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Delineation of geological formations and their influence on groundwater in Umunneochi L.G.A of Abia State and Its Environs

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Abstract

For socioeconomic growth and environmental wellbeing of the populace, the availability and sustainable management of groundwater resources is very crucial. Effective management and use of this invaluable resources requires an understanding of the subsurface geological formations and their impact on groundwater. This study was carried out in other to delineate the subsurface geological formations and evaluate their impact on groundwater availability in Umunneochi Local Government Area (L.G.A) of Abia State and its environs using Vertical Electrical Sounding (VES) analysis. The study includes gathering resistivity data via a network of VES surveys carried out at twelve key locations in six selected town within Umunneochi L.G.A. The field data were subsequently interpreted using an iteration software IP2WIN to identify various geological formations and evaluate their potential as aquifers, which substantially impact groundwater occurrence and distribution. The research findings showed distinct geological units with resistivity values ranging from 0.37 - 2000Ωm, which is indicating a variety of lithological properties, with sand and gravel layers showing higher permeability representing potential aquifers. The results of this study have significant implications for groundwater management in Umunneochi L.G.A. and its surroundings, and also provide recommendations for the strategic placement of boreholes and wells to maximize groundwater extraction and long-term use.

Keywords: Aquifer; Permeability; Subsurface; Resistivity; Groundwater Extraction; Borehole

1. Introduction

Groundwater is a crucial natural resource that is essential to maintaining both human life and ecological balance. In order to meet the water needs of communities, agriculture, industry, and ecosystems, it must be available and managed properly. Umunneochi L.G.A in Abia State Nigeria is experiencing an increasing demand for groundwater due to its burgeoning population and growing economic activities. To ensure the sustainable utilization of groundwater resources in that area, it is crucial to gain a comprehensive understanding of the subsurface geology. The insufficiency in the water supply system in Nigeria has led to many citizens resorting to self-help and exploiting the underground water resources in an unstructured and uncoordinated manner [1]. In recent years, geophysical techniques Vertical Electrical Sounding analysis have emerge as a useful tools in examining the subsurface features and locating probable aquifer zones. Based on the earth's response to the flow of regulated input electric current and measurement of the resulting potential difference, this technique has grown to be one of the most popular ones in groundwater investigations in both porous and fissured media. VES technique has previously been used by many researchers for groundwater resource evaluation in different parts of the globe. [2] Investigated the groundwater potential at Lokpaukwu in Abia state using electrical resistivity method, proving its potency in determining the water table at different depth. While [3, 4], used VES

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techniques in determining groundwater potentials and its characterization. [5] Also applied VES analysis in Udi L.G.A in Enugu state and successfully delineated aquifer units and their thicknesses. Understanding the intricate relationship between subsurface geological formations and groundwater dynamics is fundamental to achieving water security, mitigating water-related challenges, and promoting socio-economic development in Umunneochi L.G.A and similar regions across the globe. The study's findings can be a useful guide for prospective groundwater exploration and management in related geological contexts.

2. Material and Methods

2.1. Study Area

The study location comprises Lokpanta, Mbala, Eziama, Lokpaukwu, Lekwesi and Leru, all in Umunnochi L.G.A. of Abia State (Fig 1). Umunneochi is situated in the Northern part of Abia State Southeastern Nigeria, and located between Lat. 5.6842° N to 5.8402° N and Longitude: 7.3450° E to 7.6258° E. According to 2006 Nigerian National Census, Umunneochi is home to 163,928 people and covers an area of 365km2. A number of minerals are deposited in Umunneochi L.G.A and they include granite, quorite, and laterite. Farming is a major source of livelihood for the dwellers of Umunneochi LGA with crops such as black beans, cocoyam, cashew, and oil palm grown in the area. Other important economic activities that take place in Umunneochi LGA include trade, animal rearing, and hunting.

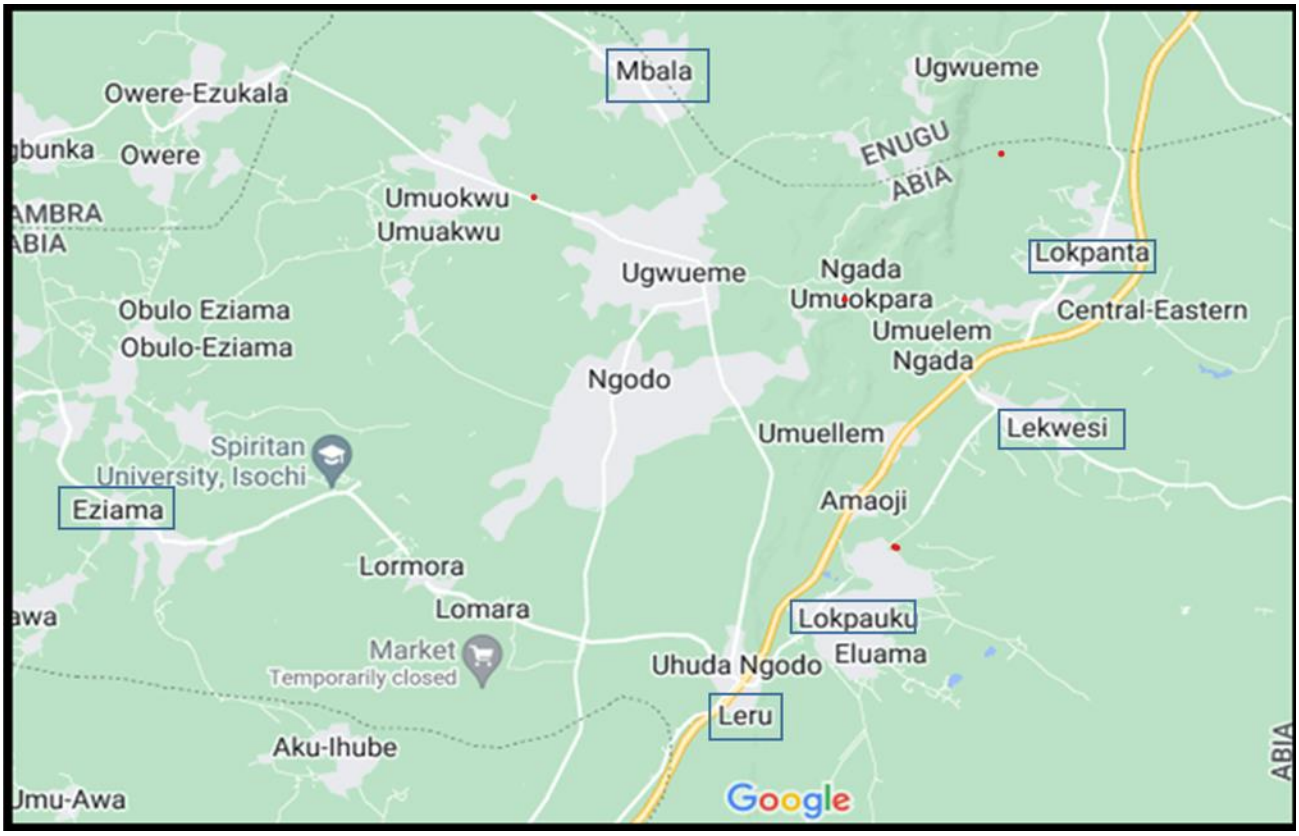


Figure 1 Map of Umunneochi L.G.A Showing the study locations. (Google Map)

2.2. Geology of the Study Area

The study area is situated in the Lower Benue Trough's Southeastern region. There are two major geologic formations that underlie the region. The Nkporo and Asu River Group [6, 7]. The complex geological setting of this region is what makes it unique. The area is underlain by rocks that range in age from the Cretaceous to the Recent, with sandstones, limestone, shales/mudstone/clay deposits constituting the primary lithological groups (Fig 2). These formations were formed by the deposition and compaction of sediments over time.

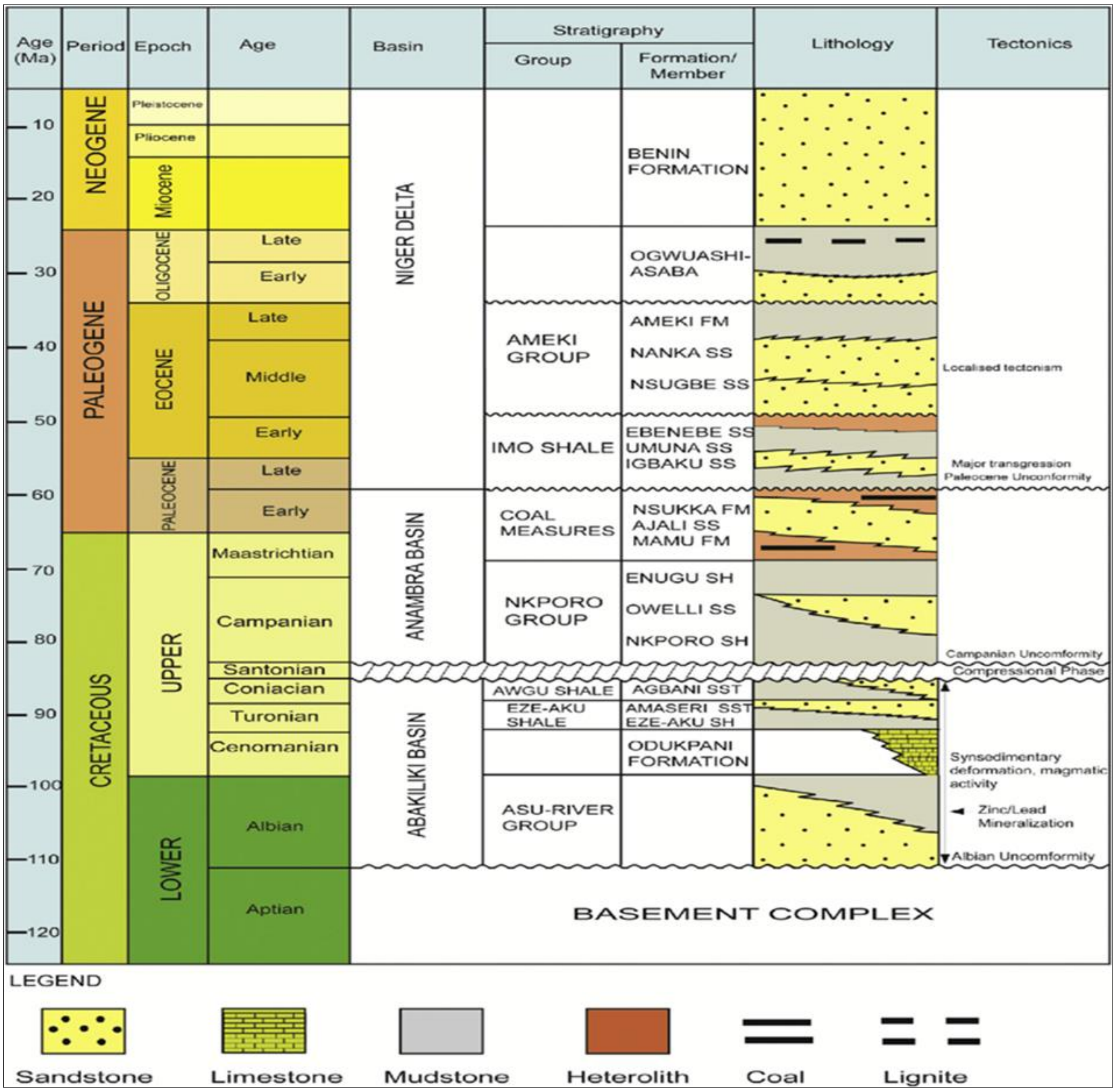


Figure 2 Lithostratigraphic formation of Nigeria [6]

The various geological formations in Umunneochi L.G.A have implications for groundwater occurrence and distribution, as different rock type's exhibit differing degrees of permeability and groundwater storage capacity. Previous studies (Fig 3) in the neighboring local government have highlighted the presence of various lithological units, such as sandstones, shales, and limestone etc.

2.3. Lithology of the Study Area

Lithological units in Umunneochi L.G.A are essential factors in understanding groundwater occurrence and movement in the area. Lithology in these region is predominantly composed of sedimentary rock formations which have been accumulated over millions of years through various geological processes. One of the main lithological units in Umunneochi L.G.A. is sandstone. It is a sedimentary rock made up of quartz that are bound together by other minerals. Another common lithological unit in the area is Shale. It is a sedimentary rock with fine grains made up of clay minerals and other substances. Shale is comparatively impermeable and can operate as an aquitard, restricting groundwater circulation across several aquifers. Limestone formations are also present in these area. It is a sedimentary rock primarily composed of calcium carbonate. Due to the production of karst topography, which includes sinkholes and caves, limestone formations can have a considerable impact on the groundwater movement in the area.

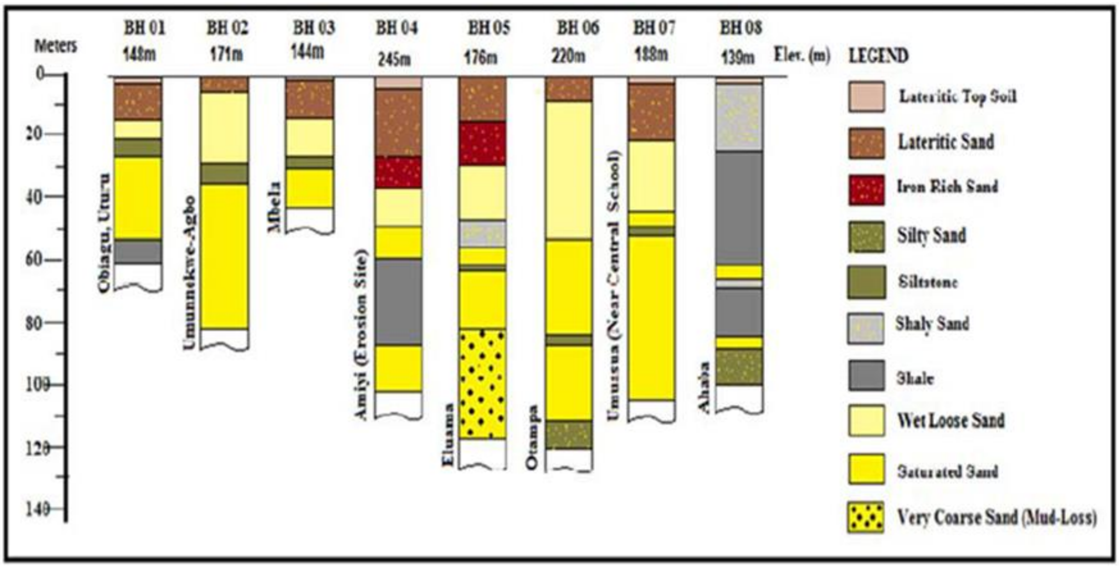


Figure 3 Borehole lithology log of Isuikwuato, a L.G.A bounded with Umunneochi [8]

2.4. Theory of Electrical Resistivity

The electrical resistivity method is utilized in diverse ways for groundwater exploration [9, 10, 11]. It is a geophysical technique commonly used for measuring the electrical resistivity of the subsurface materials to infer the presence and properties of groundwater-bearing formations. In this method, current is introduced into the ground by a pair of electrodes, while measuring the subsurface expression of the resulting potential field with an additional pair of electrodes at appropriate spacing's. Field data acquired in this method will be subjected to an iteration computer software in order to get a clear knowledge of area subsurface characteristics.

2.5. Data Acquisition and Processing

The Vertical Electrical Sounding (VES) method of electrical resistivity was employed using the Schlumberger electrode configuration (Fig.4). This technique was employed due to its ability to provide detailed information on differences in subsurface resistivity, which are indicative of various geological formations and their potential as a source of water. Resistivity meter ABEM Terrameter SAS300B and its other accessories such as electrodes, connecting wires, etc, was used in the field data acquisition. A total of 12 sounding stations were carried out, 2 apiece in each of the six selected town. At each VES location, current was sent into the subsurface through the current electrodes and the resulting potential difference (p.d) between M and N was measured. The computation of apparent resistivity from the measured resistance was done using the equation below.

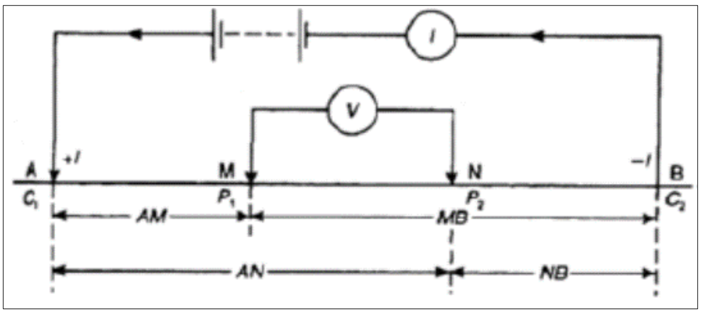


Figure 4 Electrode Configuration for Electrical Resistivity [12].

$$\rho a = \pi R \left(\left(\left(AB/2\right)^2-\left(MN/2\right)^2\right)/MN\right)$$

$$k = \left(\left(\left(AB/2\right)^2-\left(MN/2\right)^2\right)/MN\right)$$

$$k = \pi RK$$

Where: ρa = apparent resistivity (Ohm-m), R = resistance (Ohm), AB = distance between current electrodes, MN = distance between potential electrodes.

The apparent resistivity values obtained from the measurements were converted to true resistivity using an inversion software IP2WIN. Certain precautions was observed in the course of this survey.

They include:

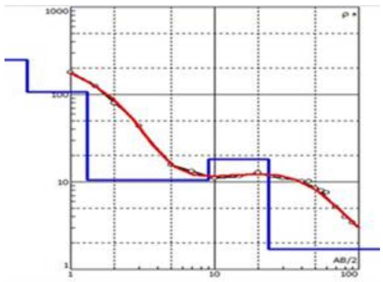
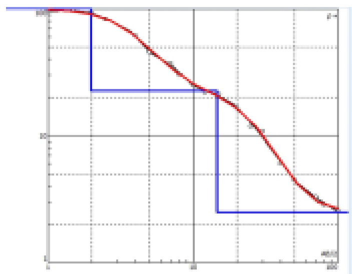
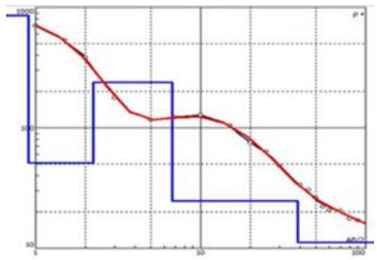
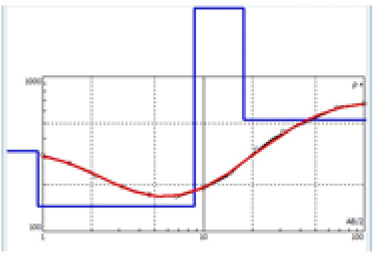
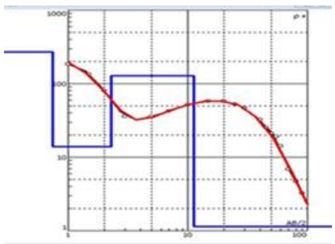
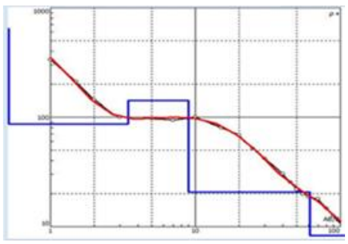
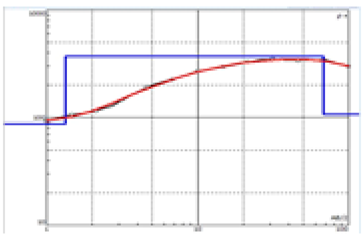
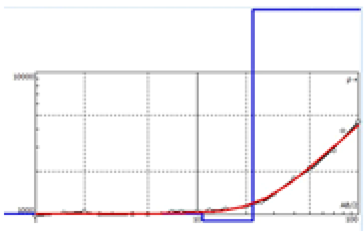
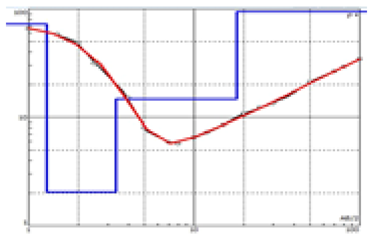
Safety was prioritized at all time

Measurement were taken far away from power lines to avoid electromagnetic interference

Battery was checked at interval and recharged when dropped.

3. Result and Discussion

The applicability of the resistivity approach for defining subsurface/lithology formations and groundwater investigation is well recognized. Its suitability is primarily based on its high depth of probe and signal resolution. (Table. 2) shows the layered parameters from the interpretation of the Twelve (12) Vertical Electrical Sounding (VES) data acquired in six selected town in Umunneochi L.G.A. The VES curve, curve frequency and its percentage are shown in Figure (5, 6 and 7).

		
VES Curve 1(Lokpaukwu 1)	VES Curve 2 (Lokpaukwu 2)	VES Curve 3(Lokpanta 1)
		
VES Curve 4(Lokpanta 2)	VES Curve 5(Leru 1)	VES Curve 6(Leru 2)
		
VES Curve 7(Lekwesi 1)	VES Curve 8(Lekwesi 2)	VES Curve 9(Mbala 1)

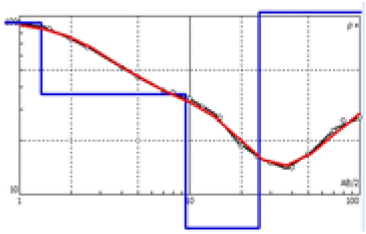
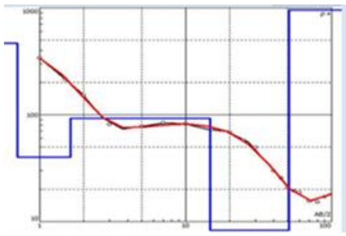
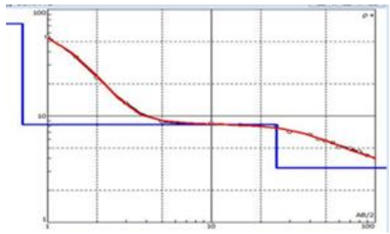
		
VES Curve 10(Mbala 2)	VES Curve 11(Eziama 1)	VES Curve 12(Eziama 2)

Figure 5 Vertical Electrical Sounding Curves of the Twelve Locations

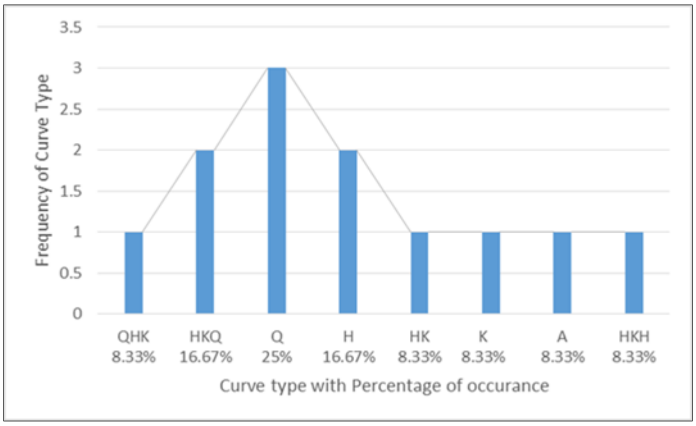


Figure 6 Frequency of curve in the study area

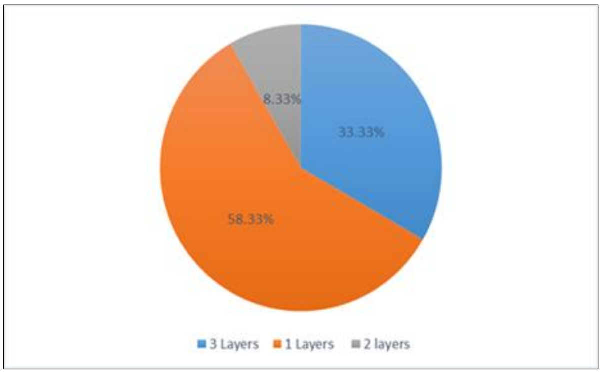


Figure 7 Geoelectric Layers in the study area

Table 1 Resistivity Range of different lithologic units

Lithologic unit	Resistivity (Ωm)
Top soil	70 – 300
Clay	1 – 100
Sand	60 – 1000
Sandstone	8 – 4000

Source: Resistivity range [12]

Table 2 Interpreted layer properties from Vertical Electrical Sounding (VES) data for Umunneochi and environs.

VES NO	LOCATION	COODINATE Lat/Long	THICKNESS $h_1, h_2, h_{...n}$ (m)	RESISTIVITY $\rho_1, \rho_2, \rho_{...n}$ (Ωm)	DEPTH (m)	CURVE TYPE
1	Lokpaukwu 1	5.930384 7.434311	0.5, 5.808, 7.73, 28.34, -	250, 107, 10.5, 120, 1.7	0.5, 6.31, 13.51,36.07	QHK
2	Lokpaukwu 2	5.927994 7.426414	0.908, 1.33, 4.48, 45.2, -	861, 50.8, 240, 200.6, 11.2	0.908, 2.24, 5.81, 49.68	HKQ
3	Lokpanta 1	5.997468 7.45575	1.98, 12.5, 24.0	101, 22.6, 20.2	1.98, 14.48, 36.5	Q
4	Lokpanta 2	5.992190 7.402725	0.93, 7.81, 33.25	333, 146, 338	0.93, 8.74, 41.06	H
5	Leru 1	5.939604 7.430878	0.741, 6.54, 15.97, -	268, 14, 129, 1.15	0.741, 7.28, 22.51,	HK
6	Leru 2	5.936531 7.428131	0.5, 2.95, 10.53, 32.3, -	643, 86.2, 142, 134.7, 0.37	0.5, 3.45, 13.90, 42.56	HKQ
7	Lekwesi 1	5.962042 7.468651	1.34, 76.7, 4.34	88, 372, 107	1.34, 78.04, 81.04	K
8	Lekwesi 2	5.957945 7.457665	10.7, 16.3, 40.5	1010, 2000, 395.0	10.7, 28.0, 56.8	A
9	Mbala 1	6.014199 7.391404	1.29, 8.11, 20.21	72.3, 2.05, 432.8	1.29, 9.4, 28.32	H
10	Mbala 2	6.016247 7.399643	1.34, 11.2, 18.9	91.1, 36.2, 32.48	1.31, 3.42, 30.1	Q
11	Eziama 1	5.989615 7.317933	0.706, 0.916, 13.1, 36.5, -	466, 39.9, 93, 89.79, 956	0.706, 1.62, 14.7, 51.2	HKH
12	Eziama 2	5.980054 7.334069	0.705, 24.2, 31.20	73.8, 8.32, 323.25	0.705, 24.9, 55.4	Q

The interpreted curve frequency as shown in (Fig. 6) ranges from QHK (8.33%), HKQ (16.67%), Q (25%), H (16.67%), HK (8.33%), K (8.33%), K (8.33%), A (8.33%), and HKH (8.33%). While the subsurface layers frequency (Fig. 7) ranges from 3 layers (33.33%), 1 layer (58.33%), and 2 layers (8.33%). The interpreted layers property (Table 2) shows layer resistivity variations across the study area. Based on the stratigraphy of the study area being of the Nkporo and Asu river group [6], the subsurface lithology is mainly composed of Sandstone, shaly sand, mudstone, and limestone. Comparing the resistivity values of the VES stations (Table 2) and the standard resistivity range of different lithological units (Table 1), the study area is mainly composed of top soil at the first layer, sand and sandstone in subsequent layers with minute clay intercalation. A study from [13] reveals that areas with thick overburden depth have high potential for groundwater. Based on the aforementioned analysis, overburden thickness, curve types, and resistivity values, groundwater development will be feasible in all of the places at a depth of 30.1 to 81.04 meters, and thickness of 18.9 to 45.2m with the exception of Leru 1 and Mbala 1, where the aquifer is a little bit shallow.

4. Conclusion

Vertical electrical Sounding is an electrical method of investigating the variation of the conductivity and resistivity of the subsurface material with depth. This study uses the analysis and interpretation of Vertical Electrical Sounding (VES) data to look at the subsurface geological conditions of Umunneochi L.G.A. The interpreted subsurface resistivity/parameters suggests that the research area is underlain by relatively low/medium resistivity rocks, which have been identified to be sandstone, limestone and mudstone/clay/shale. The findings of these research has practical implications for groundwater resource management and environmental planning. The identification of potential aquifer zones can guide sustainable water extraction practices and contribute to better-informed land-use decisions

Compliance with ethical standards

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Disclosure of Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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