Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: https://atbuscienceforum.com.ng/index.php/jpas

Geology and Geophysical Investigation of Groundwater Potential around Boh and Environs, Gongola Arm of the Northern Benue Trough Northeastern Nigeria

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Abstract

Groundwater exploration within crystalline basement and sedimentary terrains requires the integration of geological and geophysical investigations to accurately delineate aquifer systems and identify viable groundwater targets. This study employed detailed geological mapping and Vertical Electrical Sounding (VES) to evaluate the groundwater potential of Boh and its environs within the Upper Benue Trough, northeastern Nigeria. Thirteen VES stations were established using the Schlumberger electrode configuration with a maximum current electrode half-spacing (AB/2) of 100 m. The acquired resistivity data were interpreted using WinResist Version 1.0 software to determine subsurface resistivity distributions and layer thicknesses. The geoelectrical interpretation revealed three major subsurface units. The uppermost unit comprises lateritic/topsoil materials characterized by resistivity values ranging from 13.7 to 147.7 Ωm. Beneath this layer occurs a weathered/fractured basement and saturated sandstone horizon, interpreted as the principal aquifer unit, with resistivity values varying between 29.3 and 915.1 Ωm. The deepest unit corresponds to the fresh basement complex, exhibiting relatively high resistivity values ranging from 242 to 2359 Ωm. Variations in resistivity and thickness indicate considerable heterogeneity in subsurface hydrogeological conditions across the study area. Aquifer evaluation identified VES locations 1, 7, 9, 11, 12, and 13 as the most promising borehole sites due to the occurrence of relatively thick aquiferous zones with resistive to moderately conductive characteristics favorable for groundwater storage and transmission. Overall, the groundwater potential of the area is classified as low to moderate, largely constrained by limited aquifer thickness and poor fracture connectivity. The study highlights the importance of careful borehole siting and recommends the integration of complementary geophysical methods to enhance fracture characterization and support sustainable groundwater development.

Keywords
Boh,
Geological Mapping,
Vertical Electrical Sounding,
Groundwater Potential,
Gongola Arm,
Northeastern Nigeria.

ISSN 1119-4618
JPAS
1119 4618
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INTRODUCTION

Water scarcity poses a significant and growing global challenge, particularly in arid and semi-arid regions of sub-Saharan Africa. The demand for clean and accessible water is intensifying due to rapid population growth, urbanization, and climate change (Musa et al., 2016). With over two billion people worldwide depending on groundwater as a primary source for domestic, agricultural, and industrial needs, the sustainable exploration and management of these hidden resources have become a critical priority (UNESCO, 2022). In light of this, combining geological and geophysical methods offers a robust approach for identifying and characterizing potential groundwater reservoirs.

Geological mapping provides the foundational framework for hydrogeological studies by documenting the distribution of rock types, structural features, and stratigraphic relationships. These elements directly influence the occurrence and movement of groundwater. However, in regions with limited surface exposure or complex subsurface geology, surface-based geological mapping alone is insufficient to fully understand groundwater potential.

This is where geophysical methods, such as the Vertical Electrical Sounding (VES) technique, prove invaluable. VES is a cost-effective and widely adopted resistivity method that provides essential insights into subsurface geo-electric layers, helping to delineate water-saturated zones (aquifers) by detecting their characteristic low resistivity values (Aizeboekhai et al., 2016; Maikomo et al., 2024).

The study area, Boh and its environs, is located in the Gongola arm of the Northern Benue Trough, a relatively under-explored geological region of Northeastern Nigeria. Previous research has primarily focused on the regional tectonics and stratigraphy of the basin, leaving significant gaps in the knowledge of its local hydrogeological potential (Zaborski et al., 1997). This research aims to bridge this knowledge gap by providing a detailed lithological description of the area through geological mapping and, more importantly, by evaluating its groundwater potential through a comprehensive geophysical investigation.

The primary objective of this study was to combine geological and geophysical investigations to assess groundwater potential around Boh and its environs. Specifically, the research sought to: produce a detailed geological map of the area, characterize the resistivity and thickness of subsurface layers, correlate these geo-electric parameters to potential aquifers, and identify and recommend promising locations for sustainable groundwater development. The study area, covering approximately 18 km^2, is situated between Latitudes 9◦46′00"N–9◦48′30"N and Longitudes 11◦15′00"E–11◦17′00"E within the Kaltungo sheet 173 NW.

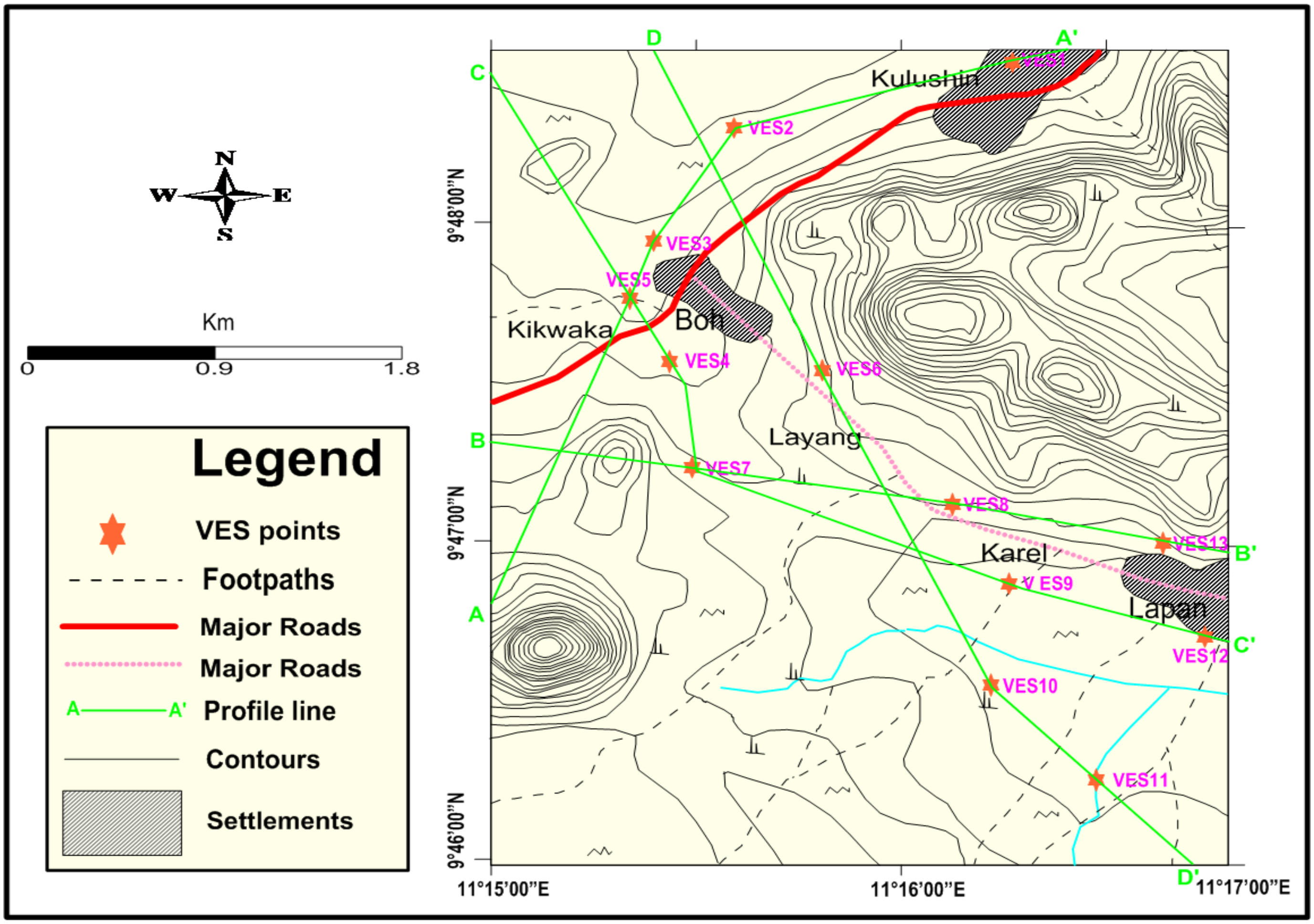

Figure 1: Topographic map of the study area showing VES location and profiles AA' - DD'

MATERIALS AND METHODS

Materials

The equipment used during resistivity data acquisition includes; Direct Resistivity Meter (DDR-3) water stone, Cable wires (two potential and two current cables), Electrodes, hammers, crocodile clips, measuring tapes, GPS (Global Positioning System). A Personal computer, WinResist version 1.0 Software package were used for data analysis.

Methods

Geological Mapping: The geological field mapping was carried out in early the month of May 2020 and it lasted for four days. This includes reconnaissance survey to establish the extent of the study area and strategy to be employed during the field study. Mapping by random sampling, this involves ground traverses along footpaths, cattle tracks, farmlands, streams channels and other paths forming the access route in the study area with the use of topographical map. During mapping, detailed description of rock types, delineation of lithologic boundaries, and measurement of different structures were made. Features like weathering effects, textures and structures were observed and recorded. Where there is rock exposure, detailed examination of the exposure was carried out and a description recorded. The extent of the study area was about $18\ km^2$.

Geophysical Data Acquisition: the resistivity meter used in this research was Direct Resistivity Meter (DDR-3) water stone, in view of its high resolution and depth probe, the Schlumberger configuration was used for this survey. The resistivity meter is placed at the exploration site which is suitable for lateral spreading of the cable wires in either direction. The non-polarizing electrodes (inner electrodes) needed for measuring the potential differences are placed at predetermined distances on either side of chosen center near to the measuring equipment and current electrodes (outer electrodes) were also placed on either side.

Covered cable is connected to the potential electrodes as also the current electrodes are connected to the proper terminals on the equipment. The power supply pack is also connected to the instrument. The current electrodes are driven into the ground at least 10 to 15 cm deep each on either side of the center with use of hammer. The working of the instrument begins and is operated as per the principles used in the instrument. Current is passed through the two extreme electrodes (current electrodes); the potential difference was received by potentiometer of DDR-3 meter between the two inner electrodes spaced at $\left({}^{MN}/_{2}\right)$ = 0.5 m, 2 m, 10m.

While AB = 200m due to the fact that the overburden in the area is not as thick as to require a large current electrode spacing for deeper penetration and current electrodes were moved equally on the either side (as the distance between electrodes increases, the depth of penetration also increases) of the station point according to designed acquisition parameters in the study. The design was 1.5, 2, 3, 4.5, 7, 10, 10, 14, 17, 20, 25, 30, 45, 45, 60, 70, 80 and 100m.

A total of thirteen (13) VES point (Fig. 1) were marked out for the survey and the data of each VES point were recorded on data sheet, the locations (co-ordinates and elevation) of each VES point was also recorded with the aid of GPS (Global Positioning System) meter.

RESULTS AND DISCUSSION

Geological Field Mapping

The geological mapping shows that Boh is situated within the Gongola arm of the northern Benue Trough, where older Precambrian basement rocks are intersected by younger lithologies and topped with the Bima Sandstone (Baba, 2017). The basement rock of the area are of crystalline rocks of the Upper Benue Trough collectively known as the Older Granites and covers about 80% of the study area (Fig. 2), this includes coarse grained biotite granite, pegmatite rock and Basaltic intrusion.

The coarse-grained biotite granite occupies the central part and it represents the larger portion of basement rocks in the study area (Fig. 2). The rock composes of mineral that are medium to very coarse grained in size and are mainly quartz, feldspar and biotite mica and the rock unit is mesocratic in color.

The Pegmatite occupies a small portion of the north western part of the study area. It is an intrusive igneous rock and the mineralogy composed of interlocking phaneritic crystals usually large in size. It is dominantly composed of quartz and feldspar.

Bima sandstones is the oldest sedimentary rock formation overlying the basement rocks in the study area, it is cross-bedded and of continental (fluvial, deltaic, lacustrine) in origin, it’s made up of medium to coarse grained sandstones. They are highly compacted sandstones and lie unconformably on Precambrian Basement rocks.

The Basaltic intrusion out crop within the Bima Sandstone towards the South-Eastern part of the study area, it occurs in form of intrusion and it is dark (melanocratic) due to the presence of mafic minerals such as olivine and pyroxenes and is very fine grained

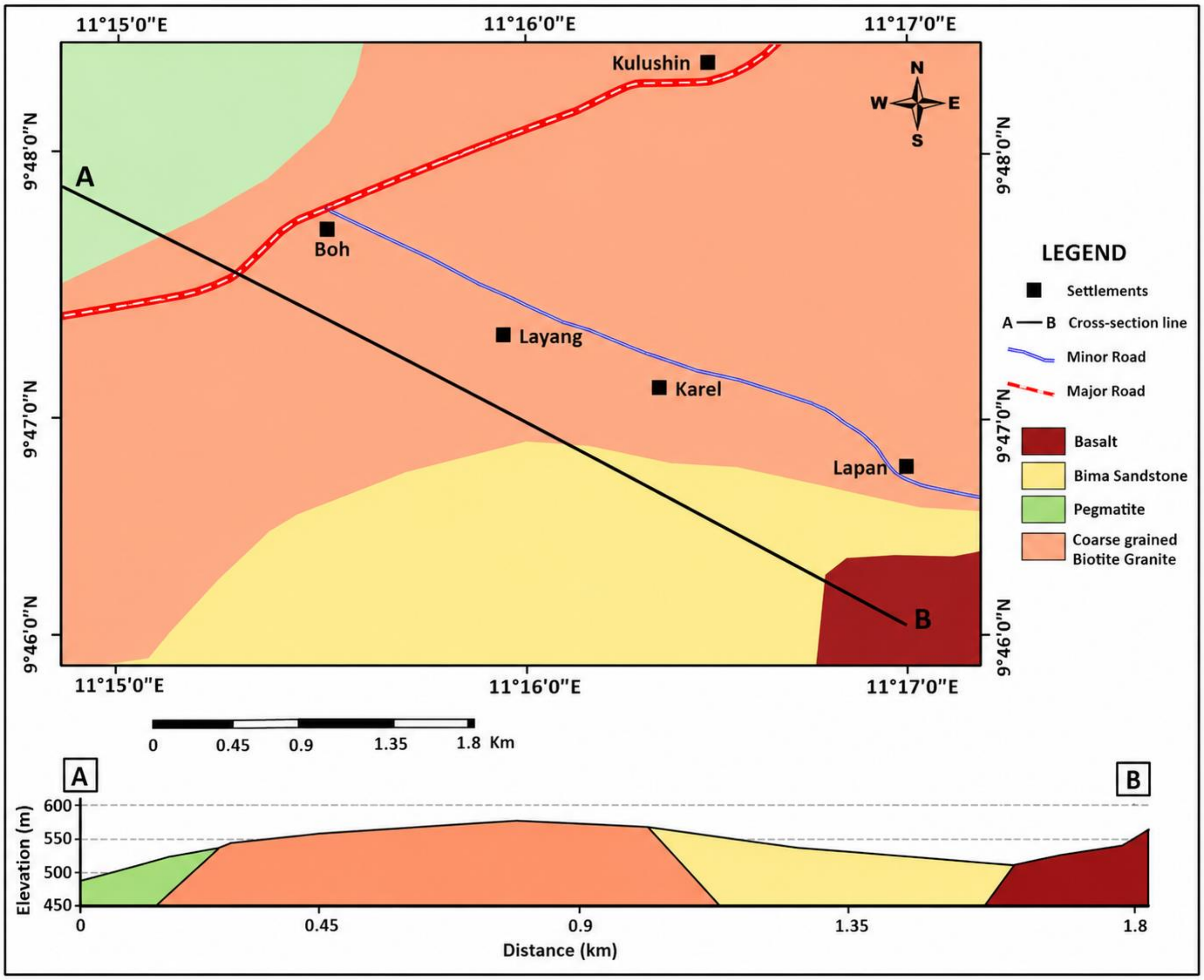

Figure 2: Geological map of the study area; showing the spatial distribution of the various rock types in the area

Analysis of Interpreted Field Curves

Thirteen Vertical Electrical Soundings (VES) positions were occupied using the Schlumberger electrode configuration with a maximum current electrode of AB/2 = 100 m. The results revealed the resistivity of layers, thickness of layers, depth to interface and curve-types of the 13 VES points in the study area (Table 1). The area is underlain by three geo-electric layers. The first layer represents the top/lateritic soil. The second layer is a weathered/fractured basement or weathered/saturated sandstones (at the VES points which fall within the sedimentary terrain). The third layer is fresh basements.

Table 1: summary of the interpreted VES curves

VES No.	Location/Elevation	Layer No.	Resistivity (Ωm)	Layer thickness(m)	Depth to interface (m)	Inferred lithology	Curve type
VES 1. Kulushin	N 9°48'26"	1	47.1	7.5	7.5	Top soil	Q
	E11°16'25" Elev. 550m	2	915.1	6.3	13.88	Weathered/fractured Basement	
		3	1678.2			Fresh Basement	
VES 2. Kulushin	N9°48'12"	1	43.7	6.3	6.3	Top soil	Q
	E11°15'40" Elev. 561m	2	355.8	3.9	10.2	Weathered/fractured basement	
		3				Fresh basement	
VES 3. Boh	N9°47'55"	1	140.5	9.1	9.1	Top soil	H
	E11°15'28" Elev. 548m	2	40.9	9.2	18.3	Weathered/fractured Basement	
		3	945.7			Fresh Basement	
VES 4. Boh	N9°47'33"	1	147.7	8.4	8.4	Top soil	H
	E11°15'23" Elev. 520m	2	58.7	8.1	16.5	Weathered/fractured Basement	
		3	308.3	30.2	46.7	Fresh Basement	
VES 5. Boh	N9°47'33"	1	118.1	9.2	9.2	Top soil	H
	E11°15'32" Elev. 492m	2	62.9	9.9	19.1	Weathered/fractured Basement	
		3	485.6	30.3	49.4	Fresh Basement	
VES 6. Layang	N9°47'29"	1	14.1	5.8	5.8	Top soil	Q
	E11°15'54" Elev. 580m	2	166.5	58	66.6	Weathered/fractured Basement	
		3	525.4			Fresh Basement	
VES 7. Layang	N9°47'15"	1	16	4.3	4.3	Top soil	Q
	E11°15'33" Elev. 586m	2	29.3	20	24.3	Weathered/fractured Basement	
		3	1010.7			Fresh Basement	
VES 8. Layang	N9°47'18"	1	13.7	6.1	6.1	Top soil	Q
	E11°16'8" Elev. 587m	2	132.8	8.9	14.9	Weathered/fractured basement	
		3	353.4			Fresh Basement	
VES 9. Karel	N9°46'52"	1	29.8	2.8	2.8	Top/Lateritic soil	Q
	E11°16'26" Elev. 563m	2	764.2	35.5	38.3	Weathered/Saturated sandstone	
		3	1388.7			Fresh Basement	
VES 10. Karel	N9°46'34"	1	43.2	6.2	6.2	Top/lateritic soil	Q
	E11°16'16" Elev. 557m	2	896.7	25.6	31.8	Weathered/saturated Sandstones	
		3	2359.1			Fresh Basement	
VES 11. Lapan	N9°46'42"	1	46.3	13.1	13.1	Top/lateritic soil	Q
	E11°16'58" Elev. 549m	2	496	16.7	29.9	Weathered/saturated Sandstones	

		3	1311.9			Fresh Basement	
VES 12. Lapan	N9°46'57" E11°17'08" Elev. 570m	1	46.6	4.2	4.2	Top soil	Q
		2	76.9	28	32.2	Weathered/fractured Basement	
		3	1373.1			Fresh Basement	
VES 13. Lapan	N9°46'16" E11°16'45" Elev. 563m	1	46.5	7.7	7.7	Top soil	Q
		2	223.1	14.3	22	Weathered/fractured Basement	
		3	242			Fresh Basement	

Curve types identified are simple H and Q types (Figure 3 a-d), characterized by three layers, reflecting lithological variations in the area. The Q curve types were the most dominant curve type suggesting high increase in resistivity from first to third layer, the H curve types indicating the low resistive layer overlain and underlain by high resistive layers. The general signature of the curves suggests alternate sequence of conductive-reflective, resistive-conductive layers, reflecting topsoil, weathered/fractured zone, porous and permeable un-weathered crystalline rocks nature of the study area, while in the sedimentary portion of the study area, the resistivity values were observed to be associated with un-consolidated and highly consolidated sandstones of the Bima group. It was responsible for the discrete resistivity layers obtained in the curves.

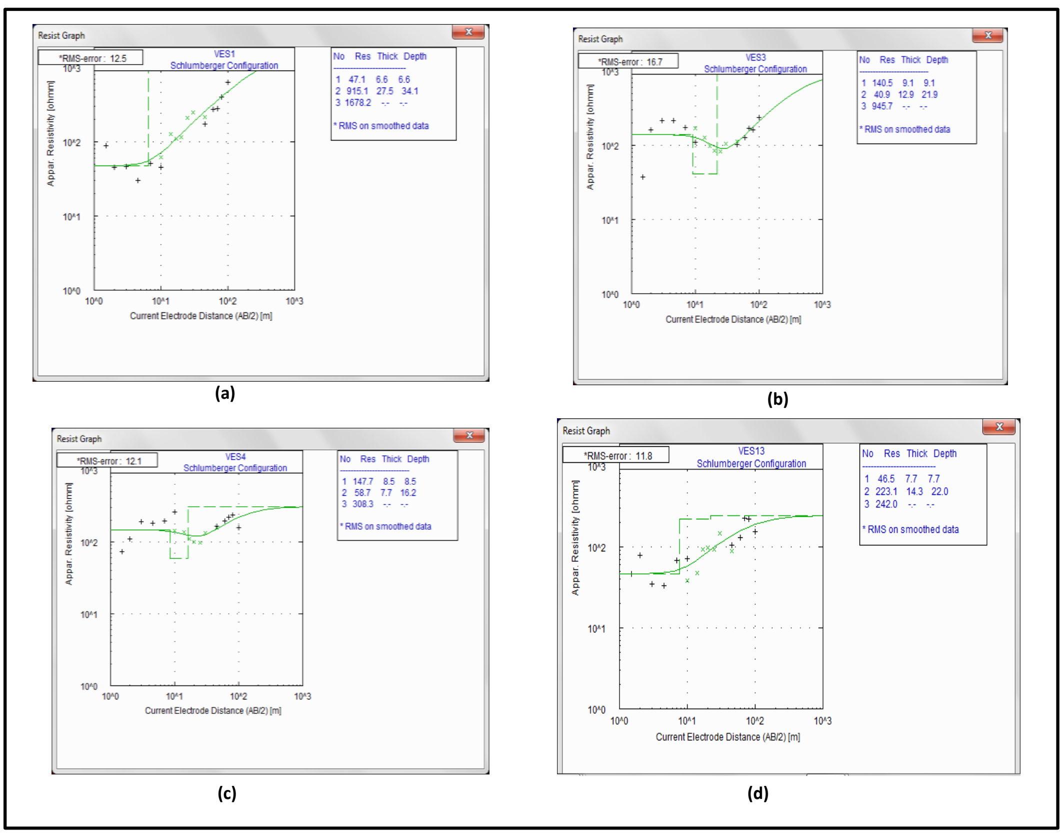

Figure 3: Some Selected Interpreted Field Curves

Analysis of Geo-electric Cross Sections

The final digital inversion results of VES interpretation (using WinResist software) were used for the construction of four geo-electrical cross-sections. The four geo-electric cross-sections were constructed along four profiles [figure 4 (**A-A'**, **B-B'** ***C-C'*** and **D-D'**)]

Profile **A-A'**, made up of four (4) VES points (figure 4a). This section revealed the presences of three geo-electric layers, the top soil, weathered/fractured basement and fresh basement. The top soil has resistivity ranging from 43.7 to 147.7 Ωm and with average thickness of about 7.5 m. The second layer is weathered /fractured basement has resistivity value ranging from 40.9 to 915.1 Ωm, the thickness is about 8 m to 9.5 m at VES 4 to VES 2, at VES 1 the thickness is about 27 m the layer lied at a depth of about 34 m suggesting good points for sitting borehole. The third layer is a fresh basement and has resistivity values ranging from 308.3 to 1678.2 Ωm with an infinite thickness.

Profile **B-B'**, is made up of three VES points (figure 4b). The first layer which is top soil has resistivity values ranging from 13.7 to 46.6 Ωm. The thickness at VES 7 is about 4 m and increased to 7.7 m at VES 13. The second layer is a weathered/fractured basement and or weathered/saturated sandstones at VES 13, it has resistivity values ranging from 29.3 to 223.1 Ωm and the thickness at VES 7 is 20 m, thinned to 8.7 m at VES 8 then increased to 14.3 m at VES 13; therefore VES 7 VES 13 are suitable for sitting of borehole which is typical of basement terrain (Mohammed et al., 2007). The third layer is fresh basement and has resistivity values ranging from 242 to 1010.1 Ωm and an infinite thickness.

Profile ***C-C'*** revealed the presence of three geo-electric layers, top lateritic soil, weathered/fractured basement at VES 4, 5, 7 and 9, and weathered/saturated sandstone at VES 12 and the fresh basement comprising of five VES points (figure 4c). The top soil has resistivity ranging from 16 to 147.7 Ωm, and thickness of about 9 m at VES 4 and 5 then thinned out toward VES 12. The second layer is a weathered/fractured basement or saturated sandstone at VES 12 with resistivity values ranging from 29.3 to 764.2 Ωm and the thickness of about 9 m at VES 4 and 5 then increased to 20, 28 and 35m at VES 7, 12, and 9, suggesting suitable site for sitting borehole at VES 7, 9 and 12. The third layer is a fresh basement it has a resistivity values ranging from 308.3 to 1388. 7 Ωm and is having an infinite thickness.

Profile **D-D'**, is made up of four VES points (figure 4d). The first layer which is top soil has resistivity values ranging from 13.7 to 46.3 Ωm, and the thickness increase toward VES 11 having the thickness of about 13 m. The second layer is a weathered/fractured basement, has resistivity values ranging from 132.8 to 896.7 Ωm and the thickness is 6 m at VES 6 and increased toward VES 11 to about 16.7m, VES 11 having thickness of 16.7 m which extend to a depth of about 30m can be a suitable point for sitting of borehole which is typical of basement terrain (Mohammed et al., 2007). The third layer is fresh basement and has resistivity values ranging from 353.4 to 2359.1 Ωm and an infinite thickness.

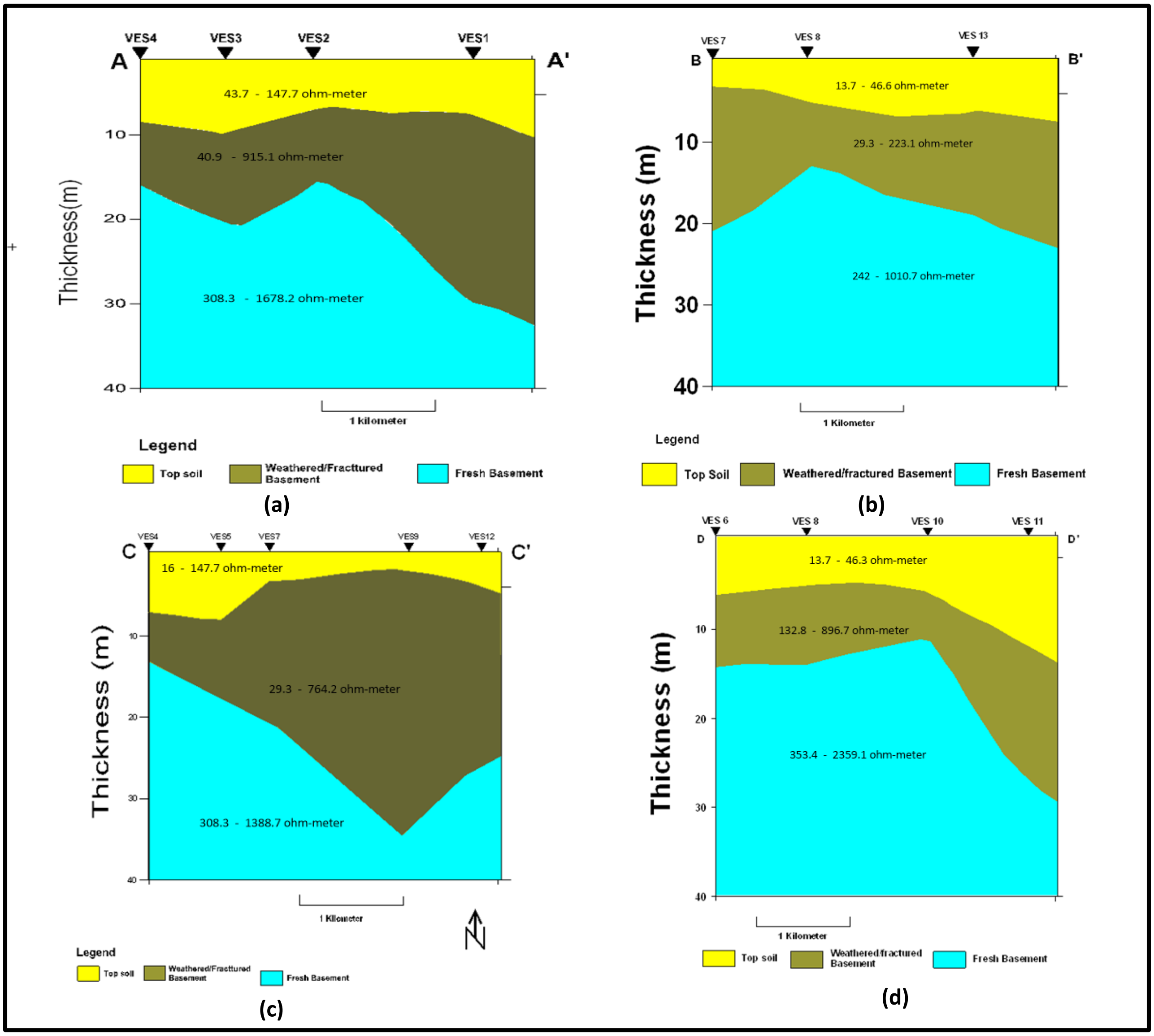

Figure 4: Geo-electric cross-section (Profile AA' - DD'); showing the various resistivity values and the corresponding rock types within the study area

Consequently, for effective groundwater development in this area, it's crucial to carefully choose borehole locations within fracture corridors or in spots where the Bima Sandstone is saturated. Employing additional geophysical techniques, such as electromagnetic surveys or lineament mapping, could significantly enhance the identification of fracture systems prior to drilling.

CONCLUSION AND RECOMMENDATIONS

The geological field mapping around Boh and its surroundings unveiled three lithologies namely: coarse grained biotite granite, pegmatite, Bima sandstone and basaltic with the coarse-grained biotite granite dominating.

The subsurface geophysical interpretation showed that the area is made up of three distinct geo-electric layers. The productive aquifer zones in the area are found within the weathered and fractured basement, as well as in the saturated sandstones, particularly at

VES points 1, 7, 9, 11, 12, and 13. When planning borehole locations, it's best to focus on areas where the second layer is the thickest and shows good hydraulic connectivity.

To refine our understanding of the fracture corridors before drilling, we suggest conducting additional reconnaissance using electromagnetic survey or lineament-mapping techniques. This is essential for proper sustainability of groundwater management in the study area considering the generally limited thickness of aquifers as revealed from the analysis of the interpreted field curves and the geo-electric cross sections.

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