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Characterization of Aquifers Using Geo-electrical Methods in parts of Abia State, Southeastern Nigeria

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Abstract

This study was carried out to map and characterize the water bearing formations (aquifers) in Abia State, southeastern Nigeria. Vertical electrical resistivity depth sounding for inferring the resistivity and thicknesses of the vertical succession of different conducting zones in the subsurface was employed in characterization of the subsurface aquiferous units. The depth of the boreholes drilled varies from 21.02m - 250m, while the static water level (SWL) varies between 4.57m around Ukwa-West to about 35.97m around Aba South. The depth range of 9.15m to 53.05m to the aquiferous zone for Umuahia Local Government Area is in agreement with the value of 35.0m. Very productive aquifers in Abia State are limited to the alluvial deposits and the Coastal Plain Sands lithologies comprising: fine, medium and coarse-grained and often pebbly sands with some intercalations of clays. The alluvium occurs mainly in Ukwa West and East Local Government Areas. Drilling depths in this aquifer range from 30 to 140m. Prolific production is expected from this alluvium which has an approximate permeability of 35m^2/day. The High production rate (Permeability = 35m^2/day) is expected in the Coastal Plain Sands sediments found in all Local Government Areas stretching south of Umuahia and Bende. Drilling depths ranging from 40 to 250 m are recommended for boreholes in these LGAs. However, more precise drilling depths must be confirmed by hydro-geophysical site survey, because the geology of Abia State becomes more complicated north of Umuahia and Bende LGAs. This complication in geology affects all other LGAs north of Umuahia.
Keywords: Geo-electrical method; Aquifers; Lithology; Vertical electrical sounding; Boreholes.

1. Introduction

A geophysical investigation of the earth's interior involves taking measurements at or near the earth's surface that are influenced by internal distribution of its properties. Electrical resistivity methods of geophysical prospecting are well established and the most important method for groundwater investigations. The electrical resistivity method is one that has been widely used because of the theoretical, operational and interpretational ease. The advantages of electrical methods also include control over depth of investigation, portability of the equipment, availability of wide range of simple and elegant interpretation techniques, and the related software etc. Direct current (D.C.) resistivity (electrical resistivity) techniques measure earth resistivity by driving a D.C. signal into the ground and measuring the resulting potentials (voltages) created in the earth. From the data obtained, the electrical properties of the earth (the geoelectric section) can be derived. In turn, from those electrical properties we can infer the geological characteristics of the earth. This study uses the Vertical Electrical Sounding (VES) method to investigate the electrical properties of the subsurface. Geophysical methods, particularly electrical Resistivity techniques have been extensively used for wide variety of environmental and engineering problems [1, 2]. This geophysical method is used because it is one of the simplest and less costly methods. Electrical Resistivity survey is relatively easy to perform and can be used to identify geological structures [3]. The vertical electrical sounding VES had been used to delineate the different subsurface layers [4]. It is also used delineating the aquifer units and their characteristics, the subsurface units and their characteristics, the subsurface structures and the depth to water table [5].

This study therefore is aimed at delineating the subsurface geologic layers and evaluating the aquifer potential as well as to delineate the groundwater level using Resistivity methods (VES). The objectives include defining the sub-surface lithology of the study area as well as determining the groundwater level in the study area.

1.1. Description of the Study Area

The study area, Abia State is located in the south-eastern part of Nigeria (Fig. 1). The State is known for its commercial activities centered at Aba, which was formerly a British Colonial Government outpost. The entire state lies approximately between latitudes 4º48'N and 6 º02'N and Longitudes 7º09'E and 7º58'E of the Greenwish Meridian (Fig. 2). On the north and the northeast, the state is bounded by Enugu and Ebonyi states respectively. The eastern boundary is occupied by the Cross River State, while the southeast border is shared by Akwa Ibom State. Rivers State occupies the southern and southwest boundaries. The western and northwest borders are occupied by

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Imo and Anambra States respectively. The entire State is divided into seventeen (17) administrative units called Local government Authorities (LGAs) (Fig. 2).

Fig-1. Map of Nigeria showing the study area (Abia State)

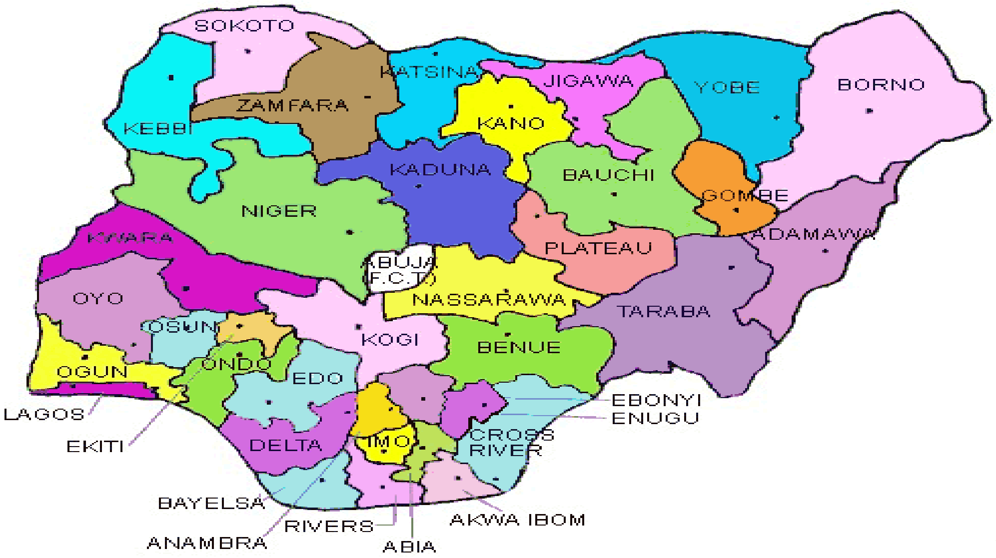
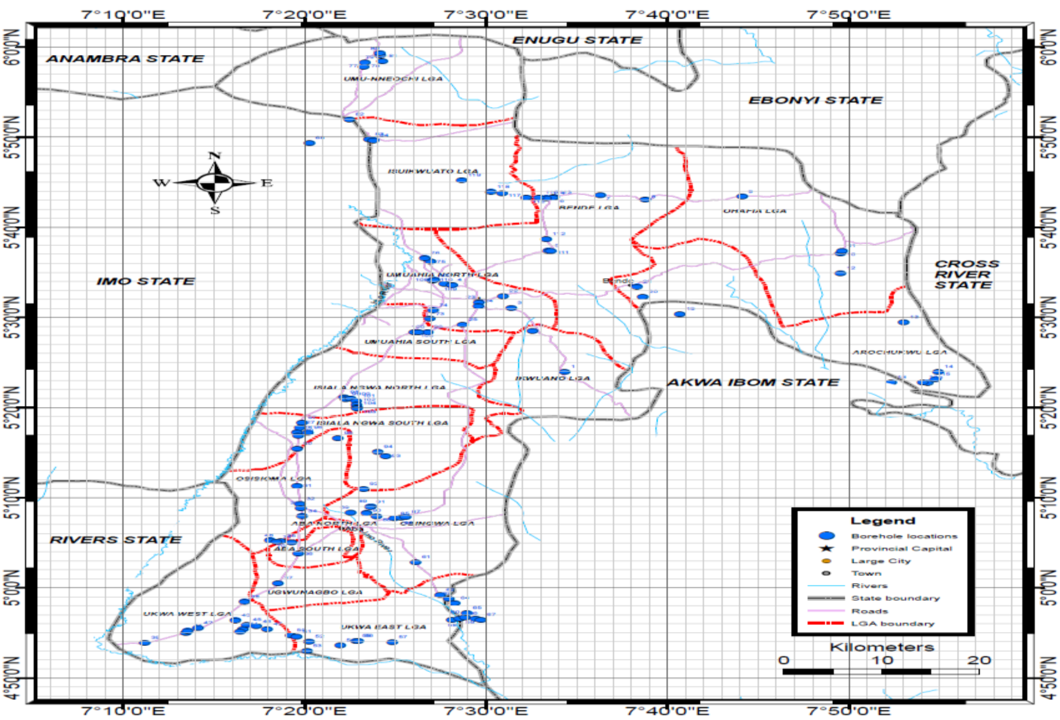
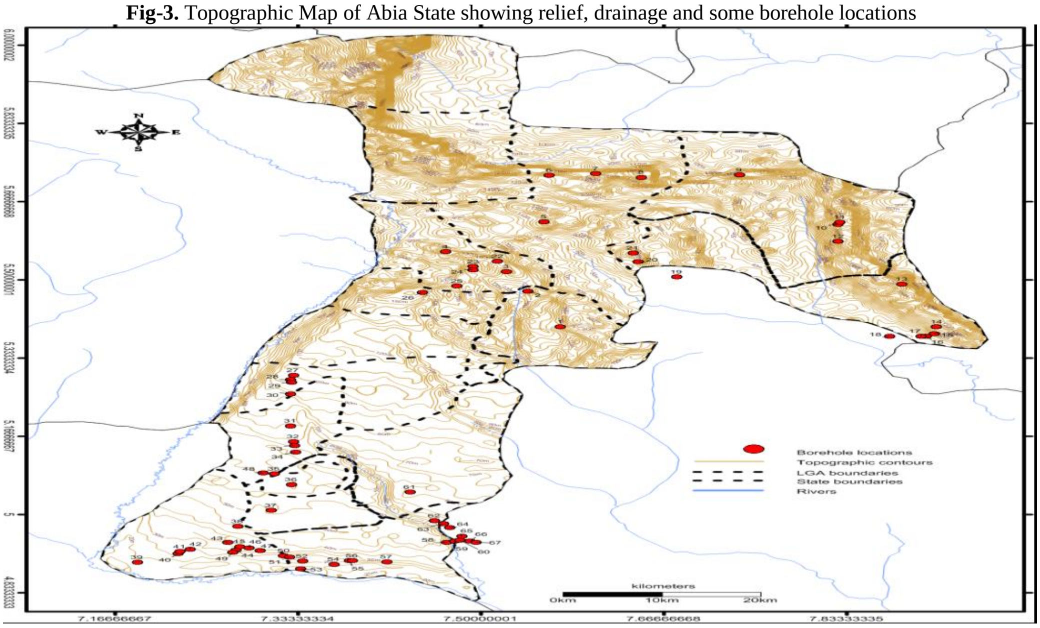


Fig-2. Map of Abia State showing the Local Governments Areas and some borehole locations



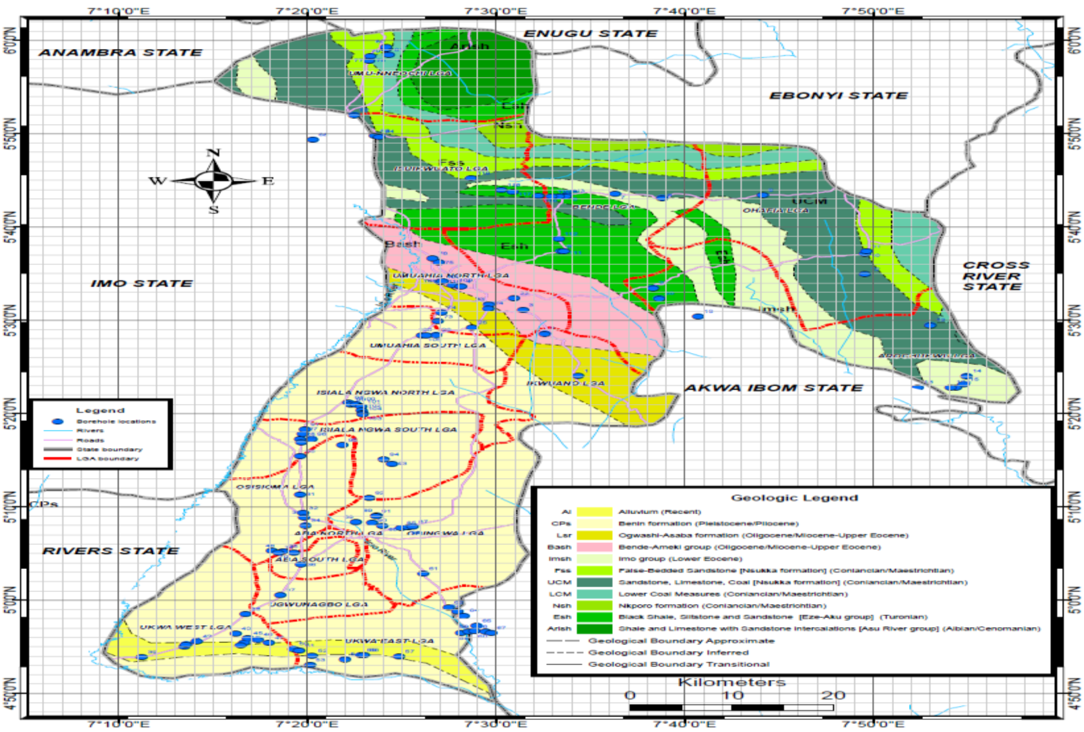
The physiographic information on Abia State reveals that the climate of the area falls within the equatorial climatic belt with alternating dry and wet seasons [6]. The wet season starts from March and ends around October, while the dry season spans between November and February each year. The seasonal variation in the climate of the state is caused by the northeast trade wind that blows across the Sahara Desert and the southerly humid marine air mass that blows across the Atlantic Ocean. The annual rainfall is between 2000 mm and 2250 mm in the south, and between 1250 and 2000 mm in the northern part of Abia [6]. The topography in the southern part of the state is low-lying while the other parts of the state have moderately high plains with elevations ranging between 20 and 200 metres above sea level (Fig. 3). The vegetation of the area is that of the rainforest comprising various species of shrubs and high forest trees all over the area - both within the hilly and depressed areas.

Fig-3. Topographic Map of Abia State showing relief, drainage and some borehole locations



Geologically, Abia State is located within the transition zone of the Benin and Ogwashi-Asaba Formations of the coastal sedimentary rocks of the northern Niger Delta. Therefore, the major geologic sequences encountered in the area include the Coastal Plain Sands otherwise known as Benin Formation, the Ogwashi-Asaba and Bende-Ameki Formations (Fig. 4). These lithologies are underlain by the Paleocene Imo shales which are conspicuous in the northern part of the study area. The Benin Formation (Late Tertiary-Early Quaternary age) is the most predominant and it is overlain by the Recent Alluvium and underlain by the Ogwashi-Asaba Formation. The Benin Formation is about 200m thick [7] and the lithology is unconsolidated fine-medium-coarse-grained, cross bedded sands occasionally pebbly with localized clays and shales [8]. Most of the aquifers in the study area tap from this formation. The yield is prolific. The Ogwashi-Asaba Formation is made up of variable succession of clays, sands and grits with seams of lignite. It is directly underlain by the Bende-Ameki Formation.

Fig-4. Geologic Map of Abia State showing LGA boundaries and some boreholes



1.2. Methods of Study

Vertical electrical resistivity depth sounding, a well-known hydro-geophysical survey method for inferring the resistivity and thicknesses of the vertical succession of different conducting zones in the subsurface was employed in characterization of the subsurface aquiferous units in the study area. In this method, direct current or very low frequency (VLF <1Hz) is introduced into the ground through two steel electrodes, A and B to set up electrical potential difference which is measured between a pair of potential electrodes M and N. The four electrodes, A-M-N-B are kept in a straight line such that AB ≥ 5MN (the Schlumberger array). The instrument for the investigation was the ABEM SAS 300C Terrameter, a simple resistivity meter with potentiometric arrangements. Depth penetration was achieved by simply increasing the current electrode spacing in line with the Schlumberger array. Equation (1) was used to obtain apparent resistivity values for the subsurface zones from the field data.

$$\rho_a = \frac{\pi (AB^2 - MN^2)R}{2} \quad \text{………………(1)}$$

Where:

ρ_a = apparent resistivity in ohm-m
AB = current electrode spacing
MN = potential electrode spacing
R = field resistivity in ohms

These surveys were carried out across major geologic terrains in the state namely the Niger Delta basin, the transitional boundary, and the Lower Benue trough and data interpreted using the IP2 WIN resistivity software.

2. Results and Discussion

2.1. Hydro-Geophysical Characteristics

Typical field curves of the geolectric sections acquired during this study are presented in Figs.5 - 9 typical of the three basin settings namely (1) Niger Delta (2) Niger Delta - Lower Benue Trough Transition basin boundary and (3) Lower Benue Trough in Abia State. The summary of the geolectric layers and their respective thickness are presented in Tables 1and 2 in which the inferred subsurface geologic sections across the study area based on geolectric data, drilled lithologic and geoloelctric model correlations. Results revealed that most of the boreholes drilled in the southern part of the state (Umuahia South, Ikwuano, Isiala Ngwa North, Isiala Ngwa South, Osisioma, Obingwa, Aba North, Aba South, Ugwunagbo, Ukwa West, and Ukwa East) penetrate the Coastal Plain Sands and the recent Alluvium. The depth of the boreholes drilled within these areas varies from 21.02-250m, while the static water level (SWL) varies between 4.57m around Ukwa West to about 35.97m around Aba South. The depth range of 9.15 m to 53.05 m to the aquiferous zone for Umuahia Local Government Area is in agreement with the value of 35.0m reported by Mbonu, *et al.* [9] using similar hydro-geophysical methods of aquifer characterization. Furthermore, the northern part of Abia State consisting of Umu-Nneochi, Isiukwuato, Bende, Ohafia and Arochukwu which lie within the Lower Benue Trough basin is disparate in its hydrogeology and underlying aquifer characteristics with varying depths of occurrences and thicknesses with attendant variances in hydraulic conductivity, transmissivity and storativities of the water bearing zones. Water is observed to occur in shaley sandstone litho-units with few occurrences in fractured shales and columnar joint sets oriented NE - SW, NW - SE, ENE - WSW in line with the major fracture link that evolved from the Gulf of Guinea whose aulacogen terminated in the Benue trough. Groundwater potential is moderate to low in these parts of the state and substantial motorized boreholes are suspect and borehole depths may be as high as 150m. The aquifers units include false bedded Sandstones of the Ajali Formation, the Nsukka Formation (Upper Coal Measures), Mamu Formation (Lower Coal Measures), Bende-Ameki Formation, Asu-River Group and the Eze-Aku Group. Results of this study agree with Ebilah-Salmon and Partners [7] which report that aquifer potentials of the various formations in the Bende-Ameki and Nsukka Formations are moderate, Ajali Formation has a moderate to good aquifer potential while the Mamu Formation and Imo Shales are characterized by poor aquifer potentials.

Table-1. Interpreted geolectric layers and parameters of subsurface zones of parts of AbiaState

Location	Layer thickness (m)										Resistivity (Ωm)									
	h_1	h_2	h_3	h_4	h_5	h_6	H_7	H_8	h_9	h_{10}	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	ρ_8	ρ_9	ρ_{10}
Ovim-1 (ABA)	0.94	1.09	0.94	1.39	2.05	37.24	20.4	-	-	-	567.5	441	602	945	1421	1819	1523	1270		
Ovim-2	0.75	0.87	187	1.63	5.90	23.84	16.30	23.94	-	-	51	82	190	296	440	386	916	2746	9390	
Ohambele-1	0.85	0.97	2.11	10.31	16.45	30.90	-	-	-	-	226	335	543	904	1173	1219	1162	-	-	
Ohambele-2	0.94	1.09	0.96	3.44	2.99	20.30	34.3	-	-	-	1639	1218	1763	2413	1564	929	1095	892	-	
Ohanso 1	1:1	7	35	75	-	-	-	-	-	-	1324	4667	334	15	198	-	-	-	-	
Ohanso 2	0.8	17.2	36	52	-	-	-	-			534	1998	432	435	211	-	-	-	-	
Ndi Uduma	0:76	0.36	0.52	0.77	1.13	1.65	11.22	7.6	11.3	16.5	82.	192	438	957	2030	4059	1044	7879	2071	1331
Ndi Nduma	0.75	1.62	1.12	1.63	11.1	7.6	27.4	23.9	-	-	171	299	703	1496	2320	1253	966	1770	1090	
Aba, Urath	0.5	3.0	5.6	16.4	36.7	31.0	41.0	46.5	39.0	-	40	1130	472	2870	199	758	1990	10	1580	3330
Umuoro	3	8	13	26	70	-	-	-	-	-	101	1434	2310	7310	1620	1100	-	-	-	
Umuika-Ofeme	0.8	2	5.3	11	17	50	90	-	-	-	37	86	9	4	5	3	7	76	-	-
Ndi Ojira Aodina	9.2	12.3	26.7	21.6	22.8	-	-	-	-	-	2840	1070	2570	2570	5650	4100	-	-	-	
Abaki-1	1	7	35	75	-	-	-	-			1324	4667	334	334	198	-	-	-	-	
Abaki-2	0.6	152	33	55	-	-	-	-			532	1990	432	432	213	-	-	-	-	
Ochuche-Umuodu	1.1	1.5	2.4	22.1	28.1	35.8	>91	-	-	-	141.	209	11	168	217	439	1130			

Table-2. Summary of aquifers and characteristics

Basin Section	Aquifer number	Resistivity (Ωm)	Aquifer thickness (m)	Average depth (m)	Litho-composition	Pospectivity
Niger Delta Basin	1st	211	40 - infinity	35 - infinity	Sands	Good to Excellent
Transitional Boundary	1st	7310	35	50	Shaley sandstones	Moderate to Good
	2nd	1620	Infinite	120	Sands	Good to Excellent
Lower Benue Trough	1st	440	25-32	35	Shaley sandstone	Poor to Fair
	2nd	916	Infinite	80	Shaley sandstone	Moderate to Good

Fig-5. Vertical electrical sounding field geolectric curve of Obohia (Niger Delta basin)

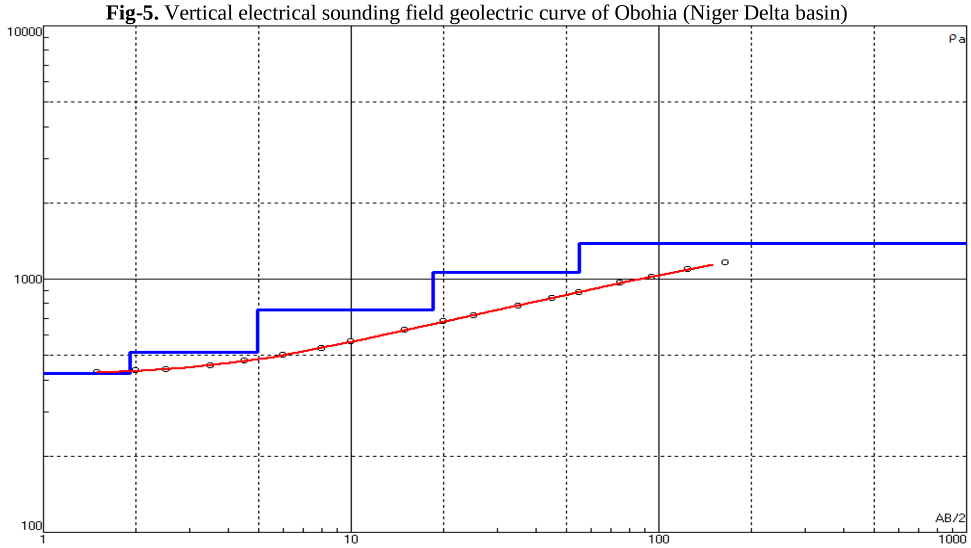


Fig-6. Vertical electrical sounding field geolectric curve of Ohambele (Niger Delta basin)

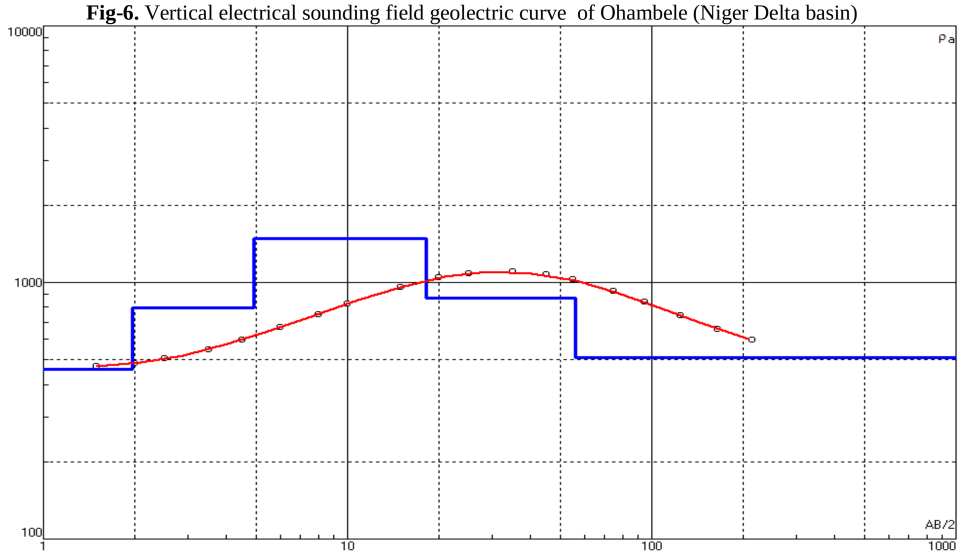


Fig-7. Vertical electrical sounding field geolectric curve of Umuahia (Transitional boundary between Niger Delta and Lower Benue Trough basins).

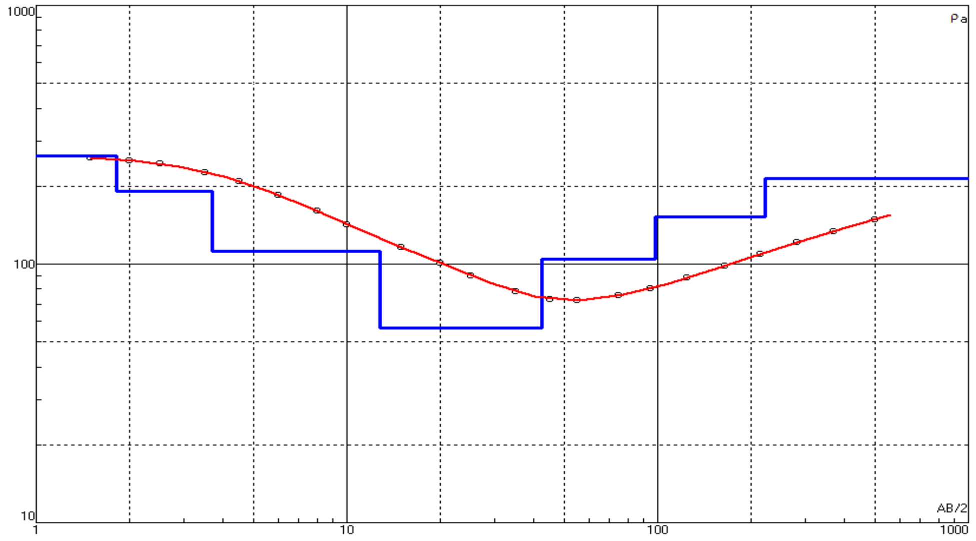


Fig-8. Vertical electrical sounding field geolectric curve of Ohanso (Niger Delta basin)

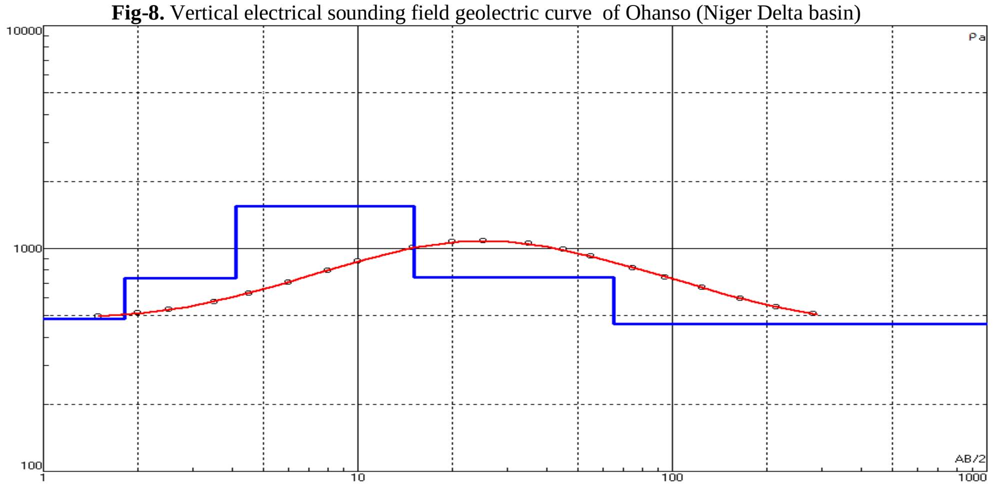
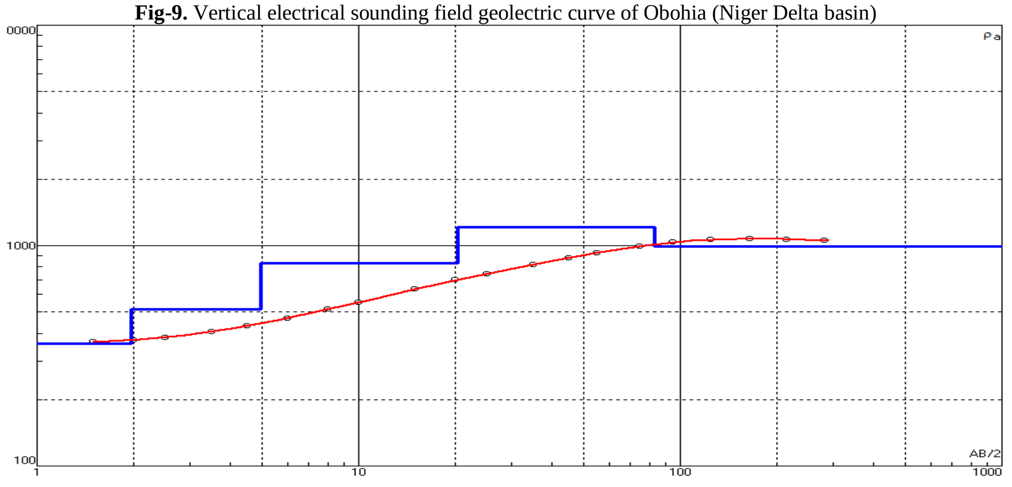


Fig-9. Vertical electrical sounding field geolectric curve of Obohia (Niger Delta basin)



3. Conclusion

This study revealed the usefulness of vertical electrical resistivity (VES) depth sounding for inferring the resistivity and thicknesses of the vertical succession of different conducting zones in the subsurface. This was employed in the characterization of the subsurface aquiferous units. The depth of the boreholes drilled varies from 21.02m - 250m, while the static water level (SWL) varies between 4.57m around Ukwa-West to about 35.97m around Aba South. The depth range of 9.15m to 53.05m to the aquiferous zone for Umuahia Local Government Area is in the value of 35.0m. Very productive aquifers in Abia State are limited to the alluvial deposits and the Coastal Plain Sands lithologies comprising: fine, medium and coarse-grained and often pebbly sands with some intercalations of clays. The alluvium occurs mainly in Ukwa West and East Local Government Areas. It is however recommended that more precise drilling depths be confirmed by hydro-geophysical site survey, because the geology of Abia State becomes more complicated north of Umuahia and Bende LGAs. This complication in geology affects all other LGAs north of Umuahia.

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