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Geophysical Determination of Aquifer Parameters in Basement Complex Rocks through Vertical Electrical Sounding Data Analysis from part of Ilorin East Southwestern Nigeria

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Abstract

This research employed vertical electrical sounding data collected from the Ilorin East region of Southwest Nigeria to analyse aquifer properties within Basement Complex rocks. Its objective was to assess the aquifer's attributes in the area through statistical methods and electrical resistivity. Geoelectrical profiling revealed four distinct layers beneath the surface: lateritic layer, topsoil, weathered rock, and fresh basement. The third and fourth layers were identified at depths between 8.47 and 33.2 meters, with aquifer resistivity values ranging from 76.6 to 1576 Ωm. The fractured rocks in the region possess a moderate permeability due to moderate weathering. The aquifer's characteristics were evaluated based on four parameters: transmissivity, apparent resistivity, depth to bedrock, and aquifer thickness. The findings ranging from 0.74- 33.2 m indicate varying groundwater potential across the study area, ranging from low to high.
Keywords: Aquifer, Basement Complex, Electrical-Resistivity, transmissivity.

1. Introduction

Groundwater from subsurface aquifers is widely regarded as a vital renewable resource for supporting human life and sustaining ecosystems (Das 2017; Anim-Gyampo *et al*. 2019). This importance stems from the fact that surface water is often unreliable, as it is highly susceptible to large-scale pollution and various environmental factors, making groundwater a more dependable alternative. This study's objective is to use electrical resistivity techniques to describe the properties of an aquifer in the Basement Complex region of southwest Nigeria's Ilorin East area. Electrical resistivity has been used in numerous studies to identify aquifer characteristics, and the results are validated through borehole drilling (Ajayi *et al.,* 2021; Ale *et al*., 2015). In this work, we suggest an alternative method for establishing relationships between aquifer parameters and data from electrical conductivity surveys in areas where Basement Complex rocks are present: statistical methods. With the use of this method, aquifer parameters in crystalline rock terrains can be categorized according to how they interact with one another and affect groundwater.

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Aquifers are classified based on factors such as lithology, structure, hydraulic properties, texture, and water mobility. Structurally and hydraulically, they can be categorized as "free," "unconfined," or "semi-confined." A "free" aquifer is one where shallow groundwater is in direct contact with the atmosphere, meaning its pressure is equal to atmospheric pressure, and there is no impermeable layer above it. In an unconfined aquifer, the groundwater is in direct contact with the unsaturated soil zone, with the water table fluctuating seasonally—rising during the wet season and falling during the dry.

Location and Geology of the Study Area

The study area is located in Oke-Oyi, Local Government area Ilorin East of Kwara State, Nigeria. It is located within longitude 4°.30’ to 4°.40’E and latitude 8°30’ to 8°36’N (Fig. 1). The area is accessible by a network of roads. The soil in this area is fertile and rich for agricultural purposes. The two seasons of the year which are raining (April to September) and dry (October to March) seasons favours the cultivation and production of crops such as corn, cassava, yam and plantain. The area has an elevation of between 293 and 351 m above mean sea level with annual temperature of 28 °C and an average rainfall of 2000 m. Three rock types were found in the study area which includes Migmatite Gneiss, Granite Gneiss and Granite.

The Northwestern part of the mapped area shows a widespread occurrence of migmatitic gneiss. Its occurrence is widely spread around Eleko-Yangan showing intrusions such as quartz vein and pegmatite vein. They are medium grained, foliated and shows bands of light and dark colored minerals. The foliation trend in the North-East, South-Western direction.

Granite Gneiss outcrops were found in many places of the study area particularly the northeastern, northwestern and southern parts of the study area. The minerals formed from hand specimen include quartz, feldspar, biotite and muscovite. From field observation three distinct types of granitic outcropps were sighted and characterised by grades of heterogeneity as some portions appear granitic while some others appear foliated.

2. Materials and Method

Geophysical well logging of the subsurface

According to the vertical electrical sounding data acquired from Lower Niger River Basin. Boreholes drilled in the study area to a depth of 60 m. Depth of hand dug wells were measured in the area. The measuring tape was lowered into the well and at an interval of 5 m. The geoelectric sections and lithologs presents one aquitards and sand aquifer with fined to medium grained.

Schlumberger's Electrical Resistivity Method

Electrodes C1 and C2 are used to introduce an electric current into the ground in the electrical resistivity method. According to Wenner arrays (Telford *et al*., 2001; Virba, 1999) and Schlumberger (Figure 1) (Olasehinde *et al*., 2015), the voltage difference that results is measured using another pair of electrodes, P1 and P2. The central portion of the electrode array stays fixed while the distance between the electrodes is gradually increased (Olasehinde and Taiwo, 2000). The current electrode spacing is almost equal to the resistivity of the surface materials when the electrode spacing is small (Olasehinde *et al*., 2015). The current travels deeper into the ground as the spacing between the current electrodes increases, reflecting the resistivity of deeper layers in the apparent resistivity; Olasehinde and Awojobi, 2004; Olugboye, 2008). Water bodies found in permeable rock that are sandwiched between two impermeable layers are known as "confined" aquifers. Water in these aquifers is under pressure higher than that of the atmosphere, completely filling all of the pores and voids in the underlying geological formation. Nothing exists in the "unsaturated zone." Drilling a confined aquifer causes the water level to rise to the saturation level in the recharge area of the aquifer. Rainfall only reaches these aquifers when the material above them is permeable, usually at locations distinct from the main body of water.

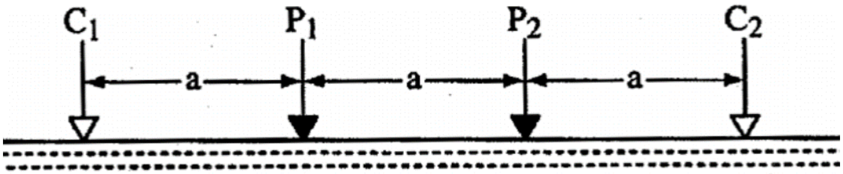


Figure 1: Schlumberger configuration adapted from (Olasehinde et al 2015).

Geophysical Field Mapping Approach

This study selected nine sounding points using the electrical resistivity (Vertical Electrical Sounding) method. Using two current electrodes, an electric current (either D.C. or low-frequency A.C. current) is passed into the subsurface using this technique. The ground's apparent resistivity, which is computed from measurements of the current and potential difference between electrode pairs positioned on the surface, is used to calculate the resistivity of subsurface layers. For this investigation, the Schlumberger configuration (Fig. 2) was employed. Four electrodes are arranged linearly with different interelectrode spacings in the Schlumberger electrode array. The electrodes are arranged so that the current electrode distance (AB) is at least five times the potential electrode distance (MN). While the current electrodes are dispersed until the maximum necessary separation is reached, the potential electrodes stay fixed at the data station.

$C_1P_1=C_2P_2=P_1P_2$

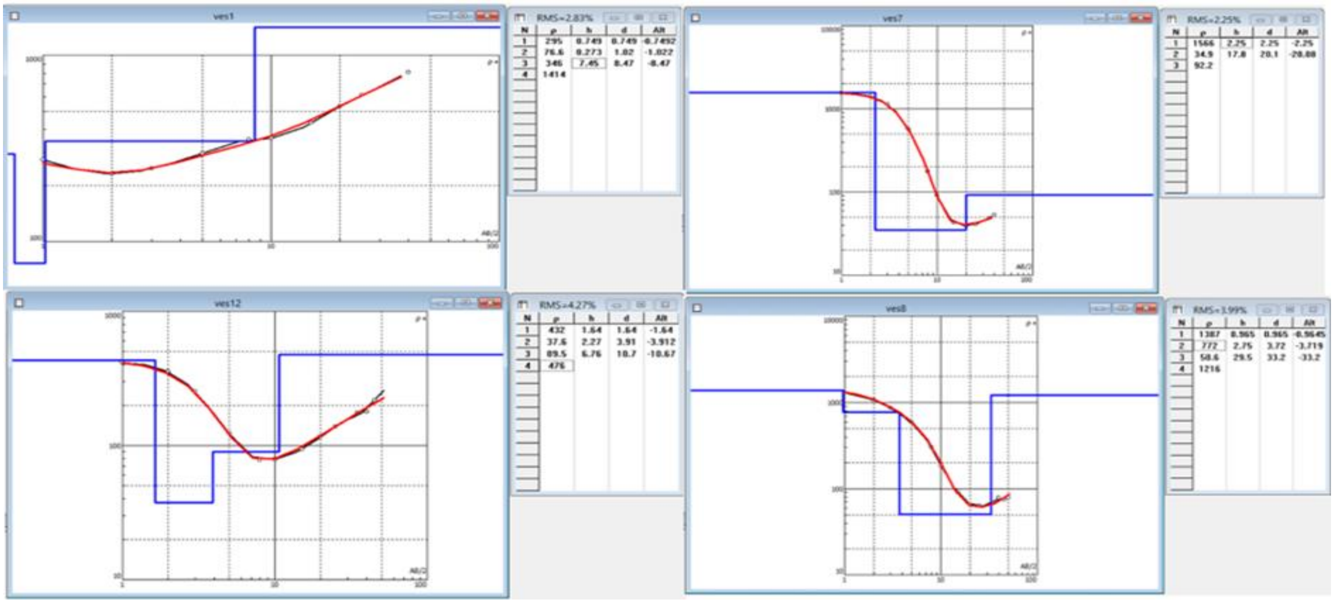
K is the geometric factor = $$\frac{\pi\left[\left(\frac{C_1C_2}{2}\right)^2-\left(\frac{P_1P_2}{2}\right)^2\right]}{2*\left(\frac{P_1P_2}{2}\right)}$$

where P is potential and C is current.

Data processing

Visual inspection of the curve types is necessary for the qualitative interpretation of VES data (Fig. 4). Determining the resistivity and thickness of each layer, in addition to the number of layers represented by the curves, are components of the quantitative interpretation. Direct interpretation and partial curve matching (auxiliary point method) are steps in the quantitative interpretation process. Two- and three-layer curves are used in partial curve matching in conjunction with one or more charts from the families of auxiliary curves. Without the need for preliminary geoelectric sections, layer thickness and resistivity can be directly interpreted from the VES curve using Winresist software.

3. Results and Discussions



RMS=2.83%

N	ρ	h	d	Alt
1	295	0.749	0.749	-0.7492
2	76.6	0.273	1.02	-1.022
3	346	7.45	8.47	-8.47
4	1414			

RMS=2.25%

N	ρ	h	d	Alt
1	1566	2.25	2.25	-2.25
2	34.9	17.8	20.1	-20.08
3	92.2			

RMS=4.27%

N	ρ	h	d	Alt
1	432	1.64	1.64	-1.64
2	37.6	2.27	3.91	-3.912
3	89.5	6.76	10.7	-10.67
4	476			

RMS=1.99%

N	ρ	h	d	Alt
1	1387	0.965	0.965	-0.9645
2	772	2.75	3.72	-3.719
3	58.6	29.5	33.2	-33.2
4	1216			

Figure 2: Curve matching of some of the soundings

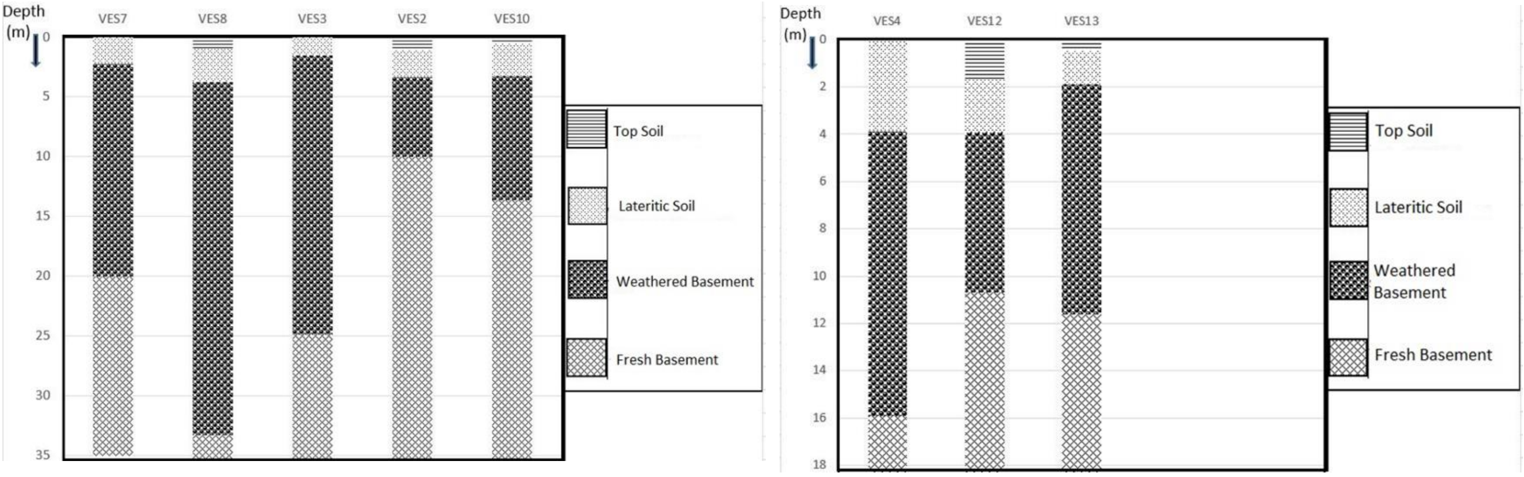


Figure 4: Inferred Geologic and Geo-Electric Sections for VES 2,3,4, 7,8,10,12, and 13.

Table 1: Geoelectric interpretation result

VES STATION	**No. of Layers**	**Resistivity (Ωm)**	**Thickness**	**Depth to Bedrock**	**Curve Type**	**Remark**
VES1	4	295	0.749	8.47	HA	Topsoil
		76.6	0.273			Lateritic Soil
		346	7.45			Weathered Basement
						Fresh Basement.
VES2	4	639	1.08	10.00	H	Topsoil
		168	2.26			Lateritic Soil
		112	6.66			Weathered Basement
		1394				Fresh Basement.
VES3	3	133	1.57	24.8	A	Laterites,
		475	23.3			Weathered Basement
		1576				Fresh Basement.
VES4	3	362	3.88	15.9	A	Laterites,
		740	12			Weathered Basement
		2124				Fresh Basement.
VES5	4	166	0.717	18.4	H	Topsoil
		302	4.62			Lateritic Soil
		165	13.1			Weathered Basement
		82.3				Fresh Basement.
VES6	4	354	0.744	26.1	H	Topsoil
		161	7.37			Lateritic Soil

		626	18			Weathered Basement
		107				Fresh Basement.
VES7	3	1566	2.25	20.1	KH	Lateritic Soil
		34.9	17.8			Weathered Basement
		92.2				Fresh Basement
VES8	4	1387	0.965	33.2	KH	Topsoil
		772	2.75			Lateritic Soil
		50.6	29.5			Weathered Basement
		1216				Fresh Basement.
VES9	4	1460	1.97	20.1	QH	Topsoil
		174	3.6			Lateritic Soil
		32.7	14.5			Weathered Basement
		772				Fresh Basement.
VES10	4	890	0.5	13.6	H	Topsoil
		169	2.81			Lateritic Soil
		68.2	10.3			Weathered Basement
		1414				Fresh Basement.
VES11	4	704	0.5	10.8	A	Topsoil
		215	1.19			Lateritic Soil
		60.3	9.09			Weathered Basement
		219				Fresh Basement.
VES12	4	432	1.64	10.7	HA	Topsoil
		37.6	2.27			Lateritic Soil
		89.5	6.76			Weathered Basement
		476				Fresh Basement.
VES13	4	478	0.423	11.6	HA	Topsoil

There were five different types of sounding curves found in the study area, ranging from three to layers (Table 1). Each of the curves: KH, A, H, HA, and QH. This geological terrain frequently exhibits the H and A-type curve (Olorunfemi and Oloruniwo, 1985). (According to Oloruntola and Adeyemi (2014), the intermediate layer in the H-curve usually has high resistivity and is made up of top-soil, lateritic soil, weathered and fresh basement. Topsoil, lateritic soil is found on top of weathered, fractured rock in the HA type curve. Four geologic layers were identified by the study (Figs. 4): weathered basement, fractured basement/fresh basement, lateritic soil, and topsoil. There is a range of 166 to 1460 Ω/m in the resistivity of the topsoil (Table. 1), with an average of 686.24 Ω/m and a standard deviation of 26.196 Ω/m. The topsoil has an average thickness of 0.9288 meters and ranges in thickness from 0.5 to 1.97 meters. The geoelectric sections (Figs. 4) along VES 2,3,8,7,10 was created using the interpreted curves to show the vertical distribution of resistivity within the subsurface in the study area. These sections are made up of a series of layers that are all uniformly horizontal (or slightly inclined), and each layer is distinguished by its thickness and actual resistivity. Beneath these sections, up to five subsurface geoelectric units were found: the lateritic layer, weathered rock, the fresh basement, and the topsoil. The topsoil, which is composed of gravel, sand, and is located above the water table, has a medium aquifer potential because its resistivity values vary. With resistivity values ranging from 166 to 1460 Ω/m, the second layer—weathered basement—indicates a high aquifer potential. The resistivity values and thickness values of the third layer, fractured basement, range from 32.7 to 740 Ωm and 82.3

to 1394 Ωm, respectively, indicating a medium to high potential for an aquifer. In most places, the bottom layer—which makes up the bedrock—has a resistivity value ranging from 107 to 1507 Ωm, making it extremely resistive. The analysis of reflection coefficient was utilized to ascertain whether the bedrock is new or fractured

4. Conclusion

In conclusion, the electrical resistivity method has proven effective in determining the aquifer properties in the Basement Complex terrain of Eastern Ilorin, Southwest Nigeria. The analysis indicates that the aquifer units consist primarily of weathered basement formations, with 60% of the aquifers demonstrating high groundwater potential and the remaining 40% showing medium potential. Based on the assessment of five key parameters, the region contains a moderate quantity of groundwater. A detailed statistical evaluation further reveals that the aquifer characteristics are significantly influenced by four main factors: transmissivity, aquifer thickness, depth to the aquifer, and apparent resistivity. These findings provide valuable insights into the area's groundwater potential.

Recommendations

Based on this study, it is recommended to integrate statistical methods with electrical resistivity techniques for effective characterization of aquifer properties in areas with Basement Complex rocks. This approach provides an alternative for analysing relationships between aquifer parameters and data from electrical conductivity surveys, allowing for a more detailed classification of aquifer characteristics in crystalline rock terrains and their influence on groundwater dynamics.

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