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RESEARCH ARTICLE

DELINEATION OF HYDROGEOLOGICAL UNITS USING VERTICAL ELECTRICAL SOUNDING TECHNIQUE IN IYOWA, EDO STATE, NIGERIA

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ABSTRACT

This study employed vertical electrical sounding (VES) to delineate hydrogeological zones in the study area with the overall objective of determining the feasibility of groundwater development in Iyowa, community, Edo State. The study area is part of the Benin formation of the Niger Delta sedimentary Basin. Five VES in Schlumberger array configuration were randomly conducted in the study area. The Petrozenith Terrameter was used to conduct the vertical electrical sounding (VES) with total spread of 800m (AB/2=400). Field data were iterated using the Interpex ID software. The result indicated six (6) geoelectric sections and the main aquiferous units were delineated as unconfined and semi-confined consisting of medium sand grained, and coarse sand grained with resistivities ranging from 516.46-2603 Ωm, thickness 23.49-129.21m and depth ranging from 62.17-206.76m. The sounding curves were HAK, HAQ, AAK, and AKQ types. The recommended drill depth in the study area is 72.30m.

KEYWORDS

Configuration, vertical electrical sounding, aquiferous, unconfined and semi-confined

1. INTRODUCTION

Water is often termed the "medicine of life" due to its fundamental role in sustaining ecosystems in a sustainable manner (Akanwa et al., 2017). Surface water, however, is vulnerable to pollution from both human activities and natural sources because of its exposure to environmental elements (Gamble and Babbar-Sebens, 2012). Consequently, groundwater emerges as a superior alternative to meet the water demands of agricultural, industrial, and domestic purposes (Chandra et al., 2010; Putra and Yuskar, 2017). Groundwater is located beneath the Earth's surface, specifically within fractures and voids in soil particles, sand, and rock formations. It is stored beneath the Earth and migrates slowly under low pressure through geological formations known as aquifers. Generally, groundwater is categorized into two types: confined aquifers and unconfined aquifers, distinguished by the presence or absence of an impermeable layer above the aquifer (Suryadi et al., 2018).

The development of groundwater resource requires a detailed knowledge of hydrogeological and lithological characteristics of the subsurface layers in order to adequately constrained the aquiferous settings (shallow and deep aquifers, confined or unconfined) of an area including the information on depth to water table, static water level and stratigraphical sequence of rock units. Several geophysical methods are employed in groundwater exploration in order to identify suitable locations for productive boreholes, with the electrical resistivity method being among the most commonly used. The electrical method includes techniques such as Vertical Electrical Sounding (VES) and Horizontal Profiling (HP) (Omosuyi et al., 2008). VES is a geophysical technique used to examine subsurface electrical properties by measuring resistivity at different depths. It involves infusing electrical current into the ground through a pair of electrodes and measuring the resulting potential difference. By systematically increasing the distance between the current and potential electrodes, data are gathered that reveal changes in resistivity with depth (Emmanuel et al., 2011). The primary goal of VES at a specific location is to ascertain the subsurface electrical resistivity distribution, providing crucial insights into the area's lithological and hydrological properties (Hamill and Bell, 1986).

Although the study area is situated in the Benin Formation that is widely known as the most prolific aquifer in the Niger Delta Basin, several cases of borehole failures, low yield and poor water quality have also been reported in the area. These failures could be linked to ignoring geological and locational peculiarities by contractors and borehole developers This study employs vertical electric sounding (VES) to constrained the aquifer properties and subsurface geology that are favorable to groundwater development at Iyowa, Edo State, since data on conventional methods such as pumping test and grain size analysis are quite invasive and relatively expensive. The study provides pre-drilling geophysical data that would serve as a working guide to prospective groundwater developers; indicating estimated drill depths and different lithologic units and also assisting environmental geologist and policy makers with relevant details for the proper siting and design of suitable landfill in the area with a view of mitigating against risk of contamination.

2. MATERIALS AND METHODS

The Vertical Electrical Sounding (VES) was done using the Schlumberger electrode array configuration. The VES was conducted randomly at five (5) different points within the study location. The total spread length for the VES is 800m. The VES covered a spread of 400m on the left side and 400m on the right side of the spread with AB (total spread) is 800m and AB/2 = 400m. The investigation involved the electrical resistivity method which employs an artificial source of current which is introduced into the ground through point electrodes known as current referred to as potential electrodes. The apparent resistivity of the ground is the product of the measured resistance and the geometric factor of the electrode array

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employed. The theoretical background of the method is based on the fact that the earth conducts electricity through ionic/electrolytic means, a phenomenon associated with the presence of pore fluids within the subsurface. The Ohm's law was therefore handy as the theoretical basis of the electrical resistivity method based on the aforementioned facts (Sunnetha and Gupta, 2018).

- Ohm's law: R=ΔV/I
- Where R = Resistance, ΔV = potential and I= current.

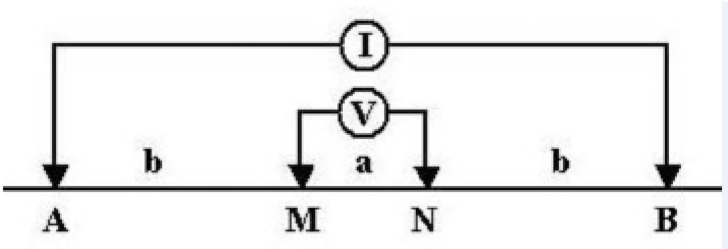

Figure 1: Schlumberger array profiling

2.1 Data Analysis

Field data was first subjected to manual processing and secondly to computer processing and analysis using INTERPEX 1-D. The field data inputted into the software (INTERPEX 1-D) for generation of sounding curves were resistance and apparent resistivity. The thickness and apparent resistivity derived from interpretation of sounding curves through partial curve matching techniques.

2.2 Geology and Hydrogeology of the study area

The study area is located in Iyowa, Benin city, and lies between Latitude 6°29.141′N to 6°29.169′N and Longitude 5°36.184′E to 5°36.879′E with an elevation of 165m. The study area is underlain by the Benin formation which is a part of the Niger Delta basin. The upper section of the Benin Formation is the Quaternary deposits which is about 40-150m thick and comprises sand and silt/clay with the later becoming increasingly seaward. The Benin Formation has significant groundwater potential consisting predominantly of freshwater continental sands and gravel with intercalations of shale and with thickness of about 2100m at the center of Basin. Hydraulic conductivities of the Quaternary sand aquifer vary from 3.82×10-3 to 9.0×10-2 cm/sec indicative of a potential productive aquifer and specific capacities recorded from different areas within this formation vary from 6700 lit/h/m to 13,500lit/h/m downward (Nwankwo et al., 2023).

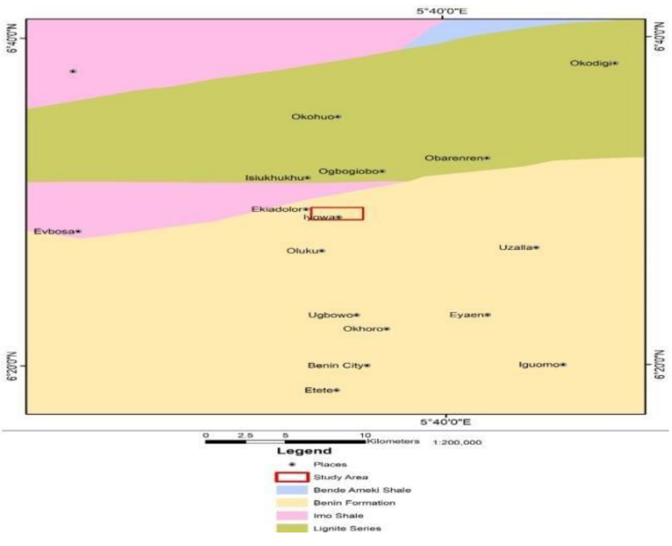

Figure 2: Geologic map of the study area (Source: Nigerian Geological survey agency, modified by Ojeaga and Okoro, 2023)

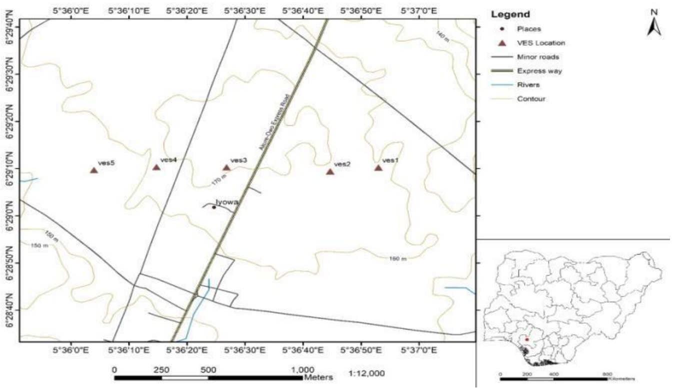

Figure 3: Sampling location map showing VES points (Source: Ojeaga and Osauzou, 2024)

3. Results and Discussion

3.1 Geoelectric Layers

The result of five (5) vertical electric soundings conducted in the study area as shown in Tables 1,2,3,4 and 5 presents six geoelectric layers with varying resistivities and thicknesses within each VES point. The first layer (topsoil) which is composed of unconsolidated sand has resistivities ranging from 217.08- 529.62Ωm, thickness varying from 0.3049m to 1.8295m and depth ranging from 0.3 to 1.9m. The second layer composed of lateritic soil is characterized by resistivities ranging from 171.91-432.82Ωm, thickness ranging from 1.5767-2.8092m and depth ranging from 2.68 to 6.20m. The third layer consists of fine to medium sand, sandstone, clay and medium to coarse sand and has resistivities ranging from 445.20-15191Ωm with thickness values ranging from 5.7993-21.830m and depth ranging from 9.07 to 28.03m. The fourth geoelectric layer consist of sandstone, medium to coarse sand and medium sand and has resistivities ranging from 1540.9-14004Ωm, thickness varying from 16.022-48.512m and depth ranging from 33.33 to 76.55m. The fifth geoelectric layer was composed mainly of medium sand, fine to medium sand, fine sand and medium to coarse sand with resistivities varying from 516.46-2603.4Ωm and thickness 23.493-129.21m and depth ranging from 62.17 to 206.76m. The sixth geo electric layer has apparent resistivities ranged from 56.06 to 1076 Ωm with undetermined thickness and depth which was denoted as by the infinity symbol ∞. According to a study, the configuration of the Vertical Electrical Sounding (VES) curve is influenced by the thickness of individual layers, the number of subsurface layers, and the resistivity ratios of these layers (Kwami et al., 2019).

Table 1: Resistivity data of VES 1

VES 1 Data				Resistivity model		
S/N	AB/2 (m)	MN/2 (m)	Adjusted Resistivity (Ωm)	Resistivity (Ωm)	Thickness (m)	Depth (m)
1	1	0.5	504.89	529.62	0.5963	0.5963
2	1.47	0.5	480.76	432.82	2.7825	3.3788
3	3.16	0.5	477.22	819.38	11.752	15.131

Table 1 (cont): Resistivity data of VES 1

4	4.64	0.5	493.28	20137	23.554	38.686
5	10	0.5	649.76	1175.4	23.493	62.178
6	14.7	2.0	789.91	56.066	Undetermined	Undetermined
7	21.5	2.0	987.60	-	-	-
8	31.6	2.0	1322.95	-	-	-
9	46.4	2.0	1701.74	-	-	-
10	68.1	10.0	2381.42	-	-	-
11	100	10.0	2881.90	-	-	-
12	147	10.0	3117.82	-	-	-
13	178	10.0	3007.16	-	-	-
14	215	10.0	2760.94	-	-	-
15	250	10.0	2337.15	-	-	-
17	300	10.0	1927.85	-	-	-

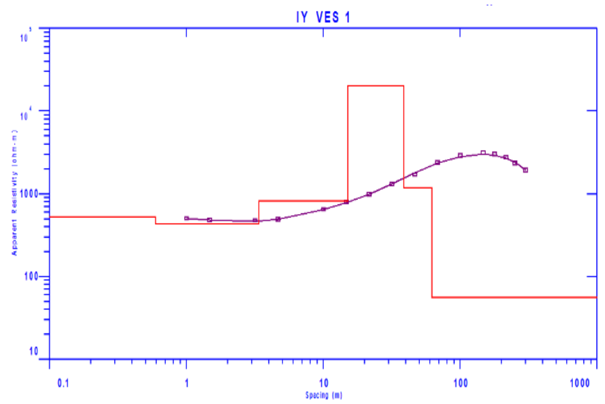

Figure 4: Hydrogeophysical sounding curve, VES 1

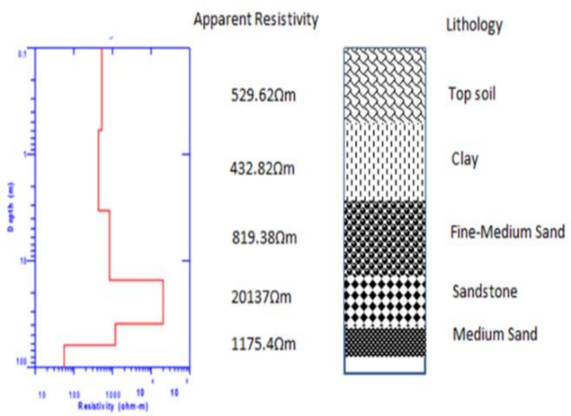

Figure 5: Layered Inversion Model and Lithology of the study area in VES 1

Table 2: Resistivity data of VES 2

VES 2 Data				Resistivity model		
S/N	**AB/2 (m)**	**MN/2 (m)**	**Adjusted Resistivity (Ωm)**	**Resistivity (Ωm)**	**Thickness (m)**	**Depth (m)**
1	1	0.5	408.89	416.26	1.8295	1.8295
2	1.47	0.5	417.02	360.75	4.3779	6.2074
3	3.16	0.5	407.22	8498.7	21.830	28.037
4	4.64	0.5	431.83	2435.3	48.512	76.549
5	10	0.5	581.64	847.91	129.21	205.76
6	14.7	2.0	789.91	1076.9	Undetermined	Undetermined
7	21.5	2.0	1165.60	-	-	-
8	31.6	2.0	1522.95	-	-	-
9	46.4	2.0	2002.24	-	-	-
10	68.1	2.0	2381.42	-	-	-
11	100	10.0	2620.11	-	-	-
12	147	10.0	2647.82	-	-	-
13	178	10.0	2361.09	-	-	-
14	215	10.0	2247.88	-	-	-
15	250	10.0	2037.15	-	-	-
17	300	10.0	1685.10	-	-	-
18	400	10.0	1377.30	-	-	-

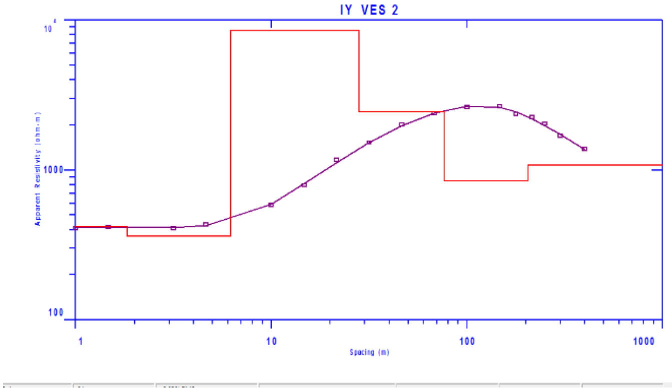

Figure 6: Hydrogeophysical sounding curve, VES 2

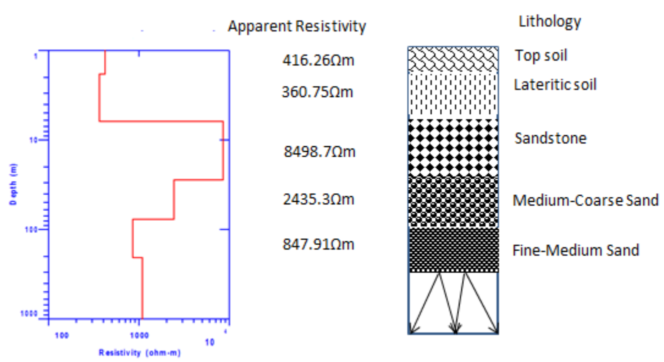

Figure 7: Layered Inversion Model and Lithology of the study area in VES 2

Table 3: Resistivity data of VES 3						
VES 3 Data				**Resistivity model**		
S/N	**AB/2 (m)**	**MN/2 (m)**	**Adjusted Resistivity (Ωm)**	**Resistivity (Ωm)**	**Thickness (m)**	**Depth (m)**
1	1.00	0.5	304.66	217.08	0.3049	0.3049
2	1.47	0.5	347.02	398.67	4.8360	5.1409
3	3.16	0.5	397.38	15191	13.087	18.228
4	4.64	0.5	443.68	3282.0	16.022	34.250
5	10.00	2.0	702.16	516.46	24.388	58.639
6	14.70	2.0	989.91	452.03	Undetermined	Undetermined
7	21.50	2.0	1385.60	-	-	-
8	31.60	2.0	1875.77	-	-	-
9	46.40	10.0	2399.52	-	-	-
10	68.10	10.0	2701.42	-	-	-
11	100.00	10.0	2733.01	-	-	-
12	147.00	10.0	2317.82	-	-	-
13	178.00	10.0	2061.09	-	-	-
14	215.00	10.0	1671.95	-	-	-
15	250.00	10.0	1237.15	-	-	-
16	300.00	10.0	898.27	-	-	-
17	400.00	10.0	677.30	-	-	-

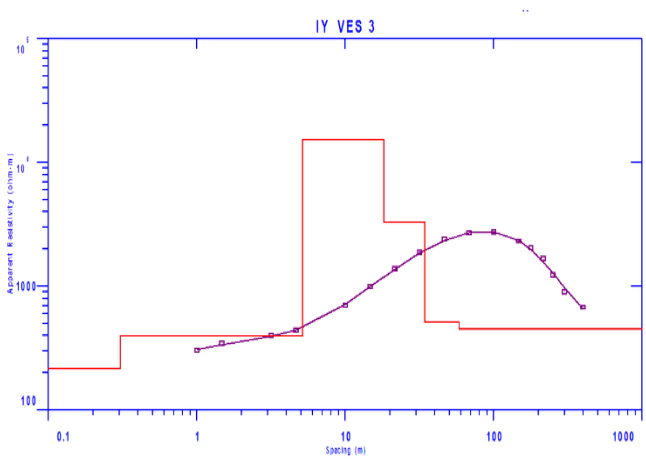

Figure 8: Hydrogeophysical sounding curve, VES 3

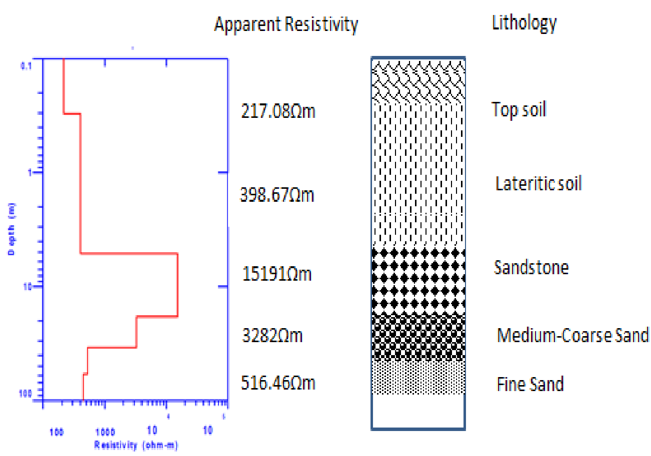

Figure 9: Layered Inversion Model and Lithology of the study area in VES 3

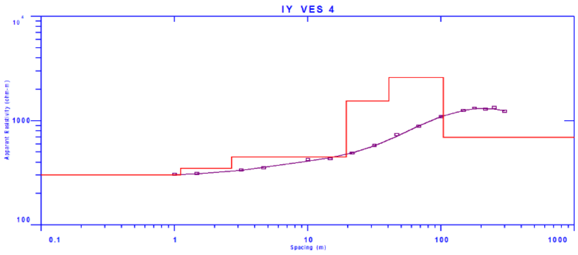

Figure 10: Hydrogeophysical sounding curve, VES 4

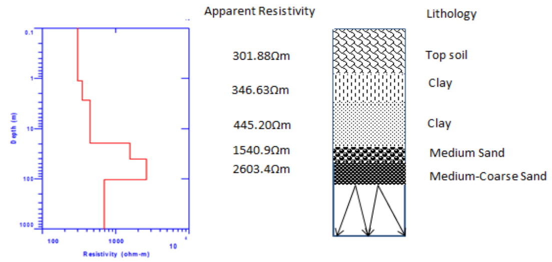

Figure 11: Layered Inversion Model and Lithology of the study area in VES 4.

Table 4: Resistivity data of VES 4						
VES 4 Data				**Resistivity model**		
S/N	**AB/2 (m)**	**MN/2 (m)**	**Adjusted Resistivity (Ωm)**	**Resistivity (Ωm)**	**Thickness (m)**	**Depth (m)**
1	1.00	0.20	304.89	301.88	1.1096	1.1096
2	1.47	0.20	310.76	346.63	1.5767	2.6862
3	3.16	0.20	337.22	445.20	16.815	19.502
4	4.64	0.20	353.12	1540.9	21.156	40.658
5	10.00	2.00	423.96	2603.4	63.623	104.28
6	14.70	2.00	429.91	689.51	Undetermined	Undetermined
7	21.50	2.00	487.60	-	-	-
8	31.60	2.00	576.47	-	-	-
9	46.40	10.0	735.91	-	-	-
10	68.10	10.0	880.48	-	-	-
11	100.00	10.0	1089.90	-	-	-
12	147.00	10.0	1247.82	-	-	-
13	178.00	10.0	1317.16	-	-	-
14	215.00	10.0	1286.70	-	-	-
15	250.00	10.0	1337.15	-	-	-
17	300.00	10.0	1227.85	-	-	-

3.2 Geoelectric curves

The geoelectric curves obtained from the geophysical sounding in the area were HAK, HAQ, AAK, and AKQ types as shown in 4,6,8,10, and 12.

Table 5: Resistivity data of VES 5						
VES 5 DATA				**RESISTIVITY MODEL**		
S/N	**AB/2(m)**	**MN/2**	**Adjected Resistivity (Ωm)**	**Resistivity (Ωm)**	**Thickness (m)**	**Depth (m)**
1	1	0.2	191.52	282.59	0.46263	0.4626
2	1.47	0.2	208.75	171.91	2.8092	3.2718
3	2.15	0.2	226.80	1564.4	5.7993	9.0711
4	3.16	0.2	295.22	14004	24.260	33.332
5	4.64	0.2	361.66	1658.9	39.931	73.263
6	6.81	0.2	537.63	637.98	Undetermined	Undetermined
7	10.0	2.0	722.20	-	-	-
8	14.7	2.0	868.60	-	-	-
9	21.5	2.0	1141.2	-	-	-
10	31.6	10.0	1259.75	-	-	-
11	46.4	10.0	1586.72	-	-	-
12	68.1	10.0	2205.86	-	-	-
13	100	10.0	2769.45	-	-	-
14	147	10.0	3580.462	-	-	-

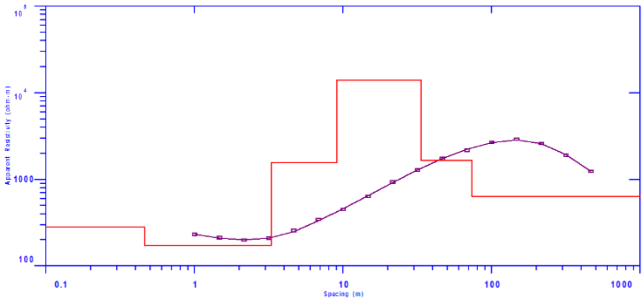

Figure 12: Hydrogeophysical Sounding Curve, VES 5

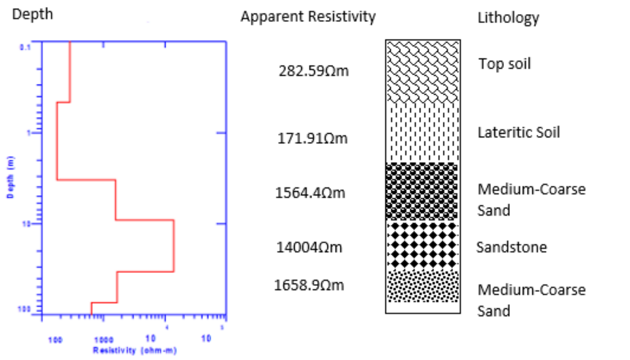

Figure 13: Layered Inversion Model and Lithology of the study area in VES 5.

3.3 Recommended Drill Depth

The deductions of different lithologies from the layered inversion models presented in (Figures, 5, 7, 9, 11 and 13) showed that the groundwater bearing unit (aquifer units) in VES 1 was medium sand grained with recommended drill depth of 62m. VES 2 indicated that medium to coarse and fine to medium sand grained was the aquiferous layers with an average drill depth of 140m. In VES 3 the aquiferous unit is medium to coarse sand grained with average drill depth of 46m. The aquiferous layer in VES 4 comprised medium to medium-to-coarse grained sand, with an average recommended drilling depth of 72.47m. In VES 5 the groundwater bearing layer was composed of medium to coarse-grained sand with a suggested drilling depth of 41.04m. Therefore, it can be inferred that the total recommended averaged drill depth of groundwater in the study area is 72. 30m. The primary aquiferous layer consists of medium to coarse-grained sand.

4. CONCLUSION

The study delineated aquiferous layers in the study area by the application of geophysical techniques. The study recognizes geological peculiarity as a key factor that must be considered for seamless development of groundwater resources. The result of five VES conducted shows 6 (six) geoelectric layers and 4 four different curve types. The recommended drill depth in the area is 72.47m and the aquiferous layers was medium to coarse sand grained. The study has shown that the aquifer type in the area includes both semi-confined and unconfined aquifers.

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