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(RESEARCH ARTICLE)

DELINEATION OF QUATERNARY AQUIFER USING VERTICAL ELECTRICAL SOUNDING (VES) IN OGBIA AREA, BAYELSA STATE, NIGERIA

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ABSTRACT

Electrical resistivity method using the schlumberger configuration were employed to delineate the quaternary aquifer in Ogbia area of Bayelsa State, Nigeria. The aim of this research is to determine the viability of the aquifer for borehole drilling. 10 VES points were carried out in Ogbia Area. They were interpreted by the use of IP12Win software. The interpreted VES data revealed 4-5 delineated layers of silty-clay, clay, clayey sand, sandy-clay, fine to coarse sand. Five sounding curve types were identified in the study area and they are of the KA, HA, QH, AK, and HKH types. The 4-layer geo-electric section were dominant compare to the 5-layer. The first aquifers were delineated at average depth of 23m and 30m with thicknesses ranging from 13m to 20m and resistivity values ranging from410 to 2155Ωm while the 2nd aquifer were delineated at average depth of 35m to 43m with thicknesses ranging from 21m to 27m and resistivity values ranging from 740 to 9086Ωm. The second aquifer in the area are more reliable as sources of groundwater because they are less vulnerable to infiltration of surface contaminants and as well as posses better indices for higher groundwater yield due to their texture and greater thickness when compare to the first aquifer.

Keywords: Groundwater, VES, Geo-Electric Layers, Aquifer, Resistivity, Ogbia

1 INTRODUCTION

Groundwater is the water found within the saturation zone in the subsurface and it is currently preferred as the source of water supply in the area. The growing need for potable and reliable water has increased the necessity for the groundwater investigation, particularly in rapidly urbanizing areas. Groundwater is a crucial resource for municipal and industrial use, especially in locations where the surface water sources are limited or contaminated (Beabu et al, 2024). In many parts of Nigeria, including Ogbia zone, the increasing demand for portable water has placed pressure on the available surface and groundwater resources. Urban expansion, population growth and climate variability have further exacerbated water scarcity, especially in semi-urban zone like the Ogbia area.

Groundwater being relatively protected from surface contamination and available all year round has become a vital source of water supply in most communities. Groundwater accounts for a significant portion of Nigeria's domestic and agricultural water supply. According to the Nigeria Hydrological Services Agency (NHSA), 2023, over 60% of rural communities rely on groundwater for drinking and sanitation. In urban and semi-urban areas, boreholes supplement municipal water systems, especially during dry season. However, groundwater development faces challenges such as poor sitting of boreholes, over-extraction and contamination from domestic and industrial wastes (Nwankwoala et al, 2013).

The study uses geophysical method, particularly, the vertical electrical sounding (VES) as a veritable tool for the subsurface investigation. The VES is a non -invasive, relatively cheap quantitative evaluation technique used for locating sites/depth, for the groundwater exploitation (Oborie et al, 2013). It aids in delineating the aquifers, the assessment of their thickness, and the estimation of groundwater depth by measuring the difference in electrical resistivity at various depths. The method's capacity to distinguish between saturated and unsaturated strata, as well as expose the resistivity contrast between different rock types, make it a dependable instrument for groundwater investigation (Beabu et al, 2024).

Electrical resistivity methods has gained prominence in hydro-geological studies due to their ability to detect subsurface features based on electrical properties. The VES technique involves injecting current into the ground and measuring potential differences that will be used to calculate the apparent resistivity. Variations in resistivity correspond to different lithologies, allowing for identification of aquifer zones.

The schlumberger array used in this study is particularly effective for shallow and deep investigation. It provides high resolution data and is less sensitive to lateral heterogeneities compared to other configurations. Data interpretation involves plotting resistivity curves and generating geo-electric sections that visualize subsurface layers. These parameters help to estimating aquifer depth and thickness for borehole design and groundwater management (Oghonyon et al, 2025).

Previous studies in the Niger Delta have confirmed the effectiveness of electrical resistivity methods to delineate aquifer. For instance, Oborie et al, 2013 carried out a geo-electrical delineation of aquifer in some parts of Bayelsa State where productive aquifer were identified within the Benin formation. Their findings support the use of similar techniques in the Ogbia area.

Bayelsa state is located within the transition zone of the coastal sedimentary lowlands hydrogeologic province in southern Nigeria. The area is underlain by thick succession of sedimentary rocks. Due to this fact, the area has been taken for granted as a sustaining source of abundant groundwater.

This study addresses the critical need for scientific investigation in groundwater exploration, by employing geo-electrical resistivity method. The findings of this work will provide a reliable assessment of subsurface condition which will help to identified potential aquifer zones that will guide borehole drilling and reduce the risk of failure in the area.

2 GEOLOGY AND HYDROGEOLOGY OF THE AREA

The study area is located between latitudes 4^0 35'51.76'' N and 4^0 58'32.391'' N and longitudes 6^0 10'54.845''E and 6^0 27'47.484'' E (Fig. 1). It is located within the lower section of the upper flood plain deposits of sub-aerial Niger Delta (Allen, 1965). The Niger Delta is a large and ecologically sensitive region, in which various water species including surface and subsurface water bodies exist in a state of dynamic equilibrium (Udom, G. J. 1999).

Stratigraphically, the Niger Delta is divided into Akata, Agbada and Benin formations in order of decreasing age. The Akata formation is the oldest formation in the Niger Delta. It consists of massive dark gray shales which are deposited in marine environment. The age of the formation is paleocene to recent and its thickness is 0 to 625metres (short and stauble,1967). While the Agbada formation underlies the Benin formation. It consists of inter bedded shales and sands and is been deposited in fluvio-marine environment. The formation varies in thickness from 0 to468metres (Short and Stauble, 1967).

The Benin formation consists of 90% of coarse sand with localized clay/shale interbeds (Allen, 1965). Its thickness is about 656metres and is overlain by quaternary deposits in some places (Akpokodje, 1990). The hydrogeology of the area has been described by various scholars which includes; Etu-Efeotor(1981), Akpokodje et al; (1990),Edet et al, (2001), Udom et al; (1998,1999) and Nwankwoala et al; (2011,2013). The Benin formation is the water bearing zone of the area and is overlain by the quaternary deposit (40 to 150metres) thick which consist of alternating sequence of sands and silty clays with the latter become increasingly more prominent seawards. The clayey intercalations within the Benin formation have given rise to multi- aquifer system in the area (Etu –Efeotor 1981, Etu-Efeotor and Odigi 1983, Etu-Efeotor and Akpokodje, 1990). The Benin formation is highly permeable, prolific and productive, and is the most extensively tapped aquifer in the Niger Delta. The first aquifer is commonly unconfined while the rest are confined.

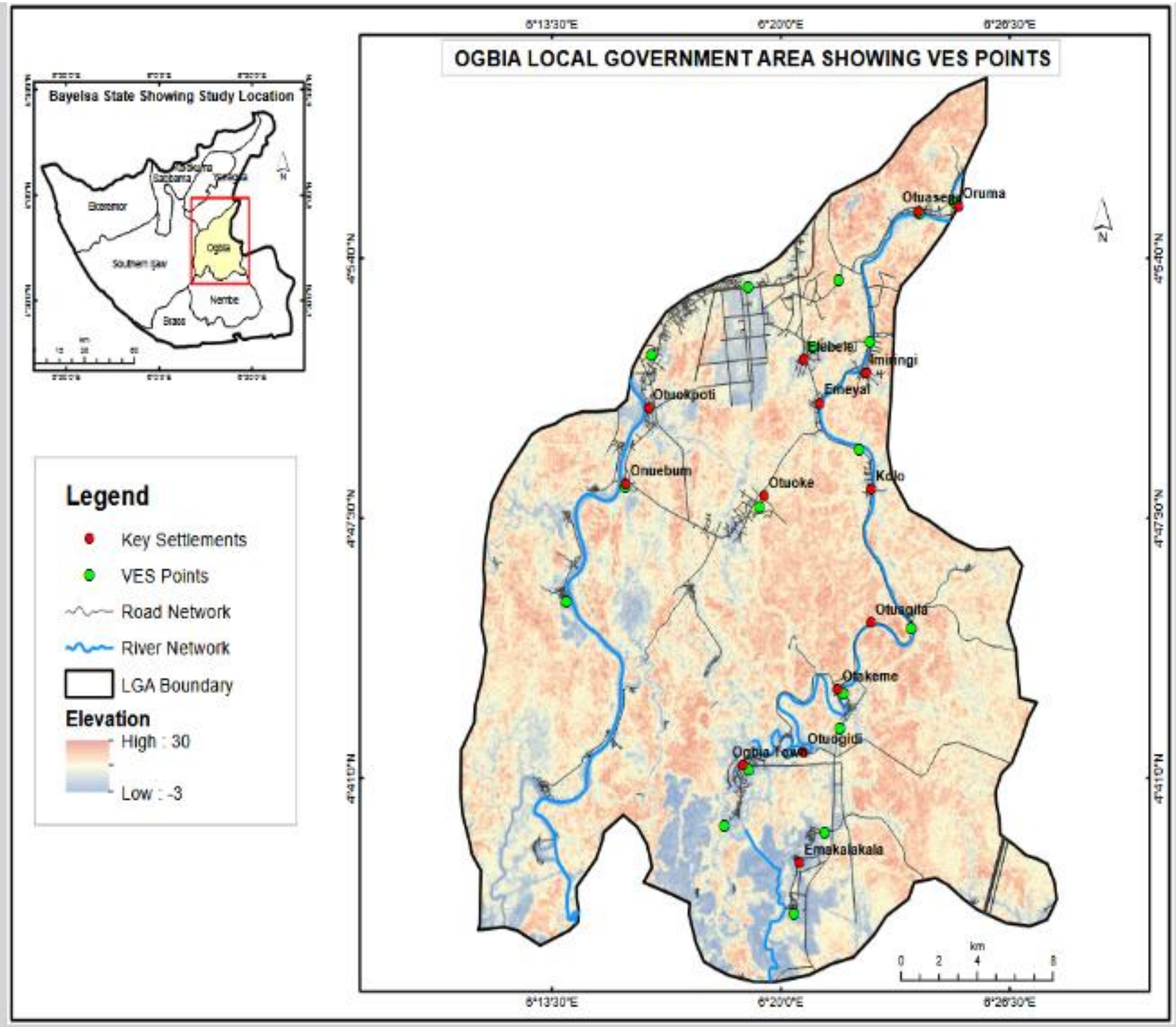

Figure 1: Map of the study area

Overlying the Benin formation is the quaternary sediments, which consist of mainly silt, clay and sand of different sizes. Most boreholes are drilled within the quaternary sediments in the study area. The average depths of boreholes in the study area are between 30-40metres (Daniel et al, 2015). The static water level in the area ranges from 0-1metre during the wet season and 1-3metres during the dry season. The main source of recharge is through direct precipitation where annual rainfall is as high as 3000mm (Amadi and Ofoegbu, 1989). The water infiltrates through the highly permeable sands to recharge the quaternary aquifers. Groundwater in the first aquifer in the area occurs under water table conditions (Udom, 1999). The study area has been noted to have poor groundwater quality due to objectionable high concentration of certain groundwater parameters and encroachment of saltwater or brackishwater into the freshwater aquifers (Udom,1999, and Nwankwoala et al; 2011).

3 MATERIALS AND METHOD

Electrical resistivity survey using the schlumberger electronic configuration with a maximum current electrode spread of 200m was deployed for the investigation. A total of ten (10) vertical electrical sounding (VES) were carried out in the study area. The ABEM terrameter SAS 1000, a self–averaging digital device was used for the field operation. A computer aided modelling technique using IP12WIN software was employed for the data interpretation. The field procedure was carried out by applying current to the ground through two electrodes A and B and then measuring the resultant potential difference ΔV between the potential electrodes M and N which were fixed between the current electrodes. The midpoint of the electrode array remained fixed but the spacing of the current and the potential electrodes was increase in line with the sounding procedure for deeper ground penetration. The vertical electrical sounding (VES) data were acquired in overlapping pattern because at each step of AB spacing, the signals of the resistivity meter become weaker. Therefore, MN spacing was expanded and two values for the same AB/2 were measured, one for the short and the other long MN spacing. The schlumberger configuration was used because it is faster, cheaper, not easily affected by lateral variation and requires a lower number of operators.

4 RESULTS AND DISCUSSION

The results of the vertical electrical sounding (VES) data obtained from the various locations and their interpretation are presented in Table 1 and Figure 2-4

The vertical electrical sounding data presented as sounding curves were obtained by plotting graphs of apparent resistivity versus half electrode spacing on double logarithmic graph sheet. The field data were interpreted and processed qualitatively and quantitatively using partial curve marching and a computer software IP12WIN to obtain the resistivity values of different subsurface layers and their corresponding thicknesses.

The apparent resistivity values, which is a function of the electrode spacing, were then converted to true resistivity values with a computer base software to provide the sounding curves

Table 1: Lithologic Delineation of Aquifers in Study area

VES Points	Layer	Resistivity (Ωm)	Thickness (m)	Depth(m)	Lithology	Curve type
VES 1	1	72.7	0.50	0.50	Topsoil	KH
Otuokpoti	2	1006	1.65	2.15	Fine-Sand	
	3	715	4.42	6.57	Silty-Clay	P1<p2>p3>p4<p5
	4	301	9.20	15.80	Medium-Sand	
	5	9086	27.4	43.20	Coarse-Sand	
VES 2	1	174	0.85	0.85	Topsoil	HA
Oruma	2	93.8	2.05	2.90	Fine-Sand	
	3	263	5.37	8.27	Silty-Clay	P1>p2<p3<p4
	4	3088	27.40	35.60	Medium-Sand	
	5					
VES 3	1	132	0.50	0.50	Topsoil	
Otuasega	2	57.4	1.24	1.74	Clay	QH
	3	31.9	4.57	6.31	Fine-Sand	P1>p2>p3<p4
	4	728	27.10	33.40	Medium-Sand	
	5					
VES 4	1	194	0.50	0.50	Topsoil	
Imiringi	2	49.9	1.87	2.37	Silty-Clay	HA
	3	5360	9.46	11.8	Medium-Sand	P1>p2<p3<p4
	4	8254	26.50	38.30	Coarse-Sand	
	5					
VES 5	1	191	0.54	0.54	Topsoil	
Otuoke	2	76.8	2.94	3.48	Silty-Clay	HA
	3	130	8.35	11.83	Fine- sand	P1>p2<p3<p4
	4	825	16.90	28.70	Medium-Sand	
	5					
VES 6	1	82.9	0.60	0.60	Topsoil	

Emeyal	2	95	1.70	2.30	Silty-Clay	KH P1<p2>p3<p4
	3	23.7	12.30	14.60	Clay	
	4	1468	13.0	27.60	Medium-Sand	
	5					
VES 7 Elebele	1	56.4	0.45	0.45	Topsoil	KH P1<p2>p3<p4
	2	166	1.30	1.75	Clayey-Sand	
	3	31.6	11.90	13.70	Clay	
	4	453	20.60	34.30	Fine-Sand	
	5					
VES 8 Kolo	1	51.6	0.43	0.43	Topsoil	HA P1>p2<p3<p4
	2	20.4	2.81	3.24	Clay	
	3	113	5.42	8.66	Fine-Sand	
	4	2155	24.50	33.20	Medium-Sand	
	5					
VES 9 Otuegila	1	16.4	0.90	0.90	Topsoil	AK P1<p2<p3>p4
	2	255	1.83	2.73	Silty-Sand	
	3	1031	6.75	9.48	Medium-Sand	
	4	590	23.0	32.50	Fine-Medium sand	
	5					
VES 10 Otakeme	1	420	0.50	0.50	Topsoil	HKH P1>p2<p3>p4
	2	20.0	1.01	1.51	Clay	
	3	180	3.46	4.97	Sandy-Clay	
	4	14.2	8.55	13.50	Clay	
	5	740	21.50	35.10	Fine-Medium	

Table 2: Co-ordinates of VES locations in Study area

S/N	VES LOCATION	VES CO-ORDINATES	
		Latitude (N)	Longitude (E)
1	Otuokpoti	4.859444	6.271917
2	Oruma	4.923157	6.415532
3	Otuasega	4.918278	6.398834
4	Imiringi	4.865278	6.375278
5	Otuoke	4.795772	6.322972
6	Emeyal	4.853055	6.337957
7	Elebele	4.863056	6.348056
8	Kolo	4.819917	6.370278
9	Otuegila	4.745556	6.394722
10	Otakeme	4.718463	6.362784

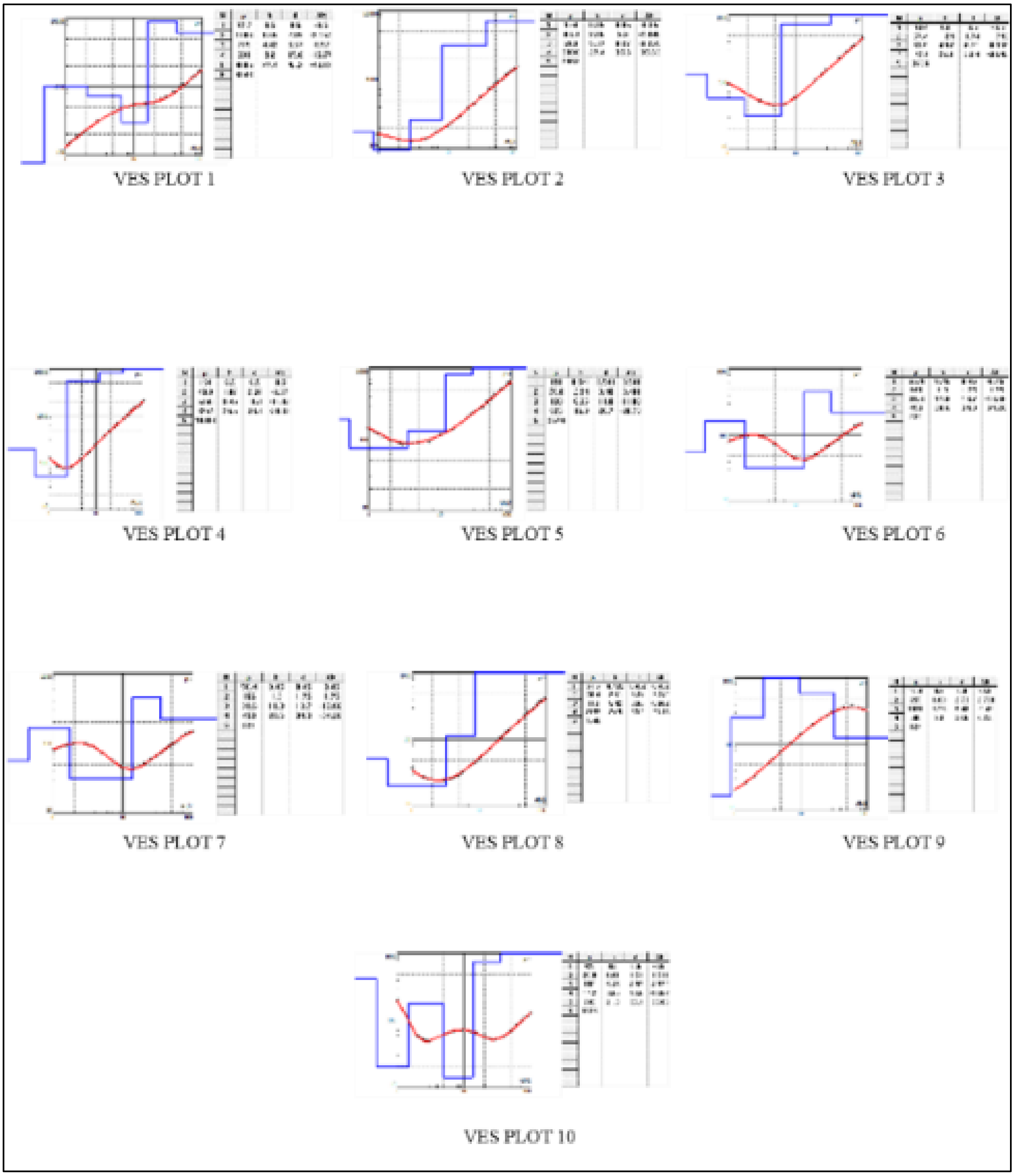

Figure 2: VES Plots and obtained obtained data of the study area

Ten (10) VES were carried out in the study area, the processed results obtained indicate a 4-5 geo-electric layers and exhibit KH, HA, QH, AK and HKH curve types.

From the quantitative interpretation, the study area broadly consists of silty-clays, clayey- sand, sandy-clay and fine -coarse sand with intercalation of minor clays (Figure 3). The quantitative analysis of the data obtained shows that the top layer thickness range between 0.5-0.9m with resistivity values of 51.6 -194Ωm respectively and is designated as the topsoil (Table 1 and Figure 3). The second layer thickness and resistivity values range between 1.24-2.94m and 49.4-255Ωm respectively with variable degrees of water saturation. The composition of this layer ranges from clayey-sands, silty-sands, and fine sands (Table 1 and Figure 3).

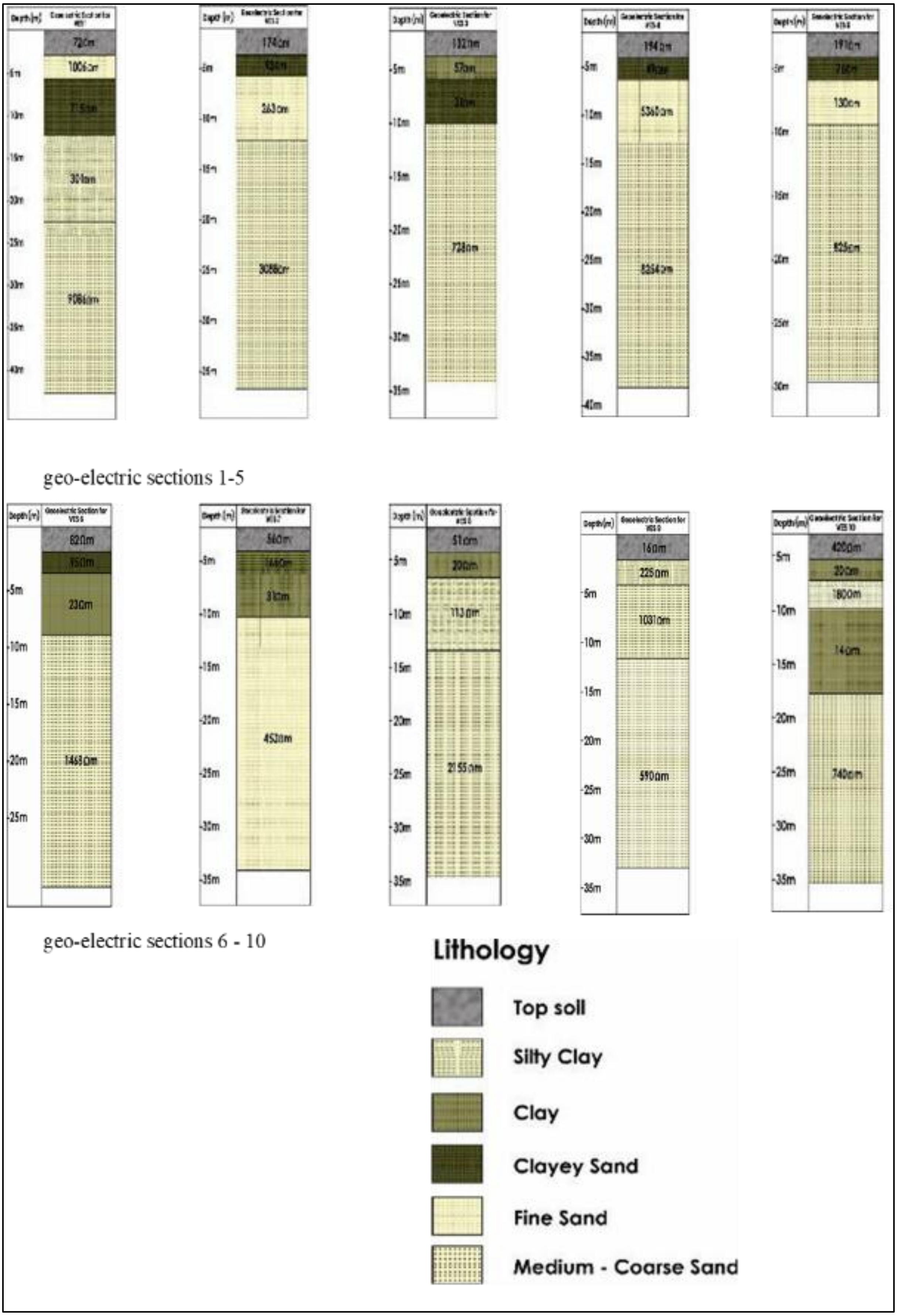

Figure 3: Geo-electric Sections of the study area

The thickness of the third layer range between 4.42 – 12.3m, with a minimum resistivity value of 14.2Ωm at VES 10 and a maximum resistivity value of 5360Ωm at VES 4 with average depth of 9.5m. This layer is considered as intermediate/

transition layer between the unsaturated zone and the saturated zone. It is variably composed of silty-sand, fine–medium sand and considered to be the first aquifer. However, due the shallowness of this aquifer, it is not economically regarded as a viable aquifer. The fourth and fifth layers were identified as the aquifer layers as evident in significantly higher resistivity values. The fourth layer resistivity values range from 301Ωm at VES 1 to 8254Ωm at VES 4 with thickness ranging from 9.2-26.5m, occurring at an average depth of 34m from the ground surface. The lithological composition is inferred to be of fine–medium sand, which are porous and permeable. Therefore, this layer is considered to be the 1st viable aquifer zone in all the 4- layers geo-electric stations. The fifth layer has a thickness and resistivity values range between 19.2-27m and 740- 9086Ωm respectively with a depth range of 37- 43m (Table 3). It is mainly composed of medium- coarse sand, which are very porous and permeable. It is the water bearing zone and considered to be the 2nd viable aquifer. The geo-electric sections of the study area are shown in Figure 3.

Table 3: Summary of aquifer parameters in study area

Aquifer	Resistivity(Ωm)	Thickness(m)	Average depth(m)	Composition
1st	310-8254	9.2-26.5	24-34	Fine-medium sand
2nd	740-9086	19.2-27	37-43	Medium-coarse sand

Four boreholes lithologic data with depth of penetration ranges from 30-40m were used to correlate with the inferred lithologic VES data in the study area. Comparison of the VES inferred lithology and the borehole logs data are shown in Figure 4. The result of the correlation shows that the area under study can be generally interpreted as 4-5 geo-electric zone down to the depth of investigation. The selected boreholes logs data that were correlated with the geo-electric sections are shown in Figure 4.

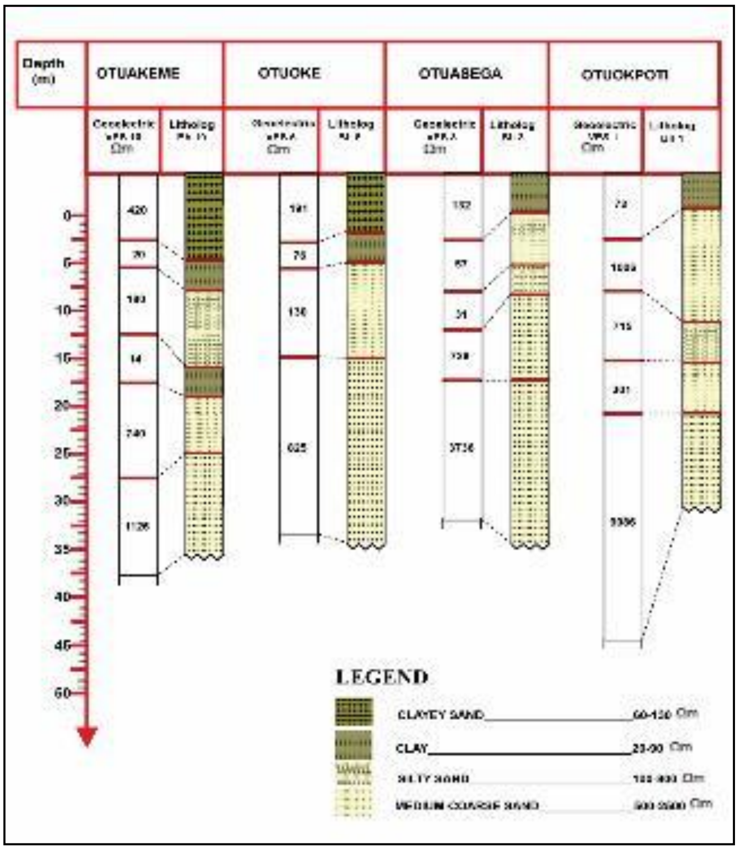

Figure 4: Correlation of geo-electric sections with lithologic logs of existing boreholes in study area

For layer, 1 (0m-5m); both borehole logs and the geo-electric section identify silty sand as the topsoil but with variation in thicknesses of the topsoil across the section (Figure 4). For layer, 2 (5m-14m); borehole logs 10,5 and geo-electric sections for VES 3 and 10 interpretation identify a thin clay, while borehole logs 1,3 and geo-electric sections for VES 1,3 identify fine sand, also with variation in thicknesses (Figure 4). For layer, 3 (14m-21m); both borehole logs data and geo-electric sections for VES identify fine sand but with variation in thicknesses (Figure 4). For layer, 4 (21m-27m); only borehole log 10 and geo-electric sections for VES 10 identify a thin clay while borehole 1,3,5 and geo-electric sections for VES 1,3,5 identify fine-medium sand but with variation in thicknesses This little discrepancy could be due to limitation of VES in resolving layers or the averaging effect of the technique. For layer, 5 (27m-42m); both borehole logs and geo-electric sections for VES interpretation identify medium-coarse sand but variation in thicknesses. This is assumed to be the aquifer zone because medium-coarse sand are very porous and permeable and can have the capacity to withhold good quantity of water. This correlation further validates the inferred lithologic data and that of the borehole logs in the area.

Thus, this research is in agreement with the findings of Oborie E;(2015), on the hydrogeology of some parts of Bayelsa State and Ayibawari et al (2024) whose work was on aquifer delineation using vertical electrical sounding (VES) in parts of Yenagoa, Bayelsa State.

5 CONCLUSION

The result of the investigation revealed that the area is underlain by a succession of silty-sand, clay, sandy-clay, fine-sand to coarse sand. The study also delineates two major aquiferous zones of geo-electric significance and hydrogeologic importance across the study area. The aquifers are generally unconfined with variable thicknesses and depth. The 1st and the 2nd aquifers are considered to be the major aquifer in the area under investigation. The 1st aquifer has average depth of 28.5m with thickness ranging from 9.2 to 26m and resistivity values range between 310 - 8254Ωm. While the 2nd aquifer are located at the average depth of 40m with resistivity values ranging from 740Ωm to 9086Ωm and thickness range between 19.2 to 27m within the depth probed. The investigation show that the aquifers are very prolific and it is the zone where most borehole in the area tap their water from.

Recommendations

- Indiscriminate drilling of boreholes without professional advice should be discourage
- All boreholes to be sited within the study area should be in the depth range of 30m-40m where the aquifer zones are very prolific.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest;

There is no conflict of interest regarding this manuscript.

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