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[1]Department of Geography, Umaru Musa Yar'adua University, P.M.B 2218 Katsina, Nigeria
[2]Department of Geography, Bayero University Kano, P. M. B. 3011 Kano, Nigeria

***Corresponding author's email:**
mudassirhk3@gmail.com

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Geo-electrical Investigation for Groundwater Exploration in Basement Complex Terrain of Kaita Area, Katsina State, Nigeria

Mudassir Hassan[1*], and Tasi'u Y. Rilwanu[2]

Geophysical survey using vertical electrical sounding (VES) was carried out to explore groundwater prospecting areas in Kaita area, Katsina state. Data from nineteen (19) representative VES survey points using Schlumberger array configuration were acquired, processed and interpreted. The results revealed aquifer resistivity range from 55.7 to 4625 Ωm while aquifer thickness ranges between 0.792 to 21.7m. Depth to aquifer ranges between 1.16 to 22.1 m. The transverse resistance ranges between 75.752 and 34568.1 Ωm^2 whereas the range of hydraulic conductivity is 0.147 to 9.088 m/day, likewise the range of transmissivity is 0.117 to 72.761 m^2/day from the estimated values. Low spatial variability of hydraulic conductivity suggests strong homogeneity of the aquifer system. From the results, it indicated that the greater part of the study area has low groundwater potential. Therefore it is recommended that VES 6 is suitable sites for borehole drilling which could result in very good yield of water and the depth of 20 - 25m should be targeted for groundwater development.

Keywords: Groundwater exploration, geo-electrical survey, hydraulic characteristics, Basement complex, Kaita area.

1. Introduction

Aquifer systems provide a significant portion of water for human consumption, as well as agricultural and industrial use. However, available water resources are limited in some part of the globe and diminishing due to human activities such as population growth, urbanization, and improved living standards (Panagiotou, *et al.,* 2024). Currently, the water crisis is worsening due to the unsustainable use of water resources and inadequate sanitation. Consumption is accompanied by a decline in the quality of these resources, usually associated with overexploitation and aquifer pollution (Eliades, *et al.* 2023). Several factors which have been shown to affect groundwater availability and use are both natural and man-made and these include climate, geology, pollution of aquifer, over abstraction, limited supply and distribution infrastructure. Beyond present discovery, exploration and exploitation, the sustainability of groundwater resource is also very crucial in order to meet current and future beneficial uses without causing unacceptable environmental or socio-economic consequences (Bostic, *et al.,* 2023).

The amount of water within any system is a function of the geology and other factors. Various geological environment are characterised with various groundwater resources. In the Basement complex for instance, the presence of heterogenous crystalline rocks such as gneiss, granite, chanokites etc, are impermeable in nature and contains negligible groundwater resources (Akintorinwa, *et al.,* 2020). To access the groundwater potential within the Basement complex it is important to locate geological structure within the subsurface that will aid the availability of water within the weathered and fracture zones. To identify this type of geological structures, geophysical investigations is one of the prominent methods to delineate them. Geophysical methods have the ability to determine not only the area with high groundwater potential but also estimate the relative quantity of the groundwater resources within the aquifer (Ogundana, and Falae, 2024).

Groundwater resources in Katsina state predominantly lie in weathered and fractured crystalline basement aquifers, which occupy about 80% of the land area and provide water resources to millions of people in the state (Ohenhen, *et al.,* 2023). The residents of the Kaita area in extreme northern Nigeria domiciled within the basement terrain have over the years suffered from water

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scarcity problems. This critical situation is due to the nature of groundwater occurrence in basement terrain, the low specific capacity of boreholes, consistent variations and discontinuities in aquifer properties as well as other complexities such as irregular subsurface structural characteristics associated with the exploration and quantitative assessment of the resources (Ebong, *et al.,* 2023). Several boreholes within the area under investigation have failed due to limited knowledge and understanding of the structural, hydrogeological, hydrological, and geomorphological conditions of the basement environment by some borehole contractors. The water needs for that area are provided from groundwater resources as the area lacks surface water. Unfortunately, these water resources are increasingly exposed to mismanagement. To ensure the long-term sustainability of aquifer yields and availability of water, there is need for wholesome consideration of protection and preservation from contamination. Therefore, this study aimed at exploring prospecting areas of groundwater of the area.

2. Materials and Methods

2.1. Study area and geological setting

Kaita area is located between latitude 13º04''50'N and 13º08''56'N and longitude 7º45''14''E and 7º75''38''E (Fig. 1). The landscape of the area is highly dominated by plain. It belongs to the tropical continental (wet and dry) climatic zone of northern Nigeria. It is characterized by short wet and long dry seasons, with very high annual temperature range. The study area receives few months of annual rainfall normally between June and October, having an annual average of about 600-650mm (Inkani, 2015). The study area recorded lower relative humidity in the months of April to May ranging between 10 - 15% when the atmosphere is most dry compared to its higher value of 70-80% in August/September when the highest amount of rainfall is received during the year (Inkani, 2015). The study area compose of Sudan Savannah vegetation belt, with scanty trees, shrubs and short grasses. The majority of the soils are derived from the Aeolian parent materials overlying quartz-rich geological formations such as crystalline rocks of the basement complex, overlain in turn by wind or water-borne deposits such as those of the Chad formation. The soils are predominantly sandy with low water holding capacity. The whole of the Katsina area is covered by Lithosols and the soils of lateritic formation formed under alternating dry and wet seasons (Danjuma, *et al* 2019)..

Geologically, about 98% of the state is underlined by the Basement Complex terrain which is characterized by nine geological formations consisting of biotite homeblend granite, coarse biotite homeblend granite, fine grained, granite gneiss, migmatite, porphyritic gneiss, ryolite, sandstone and Solicited sheared rock. The area considered in this research, Kaita area is underlain by coarse biotite homeblend granite and sandstone (Abdulkadir, *et al,* 2023).

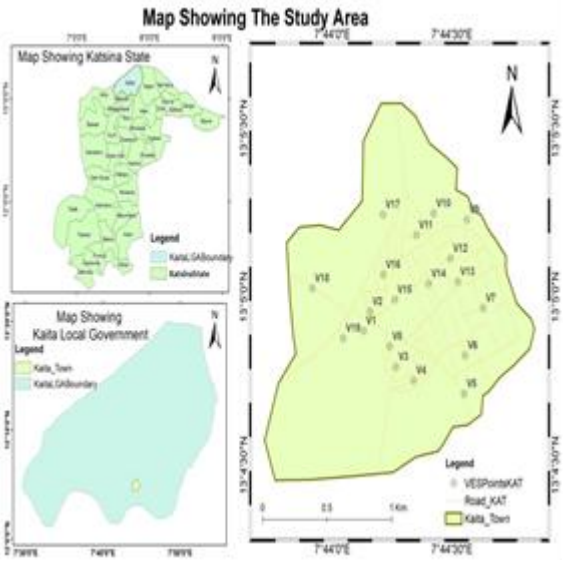


Fig. 1. Map showing the study area.

2.2. Data collection, interpretation and analysis

Vertical electrical sounding technique was employed in this investigation, ABEM Terrameter SAS 4000 was utilized in measuring the earth resistance. Nineteen (19) electric sounding were carried out using the Schlumberger array with current electrode spacing (AB/2) ranging from 1m to 100 m while potential electrode spacing (MN/2) ranged from 0.5 m to 5 m. The values of resistance (*R*) were obtained directly from the resistivity meter, and the product of resistance (*R*) obtained and geometric factor (*K*) gives the apparent resistivity (ρ). The value of apparent resistivity (ρ) against half-electrode spacing (AB/2) was first plotted manually on a logarithmic graph, and the graphs were interpreted using master curves and auxiliary charts (Orellana and Mooney 1966). Output from the quantitative manual interpretation was modelled using computer software. The IPI2Win version 1.0 interpretation software was used for the iteration and presentation of the curve in order to generate the geoelectric parameters

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2.3. Estimation of aquifer hydraulic parameters

The transverse resistance R is given by:

$R = \sum_{i=1}^{n} hp$ i

Hydraulic conductivity can be determined using:

$K = 386.40R^{\frac{-.93283}{rw}}$ ii

where K = hydraulic conductivity and R_{rw} = aquifer resistivity.

The aquifer transmissivity (Tr) was estimated using the relation (Niwas and Singhal 1981):

$Tr = K\sigma T = KS/\sigma = Kh$ iii

where r is the electrical conductivity (inverse of resistivity), S is the longitudinal conductance and T is the transverse resistance.

Equations (ii) and (iii) were used to determine the hydraulic conductivity and transmissivity of aquifers.

Table 1. Transmissivity/aquifer potential scale

S/no	Range	Potential
1	> 500 m^2/day	High potential
2	50 – 500 m^2/day	Moderate potential
3	5 – 50 m^2/day	Low potential
4	0.5 – 5 m^2/day	Very low potential
5	<0.5 m^2/day	Negligible potential

Source: (after Gheorghe, 1978).

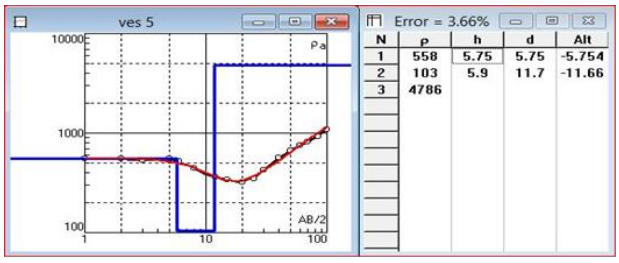


Fig. 2. Showing VES 5 curve type

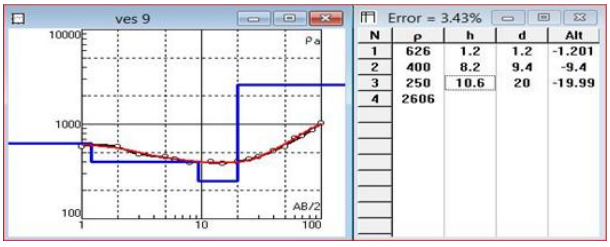


Fig. 3. Showing VES 9 curve type

3. Results and Discussion

The resistivity of the aquifererous unit (Table 2, Fig. 4) within the study area ranges from 55.7 to 4625 Ωm with the average value of 520.94 Ωm. The spatial distribution map revealed the extreme northwest and south east having the lowest resistivity values while the eastern to the central portion of the study area has the highest resistivity values. Consequently, the north-western to the southwestern and southeastern portion of the study area has a higher potential for groundwater (Fig. 4) occurrence than the central portions. This is related to the geological formation of the area.

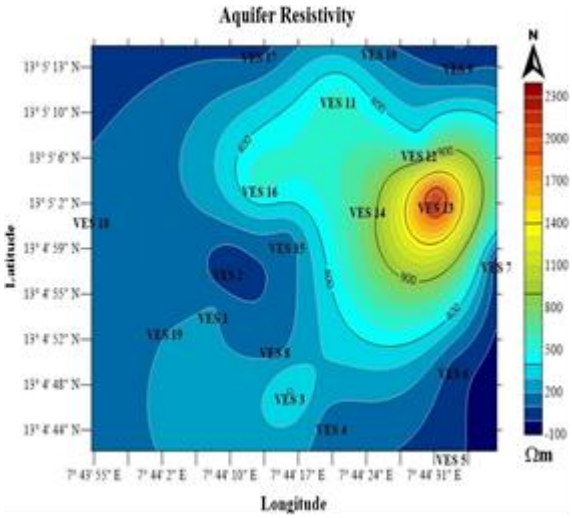


Fig. 4. Spatial distribution of aquifer resistivity.

Aquifer thickness played a critical role in characterizing the vertical extent of saturated zones within an aquifer. It serves as a controlling factor in determining the volume of water that can be stored within the aquifer, consequently influencing the potential amount of extractable groundwater (Stanly, *et al.,* 2022).The aquifer thickness, *h*, (Table 2 and Fig. 5) ranges from 0.792 to 21.7 m with a mean value of 6.178 m. The majority of the study area has a lower aquifer thickness (≤ 5 m). Low aquifer thickness can imply low water volume and by extension, low water yield to a well bore. Greater thicknesses in the southwest suggest a possible increase in groundwater storage capacity, which increases the possibility of groundwater extraction in this area. These results have important ramifications for managing groundwater resources since thicker aquifers may provide more conducive circumstances for environmentally friendly extraction methods.

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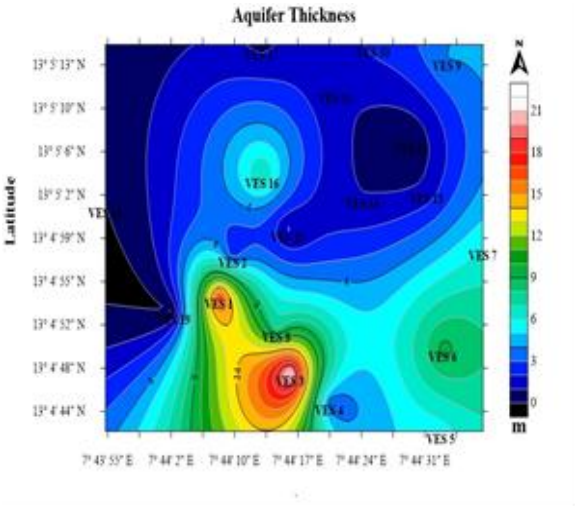


Fig. 5. Spatial distribution of aquifer thickness

The aquifer depth represents the vertical distance between the saturation zone and the overlying zones of aeration, situated above the water table (Ejepu, *et al.,* 2024). The observed depth to the aquifer (Table 2, Fig. 6) varied from 1.16 – 22.1 m with a mean value of 8.962 m. A higher depth of the aquifer was observed at the extreme southwestern parts of the study area. These variations in aquifer depth highlighted the heterogeneity of subsurface conditions and the complex interaction between hydrological processes and geological formations (George, *et al.,* 2020). Therefore, approximately about 20 to 25 m should be considered for sitting boreholes in these areas for groundwater development.

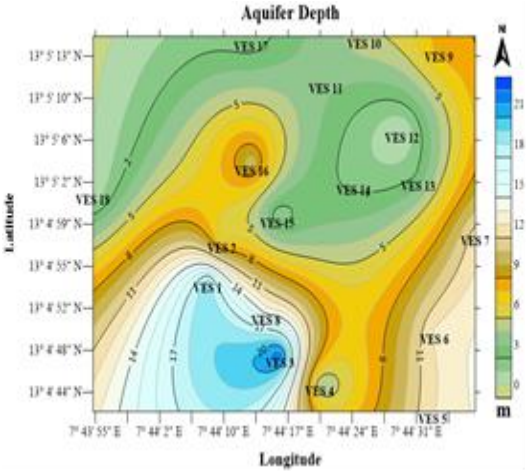


Fig. 6. Spatial distribution of aquifer depth.

Table 2: Locations and aquifer properties of the study area.

VES No.	Coordinates (UTM)	Coordinates (UTM)	Elevation (m)	Aquifer resistivity ρ (Ωm)	Aquifer thickness h (m)	Depth to aquifer (m)
1	0362912	1446509	439	210	17.2	18.4
2	0362960	1446614	439	70.2	2.38	5.81
3	0363155	1446310	437	1593	21.7	22.1
4	0363288	1446235	441	136	3.34	3.78
5	0363669	1446160	440	103	5.9	11.7
6	0363677	1446370	435	66	9.38	12.2
7	0363815	1446628	437	105	5.97	11.5
8	0363108	1446423	441	135	7.68	13.7
9	0363695	1447113	442	250	10.6	20
10	0363443	1447149	436	120	2.26	4.78
11	0363313	1447032	447	159	1.2	3.26
12	0363570	1446901	452	469	∞	∞
13	0363623	1446774	438	55.7	1.36	2.26
14	0363405	1446764	440	765	1.05	1.77
15	0363148	1446678	449	143	0.837	1.16
16	0363062	1446816	441	574	7.2	9.72
17	0363061	1447144	441	4625	0.792	1.25
18	0362525	1446743	446	123	∞	∞
19	0362757	1446470	448	196	∞	∞

Transverse resistance plays a crucial role in characterizing the resistance encountered by groundwater as it flows laterally within the aquifer. It provides insights into the level of hindrance faced by groundwater moving perpendicular to the hydraulic gradient (George, 2020; Ejepu, *et al.,* 2024). The transverse resistance (R) of the study area ranged from 75.752 to 34568.1 Ωm^2 with the mean value of 3344.271 Ωm^2. The areas around VES 3, 16 and 17 are characterized by relatively high tranverse unit resistance values, while low values are observed around VES 2, 10, 11, 13, 15. Zones with high transverse unit resistance values are likely characterised as areas with high recharge capability and thus render them the best groundwater exploitation targets in the area. The spatial distribution map (Fig. 6) revealed majority of the study area (northwest, north-eastern and south-eastern part) have low values of transverse resistance. For the purpose of analyzing

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groundwater flow dynamics, identifying possible groundwater replenishment or discharge locations, and determining the aquifer's susceptibility to contamination, an understanding of aquifer transverse resistance is vital. (Ejepu, *et al.,* 2024). This result is in agreement with the findings of Ankidawa, *et al*., (2023).

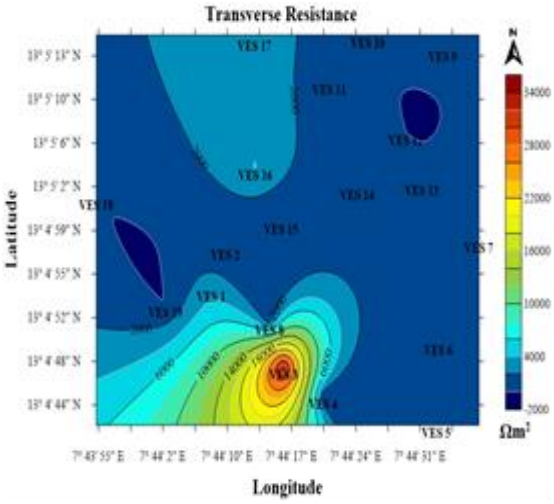


Fig. 6. Spatial distribution of transverse resistance

Hydraulic conductivity is a measure of the ease with which a fluid will pass through a medium (Heigold, *et al.,* 1979). Hydraulic conductivity of the study area was shown in Fig. 7. The aquifer hydraulic conductivity (K) ranges from 0.147 – 9.088 m/day with the average value of 3.659 m/day (Table 3). The high range of hydraulic conductivity of the aquifer may be due to the heterogeneity nature of the aquifer, a condition responsible for wide range in hydraulic conductivity (George *et al.,* 2015). The spatial distribution of hydraulic conductivity (Fig. 7) revealed low hydraulic conductivity values throughout the majority of the area, suggesting that the limited aquifers' geologic restrictions make groundwater flow in the area complex rather than simple. This study is in line with the findings of Obiora, *et al*., (2016).

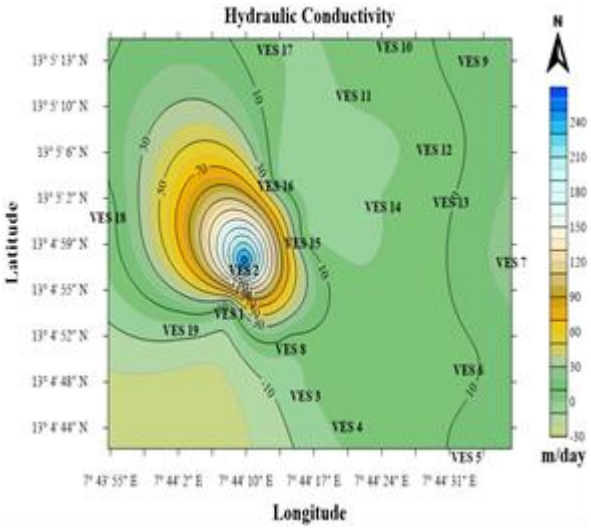


Fig. 7 Spatial distribution of hydraulic conductivity.

Transmissivity is a crucial parameter that quantifies an aquifer's ability to transmit groundwater across its saturated thickness. It represents the volume of water that can flow through a unit width of the aquifer under specific hydraulic gradient conditions. The transmissivity (Tr) value ranges from 0.117 – 72,761 m^2/day with an average value of 19.369 m^2/day (Table 3), Area with high transmissivity values can be identified as area of high water bearing potential and aquifer materials are known to be relatively permeable to fluid movement and potentially higher yields. Conversely, lower transmissivity values suggest areas with reduced permeability, limiting the groundwater flow potential. This information aids in optimizing well placement and designing sustainable extraction strategies, considering the varying transmissivity characteristics across the study area. The spatial distribution of transmissivity was illustrated in Fig. 8. The greater part of the study area has low trasmissivity. Thus, indicating that the area is of low groundwater potential.

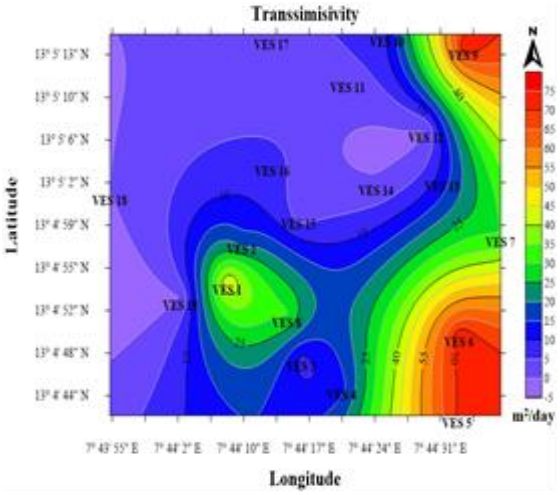


Fig. 8. Spatial distribution of transmissivity

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Table 3 Summary of aquifer hydraulic parameters

VES No.	Name of Locations	Transverse resistance R=hρ	Hydraulic conductivity K (m/day)	Transmissivity Tr = Kh (m^2/day)	Aquifer potentials
1	Unguwar yamma 1	3612	2.635	45.322	Low
2	Unguwar yamma 2	167.076	7.323	17.429	Low
3	Solan Nasha 1	34568.1	0.398	8.6366	Low
4	Solan Nasha 2	454.24	3.952	13.200	Low
5	Old SDP 1	607.7	5.122	30.220	Low
6	Old SDP 2	619.08	7.757	72.761	Moderate
7	Kofar gabas 1	626.85	5.030	30.029	Low
8	Kofar gabas 2	1036.8	3.979	30.559	Low
9	Ung. Kwalabe	2560	2.239	23.733	Low
10	Kofar arewa 1	271.2	4.441	10.037	Low
11	Kofar arewa 2	190.8	3.416	4.099	Very low
12	Unguwar Galadima	0	1.245	0	Negligible
13	Kofar fada	75.752	9.088	12.360	Negligible
14	Kalgon salame	803.25	0.789	0.829	Very low
15	Bayan kasuwa	119.691	3.771	3.157	Very low
16	Kofar yamma 3	4132.8	1.031	7.423	Low
17	Bayan asibiti	3663	0.147	0.117	Negligible
18	GSS Kaita	0	4.340	0	Negligible
19	Near L.G.A.	0	2.810	0	Negligible

4. Conclusion

The results of the study showed that the aquifer resistivity range from 26.5 to 4625 Ωm while aquifer thickness ranges between 0.792 to 21.7m, aquifer depth varied from 1.16 to 22.1m. The transverse resistance ranges between 75.752 and 34568.1 Ωm^2 whereas the range of hydraulic conductivity is 0.147 to 9.088 m/day, while the range of transmissivity is 0.117 – 72.761 m^2/day from the estimated values. It was also observed that the most part of the study area has low groundwater potential. It is recommended that VES 6 is suitable sites for borehole drilling which could result in very good yield of water and the depth of 20 - 25m should be targeted for groundwater development. Other methods of geospatial and geophysical investigation like GIS and remote sensing, electrical tomography (2D) should be used together with SAS 4000 used in this study to validate the observations herein.

Conflict of interest

The authors declare no conflict of interest.

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