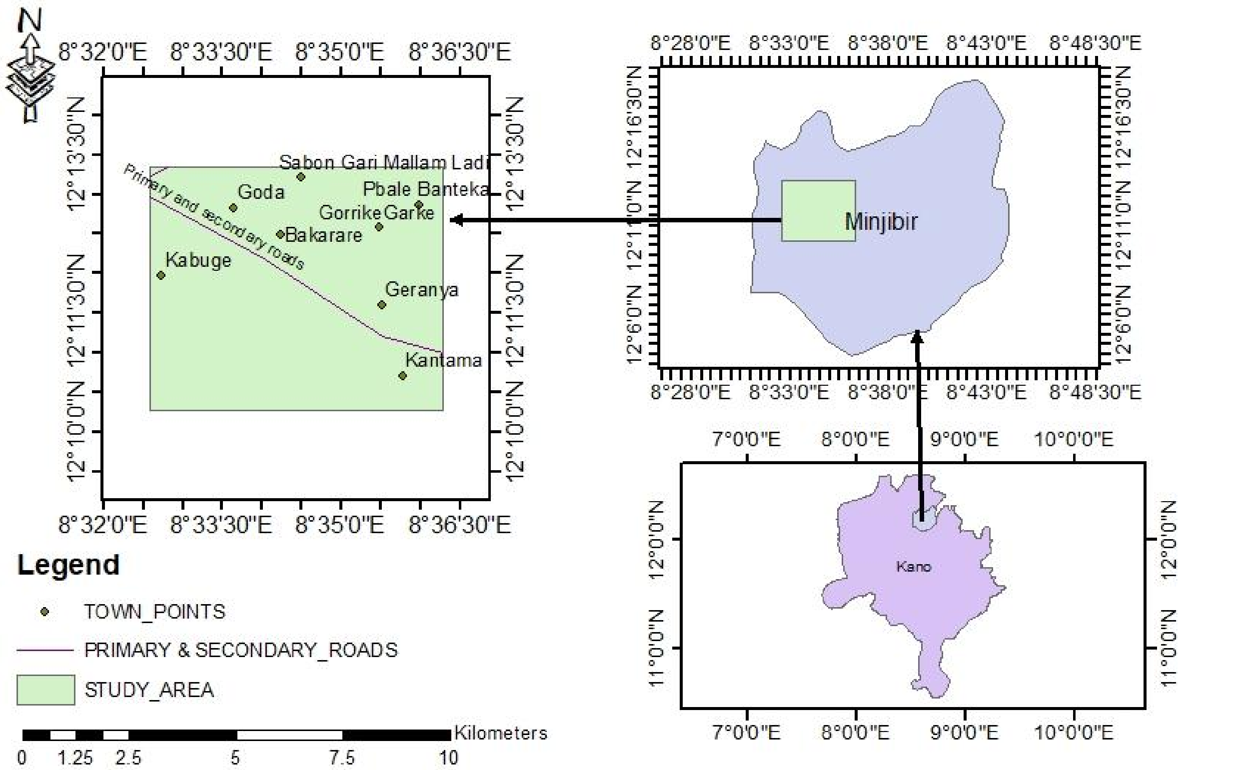

Figure 1: Location Map of the Study Area

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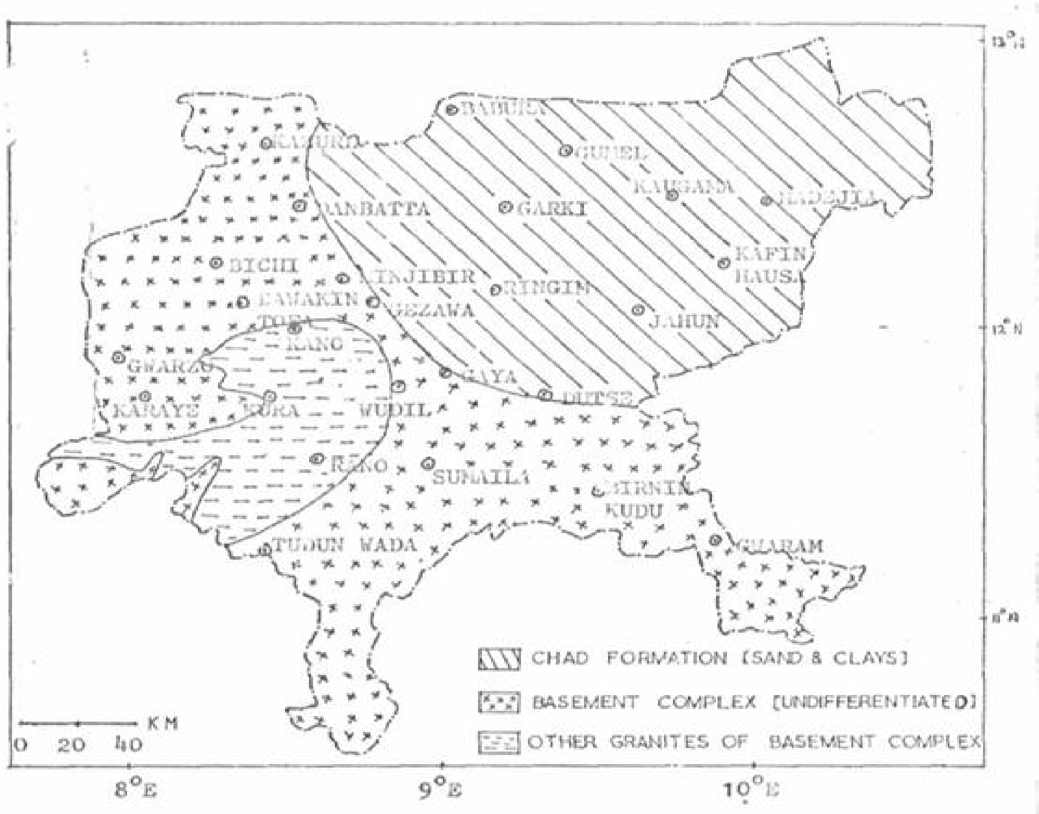

Figure 2: Geology Map Of Kano state, adapted for kano state intergrated rural deveplopment project 1979 [2]

THEORITICAL BACKGROUND

How well a substance resists electric current is determined by its electrical resistivity, which is often referred to as specific electrical resistance or volume resistivity. The ability of a material to carry electricity is measured by its electric conductivity. A low resistance material is one that easily allows electric current to flow through it. The S.I unit for electrical resistance is ohm while that of electrical resistivity is ohm-meter. According to [5], the electrical resistivity ρ of a region is expressed as

$$\rho = \frac{RA}{L} \qquad (1)$$

Where ρ = resistivity R = resistance, A = cross-sectional area of the conductor and L = length of the conductor

2.1 Direct Current Resistivity

Resistivity (ρ) quantifies a material's opposition to current flow and [5] has expressed it as

$$\rho = \frac{E}{J} \qquad (2)$$

where J and E are the current density and electric field in the region respectively.

However [5], in addition showed that the resistivity ρ can be generally expressed interms of geometrical factor (K) and resistance (R) of medium as

$$\rho = KR \qquad (3)$$

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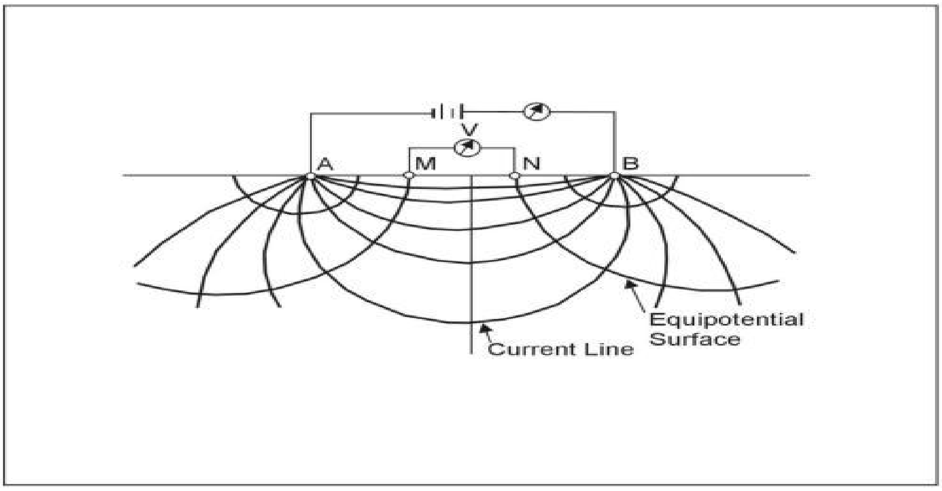

Figure 3: Equipotential surfaces and current flow lines [6]

For a four electrodes system [5] (two current and two potential electrodes) in a homogeneous and isotropic region, the K becomes

$$K = \left\{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right\} \quad (4)$$

Where r_1,r_2, r_3 and r_4 are the spacing between the electrodes respectively

There are many electrode arrangements namely, schlumbeger, wenner, Dipole-Dipole, pole-pole and pole-Dipole [5].

For schlumbeger array, [5] has shown that K assumed a particular expression as

$$K = \frac{\pi(L^2 - a^2)}{2aL} \quad (5)$$

Where a and L are the respective distances of potential and current electrodes from the investigation centre (b) (Figure 4)

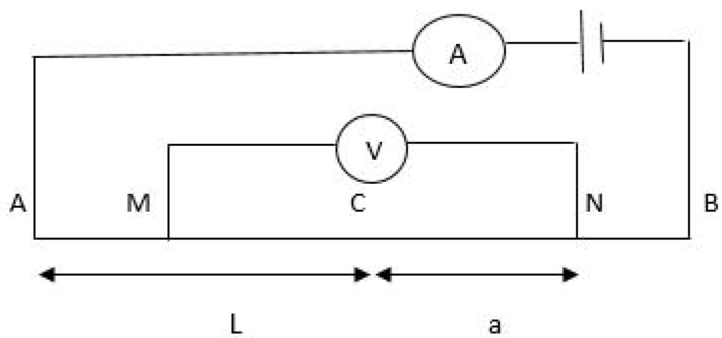

Figure 4: Schlumbeger array.

General Hydrogeology of the Study Area

According to [7] reported by [8] in his work describe that the aquifers within the basement complex region of Kano state are weathered and fractured rocks where groundwater exist under water table condition. Water table ranges at a depth generally less than 20m, and the greatest depth of boreholes rarely exceeds 60m. The hydraulic conductivity lies between 0.039 to 0.778 m/d with an average of 0.30m/d; transmissivity differs from 3.756 to 36.600 m^2/d with an average of 12.320 m^2/d; and specific capacity is between 0.054 and

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1.200m^3/d with an average of 0.360 m^3/d. [9] presents a composite hydrogeological section for the basement rocks having the general sequence as follows: lateritic sand or laterite top layer, silty sand, sandy clay, clayey sand or clay, weathered rocks and fresh bedrock. The mean depth to water table was put at 8.4 m while the maximum depth is 18.5 m.

MATERIALS AND METHODS

This section discussed the instrumentation, data acquisition, analysis and interpretation. These have been presented as follows.

Data Acquisition

This survey was conducted during rainy season from 27th Aug 2024 to 10th Sep 2024, the ABEM Terrameter SAS 1000 along with supporting components were used for data collection as were adopted by [10].

A total of 46 vertical electrical soundings (VES) were taken at regular space intervals using the Schlumberger array configuration. The survey area included both within and outside Bakarare village, as well as some parts of neighboring villages.

Inside the village, VES points were spaced 50 meters apart, while outside the village, the spacing was increased to 100 meters due to availability of space. At each VES point, geographic coordinates were recorded using GPS and apparent resistivity were measured and recorded using ABEM Terrameter SAS 1000.

The measurements were conducted using five electrodes planted in to the ground. One electrode was inserted in to the ground at the earth of the spread using hammer and this served as the reference point for the other electrodes. Two outer electrodes were placed as current electrodes to send electrical current through the ground, while two inner electrodes acted as potential electrodes to measure the electrical potential as shown in Figure 5.

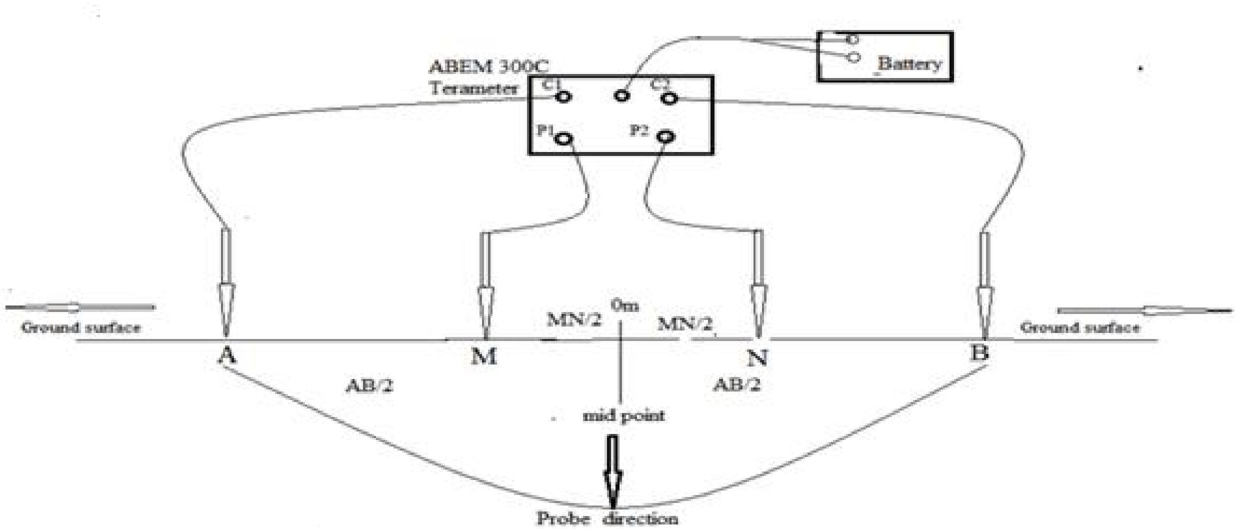

Figure 5: Schematic Diagram of schlumbeger array field method [11].

The current electrode spacing AB/2 ranged from 1 meter to 380 meters for the current electrodes, and from 0.5 meters to 15 meters for the potential electrodes (MN/2). All electrodes were arranged along a straight line, with measurements taken symmetrically from both sides of the central electrode.

For each VES point, the ABEM Terrameter was switched on, and the vertical electrical sounding mode was selected using the

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Schlumberger array. The current was set automatically. Apparent resistivity measurements were taken by entering the electrodes spacing (0.5 meters for potential electrodes and 1 meter for current electrodes) into the device, then pressing the "measure" button. The apparent resistivity values, displayed in ohm-meters, were recorded.

Subsequent measurements were made by expanding the spacing of the current electrodes, while keeping the potential electrodes fixed. Apparent resistivity were recorded for each new configuration.

After taking several readings, the potential electrodes were also moved further apart, and additional measurements were made.

Data analysis and Interpretation

IP2WIN and Surfer software were used to interpret the resistivity readings obtained in the field. The vertical electrical sounding (VES) data collected during the survey were first processed using IP2WIN. For each VES point, the resistivity values and the corresponding current electrode spacing (AB/2) were entered into the software. This created two display windows; one for the resistivity curves and another for the model parameters.

In the curve window, a graph plotting resistivity (ρ) against electrode spacing (AB/2) was generated. The graph typically included four superimposed curves. The histogram line represented the model parameter curve, while the enclosed circles denoted the actual field data. A smooth curve indicated the overall trend of resistivity variation with increasing depth, providing a clear visual interpretation of the subsurface conditions.

The model parameter window displayed important details such as the serial number, resistivity values in ohm-meters, model layer thicknesses, depths to the bottom of each layer from the surface, and altitudes of the respective layers. These details are illustrated in Figure 7 and Figure 8 as were demonstrated in the next section. In addition to the resistivity analysis, lithological data obtained from borehole logs (Figure 6) were used to construct a lithology layers table, presented in Table 1.

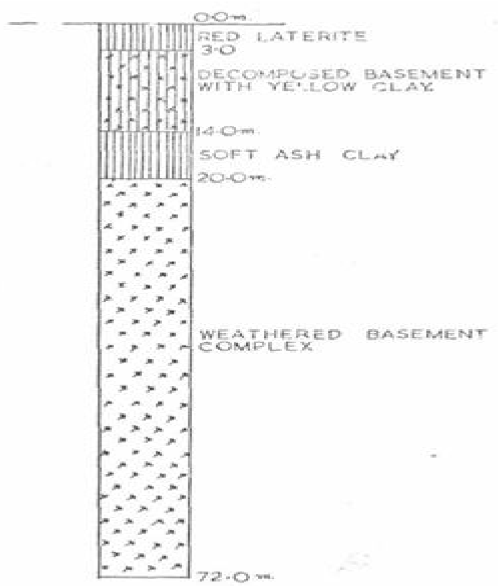

Figure 6: Lithology Borehole At Wasai [2].

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Table 1: Lithology borehole layers at Wasai

LAYERS	DEPTH (m)	LITHOLOGY
1	3	Laterite
2	14	Decomposed Basement with yellow clay
3	20	Soft Ash Clay
4	72	Weathered Basement complex

This lithology table was then compared with the model parameter data from IP2WIN (Figures 7 and 8 as were shown in the next section) to derive the interpreted layer parameters for resistivity, (which were shown in Table 3 as demonstrated in the next section). This step was essential for linking geophysical observations with geological interpretations and for preparing data for contour mapping.

To produce contour maps, the processed resistivity data were imported into Surfer software. The data for each VES station including resistivity values, layer depths, and thicknesses were compiled into an Excel spreadsheet. After importing this data into Surfer, a gridding process was performed to interpolate values between known points, allowing for the generation of smooth contour lines.

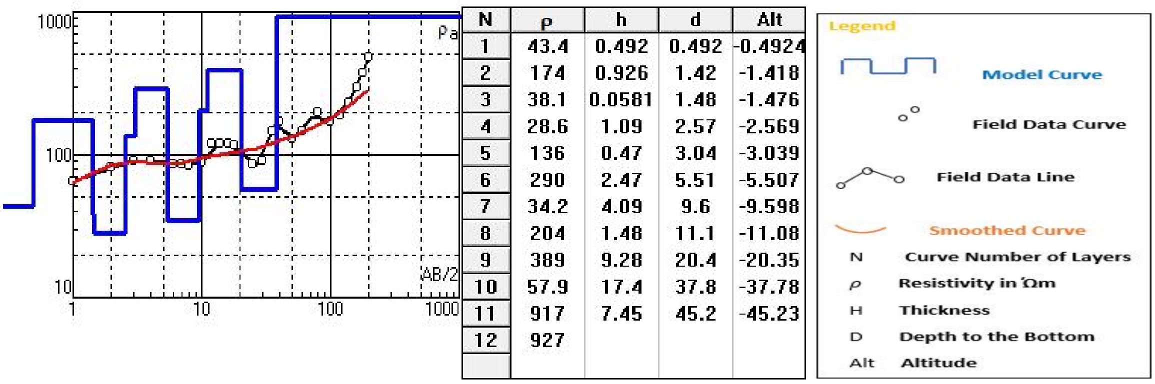
Based on this process, three contour maps were created. These include maps showing the thickness of the laterite layer, the aquifer layer, and the overburden. Each map provided insight into the subsurface distribution and geometry of these geologic units. The final maps are presented in the next section in Figures 9, 10, and 11.

Table 2: Conventional Classification of Resistivity in Relation to Groundwater Source: [12]

S/N	Resistivity (Ohm-m)	Depth (m)	Remark on Groundwater Occurrence
1	Above 500 Ohm-m	<10 – 20	Low
2	300 – 450	20 – 30	Moderate
3	30 – 400	30 to Above	High

RESULTS AND DISCUSSION

Figure 7 presents the result of VES 1 obtained from the resistivity analysis. In this figure, the modelled layer table window was cross correlated with the lithology layers shown in Table 1. The comparison revealed three distinct geologic layers: Laterite, Decomposed Basement with yellow clay, and Weathered Basement Complex.



N	ρ	h	d	Alt
1	43.4	0.492	0.492	-0.4924
2	174	0.926	1.42	-1.418
3	38.1	0.0581	1.48	-1.476
4	28.6	1.09	2.57	-2.569
5	136	0.47	3.04	-3.039
6	290	2.47	5.51	-5.507
7	34.2	4.09	9.6	-9.598
8	204	1.48	11.1	-11.08
9	389	9.28	20.4	-20.35
10	57.9	17.4	37.8	-37.78
11	917	7.45	45.2	-45.23
12	927			

Figure 7: Digitized Model of Interpreted VES 1.

The depths to the base of each layer were identified as follows: 2.57 meters for the Laterite, 11.1 meters for the Decomposed Basement with yellow clay, and 45.2 meters

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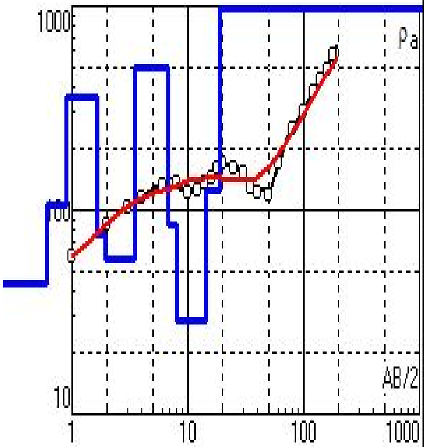
for the Weathered Basement Complex. These interpretations were based on the close agreement between the resistivity data and the borehole lithology log.

The model layer table also provided the resistivity ranges and thicknesses for each of the three layers. The Laterite layer exhibited resistivity values ranging from 43.8 Ωm to 28.6 Ωm, with a thickness of 2.57 meters. The Decomposed Basement with yellow clay had resistivity values between 136 Ωm and 204 Ωm, with a thickness of 8.57 meters. The Weathered Basement Complex showed higher resistivity values ranging from 389 Ωm to 917 Ωm and had a thickness of 34.13 meters. All corresponding values were recorded and compiled in Table 3.

Figure 8 displays four geologic layers as interpreted from the model layer table and cross-referenced with the lithology table in Table 1.



N	ρ	h	d	Alt
1	43.6	0.601	0.601	-0.6012
2	104	0.292	0.894	-0.8936
3	354	0.747	1.64	-1.64
4	76.7	0.332	1.97	-1.972
5	57.1	1.54	3.51	-3.512
6	499	3.21	6.72	-6.723
7	84.2	1.38	8.1	-8.105
8	28.4	6.37	14.5	-14.48
9	125	4.33	18.8	-18.81
10	6639	17.4	36.2	-36.19
11	23597	50.9	87.1	-87.05
12	23597			

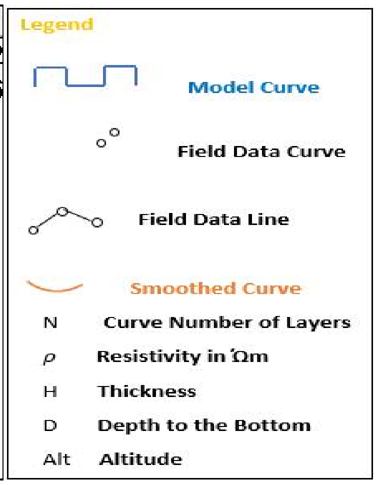


Figure 8: Digitized Model of Interpreted VES 2.

The first layer, identified as Laterite, has a low resistivity range of 43 Ωm to 76 Ωm. It occurs at a depth of 1.97 meters and has a thickness of the same value. According to Table 2, this resistivity range corresponds to a lithology with high groundwater potential.

The second layer, Decomposed Basement with yellow clay, shows a resistivity range between 57 Ωm and 84.2 Ωm. It is located at a depth of 8.1 meters and has a thickness of 6.13 meters. This layer is also interpreted to have high groundwater potential based on its resistivity and lithological characteristics.

The third layer, composed of Soft Ash Clay, presents a relatively low resistivity range from 28.4 Ωm to 125 Ωm. It appears at a depth of 18.8 meters with a thickness of 10.7 meters. This layer, too, is considered a high groundwater potential zone due to its low resistivity and composition.

The fourth and final layer shown in Figure 8 is the Weathered Basement Complex. It exhibits a very high resistivity value of 23,597 Ωm, suggesting a very low groundwater potential. This layer occurs at a depth of 36.2 meters and has a thickness of 17.4 meters. All these values have been recorded in Table 3.The same interpretation procedure was applied to the remaining 44 VES points.

Table 3 shows the interpreted layer parameters that were obtained from the resistivity analysis as were revealed in Figure 7 and Figure 8 when compared with borehole log data as demonstrated in Table 1.

Bima Journal of Science and Technology, Vol. 9(2A) Jun, 2025 ISSN: 2536-6041

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Table 3: Interpreted layer parameters for resistivity.

VES No	Latitude (°N)	Longitude (°E)	No of Layers	Resistivity Range (Ωm)	Depth (m)	Thickness (m)	Lithology
VES 1	12.20805	8.569167	1	43.4-28.6	2.57	2.57	Literate
			2	136 -204	11.1	8.57	Decomposed Basement with yellow clay
			3	389– 917	45.2	34.13	Weathered Basement complex
VES 2	12.2074	8.569817	1	43.6-76.7	1.97	1.97	Literate
			2	57.1-84.2	8.1	6.13	Decomposed Basement with yellow clay
			3	28.4 -125	18.8	10.7	Soft Ash Clay
			4	66-39	36.2	17.4	Weathered Basement complex

In VES 1, the first layer shows a high concentration of water, as indicated by its low resistivity values. Likewise, due to its low thickness, this layer is inadequate for significant groundwater storage. Although water is present, the volume is not enough to support continuous extraction.

The second layer in VES 1 also demonstrates low resistivity values, suggesting the presence of groundwater. Yet, like the first layer, its limited thickness makes it unsuitable for sustained water supply. On the other hand, the third layer exhibits moderate resistivity values, pointing to a moderate concentration of groundwater. Unlike the shallower layers, this zone has substantial thickness, making it a reliable aquifer for continuous groundwater extraction.

In VES 2, the first layer also indicates a high concentration of groundwater due to its low resistivity. However, the layer is too thin to support meaningful water extraction. The second layer mirrors this pattern low resistivity but insufficient thickness making it unreliable for water use. The third layer displays low to moderate resistivity, indicating moderate groundwater presence. With its moderate thickness, this layer could support limited extraction, but not heavy use.

The fourth layer in VES 2 shows very high resistivity values, which suggests the absence of groundwater. As a result, this layer cannot be considered a potential aquifer and is unsuitable for groundwater development.

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Thickness plays a critical role in assessing groundwater potential. Therefore, values for laterite thickness, aquifer thickness, and overburden thickness were extracted from Table 3 and presented in Table 4. The laterite thickness corresponds to the first/topsoil layer. The aquifer thickness was calculated by summing the decomposed basement with yellow clay (moderate aquifer) and the weathered basement complex (highly productive aquifer). Overburden thickness was obtained by adding the thicknesses of the laterite, soft ash clay, and aquifer layers.

This same analysis was applied to the remaining 41 VES points.

Table 4: Laterite thickness, Aquifer thickness and Overburden thickness.

VES NO	Longitude (°E)	Latitude (°N)	Laterite Thickness (m)	Aquifer Thickness (m)	overburden Thickness (m)
VES 1	8.569167	12.20805	2.57	42.7	45.27
VES 2	8.569817	12.2074	1.97	23.53	36.2
VES 3	8.570467	12.20679	2.39	57.55	70.01
VES 4	8.571167	12.20623	2.5	27.78	41.48
VES 5	8.571883	12.20565	1.76	56.38	68.72

From Table 4, the laterite thicknesses at VES 1, VES 3, and VES 4 are classified as moderate, while VES 2 and VES 5 exhibit thin laterite layers. This suggests that VES 1, 3, and 4 may have slightly more potential for near-surface groundwater storage compared to VES 2 and 5.

In terms of aquifer thickness, VES 3 and VES 5 demonstrate high values, indicating strong groundwater storage potential and suitability for continuous extraction. VES 1 and VES 4 have moderate aquifer thicknesses, while VES 2 has a thin aquifer layer, suggesting limited groundwater potential.

Overburden thickness also varies among the sites. VES 3 and VES 5 show high overburden thicknesses, supporting significant groundwater accumulation and protection from surface contamination. VES 1 and VES 4 exhibit moderate overburden thicknesses, and VES 2 shows a thin overburden, making it less favorable for sustainable groundwater extraction.

These observations were extended to the remaining 41 VES points. The results were analyzed and plotted using Surfer software to produce maps indicating regions with high, moderate, and thin thicknesses. These spatial distributions for groundwater extraction potential are displayed in Figure 9 (laterite thickness), Figure 10 (aquifer thickness), and Figure 11 (overburden thickness).

Two locations, marked in red on the map, exhibit the greatest laterite thickness, ranging from 2.5 meters to 3.0 meters. These zones suggest higher potential for groundwater storage within the laterite layer, but they also indicate reduced infiltration or recharge to the deeper aquifer zones due to the thick, compact nature of the laterite.

Areas covered in yellow represent zones with moderate laterite thickness, ranging from 2.0 meters to 2.4 meters. These locations show moderate groundwater storage capacity and similarly low potential for infiltration to deeper aquifers.

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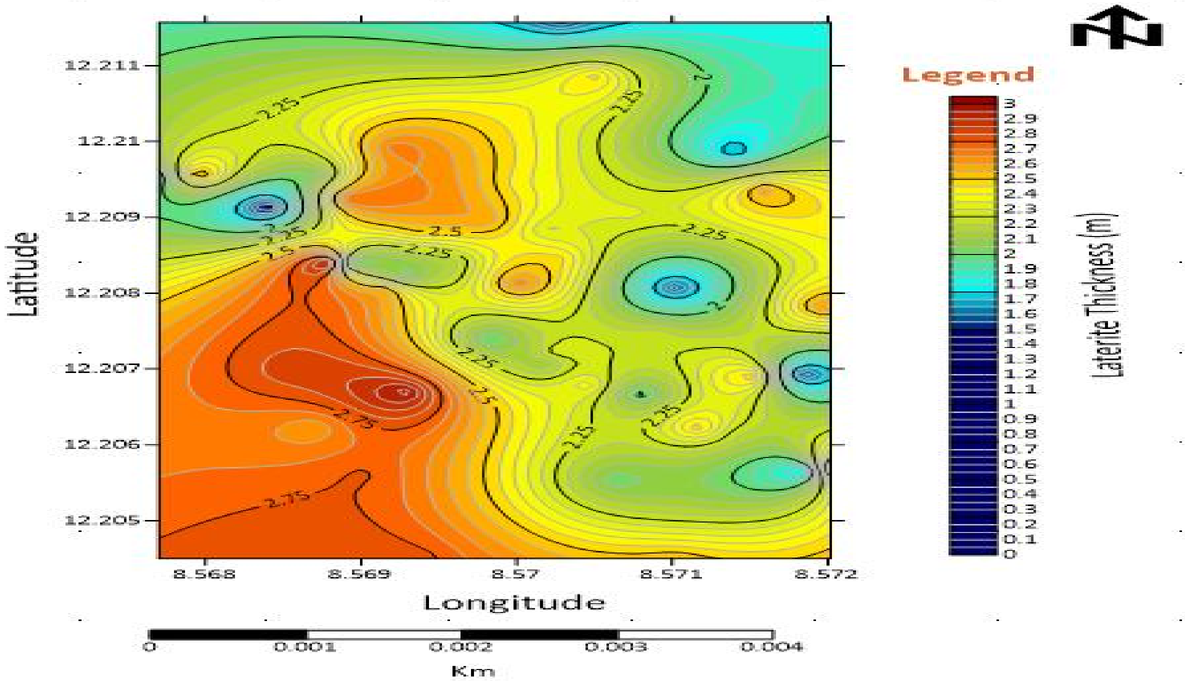

Figure 9: Laterite thickness map.

In contrast, areas shaded green, sea green, and dark blue correspond to thinner laterite layers, with thickness values ranging from 0.1 meters to 1.9 meters. These zones may store less groundwater in the laterite layer itself, but they are more favorable for recharge, allowing higher infiltration to deeper aquifer zones.

Figure 10 illustrates the distribution of aquifer thickness across the study area. Three distinct zones were identified based on variations in aquifer thickness.

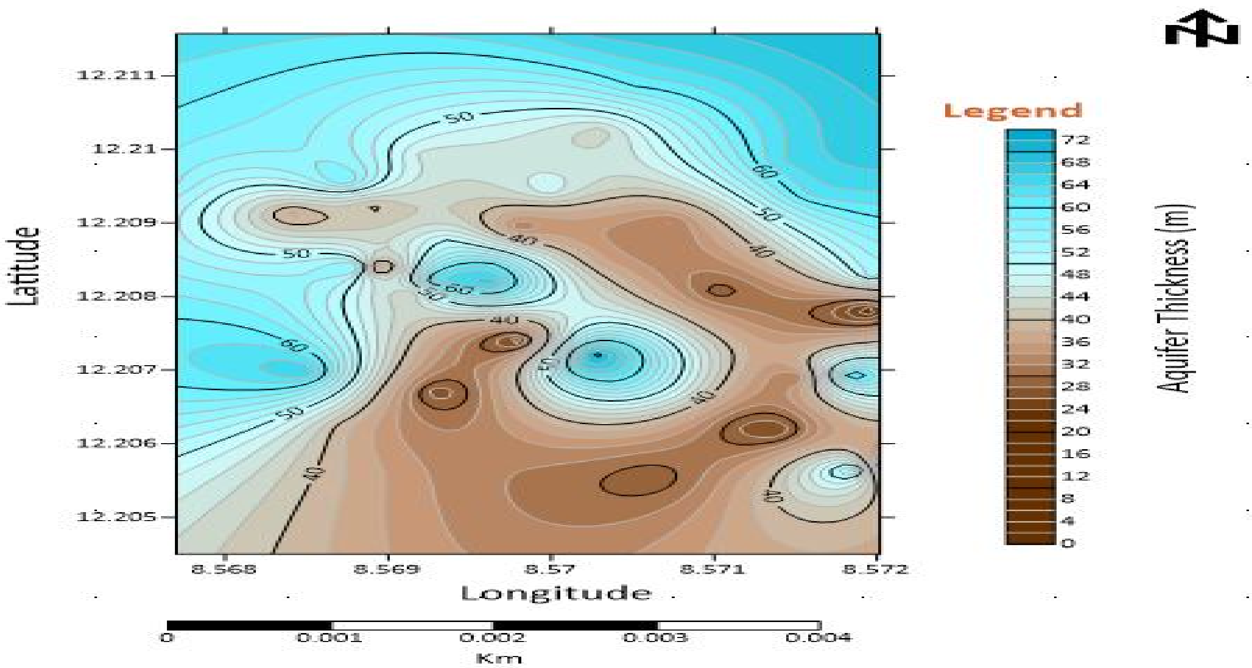

Figure 10: Aquifer thickness Map

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The first zone, which appears as sea green on the map, represents areas with high aquifer thickness, ranging from 40 meters to 72 meters. These areas indicate very promising groundwater zones with substantial accumulation. Due to the large thickness, these zones are suitable for continuous groundwater extraction over a long period.

The second and third zones are covered with brown and reddish-brown colors, corresponding to moderate and thin aquifer thicknesses, respectively. The moderate thickness ranges from 20 meters to 39 meters, while the thin aquifers range from 4 meters to 19 meters. These zones suggest moderate to low groundwater occurrence.

Figure 11, display the overburden thickness map across the study area, different colours were adopted to shows how the overburden thickness varies across the study area.

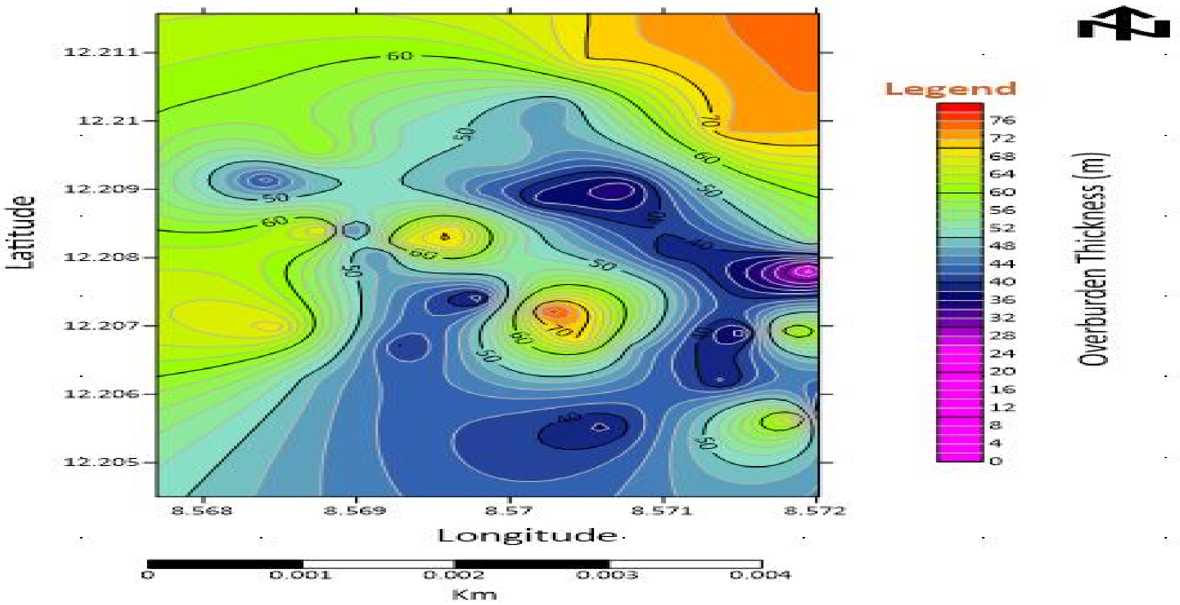

Figure 11. Overburden thickness Map

The spatial distribution of overburden thicknesses is shown in Figure 11. Areas with the greatest overburden thickness, ranging from 56 meters to 76 meters, are highlighted in red and sky green. These zones indicate regions of high groundwater accumulation, making them suitable for continuous and high-volume groundwater extraction.

In contrast, regions shaded in sea green and blue-black represent moderate and low overburden thicknesses. Specifically, moderate zones range from 56 meters to 32 meters, while low zones range from 28 meters to 4 meters. These areas are expected to have moderate groundwater accumulation and should therefore be considered for moderate levels of groundwater extraction.

According to [7], as cited by [8], borehole exploitation in basement complex areas rarely exceeds a depth of 60 meters. Based on this criterion, locations within the study area that fall within or below this depth threshold, as indicated in Table 3, are summarized in Table 5. These locations are identified as promising zones for successful borehole drilling.

Furthermore, areas with thin lateritic layers, which support rapid infiltration or recharge, along with substantial aquifer thicknesses at depths above 60 meters, should also be prioritized for drilling. These combined criteria highlight the most suitable locations

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for groundwater development in the study area, as presented in Table 5.

Table 5: Locations for groundwater potential zones interpreted from Table 5, 6 and appendix.

VES NO	Depth (m)	Laterite thickness (m)	Aquifer thickness (m)
VES 3	70	2.3	57.55
VES 5	70	1.76	56.38
VES 7	70	2.2	61.11
VES 11	70	2.98	57.54
VES 12	66.5	2.03	64.41
VES 13	69.85	2.25	67.6
VES 18	60.7	2.05	58.64
VES 21	65.1	1.54	63.55
VES 31	71	2.48	60.42
VES 32	68.1	1.55	66.53
VES 34	72	1.64	63.73
VES 36	64.8	2.29	62.25
VES 39	69.1	2.83	66.25
VES 44	68.5	2.1	66.37

CONCLUSION

This study comprehensively evaluated the groundwater potential of Bakarare village, Minjibir LGA, Kano State, Nigeria, using the Electrical Resistivity Method. The results successfully delineated groundwater potential zones and mapped the laterite, aquifer, and overburden thicknesses key parameters critical for sustainable water resource management. Fourteen key groundwater zones were identified at depths ranging from 60.7 m to 72 m and thicknesses between 56 m and 67.54 m. These zones located at VES 3, VES 5, VES 7, VES 11, VES 12, VES 13, VES 18, VES 21, VES 31, VES 32, VES 34, VES 36, VES 39, and VES 44 are highly promising for groundwater exploitation due to their favorable hydrogeological characteristics. Additionally, laterite thicknesses favorable for water infiltration or recharge to deeper aquifer zones were identified. Thin laterite layers ranged from 1.54 m to 2.10 m, while moderate laterite layers ranged from 2.25 m to 2.98 m. These layers enhance recharge potential and contribute to long-term aquifer sustainability. Overall, the findings highlight the effectiveness of the electrical resistivity method in groundwater exploration. The study provides a valuable foundation for informed decision-making regarding groundwater development and management in the study area.

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