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Original Research Article

Application of Electrical Resistivity in Delineating Potable Groundwater Layers in a Typical Coastal Community: A Case of Federated Okerenkoko, Nigeria

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ABSTRACT

Assessing potable groundwater in coastal terrain is often a daunting task due to the peculiarities of the environment. In this paper, two vertical electrical sounding (VES) were obtained using Petro-Zenith resistivity meter (PZRM) with Schlumbeger configuration to delineate a potential/viable aquifer layer for potable groundwater exploitation in Federated Okerenkoko Island, Gbaramatu Kingdom, Nigeria. A maximum current electrode spacing of 600-1200 m was probed. The result obtained showed two aquiferous horizons (confined/unconfined) below and above a thick clay layer encountered at a depth of 327.36 m corresponding to apparent resistivity of 1097.07 Ωm and a corrected resistivity of 676.96 Ωm respectively. The inferred lithological layers/units of rocks obtained in the study include an overburden of fine grain sand, dark grey laterite, clayey sand, sandy clay, clayey silt and find to medium coarse sand. Hydrogeological/geophysical curve types obtained in the study revealed the KHQ and AA type which is an indication of a deep and shallow aquifer respectively. It is recommended that to access potable groundwater devoid of external influence in the study area, a minimum depth of 762 m should be drilled.

1. INTRODUCTION

Groundwater is one of the main sources of freshwater for human consumption, particularly in the arid and coastal environments where surface water is scarce, and salt-water intrusion coupled with anthropogenic activities affect the quality of available water (Ohwoghere-Asuma and Essi, 2017; Niaz *et al.*, 2019). In regions where access to prolific and dependable layers for groundwater exploitation is demanding, adequate groundwater exploration techniques are necessary to probe into the subsurface for viable geoelectric layers that could provide commercial fresh groundwater for the benefit of mankind as a whole (Falowo and Omorogieva, 2020). Electrical resistivity (ER) method using Schlumberger array is widely used because of its ability to penetrate great depth as compared to the Wenner array. The technique also permits the development of hydrogeological model construction of the area of interest which could aid the interpretation of the subsurface lithological layers of rocks (Ogundana and Talabi, 2014; Falowo *et al.,* 2015; Okonkwo *et al.,* 2017; Niaz *et al.,* 2019; Widodo *et al.,* 2021). Electrical resistivity is hinged on the principle of physics by sending electrical current into the subsurface to delineate the various layers and their respective thicknesses as the current penetrate down the earth.

The groundwater system of the Okerenkoko community in Gbaramatu Kingdom, along Escravos River Channel, and the adjoining creeks in Nigeria is the main source of freshwater to the locals. However, recent study showed that the groundwater derived from boreholes and dug well sited in these areas are under serious threat from surface-derived contaminants occasioned by natural and anthropogenic processes (Tonjoh and Omorogieva, 2020; Ugwuja, 2022; Orobosa *et al.,* 2023). It is critical to understand the subsurface lithological characteristics and the thicknesses of the various underlying rock layers as well as aquifer parameters for proper siting and drilling of borehole (well) that would yield clean water for the locals and institutions within and around the study area. The limitation in knowledge of the subsurface information in the study area has facilitated the drilling of boreholes into aquiferous layer of poor freshwater quality. The situation has led to a major challenge in Nigeria Maritime University (NMU), the host and the adjourning communities in the coastal environment of Gbaramatu Kingdom, Nigeria. Anthropogenic and biogeochemical activities which include open defecation in the river system, leakages in crude oil pipeline, ocean vessel discharge, and the activities of artisanal illegal crude oil refining have contributed significantly to the poor surface and near surface water quality in the study area (Aghamelu *et al.,* 2013; Akinwumiju and Orimoogunje, 2013; Garing *et al.,* 2013; Chinyem, 2013; Abdullahi *et al.,* 2015; Li and Wu, 2019, Tonjoh and Omorogieva, 2020; Ugwuja, 2022; Adebayo, 2022). Due to the rapid growth of NMU and the expansion of the host community (Federated Okerenkoko), the quest for fresh water to meet daily need has become a major challenge to the concerned authorities and stakeholders.

The current study aimed at bridging the gap in knowledge identified by engaging in reconnaissance survey, and applying 1-D electrical resistivity geophysical survey (ERGS) method using vertical electrical sounding (VES) Schlumberger array to unraveled the various thicknesses and the depth of the underlying rock layers that would be free from impurities, and would be able to supply economic quantity of groundwater for drinking, domestic, irrigation and industrial purposes without further cost of treatment; this is because drilling without the knowledge of the subsurface information especially in a challenging coastal environment of this nature could be an effort in futility. The overall outcome of the study will contribute to national water planning and budgeting, provide scientific evidence base information to the people of Federated Okerenkoko and Gbaramatu Kingdom in particular, and the global community at large on how to manage and protect local groundwater resources for the overall benefit of mankind. This will eventually lead to the increase in economic productivity and rapid societal development of the region in question and the world at large.

2. MATERIALS AND METHODS

2.1. Site Description

Federated Okerenkoko is perhaps the largest community in Gbaramatu kingdom (Ugwuja, 2022; Adebayo, 2022). According to Ugwuja (2022), the area is an estuary, a transitional environment between the continent and the deep marine. Fishing, skeletal farming, lumbering and hunting formed the main stay of the people. The establishment of Nigeria Maritime University (NMU) has played a pivotal role in the global visibility of the area. The geology of the area falls within the Mangrove Swamp Formation (MSF); the Formation is one of the four suites of the Quaternary-Holocene deposits in the Western Delta (Figure 1a). These deposits have not been properly assigned formal names because they are universally considered to be recent expression of, and a continuation of the Benin Formation, the youngest Formation of the Niger Delta Sedimentary Basin (Akpoborie *et al.,* 2000; Akpoborie *et al.,* 2015; Efobo *et al.,* 2020). These sequences of fine to medium grained sands, sandy clays, silts and subordinate, lensoid clay bands are thought to have been laid down during the Quaternary interglacial marine transgressions (Oomkens, 1974; Durotoye, 1989; Edegbai *et al.,* 2019). Boreholes sited in the MSF mainly tap its groundwater from the shallow unconfined highly vulnerable aquifer of the Warri Sombreiro Deltaic Plain Sand Formation which overlay the Benin Formation (BF), a deeper prolific layer known for its economic potable groundwater yield (Oteze, 1981; Oteze, 2019; Omorogieva *et al.,* 2022). The hydrogeological profile of the study area (A - B) cross cutting the Alluvial Plain - Mangrove Swamp Strata - Beach Ridge- Ocean is indicated in the modified geological map in Figure 1a.

The geophysical data acquisition (field exercise) for the study was carried out along the earthy roads leading to NMU permanent and temporary sites respectively (Figure 1b). The sites were strategically selected to represent both NMU campuses and the host community. The coordinates of the extreme right and left of AB/2 along the earthy road leading to the permanent site are 5°37.499'N:5°23.230'E and 5°37.208'N:5°22.842'E respectively. The middle (fixed position) of VES1 is marked as VES location in Figure 1b with a corresponding coordinate of 5°37.331'N:5°23.020'E. On the other hand, the position of the extreme right, middle and extreme left of VES2 along the road towards to the temporary site are indicated in Figure 1b.

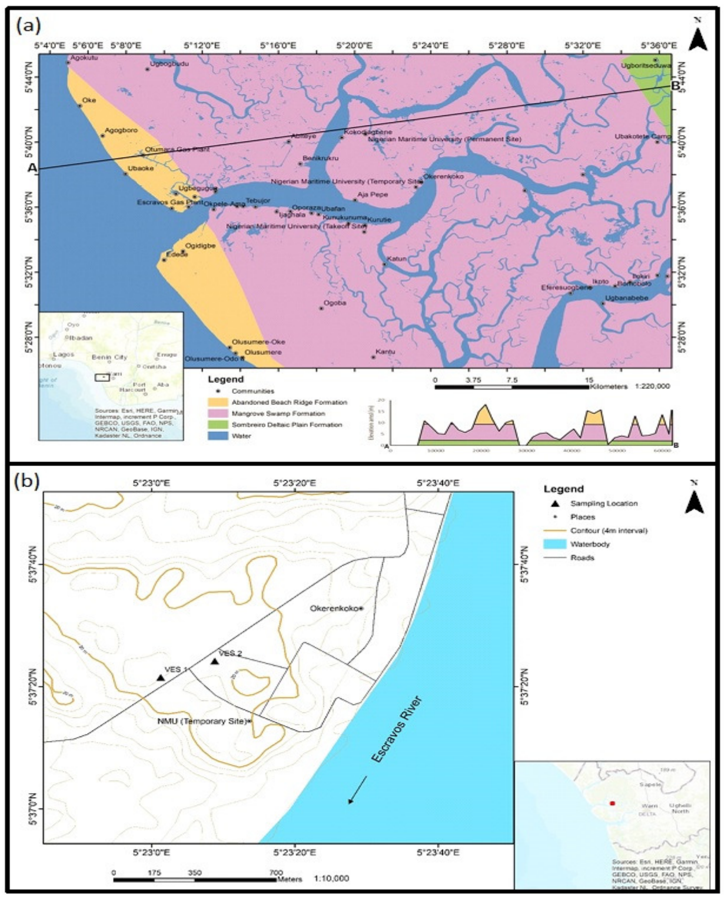

Figure 1: Maps of the study area (a) modified geological map extracted from the Nigerian Geological Survey Agency (NGSA) Nigeria 1: 50,000 map via google earth pro version 7.34.8642 (b) Study location map indicating VES1 and VES2 positions

2.2. Instrumentation/Data Acquisition

Petro-Zenith resistivity meter (PZRM) using Schlumbeger configuration was used in generating the data in the study. The materials used included two each of current and potential electrodes. In addition, cutlass, mobile device for communication, hammer for penetrating the electrodes into the earth, Global Positioning System

(GPS) for coordinate measurement, data sheet for recording and two blue and red coloured connecting cables (Ogundana and Talabi, 2014; Widodo *et al.,* 2021). The principle of electrical resistivity method is based on sending electric current into the earth subsurface through two current electrodes connected to resistivity meter. The resulting potential difference is measured across two other electrodes and the ratio of the potential difference to the current is displayed by the resistivity meter as the resistance value measured in ohms meter (Ωm). The geometric factor (GF) was calculated as a function of the electrode spacing, and the resistivity readings was multiplied by the GF to obtain the apparent resistivity value in ohms meter (Ωm). Electrode spacing was progressively increased, keeping the centre point of the electrode array fixed. In the current study, measurements of two vertical electrical sounding were recorded. The first VES1 results were obtained along the earthy road towards the permanent site of the Nigeria Maritime University with AB = 1200 m and MN = 30 m spread respectively. Conversely, VES2 was determined along the earthy road towards the temporary site of NMU directly opposite River Escravos.

Schlumberger array configuration was adopted in the study (Figure 2). The arrangement is made up of four collinear electrodes; the outer two (AB) electrodes represent current source whereas the inner two electrodes represents the potential electrodes (MN). The potential electrodes are fixed at the middle of the electrode array with short distance apart. The current electrodes are constantly increase as the geophysical survey progress whereas the potential electrodes maintain the initial position unless the voltage becomes highly reduce to probe further the subsurface information.

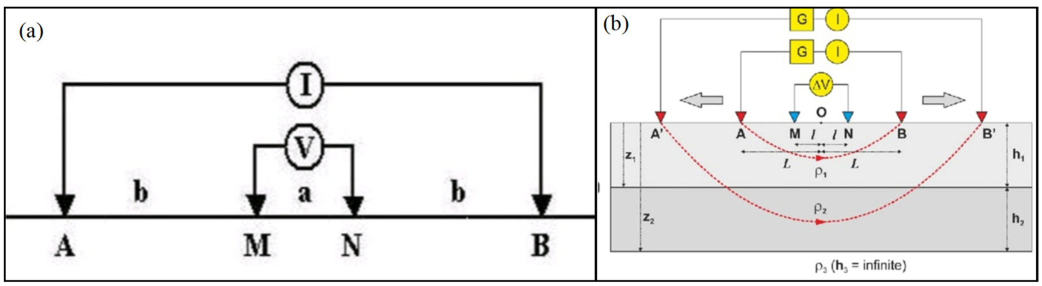

Figure 2: Schlumberger array (a) adopted from Meindinyo *et al.* (2017), (b) after Niculescu and Andrei (2019)

2.3. Data Processing

The data obtained in the study were manually processed by curve matching with standard master curves, afterward by Interprex software. The result revealed the following inferred lithological layers beginning with top fine grain sand underlain with lateritic mud soil, sand, clayey sand, sandy clay and clayey silt (Table 1). The curve types obtained in the study are KHQ and AA respectively.

3. RESULTS AND DISCUSSION

The results obtained during the field survey and the interpretation of the data sets are presented as follows:

The model obtained in VES1 show a typical KHQ curve with seven (7) inferred geoelectric layers as indicated in Figure 3. The resistivity values obtained in the model generated ranged from 159.24 Ωm to 524.34 Ωm; the rock layers of the top most geoelectric characterization indicate milky fine sand to lateritic mud rock with a thickness of 0.05 m occurring at a depth range of 0.8858m to 1.7202m. The third infer geoelectric layer was delineated as clayey sand with a thickness of 2.5234m at depth 4.2435 m corresponding to resistivity of 2483.4Ωm, while the fourth and fifth geoelectric layers are Clay and Silty sand with thickness ranges from 2.8962 m to 12.828 m at a depth range of 7.1399m to 19.968 m and a resistivity range of 159.34 Ωm to 354.45 Ωm. The sixth geoelectric layer was identified as sand with a thickness of 42.548 m at depth 62.516 m with resistivity of 524.34 Ωm. The seventh and eighth geoelectric layers had thickness range of 77.924 m to 186.92 m at a depth range of 140.44 m to 327.36 m; the corresponding resistivity in ohms meter (Ωm) range from 206.65 to 383.50. The overall inferred geoelectric layers obtained in VES1, the respective rock units and the curve type are summarized in Tables 1 and 2 as well as Figure 3.

Table 1: VES 1 data and the inferred lithological layers

S/N	AB/2 (m)	MN (m)	G.F	Resistance (m)	Apparent resistivity (Ωm)	Corrected resistivity (Ωm)	Inferred lithological equivalent
1	1.00	0.40	7.54	68.39	515.66	315.66	Top soil
2	1.47	0.40	16.66	23.10	384.85	334.85	Lateritic mud soil
3	2.15	0.40	36.00	9.15	329.40	355.40	Sandy clay
4	3.16	0.40	78.10	4.35	339.74	419.73	Clayey sand
5	4.64	1.00	112.00	5.74	642.88	542.88	Sand
6	6.81	1.00	242.00	2.80	677.60	647.60	Sand
7	10.00	1.00	524.00	1.37	717.88	717.88	Sand
8	14.70	1.00	1131.00	0.97	1097.07	676.96	Sand
9	21.50	2.00	726.00	0.66	479.16	528.56	Sand
10	31.60	2.00	1569.00	0.25	389.11	389.38	Clay
11	46.40	2.00	3382.00	0.34	1163.41	328.70	Clayey sand
12	68.10	6,00	2424.00	0.13	322.39	342.05	Clay
13	100.00	6.00	5231.00	0.06	324.32	376.37	Clay
14	130.00	10.00	5552.00	0.18	982.70	382.37	Clayey sand
15	160.00	10.00	6781.00	0.04	237.34	385.16	Clay
16	180.00	10.00	9950.00	0.11	1094.50	379.28	Clayey sand
17	200.00	10.00	9950.00	0.04	348.25	375.72	Clay
18	220.00	20.00	7245.00	0.05	391.23	393.55	Clay
19	240.00	20.00	8811.00	0.03	290.76	390.32	Clay
20	260.00	20.00	8811.00	0.02	185.03	389.70	Clayey silt
21	280.00	20.00	8811.00	0.05	449.36	377.25	Sandy clay
22	300.00	20.00	8811.00	0.01	123.35	358.38	Clayey silt
23	340.00	20.00	15676.00	0.02	297.84	350.67	Clay
24	380.00	40.00	7814.00	0.047	367.26	368.81	Clay
25	420.00	40.00	7814.00	0.044	343.82	347.81	Clay
26	460.00	60.00	9281.00	0.014	129.93	350.95	Clayey silt
27	500.00	60.00	9281.00	0.013	120.65	331.77	Clayey silt
28	540.00	60.00	9281.00	0.046	426.93	326.13	Sandy clay
29	600.00	60.00	9281.00	0.053	491.89	321.90	Sandy clay

On the other hand, Tables 3 and 4, and Figure 4 represent the resistivity layer inversion model, the various rock units and the curve type obtained for VES 2. In VES 2, six geoelectric layers were obtained; the resistivities of the rock layers range from 6.89 Ωm to 1038.3 Ωm. The inferred lithological profile down-hole indicate that the first and second layers are composed of overburden with characteristics of fine milky mud sand with a thickness and depth ranges of 0.389 m - 1.86 m and 0.3894 m - 2.25 m respectively. The third geoelectric layer was identified as sand horizon with a thickness of 21.268 m at a depth of 23.52 m; the values correspond to a resistivity value of 3139.8 Ωm. The fourth and fifth geoelectric layers were delineated to be clayey sand and sand with thickness of 54.87 m and undetermined section at a depth of 78.39 m respectively. Conversely, comparison between the inferred lithological rock units of VES 1, 2 to a well-log penetrating a considerable depth in the Niger Delta Sedimentary Basin is represented in Figure 5.

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Table 2: Data and resistivity model for VES 1

VES data					Resistivity model		
S/N	AB/2 (m)	MN (m)	Apparent resistivity (Ωm)	Corrected resistivity (Ωm)	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	1.00	0.40	515.661	315.66	319.31	0.88584	0.8858
2	1.47	0.40	384.846	334.85	235.39	0.83436	1.7202
3	2.15	0.40	329.400	355.40	2483.40	2.5234	4.2436
4	3.16	0.40	339.735	419.73	354.45	2.8962	7.1399
5	4.64	1.00	642.880	542.88	159.34	12.828	19.9680
6	6.81	1.00	677.600	647.60	524.34	42.5480	62.5160
7	10.00	1.00	717.880	717.88	350.61	77.9240	140.4400
8	14.70	1.00	1097.070	676.96	383.50	186.9200	327.3600
9	21.50	2.00	479.160	528.56	206.65	Undetermined	Undetermined
10	31.60	2.00	389.112	389.38			
11	46.40	2.00	1163.408	328.70			
12	68.10	6.00	322.392	342.05			
13	100.00	6.00	324.322	376.37			
14	130.00	10.00	982.704	382.37			
15	160.00	10.00	237.335	385.16			
16	180.00	10.00	1094.500	379.28			
17	200.00	10.00	348.250	375.72			
18	220.00	20.00	391.230	393.55			
19	240.00	20.00	290.763	390.32			
20	260.00	20.00	185.031	389.70			
21	280.00	20.00	449.361	377.25			
22	300.00	20.00	123.354	358.38			
23	340.00	20.00	297.844	350.67			
24	380.00	40.00	367.258	368.81			
25	420.00	40.00	343.816	347.81			
26	460.00	60.00	129.934	350.95			
27	500.00	60.00	120.653	331.77			
28	540.00	60.00	426.926	326.13			
29	600.00	60.00	491.893	321.90			

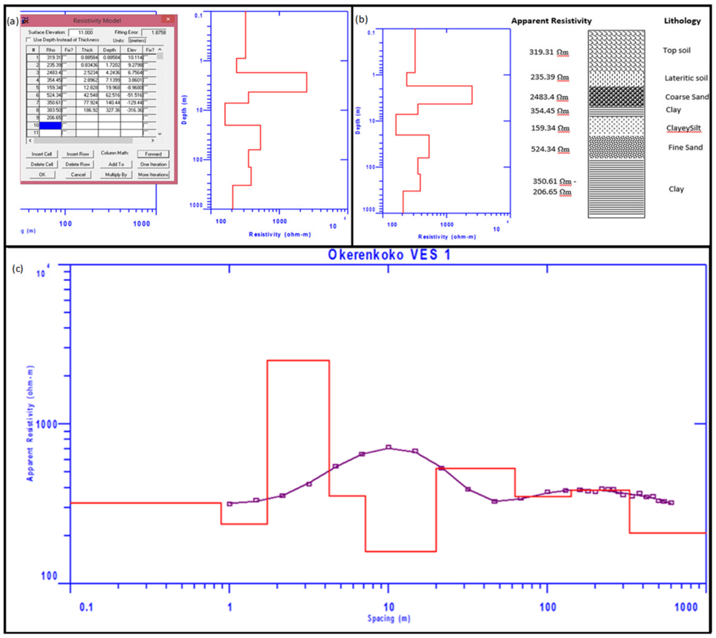

Figure 3: Subsurface information obtained in VES 1(a) Layer inversion model (b) inferred lithological rock units (c) hydrogeophysical curve type (KHQ) indicating a moderate to deep well

Table 3: Data/inferred lithological layers for VES 2

S/N	AB/2 (m)	MN (m)	Resistance (Ωm)	G.F	Apparent resistivity (Ωm)	Corrected resistivity (Ωm)	Inferred lithological layers
1	1.00	0.40	2.2109	7.54	16.67	16.67	Top soil
2	2.15	0.40	1.0653	36.00	38.35	38.35	Earthy soil
3	3.15	0.40	0.6813	78.10	53.21	53.21	Earthy soil
4	4.65	0.40	0.4971	169.00	84.01	72.01	Earthy soil
5	6.80	0.40	0.2949	364.00	107.36	107.36	Lateritic soil
6	10.00	1.00	0.2817	524.00	147.59	147.59	Clayey silt
7	14.50	1.00	0.2162	1131.00	244.48	244.48	Clay
8	21.50	1.00	0.1586	2420.00	383.90	321.90	Clay
9	31.50	2.00	0.2848	1569.00	446.85	446.85	Clayey sand
10	46.50	2.00	0.1681	3382.00	568.67	568.67	Sand
11	68.50	2.00	0.0809	7285.00	589.41	683.41	Sand
12	80.00	2.00	0.0903	8838.00	797.94	797.94	Sand
13	100.00	2.00	0.0575	15708.00	904.21	854.21	Sand
14	130	6	0.16624	5231	869.6	869.6	Sand
15	160	6	0.077392	11310	875.3	845.3	Sand
16	200	6	0.048137	16692	803.5	873.5	Sand
17	240	10	0.050312	17645	887.75	887.75	Sand
18	260	10	0.062083	17645	1095.45	895.45	Sand
19	300	10	0.049943	17645	881.25	881.25	Sand

Table 4: Data and resistivity model for VES 2

VES data					Resistivity model		
S/N	AB/2 (m)	MN (m)	Apparent resistivity (Ωm)	Corrected resistivity (Ωm)	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	1.00	0.40	16.67	16.67	6.8958	0.3894	0.3894
2	2.15	0.40	38.35	38.35	544.6600	1.8658	2.2552
3	3.15	0.40	53.21	53.21	3139.8000	21.2680	23.5230
4	4.65	0.40	84.01	72.01	469.6500	54.8740	78.3970
5	6.80	0.40	107.36	107.36	1038.3000	Undetermined	Undetermined
6	10.00	1.00	147.59	147.59			
7	14.50	1.00	244.48	244.48			
8	21.50	1.00	383.90	321.90			
9	31.50	2.00	446.85	446.85			
10	46.50	2.00	568.67	568.67			
11	68.50	2.00	589.41	683.41			
12	80.00	2.00	797.94	797.94			
13	100.00	2.00	904.21	854.21			
14	130.00	6.00	869.60	869.60			
15	160.00	6.00	875.30	845.30			
16	200.00	6.00	803.50	873.50			
17	240.00	10.00	887.75	887.75			
18	260.00	10.00	1095.45	895.45			
19	300.00	10.00	881.25	881.25			

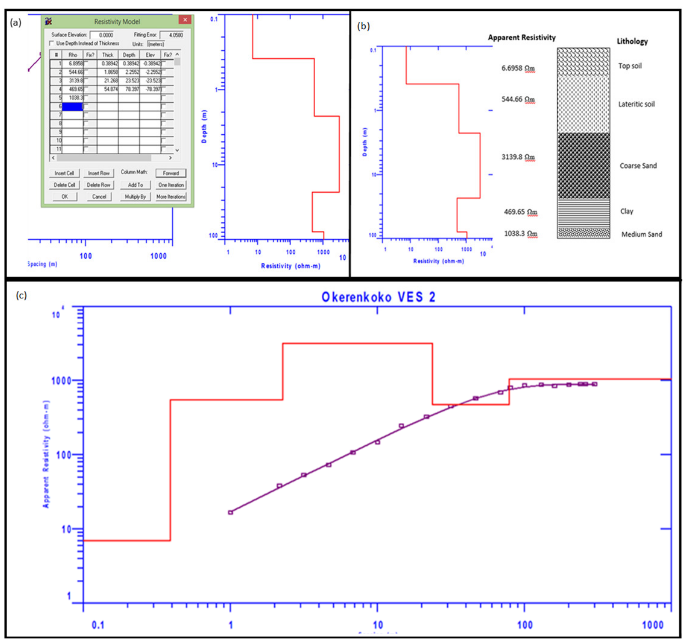

Figure 4: Subsurface information obtained in VES 2 (a) resistivity and layer inversion model (b) inferred lithological rock units (c) hydrogeophysical curve type (AA) indicating a shallow to moderate well

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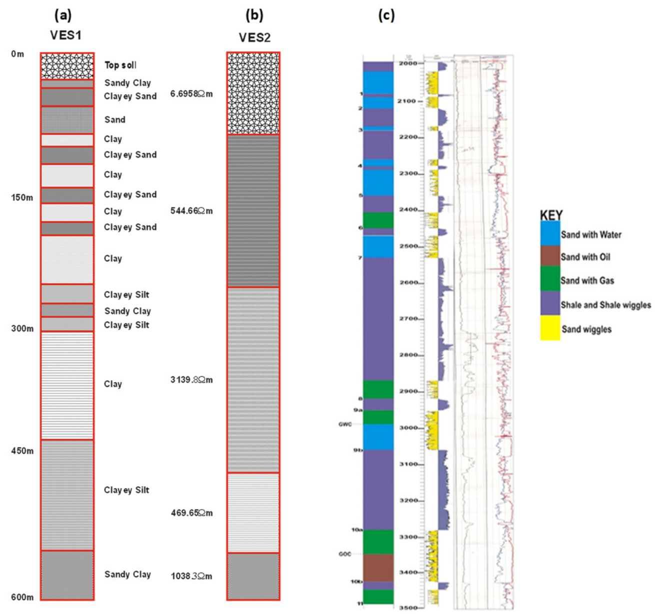

Figure 5: Comparison of inferred lithological characteristics of VES 1 and 2 to well-log log penetrating considerable depth in Niger Delta (a) lithological characteristics and depth profile of VES1 (b) lithological characteristics and depth profile of VES2 (c) well-log penetrating considerable depth in Niger Delta sedimentary basin after Ilevbare and Omorogieva, (2020)

Eighteen geoelectric layers of varying inferred rock layers were obtained in the study. The lithologic rock layers for VES 1 and 2 include fine milky mud sand, sand, clayey sand, clay, clayey silt and sandy clay. Sand layers are the dominant rock units in the study; they overly one another with varying thicknesses. A clay bed of an estimated thickness of 186.92 m was encountered at a depth range of 140.44 m to 327.36 m serve as cap to the confined aquifer beneath it and a seal to the unconfined to semi confined aquifer above it. It was observed that the aquifer above the clay bed provides the groundwater currently use by the locals. Previous studies revealed that the groundwater derived from the leaky aquifer above the clay bed contains impurities suspected to infiltrate into the leaky aquifer from surface derived contaminants and mineral mixing within River Escravos (Adebayo, 2022). The freshwater obtained from the unconfined aquifer has poor quality, reddish-brown in colour with foul smell; the attribute corresponds to AA curve types generated in the study for shallow wells. Unconfined shallow wells are susceptible to contamination as noted in the present study. Water containing impurities cannot be used for drinking, pharmaceutical and industrial purposes unless it is well treated. Interestingly, it was observed that groundwater found at the depth of 39m marked the intrusion of saltwater possibly from river Escravos and the adjoining creeks based on the low resistivity value recorded. On the other hand, below the thick clay bed represents confined aquifer. However, excessive withdrawal of groundwater from a confined aquifer may lead to the formation of a cone of depression; the occurrence can impact the hydrodynamic equilibrium that exists between the fresh and seawater layers, the process may result in the inflow of seawater into the freshwater aquifer (Ghyben-Herzberg, 2018), care must be taken in exploiting the freshwater at this depth. Figure 5 further buttresses the inferred geoelectric rock layers obtained in the study were in congruent with the well-log obtained in Niger Delta Sedimentary Basin (Ilevbare and Omorogieva, 2020). In Figure 5, it was noted that below the clay layer at about 2000 feet depth (666.67 m), the presences of sand was recorded; this may serve as a prolific aquifer for economic groundwater exploitation as noted in the study. It is important to note that coastal aquifers are highly sensitive to regional and global incidence of storm surges, sea-level rise, change in climate condition, shoreline erosion, and coastal flooding couple, can impact the quality of groundwater in coastal environment (Li *et al.,* 2019; Li *et al.,* 2021). However, aquifers below thick clay layer can provide the desire groundwater quality needed to drive economic prosperity provided the clay can be penetrated through during drilling. At a depth below the clay layer, quality reservoir of fresh groundwater could be encounter; the geology may be or have a similar characteristic of the Benin Formation that is well known for prolific groundwater exploitation. The study revealed that the geoelectric layers obtained are mainly of fine grain sand interbeded with clay and silt; the texture and the general characteristics of the soil can facilitate the mobility and infiltration of contaminants into freshwater stored in an unconfined shallow aquifer.

4. CONCLUSION

The applications of vertical electrical sounding using Schlumberger array in sourcing for quality groundwater have been proven very effective. In Federated Okerenkoko community, the method was applied in delineating prolific aquifer layers for groundwater exploitation being the only source of freshwater available in the study area. The results obtained revealed two aquiferous horizon of unconfined and confined above and below a thick clay layer occurring at a considerable depth. The inferred geoelectric layers revealed that the rock layers in the survey include overburden of fine grain sand, lateritic mud sand, fine to medium grain sand, clay, clayey sand and clayey silt. It was observed that groundwater sourced above the thick clay horizon contains impurities attributed to the infiltration of surface derived contaminants, and seawater intrusion possibly from river Escravos and the adjoining creeks. On the other hand, the confined aquiferous horizon detected below the clay bed may be able to provide the needed potable groundwater that could be used in all sphere of human endeavour without further cost on treatment. Bye and large, it is strongly recommended that boreholes for the purpose of potable water supply in the study area should be drilled below the depth of 762 m in order to obtain clean groundwater for the desired applications.

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5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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