DOI : https://doi.org/10.7186/wg481202202

Groundwater exploration using vertical electrical sounding and 2D electrical resistivity tomography in shale formation: A case study of Sabongida, Plateau State, North Central Nigeria

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Abstract: Sabongida is characterized by lots of abortive boreholes which are often shallow as a result of the complex nature of shale formation in the area and limited application of integrated geophysical techniques before drilling of boreholes. The presence of shale formation in the area makes it extremely difficult to drill productive boreholes, while the existing hand dug wells are always shallow due to the difficulty in digging deeper wells, this and other factors motivated the choice of the study location for the purpose of proffering solutions to solve the perennial water problem in the area. Twenty-two (22) vertical electric soundings data (VES) using Schlumberger array with the aid of Ohms mega resistivity meter were conducted with electrode spread of AB/2 = 215 m and eleven (11) 2D electrical resistivity tomography data (ERT) using ADMT – 600 S - X equipment were acquired. ERT was conducted using 20 m as the length of each profile with 300 m in 10 profile lines and 400 m as the depth of probing. The result of the VES interpretation shows three to five geo-electric layers while the geo-electric section revealed the aquifers to consist of sandstones with varying thicknesses. Two groundwater potential zones were delineated as shelly sandstones and clayey sand. The different color band indicates the different layers within the ground as the soil resistivity varies, blue indicates low resistivity values, green - yellow indicates moderate resistivity values while high resistivity values are brown - red. The results from the 2D images indicate the low resistivity regions, suggesting aquifer is within the depths of 150 to 300 m. Thus, the recommended depths for drilling of productive boreholes are 180 to 210 m and 270 to 300 m in Sabongida.

Keywords: Electrical, resistivity, 2D, tomography, shale, aquifer, water scarcity

INTRODUCTION

Groundwater has undoubtedly gained increased recognition in developing parts of the world today. Groundwater availability is determined by the presence of hydraulic qualities of groundwater bearing units, while portability is determined by hydrogeochemical properties and contamination/pollution vulnerability (Obiadi *et al*., 2016). Water is regarded to be a necessary resource for survival; hence its significance cannot be overstated. It is however disturbing if this all-important resource is becoming more and more scarce or difficult to explore (Christopher, 2006). According to Rosen & Vincent, 2014, water scarcity is especially acute in developing countries, where figures suggest that 67 % of the rural population lacks access to safe drinking water. This is due to the fact that people in rural regions rely on surface water from lakes, streams, ponds, and rivers to survive. Surface water bodies, on the other hand, are unreliable due to high evaporation rates, which are common in high temperate regions, and they are often polluted and infected with waterborne diseases (Gyau-Boakye *et al*., 2008). Treatment is required to supply water from these sources, primarily for home use, especially in small towns (Rosen & Vincent, 2014). People in impoverished regions who cannot afford such treatment utilize the waters as they are, resulting in epidemics of water-borne diseases including diarrhea, guinea worm infestation and bilharzia.

Due to the fact that groundwater is difficult to locate, a range of geophysical methods complimenting each other are required to offer data on its occurrence and location. Thapa *et al*. (2008) proposed that many criteria such as lithology, slope, lineaments, hydro geomorphology, land use and land cover should be understood in order to estimate groundwater potential zones of a region. Soil information is also crucial for determining groundwater potential zones. Coarse soils, for example, are generally permeable, but fine-grained soils have a lower permeability (Amaresh *et al*., 2006).

0126-5539; 2682-7549 / Published by the Geological Society of Malaysia.

Geophysics can be used to map groundwater resources as well as assess water quality (Hewaidy *et al*., 2015). Gravity, magnetics, seismic, electrical resistivity, electrical resistivity tomography, and electromagnetic approaches are just a few of the geophysical techniques that have been used to prospect for groundwater (Reynolds, 1997). The electrical and electromagnetic surveys have shown to be very useful in groundwater studies by Soupios *et al*. (2005). This is because many geological formation attributes that are important in hydrogeology, such as porosity and permeability of rocks, may be linked to electrical resistivity and conductivity signatures. Many of these geophysical approaches have since been employed to characterize groundwater, but the electrical method has once again proven to be the most successful (Eke & Igboekwe, 2011). This is why this study seeks to use the vertical electric sounding (VES) and 2D electric resistivity tomography in the search for groundwater potential zones in a predominantly shale formation in Sabongida, Langtang South Local Government Area of Plateau State, Nigeria.

In groundwater resource mapping, geophysical techniques are used for mapping out subsurface geological structure in which groundwater occurs (Araffa, 2012). Sabongida is characterized by lots of abortive boreholes which are often shallow as a result of the complex nature of geology of the area due to the presence of shale formation and, limited application of integrated geophysical techniques before drilling of boreholes. The presence of shale formation in the area makes it extremely difficult to drill productive boreholes while the hand dug wells are always shallow due to difficulties in penetrating the shale formation. Based on Soupios *et al*. (2005) and Ekwe *et al*. (2006), the vertical electrical sounding (VES) approach has been effectively employed in groundwater exploration and the computation of hydraulic properties such as hydraulic conductivity and transmissivity, with very effective and efficient results. Ojo *et al*. (2007) stated that the use of vertical electrical sounding (VES) technique has proven to be useful in achieving good lateral coverage for mapping aquifer units and drilling productive boreholes. (Onimisi *et al*., 2013) used electrical resistivity surveys to identify and locate good groundwater potential area. According to Igboekwe (2005) and Igboekwe *et al*. (2006), vertical electrical sounding (VES) is a geophysical technique for determining subsurface geology. It has also been frequently utilized for determining aquifer potential in borehole drillings. Emenike (2001), Onwuemesi & Egboka (2006) and Okoro *et al*. (2010) have also been successful with the vertical electrical approach. (Tizro *et al*., 2010) used VES to determine aquifer depths, transmissivity of rocks and soils, and the geometry of aquifers, geologic formations, and hydro stratigraphic sequences. Raouf & Mesalam (2016) studied the limestone karst system's topsoil of west Iran, while Odoh *et al*. (2012) used an integrated array of geophysical approaches to prospect for groundwater in a fractured shale aquifer of Kpiri-Kpiri, Ebonyi State, Southeast Nigeria. Also, Nejad *et al*. (2011) utilized electrical resistivity method to study subsurface layers and determine aquifer features.

Electrical resistivity tomography is a non-destructive, non-invasive, portable, and environmentally benign technique with a wide range of applications in engineering, environmental science, and subsurface geology (Metwaly, 2012). As stated by Griffiths & Barker (1994), to better understand complicated subsurface formations, electrical resistivity tomography was invented. It is utilized to obtain high-resolution images of subsurface electrical resistivity patterns. It is also used to evaluate how apparent resistivity is distributed horizontally per depth. When used in geological mapping and groundwater investigations, 2-D electrical resistivity tomography has proven to be effective (Zhou *et al*., 2004, Hsu *et al*., 2010 and Rao *et al*., 2013). Even in the presence of geological and topographical difficulties, electrical resistivity tomography (ERT) provides a more accurate 2-D resistivity model of the subsurface, where resistivity variations in the vertical as well as horizontal directions along the survey line are recorded continuously (Loke *et al*., 2013). According to Yang *et al*. (2002), Hauck *et al*. (2003), Cheng *et al*. (2008) and Crook *et al*. (2008), 2D ERT approach is a more effective and powerful way for studying shallow subsurface electrical structures in a variety of situations. Groundwater exploration and prospecting, engineering geophysics and environmental site evaluations have all made substantial use of electrical resistivity tomography (eg., Hossain, 2000; Suzuki *et al*., 2000; Demanet *et al*., 2001; Adepelumi *et al*., 2006; Gokturkler *et al*., 2008; Andrade, 2011). Using 2D electrical resistivity tomography, Alshehri & Abdelrahman (2021) investigated the groundwater supply of the Harrat Khaybar area in Saudi Arabia, determining the water bearing formation to be sub-basaltic alluvial sediments and basaltic flows. Niculescu & Andrei (2021) used electrical resistivity tomography to image sea water intrusion in the coastal aquifer of Romania's Vama Veche resort, showing abnormal zones that were 45–49 m deep and delineating potential salt water intrusion channels in the area. 2D electrical resistivity tomography play a very important role in environmental studies, one typical example is by Ugbor *et al*. (2021) that studied the influence of leachate plumes on groundwater around dumpsites.

LOCATION AND TOPOGRAPHY

The study area is located in Plateau State, Langtang South Local Government Area, in the north-central part of Nigeria. It lies within latitudes N 08° 43′ 45″ and N 08° 44′ 15″ and longitudes E 009° 42′ 15″ and E 009° 43′ 45″ on a scale of 1:10,000. It is extracted from Shendam South-west Sheet 212 with an aerial extent of 25 km^2 (Figure 1).

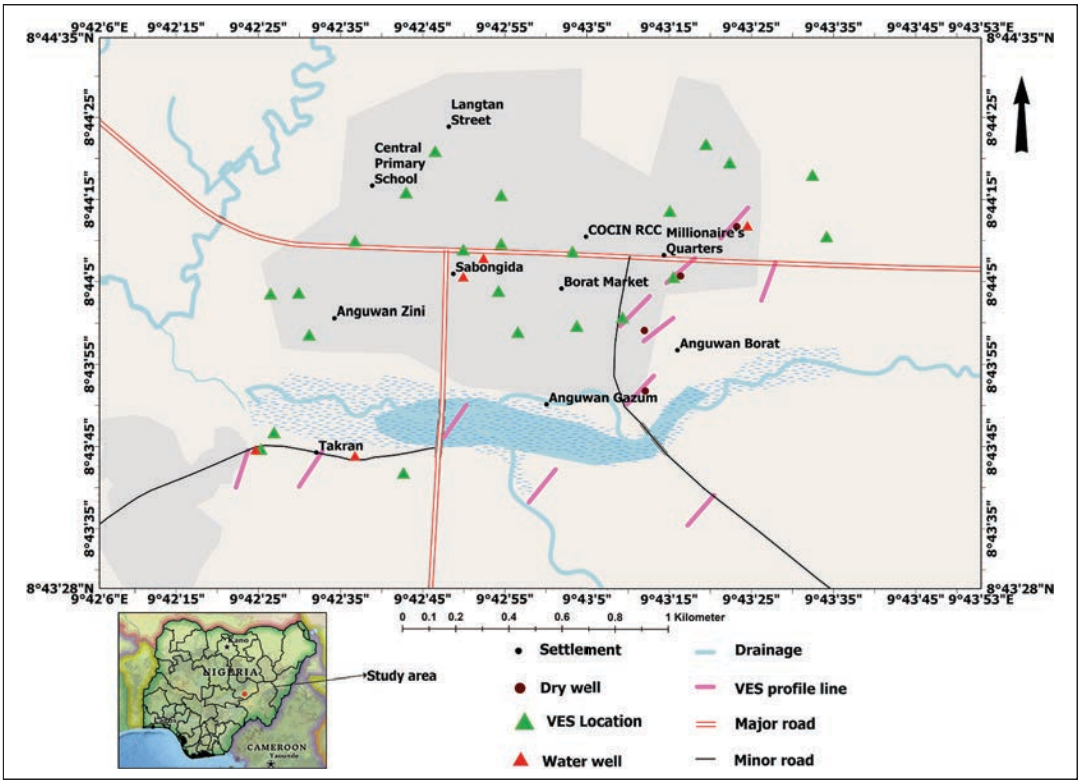

Figure 1: Location Map of Sabongida, North Central Nigeria.

The area is accessible through Yelwa–Shendam–Yelwa–Sabongida and Zamko-Mabudi Trunk 'A' and Trunk 'B' roads with many rural roads and footpaths linking the area to Sabongida. The roads are in a bad shape and this made it difficult to access the community for any groundwater exploration work. There are lots of footpaths and cattle tracks connecting the study area and other open sources of domestic water. The area lacks basic social amenities like electricity, medical care facilities, potable water and road network. The absence or lack of these basic necessities makes life difficult to the general population of the locality.

The relief of the study area is characterised by undulating planes that has been affected by erosion and weathering. The area is composed of lowland with few denudated low laying conical hill with flat tops. Laterization is also observed along most of the river channels which are situated in low elevated areas. The low-lying hills are easily noticed because the hills have been greatly reduced to almost near horizontal plain. The streams and rivers normally dry up during the dry season leaving behind mud cracks and stagnant ponds but they flow during the wet or rainy season when the ground is sufficiently recharged by rainfall. The area experience scarcity of water during the dry season. The water flow majorly from the north to the south during the rainy season. The rivers have many tributaries at various points due to the topography of the area.

GEOLOGY OF THE STUDY AREA

The study area is part of the Central Benue trough which is located between the NE-SW trending rift valley estimated to extends to 1000 km long and about 150 km wide (Obaje, 2004). The area is predominantly underlain by a shale formation (Figure 2). The Awgu Formation in the Central Benue trough plainly indicates the end of marine sedimentation (Offodile, 1976; Ofoegbu, 1990). Sandstones, siltstones and coal beds make up the formation, which includes bluish-grey to dark-black carbonaceous shales, calcareous shales, shale and limestones, sandstones, and siltstones. The major outcrop of the coal-bearing Awgu Formation is mentioned by Obaje (1994) and it does not extend to Sabongida in Langtang South in Plateau State. The Lafia Formation which is the youngest formation in the Central Benue trough does not extend to the Sabongida area, the formation was deposited under continental condition (fluviatile) in the Maastrichtian and lies unconformably on the Awgu Formation. (Obaje, 2004) subdivided the entire Central Benue trough into six stratigraphic units, they are Albian which include the Gboko Formation referred to as the Asu River Group (Offodili, 1976; Nwajide, 1990) which are overlain by Cenomanian Awe and Keana formations. The Cenomanian–Turonian Ezeaku Formation overlies the Keana Formation. The coal rich Agwu Formation which is late Turonian – Early Santonian overlies the Ezeaku Formation and is covered by the Campanon - Maastrichian

Lafia Formation which is the youngest formation (Obaje, 2004). The predominantly Agwu Formation is associated with conglomerate of laterite overlying shale (Plate 1A). The thickness of the conglomerate ranges from 1.5 to 3 m, the conglomerates serve as good materials for road constructions and also serve as overburden aquifer in shallow wells.

The lateritic formation is an unconformity between the Agwu Formation and Lafia Formation. The lateritic conglomerate is the period of the unconformity. The conglomerate deposition resulted during the change in water surge from low to high current. This conglomerate can also serve as water bearing formations, one typical example is the Kerri-Kerri Formation of the Chad basin. Unconformity separates the Agwu Formation from the Lafia Formation and this confirmed the fact that either the Lafia Formation does not extend to the study area or it may have been eroded. The thickness of the conglomerate tends to increase northwards which explains why the communities situated northwards have little water scarcity compared to those situated southward where the conglomerates thin out. Carbonaceous shales, calcareous shales, shaly limestones, sandstones, and siltstones make up the Agwu, the formation found here is the whitish type (Plate 1B), which means they were deposited at the shallow part of the Central Benue trough and therefore susceptible to oxidation.

Sabongari has no visible outcrops and the formation is relatively undeformed because there are no major structures observed during the geologic mapping. The outcrops seen are from the burrows pit excavated by a construction company.

MATERIALS AND METHODS

Vertical electrical sounding (VES)

Ohm mega resistivity meter was used for carrying out the vertical electrical sounding (VES) and ADMT 600S - X equipment for electrical resistivity tomography (ERT). A total of 22 vertical electrical soundings and 11 2D electrical resistivity tomography points were carried out. The use of the electrical resistivity method as a geophysical tool for exploration is based on the movement of electric current through the ground and rock material (Aning *et al.*, 2014). To allow electrical current to travel through the

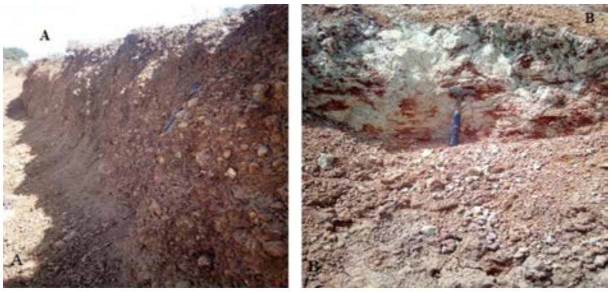

Plate 1: (A) Typical bed of conglomerate (unconformity period) overlaying shale formation, (B) Whitish grey shale deposited in an oxidizing environment.

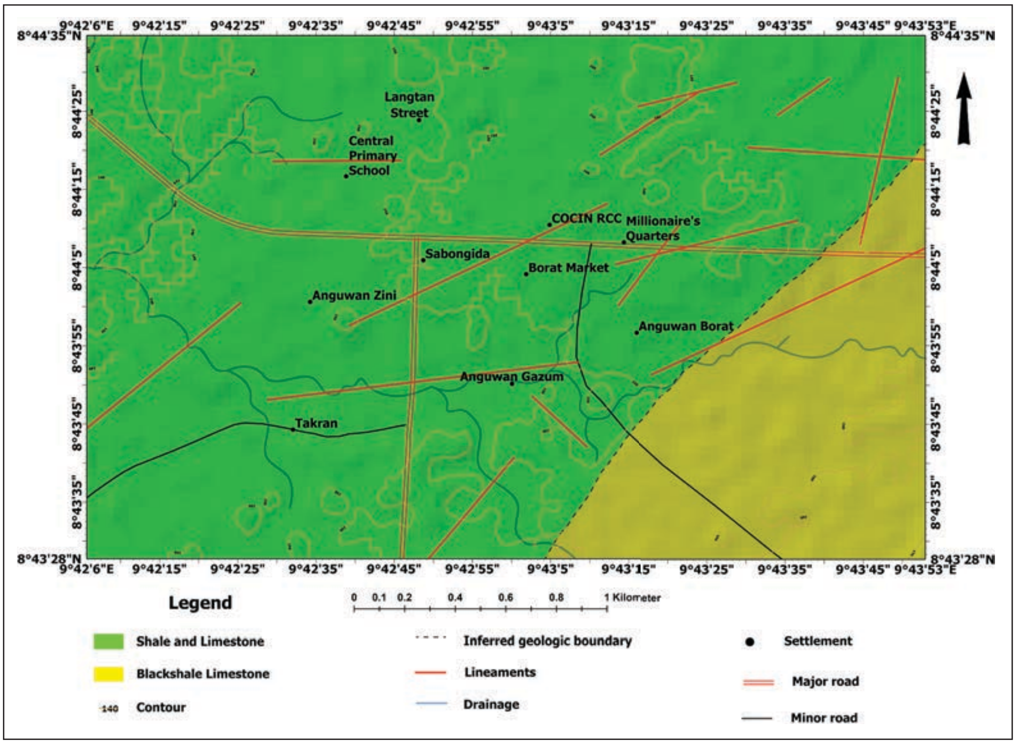

Figure 2: Geological Map of Sabongida.

ground, a rock must have some electrical resistance and the ability to store electrical charges (Aning *et al*., 2014). Vertical electrical sounding (VES) was used to determine the vertical geologic variation of resistivity in the area using a Schlumberger configuration. The relative spacing of the current and potential electrodes is maintained, and the entire spread is gradually increased around a fixed central point. On the earth's surface, four electrodes in the sequence A M N B are set in a straight line, with AB ≥ 5 MN. The apparent resistivity (a) measured with a Schlumberger array, where AM is the distance between the positive current electrode A and the potential electrode M on the earth's surface. When two current electrodes A and B are utilized, the potential difference (V) between two measured electrodes M and N is detected, the apparent resistivity can be written in the form:

$$\rho a = \pi \, \Delta V/I \text{ x } [\, ((AB/2)2 - (MN/2)2) \, / \, MN] \text{ or}$$
$$\rho a = \pi \, K \, \Delta V/I \qquad \text{(Eqn. 1)}$$

The apparent resistivity (ρ) is determined by the electrode array geometry, as defined by the geometric factor (K) (Reynolds, 1997).

2D electric resistivity tomography (ERT)

2D electrical resistivity tomography (ERT) is a technique for imaging the subsurface bulk electrical resistivity distribution. It enables the mapping of the Earth's electrical resistivity distribution, allowing for subsurface heterogeneity estimation (Slob, 2004). When current is injected into the ground using two current electrodes, the ground surface (layers of materials with different individual resistivity) may be measured, allowing the subsurface resistivity distribution to be determined (Herman, 2001; Loke *et al*., 2013). The critical part in ERT is computing the resistivity pseudo section (Everett, 2013). The observed apparent resistivity is used to match the pseudo section in ERT imaging. The ERT measurement can be converted into high-resolution resistivity images in 1-D, 2-D, and 3-D. ERT is regarded better than other electrical approaches since quantitative findings are obtained by using a regulated source of specific dimensions (Telford *et al*., 1990). Geological characteristics such as mineral, fluid content, porosity and degree of water saturation also have a significant impact on electrical properties (Loke *et al*., 2013; Aizebeokhai *et al*., 2015). The potential difference is converted into resistivity of the subsurface strata (Reynolds, 1997). 2D methodologies of electrical resistivity tomography was discussed in detailed by (Gharibi & Bentley, 2005; Chambers *et al*., 2007, 2011; Magnusson, *et al*., 2010). For the purpose of this study, the instrument ADMT 600 S - X is used for ERT. It is a geophysical instrument comprising of two electrodes, connecting cables and a main frame with touch screen or a sensor probe which could be used in place of the electrode. A measuring tape is used to measure the distance of the spread on the ground. The principles of the instrument is based on electrical resistivity method which is measured through the potential electrode and the result presented as 2D images (electrical resistivity tomography) with various color to represent different formation as the resistivity changes.

RESULTS

Vertical electrical sounding (VES)

In this study, 22 vertical electrical sounding (VES) measurements were taken. The resistivity values, layer thickness, and depth of the VES survey data collected from various places within the research region were analyzed and the results presented in Figures 3, 4, 5 and 6. 9.1 % of the curves in Sabongida are Q type and 40.9 % are HK curves while the dominant field curves in the study area are H type curve making up to 50 % of the curves. Qualitative interpretation of electrical soundings revealed a general view on the lateral and vertical variations in the apparent resistivity and geology of the study area.

The results of interpreted curves are presented in Table 1. In terms of electrical resistivity, igneous and metamorphic rocks have higher resistivity values compared to most sedimentary rocks such as shale and sandstones. The resistivity values of the first layer ranges from 70 to 750 Ωm and the thickness ranging from 1.6 to 6 m, this indicates that the layer consists of a lateritic cap. The second layer with apparent resistivity value ranging from 15 to 220 Ωm and a range of thickness from 3 to 33 m, this layer is of clayey sand and shale formations. The third layer on the other hand ranges from 1 to 65 Ωm and the thickness ranges from 10.5 to 160 m.

2D electrical resistivity tomography (ERT)

Eleven (11) profile lines were conducted, each covering a horizontal length of 20 m with a probing depth of 300 m, except for profile number 11 that has a depth of 400 m. The distance between the probes (sensors) is 2 m and the result is presented as a 2D image which is known as electrical resistivity tomography with each color representing the range of resistivity values in ohms - meter (Ωm). The results of all the 11 profiles conducted within the study area are presented as electrical resistivity tomography, the Y axis is representing the depth while the X - axis represents distance on the ground. The blue color represents range of resistivity values which are conductive in nature with low resistivity values (water saturated, shale or loose sediment) while light green to red color represent geologic materials that are average to high resistive materials or consolidated in nature. In most cases the low resistivity is attributed to factors such as the porosity, permeability, water content, temperature and clay in the soil. Figure 7(P1) shows green color indicating sandy formation from 0 to 170 m with pockets of high

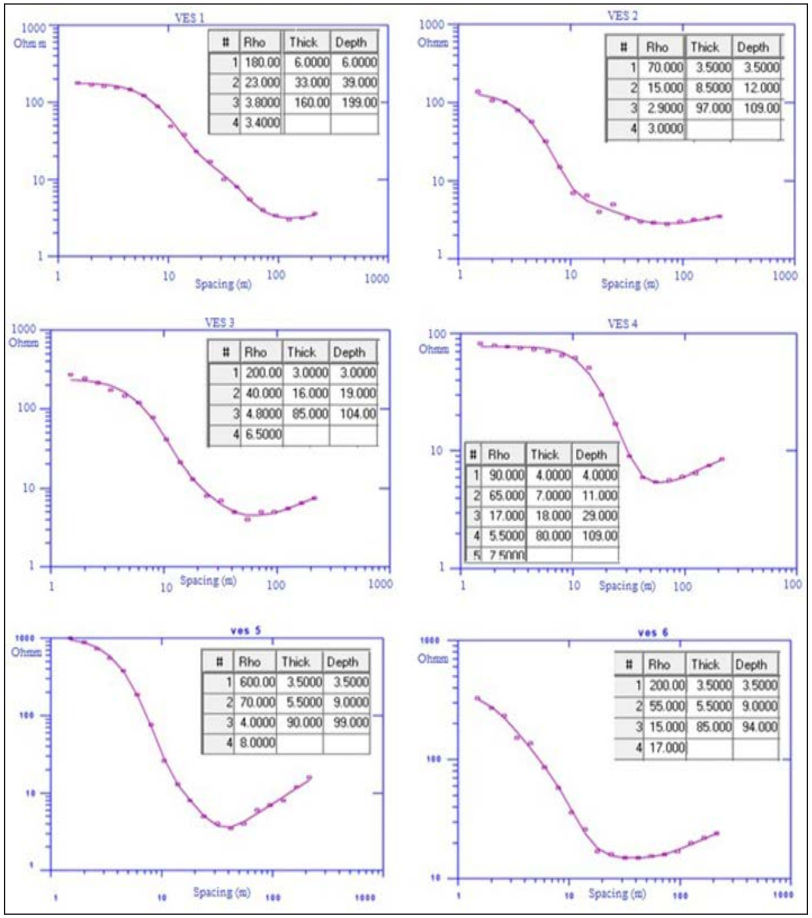

Figure 3: Vertical electrical sounding curves of VES 1 - 6.

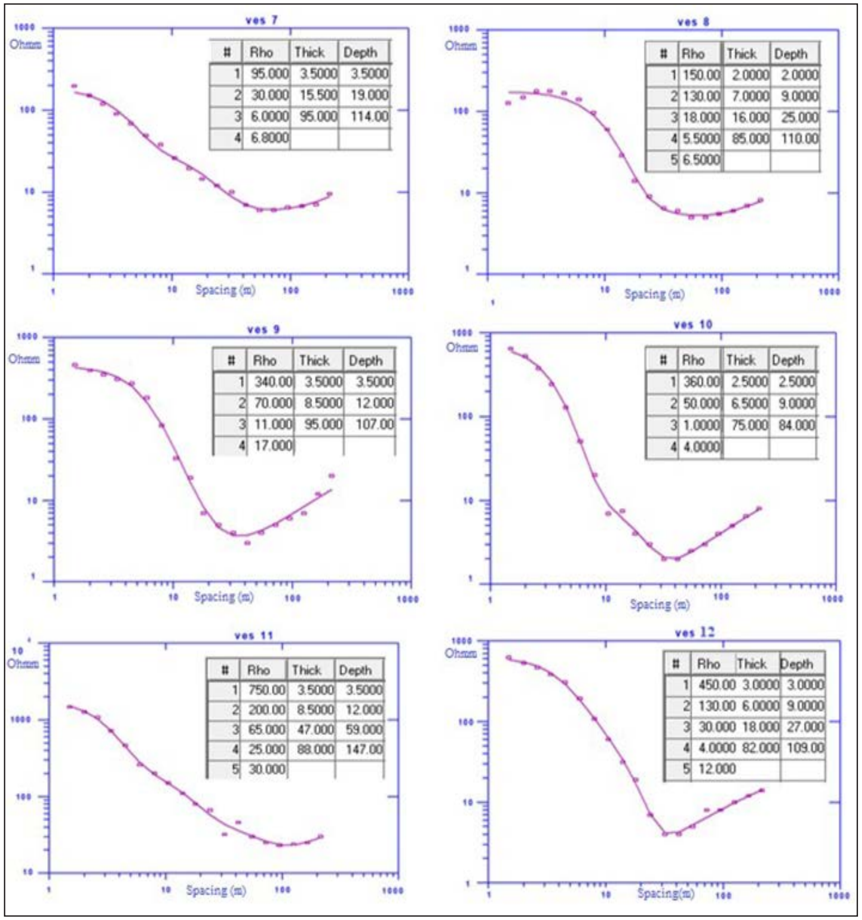

Figure 4: Vertical electrical sounding curves of VES 7 - 12.

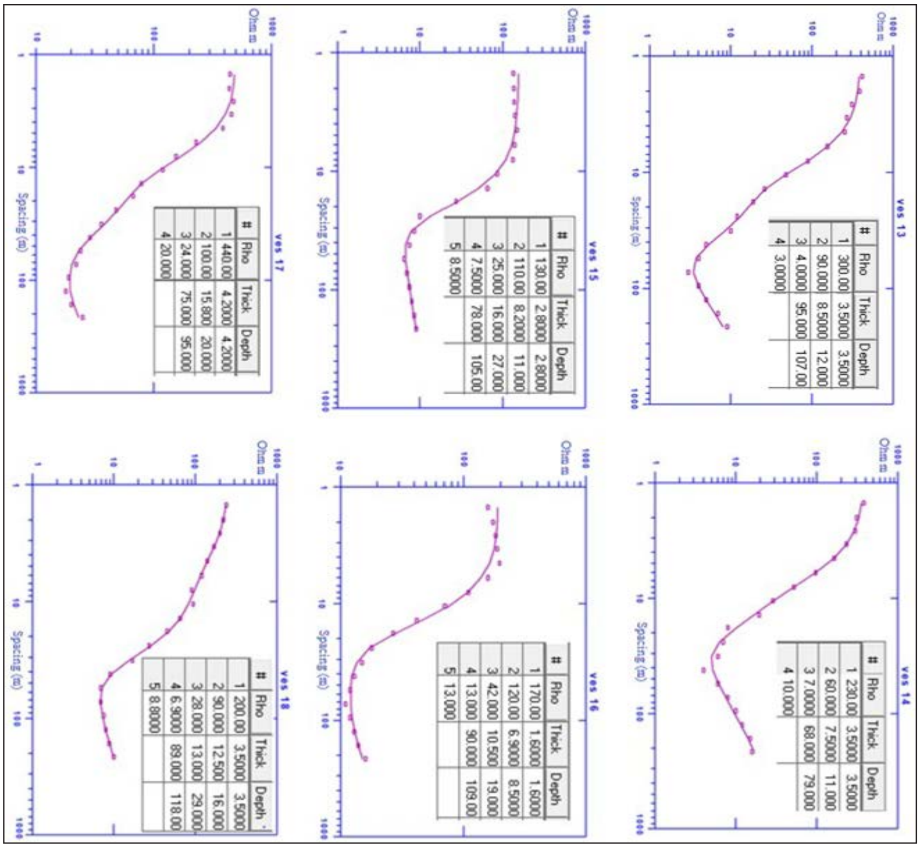

Figure 5: Vertical electrical sounding curves of VES 13 - 18.

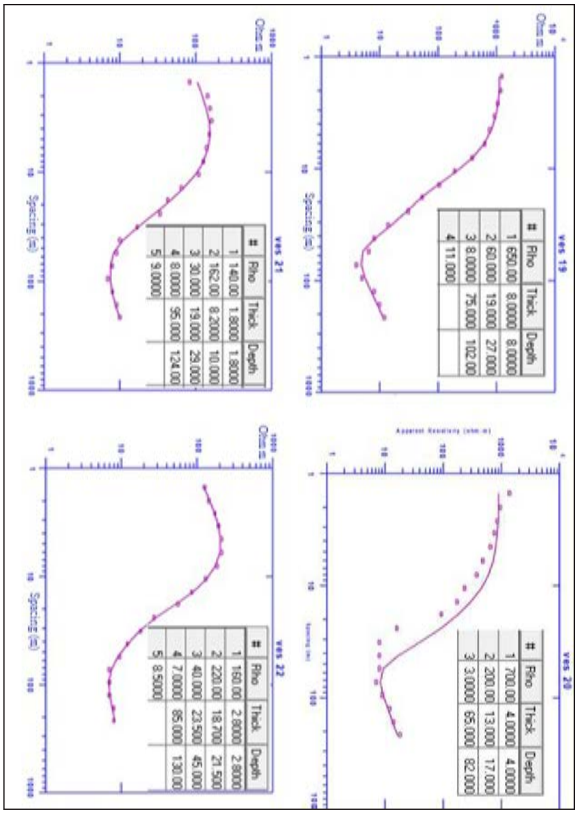

Figure 6: Vertical electrical sounding curves of VES 19 – 22.

Table 1: Vertical electrical sounding locations, coordinates and geoelectric parameters.

S/No	Location	Coordinate		Resistivity (Ωm)					Thickness (m)			
		Lat.	Long.	1	2	3	4	5	1	2	3	4
1	VES 1	08° 44’ 10.8”	009° 42’ 54.3”	180	23	3.8	3.4		6	33	160	
2	VES 2	08° 44’ 16.5”	009° 42’ 54.3”	70	15	2.9	3		3.5	8.5	97	
3	VES 3	08° 44’ 09.5”	009° 42’ 5.0 “	200	40	4.8	6.5		3	16	85	
4	VES 4	08° 44’ 16.3”	009° 42’ 43.1”	90	65	17	5.5	7.5	4	7	18	80
5	VES 5	08° 44’ 21.3”	009° 42’ 46.5”	600	70	4	8		3.5	5.5	90	
6	VES 6	08° 44’ 10.9”	009° 42’ 37.0”	200	55	15	17		3.5	5.5	85	
7	VES 7	08° 44’ 04.2”	009° 42’ 30.1”	95	30	6	6		3.5	15.5	95	
8	VES 8	08° 43’ 59.2”	009° 42’ 31.4”	150	130	18	5.5	6.5	2	7	16	85
9	VES 9	08° 43’ 45.0”	009° 42’ 25.6”	340	70	11	17		3.5	8.5	95	
10	VES 10	08° 43’ 42.8”	009° 42’ 42.7”	360	50	1	4		2.5	6.5	75	
11	VES 11	08° 43’ 21.3”	009° 42’ 37.9”	750	200	65	25	30	3.5	8.5	47	88
12	VES 12	08° 44’ 04.8”	009° 42’ 54.2”	450	130	30	4	12	3	6	18	82
13	VES 13	08° 43’ 59.5”	009° 42’ 56.5”	300	90	4	3		3.5	8.5	95	
14	VES 14	08° 44’ 00.4”	009° 43’ 03.9”	230	60	7	10		3.5	7.5	68	
15	VES 15	08° 44’ 01.6”	009° 43’ 09.1”	130	110	25	7.5	8.5	2.8	8.2	16	78
16	VES 16	08° 44’ 06.3”	009° 43’ 15.3”	170	120	42	13	13	1.6	6.9	10.5	90
17	VES 17	08° 44’ 14.4”	009° 43’ 14.9”	440	100	24	20		4.2	15.8	75	
18	VES 18	08° 44’ 09.6”	009° 43’ 03.2”	200	90	28	6.9	8.8	3.5	12.5	13	89
19	VES 19	08° 44’ 11.0”	009° 43’ 33.8”	650	60	8	11		8	19	75	
20	VES 20	08° 44’ 18.5”	009° 43’ 32.2”	700	200	3			4	13	65	
21	VES 21	08° 44’ 13.3”	009° 43’ 23.9”	140	162	30	8	9	1.8	8.2	19	95
22	VES 22	08° 44’ 20.3”	009° 43’ 22.2 “	160	220	40	7	8.5	2.8	18.7	23.5	85

resistive lateritic sand on top and toward the end of the profile with resistivity values ranging from 215 to 315 Ωm and, a thin layer of laterite intercalated with shale of 30 m thick. Figure7(P2) revealed thick layer of shale of 100 m which is overlain by sand/lateritic material and a thin resistive horizontal lateritic material on point 20. Figure 7(P3) present thin layers of shale/sand formation at different depth levels with resistivity values ranging from 115 to 220 Ωm. Deposits of sand/lateritic materials with resistivity values of 255 to 360 Ωm at 150 m. The over burden materials are predominant lateritic with resistivity values of 360 to 465 Ωm with thickness of 60 m.

The electrical resistivity tomography in Figure 8(P4, P5 and P6) are characterized by thick overburden lateritic materials of 90 m and resistivity values ranging from 160 to 345 Ωm. Thin layers of shales were observed in P4 at 150 and 180 to 230 m depths and a wide layer of sandy/lateritic materials were revealed at 240 to 300 m with resistivity values ranging from 100 to 265 Ωm.

The electrical resistivity tomography in Figure 9 reveal laterite at the top of profile P7, and underlain by a layer of sand with resistivity values ranging from 145 to 215 Ωm. Thin layer of intercalation of shale/sand were delineated at 150 to 300 m. Figure 9(P8) shows a thick layer of sand of 0 to 140 m which is separated by a thin layer of resistive lateritic material. A thin layer of shale/sand formation of 70 m thick with resistivity values of 115 to 175 Ωm were recorded. Figure 9(P9) presents a resistive lateritic/sand formation of 120 m thick which is underlain by lateral layer of shale/sand of 30 m at 180 m and 270 m.

The electrical resistivity tomography in Figure 10 (P10) revealed a thick layer of sand as the overburden formation in the area with resistivity values of 135 to 180 Ωm, and thin resistive horizontal materials suggesting lateritic materials. Thin layer of shale/sand is interbedded within lateritic materials at 260 m with resistivity values ranging from 180 to 240 Ωm. The electrical resistivity tomography in Figure10(P11) are characterized by thick shale/sandy formation of 160 to 180 m, 240 to 300 m, 320 to 340 m and 355 to 370 m with their resistivity values ranging from 70 to 150 Ωm.

DISCUSSION

The geology of the study area is predominantly underlain by late Cretaceous Agwu Formation. The Agwu Formation was deposited in a marine environment and are structurally controlled in the NE–SW direction, and

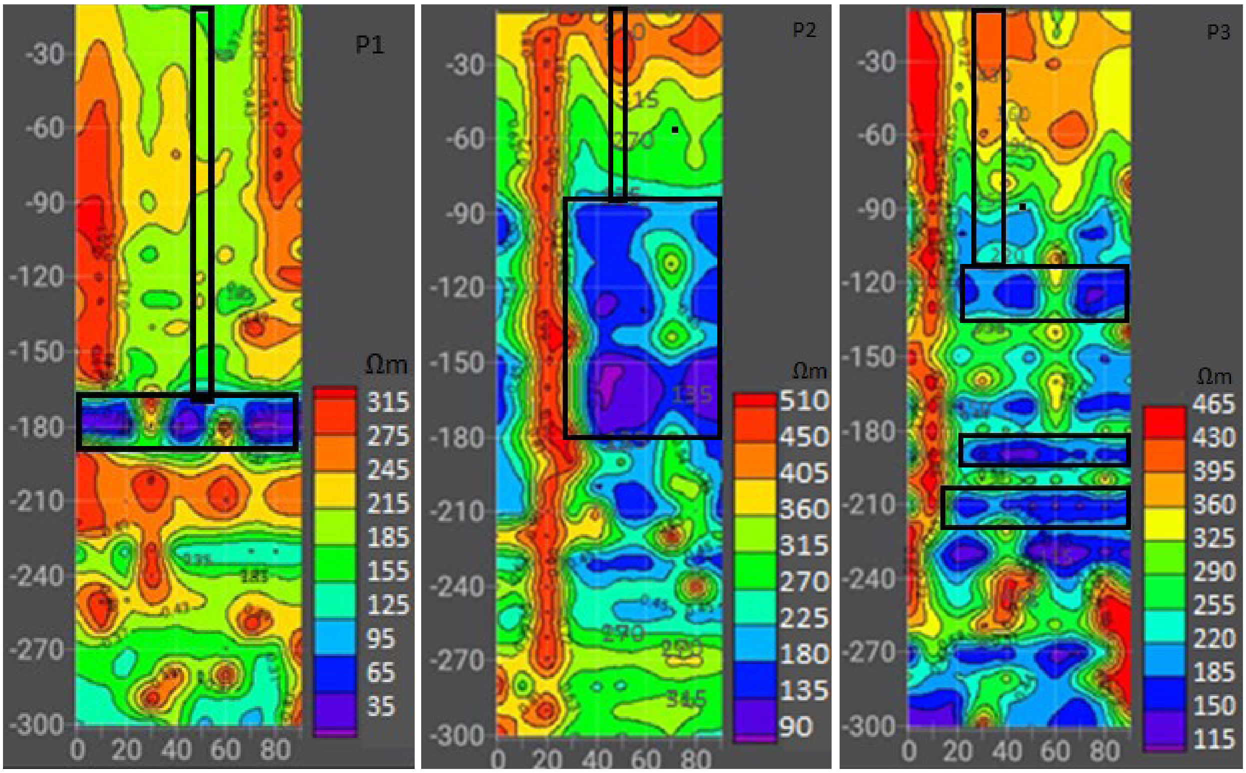

Figure 7: Electrical resistivity tomography of profile P1, P2 and P3.

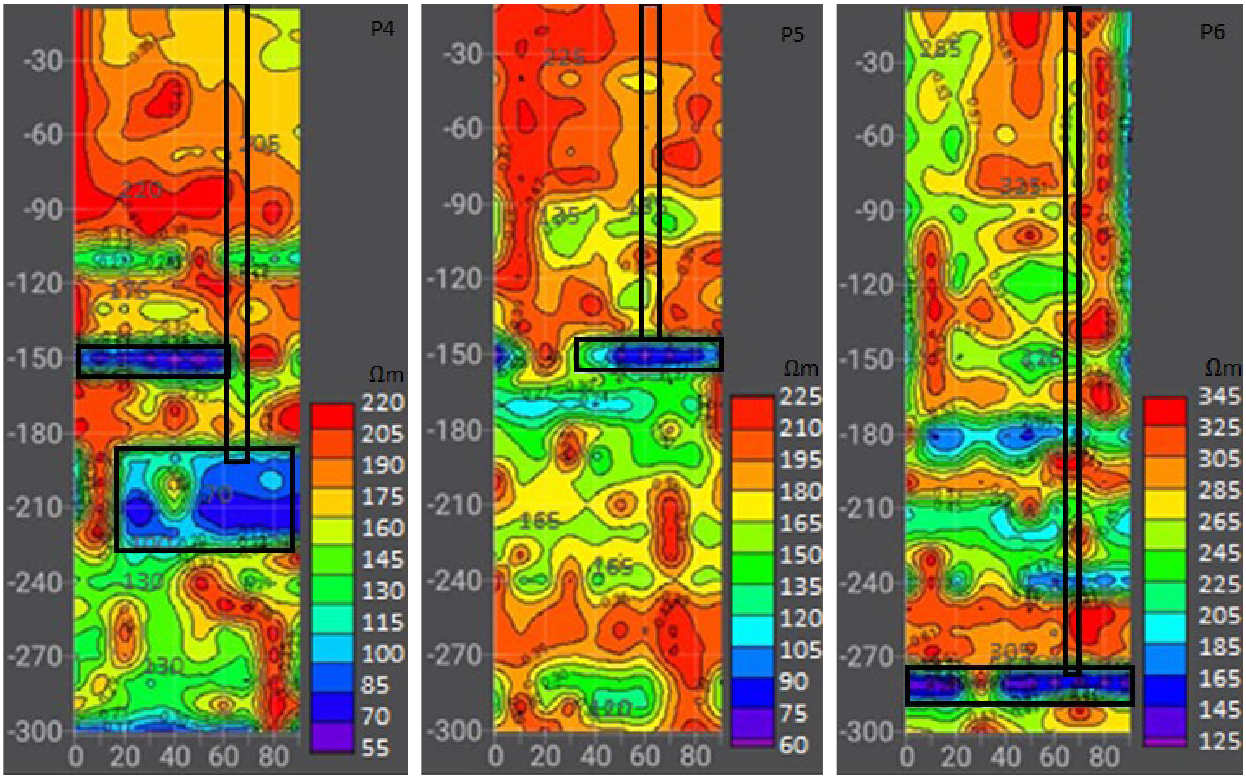

Figure 8: Electrical resistivity tomography of profile P4, P5 and P6.

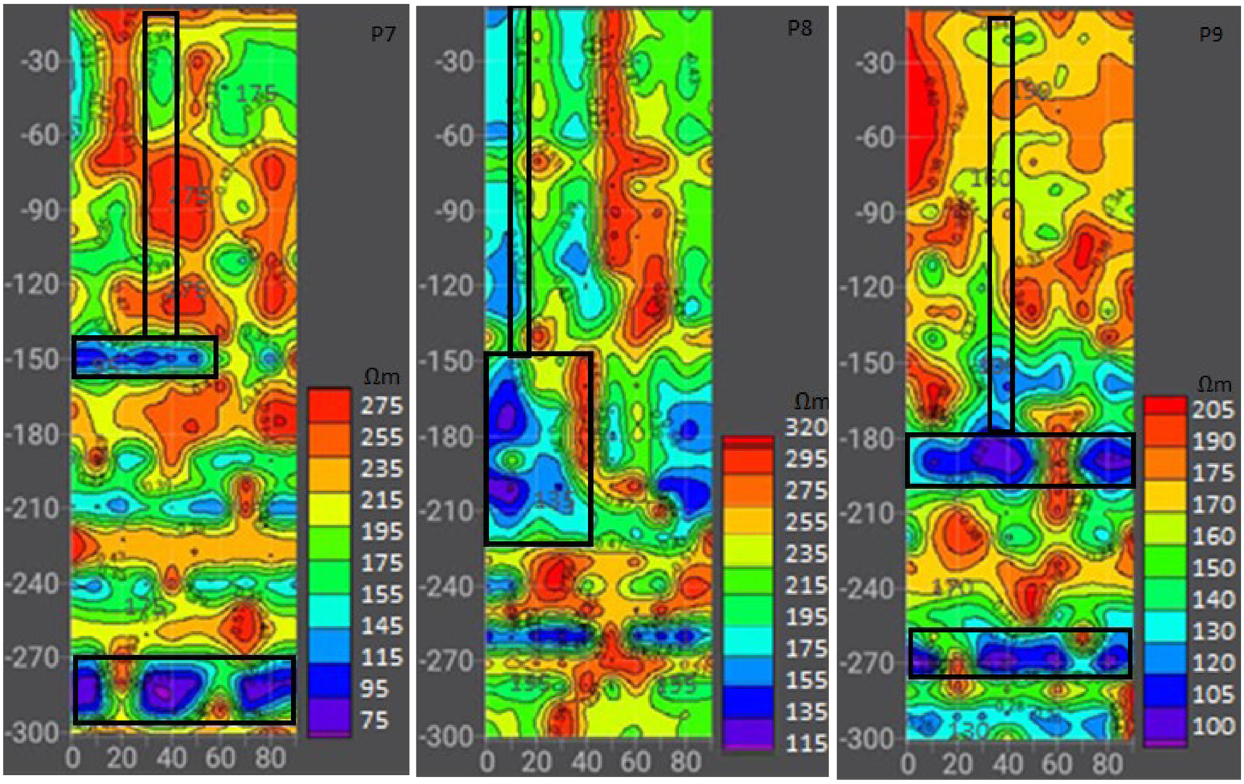

Figure 9: Electrical resistivity tomography of profile P7, P8 and P9.

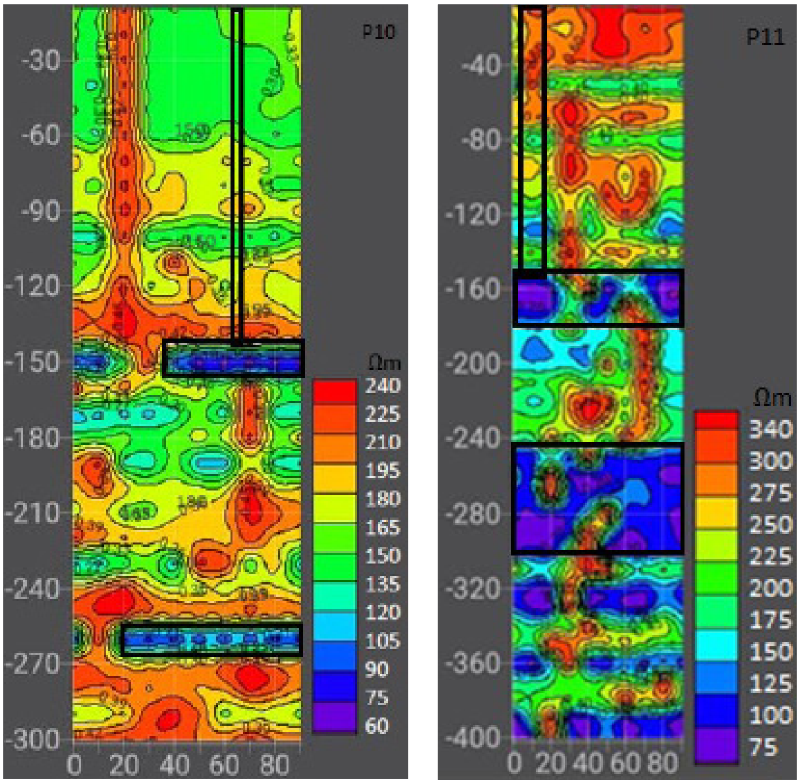

Figure 10: Electrical resistivity tomography of profile P10 and P11.

consists mainly of shale, shelly limestone, sandstone and siltstone (Agumanu, 2011). At some locations, the Agwu Formation is overlain by Agbani Formation which is sandstone in nature with an exposed thickness of 45 m. The shelly nature of the area is responsible for the difficulty in locating optimal drilling points for groundwater exploration in Sabongida. Most of the hand dug wells within the area are shallow and dry up during dry season, creating water scarcity in the community. There are no functional and productive boreholes in Sabogida because all the failed wells were drilled at a very shallow depth, thereby not reaching the potential aquifer (water bearing formation) in the area. The analysis of the results from the geophysical survey identified three different lithologies. The lithologies encountered from the surface to the depth are various lateritic formations (lateritic sand, laterites) with high resistivity values of > 500 Ωm; a shale layer with low resistivity values of < 40 Ωm, and the third layer is of silt stone/shale formation which are the zones of low to moderate resistivity ranging from 50 to 185 Ωm and these are the saturated zones or productive groundwater zones otherwise known as the aquifer in the area.

The electrical resistivity tomography (ERT) over Sabongida revealed deeper lithologic information compared to the vertical electrical sounding due to the electrode spread of AB/2 = 215 m used in this study. The ERT probed 300 m depth with better, clearer and easy to interpret 2D images in terms of the different geologic information in Sabongida. Low resistivity values observed in Figure 7(P1) at the depth of 160 to 200 m suggest saturated layer of sandstone which is a good drilling point for a productive borehole. Figure 7(P2) is characterized by thick shelly layer from 90 to 180 m with resistivity values ranging from 90 to 225 Ωm, this location if carefully screened will yield adequate groundwater to the community and end water scarcity. Figure 7(P3) revealed different layers of shale/sandstone/siltstone with resistivity values of 115 to 325 Ωm, this is in agreement with the local geology of Sabongida (Agumanu, 2011) which is characterized by thick sediments of Agwu Formation. Figure 8(P4, P5, P6) revealed high resistive conglomerate of laterite which are reddish in color. A thin lateral layer of shale/sandstone/siltstone with low resistivity values varying from 55 to 225 Ωm with the thickness of 15 to 35 m were detected, thus these profiles may not be suitable for drilling productive boreholes in the area, with the deepest layer occurring at 270 to 290 m.

Thin layer of low resistivity materials of shales/ siltstone/sand at 150 and 270 to 300 m, possible drilling site is recommended at point 4 (Figure 9(P7)) and should be drilled to the depth of 300 m, the borehole will tap water from different layers of sandstone/siltstone at 150, 210, 240 and 270 to 300 m. P8 in Figure 9 shows large area dominated by green color indicating the presence of low to medium resistivity rocks which is influenced by porosity, clay or water contents. Productive boreholes are recommended at 180 to 210 and 270 to 300 m depths of profile P9 of Figure 9. Thick layer of low to medium resistivity was observed in Figure10(P10) and a thin lateral layer of shale/sandstone/ siltstone at 150 and 260 m, while thick layer of shale/sandstone were revealed at different depth levels in Figure 10(P11), suggesting possible productive site for drilling a borehole for the community.

CONCLUSION

The Sabongida community depends largely on surface water than groundwater sources due to previous abortive boreholes drilled as a result of the complex nature of the geology. This is because the water bearing formation is underlain by a thick shale bed in the area. The results of vertical electrical sounding and 2D electrical resistivity tomography have proved their credibility beyond reasonable doubt to locate possible drilling site in the community. Water scarcity in Sabongida would be a thing of the past if strict compliance to the results and recommendations are followed. It is concluded that there is a good prospect of groundwater if the aquifer is properly located and the screen properly placed during drilling. Groundwater bearing formations are delineated and drilling is recommended to the depth of 150 to 300 m in the area.

ACKNOWLEDGEMENTS

The authors appreciate University of Jos, Nigeria for giving us ADMT 600 X-S and Ohm mega resistivity meter to use for this research work. We are also grateful to the two anonymous reviewers for their helpful comments.

AUTHOR CONTRIBUTIONS

SNY designed the concept of the research and planned the field work. HCD and CMA carried out the field work. The three authors processed and interpreted the data and put it together as a research paper.

CONFLICT OF INTEREST

The authors declare that we have no conflict of interest in this paper.

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Manuscript received 30 September 2021;
Received in revised form 25 January 2022;
Accepted 28 January 2022
Available online 26 April 2022