Communication in Physical Sciences, 2025, 12(2) 696-709

Investigation Of Basement Aquifer Hydraulics And Protective Capacity Within Jimbge And Environs, North Central Nigeria

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Received: 16 December 2024/Accepted 18 February 2025/Published: 24 February 2025
https://dx.doi.org/10.4314/cps.v12i3.4

Abstract: *Different geological elements, including faults/folds, fractures, and hydrogeological units, influence an area's groundwater availability. An evaluation of the study region's hydrological characteristics, such as groundwater availability, aquifer depth, the division of the subsurface into distinct geo-electric layers, and the categorization of the underlying geology as fresh basement, weathered basement, or fractured bedrock, is the goal of this study. Using the Schlumberger arrangement, Vertical Electric Sounding (VES) was used to collect data in 15 sites. A software called WinResist was used to process the data and plot it in order to create the curves. By doing this, the data's inherent noise and field inaccuracies are eliminated. Aquifer resistivity and thickness were calculated from the curves in order to determine the Dar Zarrouk characteristics. There are five (5) geo-electric strata, according to the results. Top soil with lateritic clay has resistivity and thickness between 9.9-288.8 Ωm and 0.9-6.6 m; the weathered basement layer has thickness and resistivity between 8.0-717 Ωm and 0.8-34.2 m; the confining fairly weathered basement has thickness and resistivity between 3.2-106.9 m and 63.6-70636.0 Ωm; and the weathered/fractured basement aquifer has thickness and resistivity between 299.1-1997.0 Ωm and 4.1-29.7 m. The resistivity of the newly constructed basement ranges from 2778.8 to 10,0000.0 Ωm, and its thickness is unknown. The range of values for the aquifer resistivity, hydraulic conductivity, and transmissivity is 299.1-5438.0 Ωm, 0.049-1.895 m/day, and 0.284-23.243 m2/day, respectively. Based on weathered and fractured aquifers, this showed that most VES areas have moderate to good groundwater potential. However, with values ranging from 0.0004-0.0405 mhom, its aquifer protection capacity is inadequate. This demonstrated the aquifer's susceptibility to pollution and the need for appropriate groundwater development both before and after drilling operations.*

Keywords*: Weathered basement, Aquifer, Resistivity, Dar-Zarrouk, Jimgbe, Central Nigeria.*

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1.0 Introduction

The availability of groundwater potentials is regulated by the basement rocks' fracturing and joints. Both shallow wells in the overburden, which dries out during the dry season, currently provide the study area's water supply. The community's sole source of water is still the surface water supply from the River Ohunene. Therefore, these sources are deemed insufficient to meet the rising community's water supply needs. Additionally, it is imperative to determine the hard rock area's groundwater potential due to the river's distance from the different villages and the inherent risk of pollution (Ajayi and Adegoke, 1988). Consequently, the existing surface water supply facility is to be expanded to provide for the projected demand (Ajayi and Adegoke, 1988; Akpah et al., 2023).

In their fresh compact condition, the majority of crystalline rocks are mostly impermeable and do not store groundwater, making them poor aquifers. However, good to very good aquifers occur in fractured and faulted zones of crystalline rocks that occur to considerable depth or weathered rocks (Kizito et al., 2023a, 2023b; Hudu et al., 2024). Wells drilled in such areas of deep weathering or intense fracture joint systems produce high yields. Yields of boreholes in crystalline rocks are highly variable but many high yield boreholes for domestic and industrial water supply have been drilled in Nigeria and many parts of the world. Olayinka and Olorunfemi (1992) also reported a borehole yield of 23 m^2/hr in Okene, Kogi State. Various researchers (Acworth, 1987 and Olayinka and Mbachu, 1992) have reported yields varying from 1.6 to 23 m^2/hr at various basement complex areas.

Environmental degradation poses significant challenges to the sustainability of ecosystems, human societies and the planet earth as a whole (Chijioke-Churuba, 2023; Chijioke-Churuba, 2024; Juliet, 2023). To make it easier to investigate and assess groundwater resources, new technology for groundwater research, improved hydrological knowledge, and effective data processing techniques are required (Kosinki and Kelly, 1981; Ayers, 1989; Agboola et al, 2024; Amarachukwu et al, 2024). Geophysical investigations are essential for evaluating and quantifying the hydrogeological properties of basement rocks. Techniques such as seismic, gravity, magnetic, electromagnetic, and electrical resistivity surveys are widely recognized in geological research (Aminu et al., 2022a; Kizito et al., 2023a). Having uses in hydrogeology, environmental geology, and geotechnical engineering, surface resistivity techniques stand out among these in a variety of field circumstances and geological settings (Beresnev et al., 2002; Vchery and Hobbs, 2003). The geographic variability of aquifer parameters, such as hydraulic conductivity, transmissivity, and depth, is often determined using a variety of study approaches (Allen et al., 1997; Adeniji et al., 2022). Pumping tests, permeameter measurements, and grain size analysis are examples of conventional techniques for figuring out hydraulic characteristics. These techniques are intrusive, costly, and frequently have a narrow scope. Usually, these techniques only offer information for a limited portion of the aquifer close to the borehole or compile data over a greater volume (Mendosa et al., 2003; Niwas et al., 2011; Obasi et al., 2023). Extrapolating aquifer characteristics between boreholes is frequently difficult because there is insufficient information to support it, claim Niwas and Lima (2011). The geographic variability of aquifer parameters, including hydraulic conductivity, transmissivity, and aquifer depth, is frequently estimated using a variety of research methodologies in order to overcome this difficulty (Allen et al., 1997; Adeniji et al., 2022).

2.0 Location and Geologic Setting

The research location can be found in the Ajaokuta Local Government area of Kogi State, Nigeria, approximately 4 km north of Jimgbe and 20 km northeast of Adogo. On a 1:25,000 scale, the region is 20 km² in size and lies between longitudes 7° 32' 00" and 7° 37'007" N and latitudes 6° 35' 58" and 6° 41' 57" E (Fig. 1). The region is typically about 150 meters above sea level.

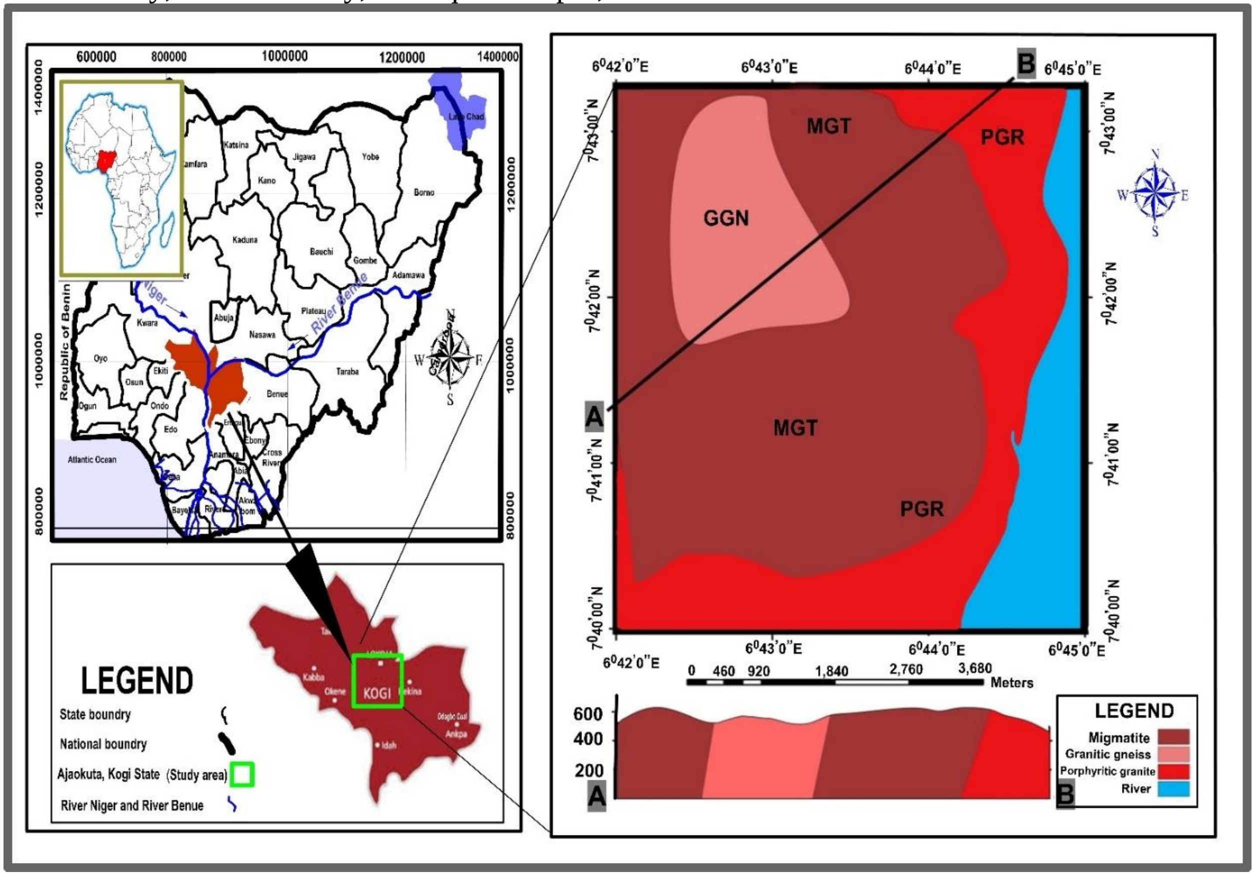

Fig. 1: Geology Map of the Study Area.

Within the studied area, the drainage pattern is dendritic, with the Osara and Uba rivers draining the region. Join Rivers Niger, a significant geomorphic feature in the region, is when the rivers flow eastward. The region has a mix of savannah and tropical forest, with a variety of grasses, trees, and plants. The region encounters a brief wet season (May–September) and a long dry season (October–April), which makes for a unique climate. It rains between 1000 and 1500 mm on average each year, and the average temperature is around 26.1°C.

The rocks found at Jimgbe are composed of meta-igneous rock and migmatized and unmigmatized parachist, and they resemble the rocks found in the basement complex (Ajayi et al., 1988). Granite gneiss and migmatitic rocks comprise the basement complex (Aminu et al., 2022b). Granite gneiss and migmatitic rocks make up the basement complex (Odinaka et al., 2023; Nanfa et al., 2022).Nigeria may have two separate provinces that make up the Basement Complex. They are the western province, which is defined by narrow, sediment-dominated, N-S trending, low-grade schist belts in a primarily migmatite-gneiss "older" basement; and the eastern province, which is primarily composed of migmatite-gneiss complex, intruded by large volumes of Pan-African granites.

The Nigerian basement rocks are believed to have been formed through major orogenic events, including deformation, metamorphism, granitization, gneissification, and remobilization. These processes are associated with the Liberian (2700±200 Ma), Eburnean (2000±200 Ma), Kibaran (1100±200 Ma), and Pan-African (600± Ma) orogenic cycles (Obaje, 2009). The region contains a variety of features, including folds, fractures, and foliation, which are attributed to the Pan-African Orogeny imprints and trend NW-SE and NE-SW. Amphiboles, Migmatite gneisses, Granites, and Pegmatites are the principal lithologies. The schists, which include muscovite, quartzite, talc-tremolite, and biotite schists, are other significant rock units (Obaje 2009). Odigi (2000) reported that the meta-igneous rocks, referred to as migmatitic gneisses in the Okene-Lokoja area, are calc-alkaline and display moderately alkaline characteristics, suggesting their derivation from an ensialic calc-alkaline magma. The most common rock types in the research region are augen gneiss, migmatites, and biotite gneiss, with pegmatites and quartzo-feldspathic veins occurring in smaller quantities (Imasuen et al., 2013). These rocks are hosted within the country rock, which predominantly comprises migmatites, the most abundant rock type in the region.

3.0 Methodology

3.1 Hydro-geophysical Survey

Using a DDR3 Geosensor resistivity meter, fifteen (15) vertical electrical sounding (VES) measurements were made throughout the research region. Using half-current electrodes (AB/2) spaced 1–200 meters apart and half-potential electrodes (MN/2) spaced 0.5–15 meters apart, the Schlumberger electrode design was used. The data acquisition process began with the lower electrode spacing (current electrode at 1 m and potential electrode at 0.5 m) and progressed to the higher electrode spacing once the apparatus was configured according to the aforementioned electrode array. Until a lower resistance value was seen and the potential electrode spacing was altered, the current electrode spacing continued to increase and the potential electrode spacing remained constant until the survey's conclusion. Resistance (R) was the result of sending current to the ground. Equation 2 produces apparent resistivity (ρa), which is the product of the obtained resistance (R) values and the geometric factor (K), as determined by equation 1. The highest percentage of current flows in the topmost layers when the electrodes are close tThe resistivity of deeper layers was shown to increase with the electrode spacing (current and potential electrodes). According to Zohdy's (1989) description, the electric resistivity was therefore calculated as a function of electrode separation.

$$K = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] \qquad (1)$$

$$\rho_a = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] R \qquad (2)$$

3.2 Data Analysis and Dar-Zarrouk Parameters

The data received from the field underwent the software (WinResist) for the computer iterative modelling on the basis of linear filter theory (Zohdy, 1989). The software generates a plot of apparent resistivity (ρa) against half-electrode spacing (AB/2), producing a smooth curve with distinct geoelectrical properties such as layer resistivity, thickness, and depth. To refine the results, each dataset underwent thirty (30) computer iterations, ensuring a smooth curve and achieving a root mean square (RMS) error of less than 10%.

Understanding the groundwater potential requires considering various combinations of the geoelectrical layer's thickness and resistivity (Zohdy et al., 1974; Maillet, 1947).

The Dar Zarrouk parameters, which are the transverse unit resistance (TU) and longitudinal conductance (S), are shown in equations 3 and 4. Using Equations 5 and 6, hydraulic conductivity (K) and transmissivity (T) were also computed (Raji and Abdulkadir, 2020b).

Transverse unit resistance

$$T_U = h\rho_a \ (\Omega m^2) \tag{3}$$

Longitudinal unit conductance

$$(S) = \frac{h}{\rho_a} \ (\text{mhom}) \tag{4}$$

Hydraulic conductivity

$$K = 386.40\ \rho_a^{-0.93283}\ (\text{m/d}) \tag{5}$$

Transmissivity

$$T = \sigma T_U = \frac{KS}{\sigma} = Kh \quad (\text{m}^2/\text{d}) \tag{6}$$

Transverse unit resistance (TU), longitudinal unit conductance (S), aquifer thickness (h), hydraulic conductivity (K), aquifer resistivity (ρa), and electrical conductivity (σ), the reciprocal of resistivity, are all used in this context.

4.0 Results and Discussion

4.1 Groundwater Potential from VES

The layer curve was plotted using the VES data collected in the field, and its interpretation was done using the analytical technique approach, which involved estimating the number of layers, their approximate resistivities, and their thickness, as shown in Fig. 2 and Table 1

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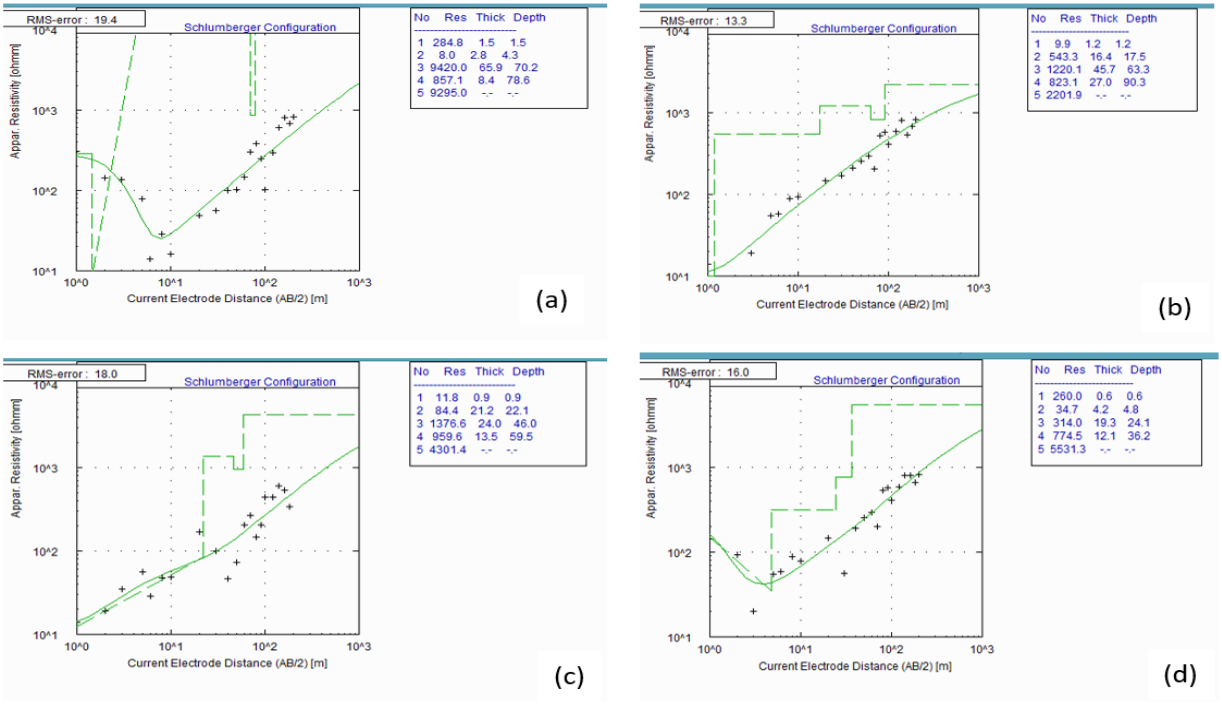

No	Res	Thick	Depth
1	284.8	1.5	1.5
2	8.0	2.8	4.3
3	9420.0	65.9	70.2
4	857.1	8.4	78.6
5	9295.0	-.-	-.-

No	Res	Thick	Depth
1	9.9	1.2	1.2
2	543.3	16.4	17.5
3	1220.1	45.7	63.3
4	823.1	27.0	90.3
5	2201.9	-.-	-.-

No	Res	Thick	Depth
1	11.8	0.9	0.9
2	84.4	21.2	22.1
3	1376.6	24.0	46.0
4	959.6	13.5	59.5
5	4301.4	-.-	-.-

No	Res	Thick	Depth
1	260.0	0.6	0.6
2	34.7	4.2	4.8
3	314.0	19.3	24.1
4	774.5	12.1	36.2
5	5531.3	-.-	-.-

Fig. 2: Common VES Curves of the Study Area for Location (a) 1, (b) 3, (c) 6, (d) 13

Five (5) major geo-electric layers were identified by the study's findings: weathered/fractured basement aquifer, fresh basement, relatively weathered basement acting as a restricting layer, topsoil with lateritic clay, and weathered basement.

The top soil with lateritic clay has resistivity and thickness between 9.9-288.8 Ωm and 0.9-6.6 m; the weathered basement layer has thickness and resistivity between 8.0-717 Ωm and 0.8-34.2 m; the confining fairly weathered basement has thickness and resistivity between 3.2-106.9 m and 63.6-70636.0 Ωm; and the weathered/fractured basement aquifer has thickness and resistivity between 299.1-1997.0 Ωm and 4.1-29.7 m.

The resistivity of the newly constructed basement ranges from 2778.8 to 10,0000.0 Ωm, and its thickness is unknown. The types of curves are A (for VES 3, 4, 5, 6, 10, 12, and 14) and HA (for VES 1, 2, 7, 8, 9, 11, 13, and 15). The presence of groundwater in the study region was not determined by the curve types.

The resistivity ranges for lithological characterization and groundwater potential of bedrock were classified by Olorunfemi and Olorunniwo (1985), David (1988), and Akanbi (2017), as presented in Table 2

Table I: Results of the Geo-electrical Layer derived from the Plotted Graphs

VES No.	Coordinates	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology	Curves Type
VES	N07˚42’02.7’’	248.8	1.5	1.5	Lateritic clay-containing top soil	HA
1	E006˚44’08.2’’	8.0	2.8	4.3	Weathered basement	
		9420.0	65.9	70.2	Confining fairly weathered basement	
		857.1	8.4	78.6	weathered basement aquifer	
		9295.0			Fresh basement	
VES	N07˚42’35.2’’	23.6	5.8	5.8	Lateritic clay-containing top soil	HA
2	E006˚44’02.9’’	115.6	1.6	7.4	Weathered basement	
		18970.6	82.3	89.7	Fairly weathered basement	
		1012.2	8.7	98.4	weathered basement aquifer	
		10669.5			Fresh Basement	
VES	N07˚41’46’’	9.9	1.2	1.2	Lateritic clay-containing top soil	A
3	E006˚44’10.5’’	543.3	16.4	17.5	Weathered basement	
		1220.1	45.7	63.3	Fairly weathered basement	
		823.1	27.0	90.3	weathered basement aquifer	
		2201.9			Fresh Basement	
VES	N07˚42’23.4’’	14.2	1.3	1.3	Lateritic clay-containing top soil	A
4	E006˚43’49.1’’	228.9	0.8	2.1	Weathered basement	
		57877.8	32.2	34.3	Fresh basement	
		5438.0	4.1	38.5	Fresh basement	
		70376.4			Fresh Basement	
VES	N07˚42’39’’	71.9	3.9	3.9	Top soil with lateritic clay	A
5	E006˚44’15.4’’	717.3	1.3	5.2	Weathered basement	
		5814.2	3.3	8.6	Fairly weathered basement	
		15180.9	5.8	14.4	fresh basement	
		100000.0			Fresh Basement	
VES	N07˚42’53.7’’	11.8	0.9	0.9	Top soil with lateritic clay	A
6	E006˚44’22.9’’	84.4	21.2	22.1	Weathered basement	
		1376.6	24.0	46.0	Fairly weathered basement	
		959.6	13.5	59.5	weathered basement aquifer	
		4301.4			Fresh Basement	
VES	N07°40'54"	86.6	4.8	4.8	Top soil with lateritic clay	HA
7	E006°43'17"	91.8	34.2	39.0	Weathered basement	
		690.9	13.3	52.2	Fairly weathered basement	

		622.2	7.1	59.3	Fracture basement aquifer	
		18240.9			Fresh Basement	
VES 8	N07°40'50"	72.0	6.7	6.7	Top soil with lateritic clay	HA
	E006°43'10"	275.6	2.5	9.2	Weathered basement	
		18313.8	106.9	116.1	Fairly weathered basement	
		758.0	29.2	145.3	weathered basement aquifer	
		2778.8			Fresh Basement	
VES 9	N07^{0} 41’ 38"	285.0	1.7	1.7	Lateritic clay-containing top soil	HA
	E 006^{0} 43’ 20”	9.6	2.8	4.5	Weathered basement	
		4551.0	19.4	23.8	Fairly weathered basement	
		1356.0	5.3	29.1	weathered basement aquifer	
		18059			Fresh Basement	
VES 10	N07^{0}41’10.5”	58.5	6.6	6.6	Lateritic clay-containing top soil	A
	E006^{0}43’25”	221.7	9.6	16.3	Weathered basement	
		63.6	16.7	32.9	Highly weathered basement	
		299.1	12.1	45.0	Fracture basement aquifer	
		14271.7			Fresh Basement	
VES 11	N 07^{0}41’10.5”	60.3	4.9	4.9	Lateritic clay-containing top soil	HA
	E 006^{0}43’25”	219.2	1.7	6.6	Weathered basement	
		60754.0	100.8	107.4	Fresh basement	
		1997.0	8.6	116.0	weathered basement aquifer	
		16696.8			Fresh Basement	
VES 12	N07^{0}42’20.51”	18.9	4.7	4.7	Lateritic clay-containing top soil	A
	E006^{0}43’35.29”	95.8	1.7	6.3	Weathered basement	
		18103.5	48.0	54,3	Fresh basement	
		1307.2	4.7	59.0	weathered basement aquifer	
		24594.0			Fresh Basement	
VES 13	N07^{0}41’58”	260.0	0.6	0.6	Top soil with lateritic clay	HA
	E006^{0}43’47.2”	34.7	4.2	4.8	Weathered basement	
		314.0	19.3	24.1	Fairly weathered basement	
		774.5	12.1	36.2	weathered basement aquifer	
		5531.3			Fresh Basement	
VES 14	N07^{0}41’52”	14.3	1.3	1.3	Lateritic clay-containing top soil	A
	E006^{0}43’28”	367.0	0.9	2.2	Weathered basement	
		70636.0	29.7	31.9	Fairly weathered basement	
		3508.4	1.8	33.7	Fresh basement	
		100000.0			Fresh Basement	
VES 15	N07^{0}42’21”	376.9	1.1	1.1	Lateritic clay-containing top soil	HA
	E006^{0}43’35”	39.5	1.9	3.1	Weathered basement	
		3086.3	3.2	6.2	Fairly weathered basement	
		12883.3	6.2	12.4	Fresh basement	
		100000.0			Fresh Basement	

Considering the VES points, only two (VES 7 and 10) had fracture basement aquifers, indicating good groundwater prospects; nine (VES 1, 2, 3, 6, 8, 9, 11, 12, and 13) showed weathered basement aquifers, indicating moderate groundwater prospects. The remaining four (VES 4, 5, 14, and 15) have poor groundwater prospects. The aquifer depth ranges from 14.4-145 m, 70% of the aquifer has a shallow depth of less than 50 m. Therefore, groundwater development within the study area should be targeted at 70-100 m deep to be able to penetrate the aquifer thickness well.

Table 2: Range of resistivity for bedrock groundwater prospects and lithological characterisation Adapted from Akanbi (2017), David (1988), and Olorunfemi and Olorunniwo (1985).

Table 2: Range of resistivity for bedrock groundwater prospects and lithological characterisation Adapted from Akanbi (2017), David (1988), and Olorunfemi and Olorunniwo (1985).

Bedrock resistivity (Ωm)	Description of the bedrock	Groundwater potential of bedrock
>1800	Fresh	Negligible
601–1800	Weak/slightly weathered	Moderate
< 600	Fractured	Good

4.2 Aquifer Hydraulics from Dar Zarrouk Parameters

Table 3 displays the results. The longitudinal conductance value has a mean of 0.0124 ohm and ranges from 0.0004-0.0405 ohm . According to Oladapo et al. (2004)'s classification of aquifer protective capacity (Table 4), this number showed that the research region has a low protective capacity and is susceptible to pollution. Transverse unit resistance has an average value of 21064.4 Ωm2 and ranges from 4417.6 to 88049.2 Ωm2 (Table 3).

Hydraulic conductivity has a mean value of 0.589 m/day and a range of 0.049 to 1.895 m/day. The research area has moderate hydraulic conductivity, according to this number, which is based on Singhal and Gupta's (1999) classification of hydraulic conductivity (Table 5). The distribution of hydraulic conductivity in the research area was depicted in Fig. 2. This showed that whereas high values are located in the southern portion of the study area, low values are primarily centred in the northern part.

According to Krasny's (1993) classification of transmissivity (table VI), the study area has very low groundwater potential (VES 4, 5, 14, and 15), The study identified low groundwater potential in VES 1, 2, 6, 7, 9, 11, 12, and 13, and intermediate groundwater potential in VES 3, 8, and 10. This suggests that the aquifer in the study area can provide water for limited, private, and local use. The transmissivity map (Fig. 4) displayed a similar pattern to that of hydraulic conductivity, with values increasing from the northern to the southern section of the study area.

Table 3: Calculated hydraulic and Dar-Zarrouk parameters

VES NO.	Coordinates	ρ_a (Ωm)	h (m)	S (mhom)	T_R (Ωm^2)	K (m/day)	T (m^2/day)
VES 01	N07˚42’02.7’’ E006˚44’08.2’’	857.1	8.4	0.0098	7199.6	0.710	5.969
VES 02	N07˚42’35.2’’ E006˚44’02.9’’	1012.2	8.7	0.0086	8806.1	0.607	5.281
VES 03	N07˚41’46’’ E006˚44’10.5’’	823.1	27.0	0.0328	22223.1	0.737	19.899
VES 04	N07˚42’23.4’’ E006˚43’49.1’’	5438.0	4.1	0.0008	22295.8	0.127	0.521
VES 05	N07˚42’39’’ E006˚44’15.4’’	5180.9	5.8	0.0004	88049.2	0.049	0.284

VES 06	N07˚42’53.7’’ E006˚44’22.9’’	959.6	13.5	0.0141	12954.6	0.639	8.627
VES 07	N07°40'54" E006°43'17"	622.2	7.1	0.0114	4417.6	0.957	6.795
VES 08	N07°40'50" E006°43'10"	758.0	29.2	0.0385	22133.6	0.796	23.243
VES 09	N07^{0} 41’ 38" E 006^{0} 43’ 20”	1356.0	5.3	0.0039	7186.8	0.463	2.454
VES 10	N07^{0}41’10.5” E006^{0}43’25”	299.1	12.1	0.0405	3619.1	1.895	22.930
VES 11	N 07^{0}41’10.5” E 006^{0}43’25”	1997.0	8.6	0.0043	17174.2	0.322	2.769
VES 12	N07^{0}42’20.51” E006^{0}43’35.29”	1307.2	4.7	0.0036	6143.8	0.479	2.251
VES 13	N07^{0}41’58” E006^{0}43’47.2”	774.5	12.1	0.0156	9371.5	0.809	9.789
VES 14	N07^{0}41’52” E006^{0}43’28”	2508.4	1.8	0.0007	4515.1	0.191	0.344
VES 15	N07^{0}42’21” E006^{0}43’35”	2883.3	6.2	0.0005	79876.5	0.057	0.353
	Minimum			0.0004	4417.6	0.049	0.248
	Maximum			0.0405	88049.2	1.895	23.243
	Average			0.0124	21064.4	0.589	7.434

Table 4: Longitudinal Conductance/Protective Capacity Rating (Oladapo *et al*., 2004)

S/N	Longitudinal Conductance (mhom)	Soil Protective Capacity Classification
1	>10	Excellent
2	5 - 10	Very good
3	0.7 - 4.9	Good
4	0.2 - 0.69	Moderate
5	0.1 – 0.19	weak
6	<0.1	poor

Table 5: Variability in hydraulic conductivity values (Singhal and Gupta, 1999)

Class	Class Interval (m/s)	Groundwater Potential
1	$1\text{-}10^{-2}$	Very high
2	$10^{-2}\text{-}10^{-4}$	High
3	$10^{-4}\text{-}10^{-7}$	Moderate
4	$10^{-7}\text{-}10^{-10}$	Low
5	$10^{-10}\text{-}10^{-13}$	Very low

Table 6: Classification of Magnitude of Transmissivity (Krasny, 1993).

S/N	Magnitude of Transmissivity (m^2/day)	Class	Designation	Groundwater Supply Potential
1	>1000	I	Very high	Regional significance
2	100 - 1000	II	High	Lesser regional significance
3	10 - 100	III	Intermediate	Local water supply
4	1 - 10	IV	Low	Private Usage
5	0.1 - 1	V	Very low	Limited Usage
6	<0.1	VI	Imperceptible	incredibly challenging to use for the local water supply

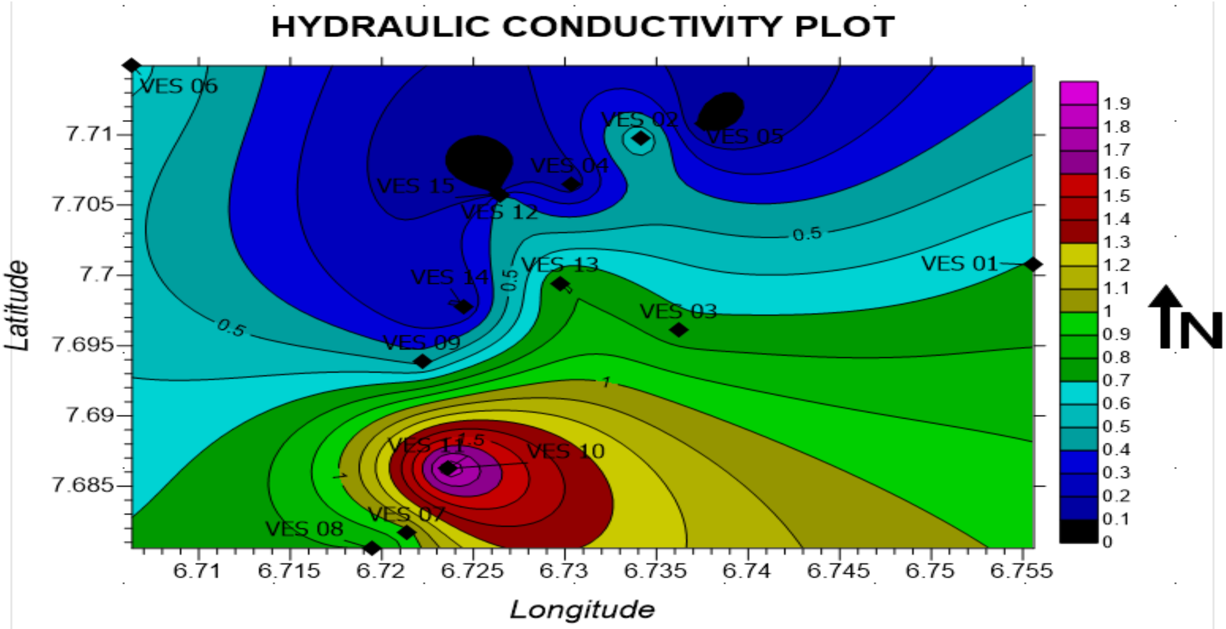

Fig. 3: Hydraulic Conductivity Map of the Study Area

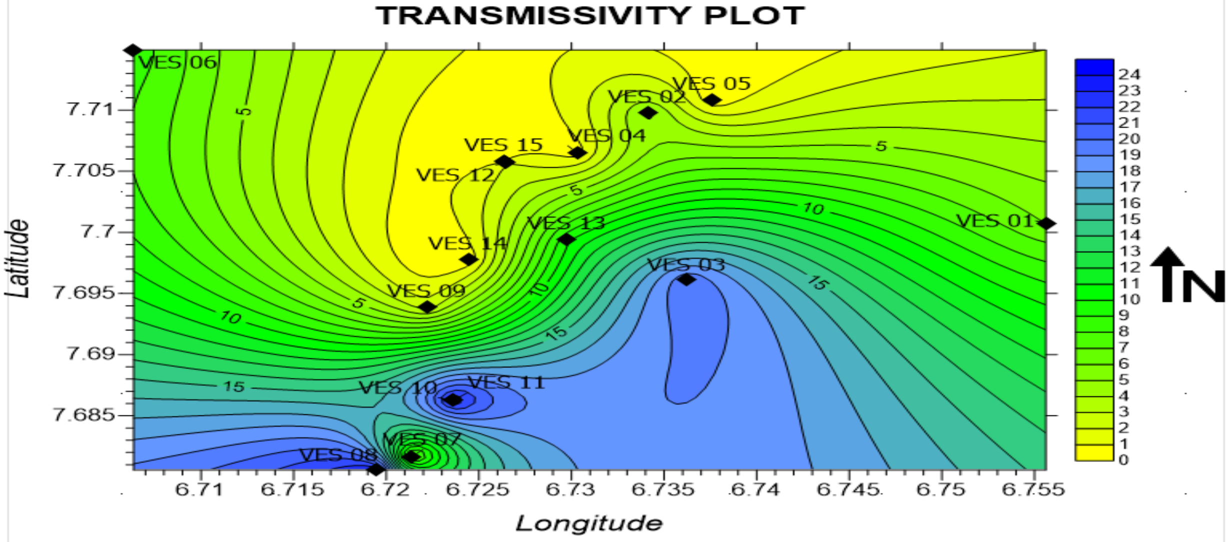

Fig. 4: Transmitivity Map of the Research Area

5.0 Conclusion

Groundwater exploration of the research area was assessed using Dar Zarrouk criteria and Vertical Electrical Sounding (VES). The results showed the following five (5) geo-electric layers in order of occurrence: lateritic clay topsoil, weathered basement, moderately weathered basement acting as a confined layer, weathered/fractured basement aquifer, and fresh basement. The type of curves (HA and A) did not indicate the presence of groundwater in the study area. Additionally, the results showed that the study area's groundwater prospects fall into one of three categories: low, moderate, or good. Since 70% of the aquifer has a shallow depth of less than 50 meters, groundwater development in the research area should aim for a depth of 70 to 100 meters to adequately penetrate the aquifer thickness. Areas with low resistivity values from the VES data, moderate to high groundwater potential, and no major fractures that could jeopardize groundwater safety are the best places to drill boreholes. The longitudinal conductance results highlighted that the research location has a low protective capacity and is vulnerable to contamination. In contrast to the transmissivity, which indicates very low, low, and intermediate groundwater potential, the hydraulic conductivity result indicated that the studied area had moderate hydraulic resistance. Conclusively, the aquifer within the research area can provide water for limited, private, and local consumption.

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Compliance with Ethical Standards Declaration

Ethical Approval

Not Applicable

Competing interests

The authors declare that they have no known competing financial interests

Funding

All aspect of the work was carried out by the author

Authors' Contribution All the authorscontributed to the development of the work.