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Aquifer evaluation in southern parts of Nigeria from geo-electrical derived parameters

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ABSTRACT

For the management of groundwater resources, understanding aquifer parameters is critical. The Vertical electrical sounding (VES) is considered one of the most common methods in groundwater exploration/aquifer vulnerability assessment. For the study, 15 VES survey was conducted using the Schlumberger configuration with a maximum electrode spacing of 200 m. The data were acquired using ABEM SAS 4000 Terrameter and processed using the WINRESIST program. The data collected were analyzed and interpreted in both qualitative and quantitative terms. Results obtained from the study area revealed that geoelectric layers range from 3 to 4, while the major kind of curve type that domain the study area is the H curve. The evaluation of aquifer protective capacity/groundwater potentials was based on the following parameters: Reflection Coefficient (Rc), Resistivity Contrast (Fc), Longitudinal Conductance (S), and Average Transverse Resistance (T). Result obtained from the study revealed that Rc, Fc, S, and T ranges from -0.70 to 0.95 with an average value of 0.10, 0.17 to 35.79 with an average value of 0.57, 822.26 to 32009.8 with an average value of 13908.8, and 0.001 Ω/m^2 to 0.25 Ω/m^2 with an average value of 0.063 Ω/m^2 respectively. Deductions from Rc and Fc suggest that the study area showed good prospects for groundwater potential. Findings from S suggest that the study is vulnerable to surface contamination due to anthropogenic activities.

***Keywords*:** Reflection coefficient, Resistivity contrast, Aquifer, Curve, Nigeria

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1. INTRODUCTION

The geophysical survey is often used to identify geoelectric parameters and aquifer units, and to further determine the depth and lateral extension of the aquifer [1, 2]. The type of geophysical survey used for a survey is mostly determined by the extent or size of the territory to be surveyed, the cost of the survey, the geology of the area, and the ease with which the data acquired may be interpreted. The geoelectric method (Vertical electrical sounding, VES), is one of the most geophysical surveys that is used to determine the depth of the water table, the lithology of subsurface layering, and enables a better level of precision in determining water-bearing unit [3, 4]. The application of various combinations of geophysical methods has resulted in an increase in the degree of precision in locating suitable groundwater reservoirs.

The geoelectrical resistivity method has been used in Nigeria to locate water-bearing units and assess formation strata [5-12], further pointed out that the VES method is mostly used to determine the vertical variation in electrical resistivity beneath the earth's surface and the potential field generated by the current in VES. This method involves implanting two electrodes in the ground and measuring the difference in potential between two electrodes, referred to as the potential electrodes. Similarly, the Schlumberger array of VES is generally used to differentiate between electrical resistivity and lithologic and/or hydrologic features [13, 14]. Their natural capacity is to detect variations in the electrical conductivity of subsurface layers that reflect their fluid content [15].

Elsewhere, several scholars have used the geoelectric to determination aquifer parameters in sedimentary and basement terrain across the world [16-25] used the geoelectric method to determine the groundwater potential of Obiaruku and environs, from their findings it was observed that water-bearing units (sandstone units) are between the range of 30 m and 136 m deep. [26], used electrical resistivity in the determination of groundwater potentials of Wadi Rahaba Shalateen, Egypt. Findings from their study suggested that the resistivity values of the fresh water-bearing formation of the Quaternary and Miocene sandstone aquifer range between 38.6 and 98.4 Ωm, and the thickness of the fresh bearing formation of the Quaternary and Miocene sandstone aquifer varies from 1.2 to 24.4 m. They went further to recommend drilling in the areas characterized by high resistivity values besides the high thickness of the aquifer. [2], used the VES to determine aquifer vulnerability in part of southern Benue Trough of the sedimentary basin in Nigeria.

Findings from their study suggested that some parts of the area are vulnerable to contamination from the surface, while areas underlain by clay and shale were considered to be less vulnerable to surface contamination. [17], on other hand, use the resistivity method to estimate groundwater potential of the lower Paleozoic to Precambrian crystalline rocks in north-central Nigeria. From their findings, it was observed that the water-bearing unit within the research area is found in weathered and fractured bedrocks. They further delineated water-bearing units into different categories; low, medium, and high water-bearing units. In the same vein, the VES method has also been used to determine aquifer protective capacity by several authors [6, 7, 27].

Report has it that various human activities pose threat to aquifers within the oil-producing communities in Delta state southern Nigeria. These activities range from oil spillage, leakage from septic tanks among others [28, 29]. Hence is urgent to need to use the VES to evaluate and determine the protective capacity of water-bearing units and groundwater potential of the study area

Location and Physiography

Fig. l shows the location of Orerokpe, is located between latitude 5°32’0”N - 5°44’0”N and longitude 5°54’E and 5°46’0”E - 6°0’0”E. Orerokpe also lies within the Sombreiro-Warri Deltaic Plain, a low-lying physiographic province Rainfall almost all through the year, with a 10 average of 2652 mm and a mean daily temperature of 31.2 °C [30].

Geology/Hydrogeology

The Niger Delta's sedimentary ecosystems and morphological characteristics have been widely researched [31-35]. The study area is underlain by the Quaternary Sombreiro-Warri Deltaic Plain deposits, which conformably overlie the Benin Formation, the youngest of the three major formations that make up the Niger Delta Basin's sedimentary fill. Massive continental/fluvial sands and gravels make up the Benin Formation. The older formations which are encountered only in the subsurface are the Agbada Formation of paralic sands and shales and the basal Akata Formation which consists of holomarine shales, silts, and clays. The Ogwashi Asaba Formation and Ameki Formation, are both of the Eocene-Oligocene age [31, 37]. The Sombreiro-Warri Deltaic Plain's sands and clays are one of four Quaternary-Holocene deposit suites in the western Delta that conceal the Benin Formation, the others being the beach ridges, freshwater swamps, and brackish water/Mangroove Swamps. Because they are universally regarded as modern manifestations of and continuations of the Benin Formation, these deposits have not been given formal names.

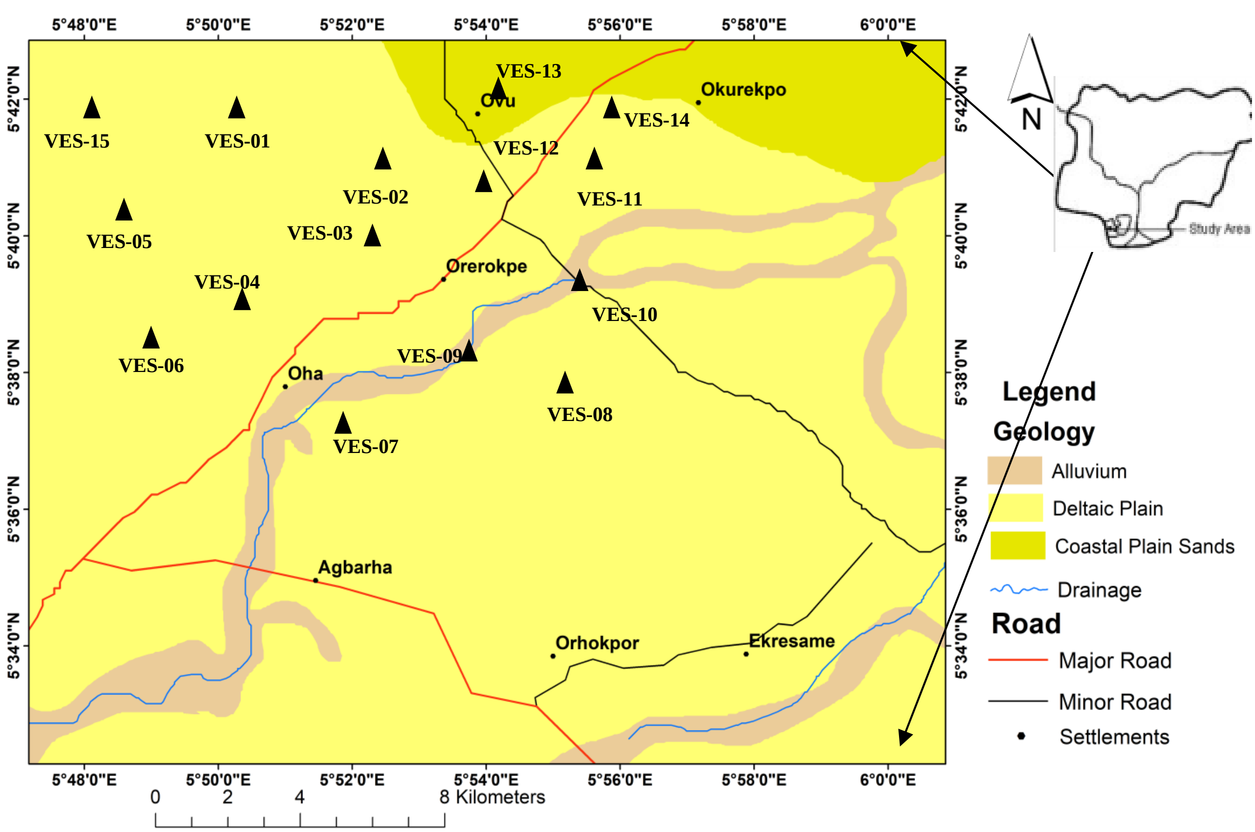

Fig. 1. Geology Map of the study area.

These sands, sandy clays, silts, and subordinate, lensoid clay bands are assumed to be deposited during Quaternary interglacial marine transgressions [34].

They're an amalgamation of fluvial/tidal channel, tidal flats, and mangrove swamp deposits, according to [31]. The sands are micaceous and feldspathic, with a roughness ranging from sub-rounded to angular, and make ideal aquifers. However, because of fast horizontal and vertical facies changes, the depth of occurrence and thicknesses are erratic and may not be accurately predicted at specific sites, either at the study area or throughout the Sombreiro-Warri Deltaic Plain as shown in Fig. 1. According to [38] and [39], most water-bearing units within the study area are within the depth range of 45 to 212 m respectively, and exist within in semi-confined.

2. METHOD

Vertical Electrical Sounding (VES)

The earth's resistance was measured using the Abem Terrameter SAS 1000, a total of fifteen (15) VES was carried out using Schlumberger configuration with an electrode spacing of (AB) ranging from 2 to 200 m and potential electrode spacing (MN) ranging from 0.52 m to 7.00 m. To calculate apparent resistivity, the electrical resistances were multiplied by the relevant geometric factor (k) for each electrode separation. The smoothened curves were first qualitatively interpreted using master curves and standard charts [14, 40], after which they were processed using the computer modeling WINRESIST program. The plotted curves automatically disclosed the number of layers, thickness, depth, and average resistivity for each layer at various VES locations. The Global Positioning System (GPS) was utilized to obtain accurate coordinates and elevation information for each VES location.

$$\rho a = KR \qquad (1)$$

where ρa is an apparent resistivity and the earth resistance (R) is given as

$$R = \Delta V \,/\, I \qquad (2)$$

The geometric factor k is represented as as

$$K = \frac{\pi(AB)^2 - (MN)^2}{MN} \qquad (3)$$

Parameters of Secondary Aquifers

The sedimentary rock reflection coefficient (R_C) and resistivity contrast (F_C) were calculated using the method of [41]

$$R_c = \frac{\rho_n - \rho_{n-1}}{\rho_n + \rho_{n-1}} \qquad (4)$$

$$F_c = \frac{\rho_n}{\rho_{n-1}} \qquad (5)$$

where ρ_n is the layer resistivity of the *n*th layer and ρ_{n-1} is the layer resistivity overlying the nth layer

[42] was used to compute the Longitudinal Conductance (S). The total longitudinal conductance for 'n' layers is

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_i}{\rho_i} + \frac{h_2}{\rho_2} + \cdots + \frac{h_n}{\rho_n} \tag{6}$$

where h = thickness and ρ = resistivity.

Average transverse resistance was calculated using [43]

$$T = \sum_{i=1}^{n} h_i \rho_i = h_i \rho_i + h_2 \rho_2 + \cdots + h_n \rho_n \tag{7}$$

3. RESULTS AND DISCUSSION

The processed VES data was utilized to create curve type geoelectric layers as shown in Table 1.

Table 1. The research area generated representative findings for interpreted layer parameters.

VES	Latitude	Longitude	Layer resistivity (ohm-m)						Layer Depth (m)						Curve Type	No of layers
			ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	d1	d2	d3	d4	d5	d6		
VES/01	5^{0}41′55″N	5^{0}51′09″E	1131.7	518.7	3207.0	∞			2.5	9.8	∞				A	3
VES/02	5^{0}40′13″N	5^{0}53′44″E	614.8	2195.6	570.6	∞			1.8	7.5	24.4	∞			H	4
VES/03	5^{0}39′55″N	5^{0}53′46″E	542.2	889.4	2606.0	∞			1.1	8.7	∞				H	4
VES/04	5^{0}38′53″N	5^{0}51′07″E	1048.5	774.7	533.8	3157.7	∞		1.1	6.5	51.1	∞			H	4
VES/05	5^{0}40′01″N	5^{0}49′03″E	441.9	933.1	512.6	2757.2	∞		1.1	5.8	19.4	∞			H	4
VES/06	5^{0}38′05″N	5^{0}49′01″E	1721.8	767.2	1289.1	1693.2	∞		1.4	5.8	15.6	∞			HK	3
VES/07	5^{0}37′17″N	5^{0}52′29″E	1601.9	697.8	600.3	1382.0	∞		1.0	7.7	16.1	∞			H	4
VES/08	5^{0}37′12″N	5^{0}55′17″E	1799.7	857.2	4644.7	458.1	∞		0.9	3.4	9.5	∞			H	4
VES/09	5^{0}37′49″N	5^{0}54′06″E	149.0	250.5	165.7	2326.6	∞		1.0	4.8	11.8	∞			A	3
VES/10	5^{0}38′17″N	5^{0}56′28″E	1489.8	1920.9	574.2	3748.0	∞		1.0	8.7	16.2				H	3
VES/11	5^{0}41′52″N	5^{0}56′09″E	252.9	596.9	1652.8	∞			1.6	10.0	∞				A	3
VES/12	5^{0}40′49″N	5^{0}55′37″E	452.7	49.3	1764.5	∞	∞		1.4	5.2	∞				H	3

VES/13	5⁰42′02″N	5⁰55′26″E	136.7	796.9	135.9	1320.2	∞		1.2	3.0	13.4	∞			H	4
VES/14	5⁰41′45″N	5⁰56′58″E	836.7	1299.4	498.1	1172.1	∞		0.6	5.6	54.6	∞			H	4
VES/15	5⁰41′58″N	5⁰49′08″E	14.7	14.6	584.1	525.5	∞		1.3	3.5	12.5	∞			A	4

VES - vertical electrical sounding; ρ - layer resistivity; d - layer depth; h – layer thickness; m-meter

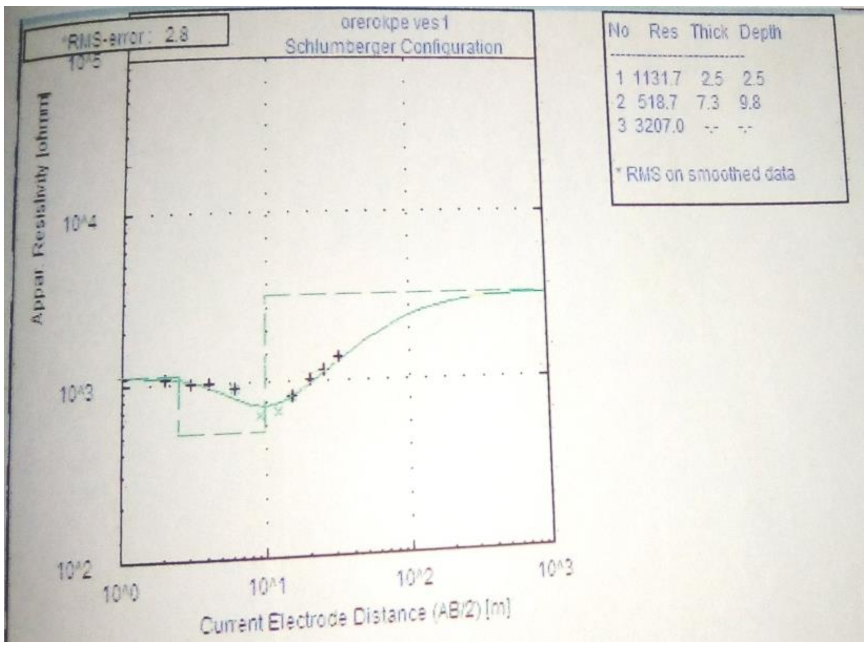

Fig. 2a. VES 1 curve type

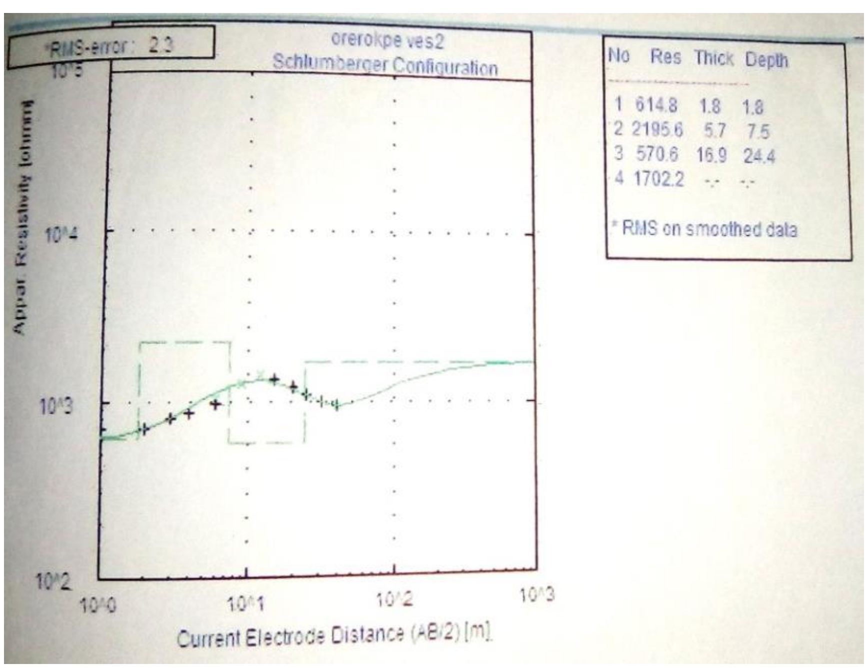

Fig. 2b. VES 2 curve type

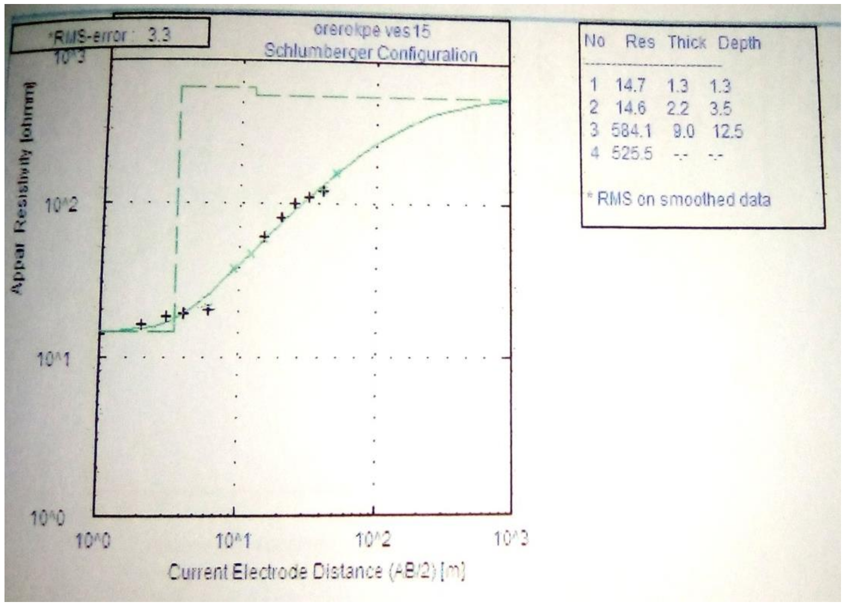

Fig. 2c. VES 2 curve type

Table 2. Results of parameters.

VES	Reflection Coefficient (Rc)	Resistivity contrast (Fc)	Average Transverse resistance (T)	Longitudinal Conductance (S)
VES-01	0.72	6.18	6615.76	0.03
VES-02	-0.58	0.25	22586.42	0.031
VES-03	0.491	2.93	7266.92	0.01
VES-04	-0.18	0.68	29144.21	0.08
VES-05	-0.29	0.54	11791.76	0.033
VES-06	0.25	1.68	18419.38	0.0013
VES-07	-0.07	0.86	7132.88	0.022
VES-08	0.68	5.41	32009.68	0.003
VES-09	-0.20	0.66	2234.6	0.062
VES-10	-0.53	0.29	20637.72	0.0176
VES-11	0.469	2.76	5358.91	0.019
VES-12	0.94	35.79	822.26	0.08

VES-13	-0.70	0.17	2963.22	0.08
VES-14	-0.44	0.38	31325.79	0.107
VES-15	0.951	0.57	5308.13	0.2534
Minimum	-0.70	0.17	822.26	0.0013
Maximum	0.951	35.79	32009.8	0.2534
Average	0.101	0.57	13908.8	0.063

Longitudinal unit conductance (S)

According to [42, 44, 45], earth materials act as a natural filter to percolating fluids; therefore their ability to retard and filter percolating ground surface polluting fluids is a measure of its protective capacity. In other words, geologic materials overlying an aquifer could act as a seal in preventing the fluid from percolating into it. The longitudinal conductance values are normally utilized in evaluating aquifer protective capacity. The aquifer protective capacity essentially assesses the natural ability of overburden units to filter or retard percolating fluid pollutants.

Table 2 shows that the value of S varies between 0.0013 and 0.2534, with an average of 0.063. Table 3 and Fig. 3 show that 13.3% of the aquifer (VES-14 and 15) has a moderate protective capacity rating, implying that the aquifer is moderately susceptible to surface contamination. While 86.7 % fell within the low protective rating capacity, hence considered prone to surface contamination. The permeability of the unconsolidated sands in the Sombreiro – Warri Plain could be the reason for this [39, 46].

Table 3. Modified aquifer protective capacity rating of the studied formation based on [44], longitudinal conductance scale from [42]

Longitudinal conductance (mhos)	Protective capacity rating	VES Locations	%
>10	Excellent		
5-10	Very Good		
0.7-4.9	Good		
0.2-0.69	Moderate	VES/14 and 15	13.3
0.1-0.19	Weak		
< 0.1	Poor	VES/ 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12 and 13	86.7

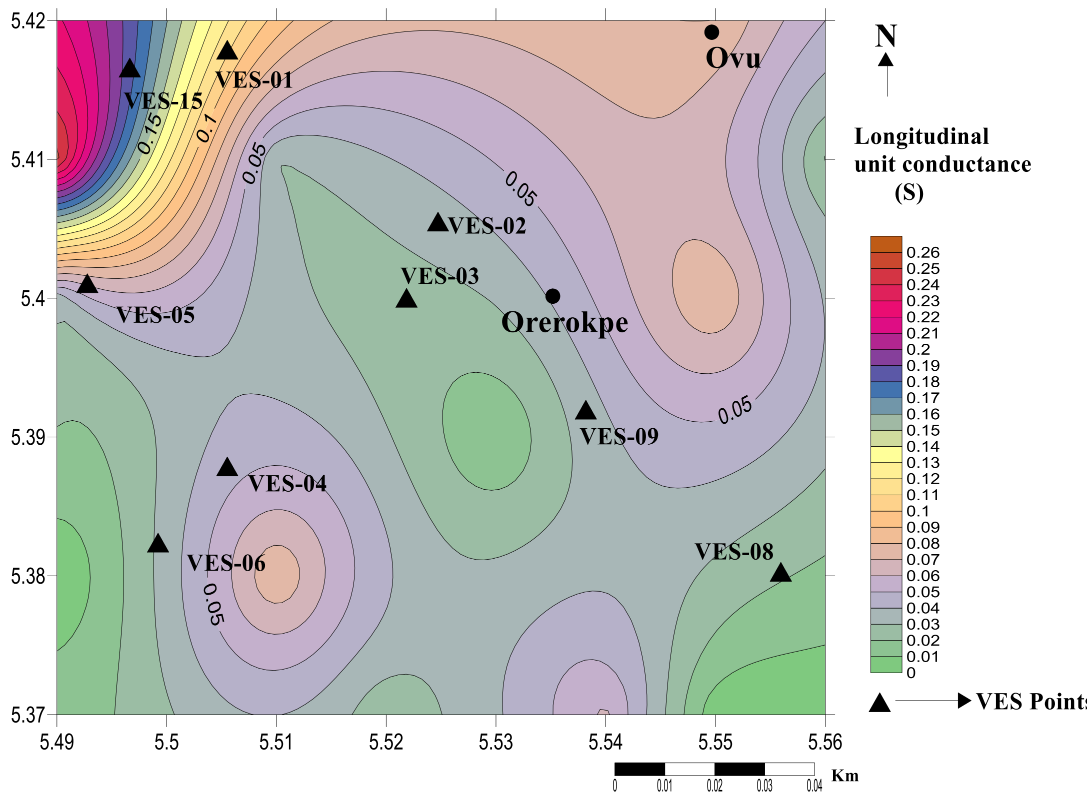

Fig. 3. Spatial distribution of longitudinal unit conductance within the study area.

Average transverse resistance (T)

High T values correspond to high transmissivity values and vice versa [42, 43, 47]. The high transmissivity values, however, suggest that the water-bearing units of the formation are highly permeable, porous, and freely allow fluid movement within the aquifer, which possibly may enhance the migration and circulation of contaminants in the groundwater/aquifer system, while low transmissivity is suggestive of a high percentage of impervious clay which retards fluid movement within the aquifer [7, 27, 48].

Similarly, T is a geoelectric parameter that is used to determine the groundwater potential area [49]. Table 2 shows that the T value for the research area ranges from 822.26 to 32009.8 Ω/m^2, with an average value of 13908.8 Ω/m^2. Figure 4 shows the distribution of T in the research area, with the central section, SW, and SE indicating areas with good groundwater potential. The high T values obtained from Table 3, back up the proof that 86.7% of water-bearing units are considered prone to surface contamination since high T values enhance fluid percolation from the surface into the ground.

The reflection coefficient (Rc) is a measurement of the difference in density between layers of a formation in a given area. It may also reflect the degree of aquifer fracture [50]. Water potentials are strong in areas with low reflection coefficient values.

As shown in Table 2 and Fig. 5, the value of Rc in this study spans from -0.70 to 0.95, with an average value of 0.101, indicating that the study area showed a good prospect of groundwater potential.

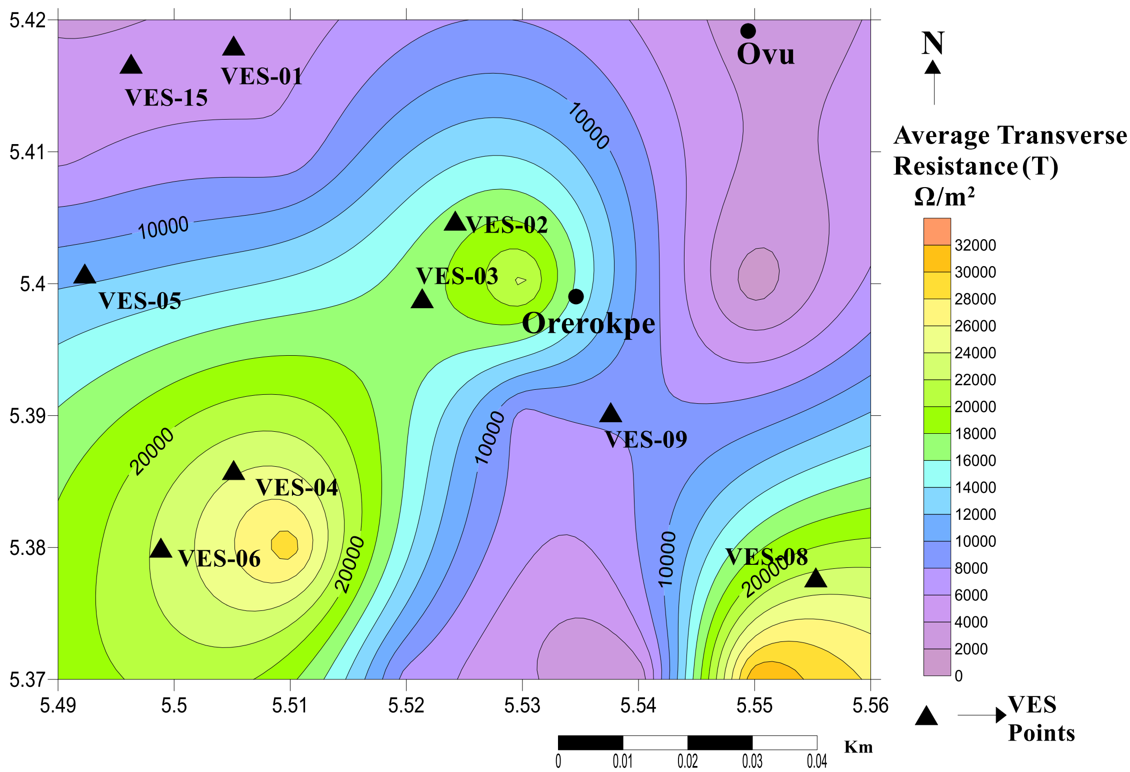

Fig. 4. Spatial distribution of average transverse resistance within the study area.

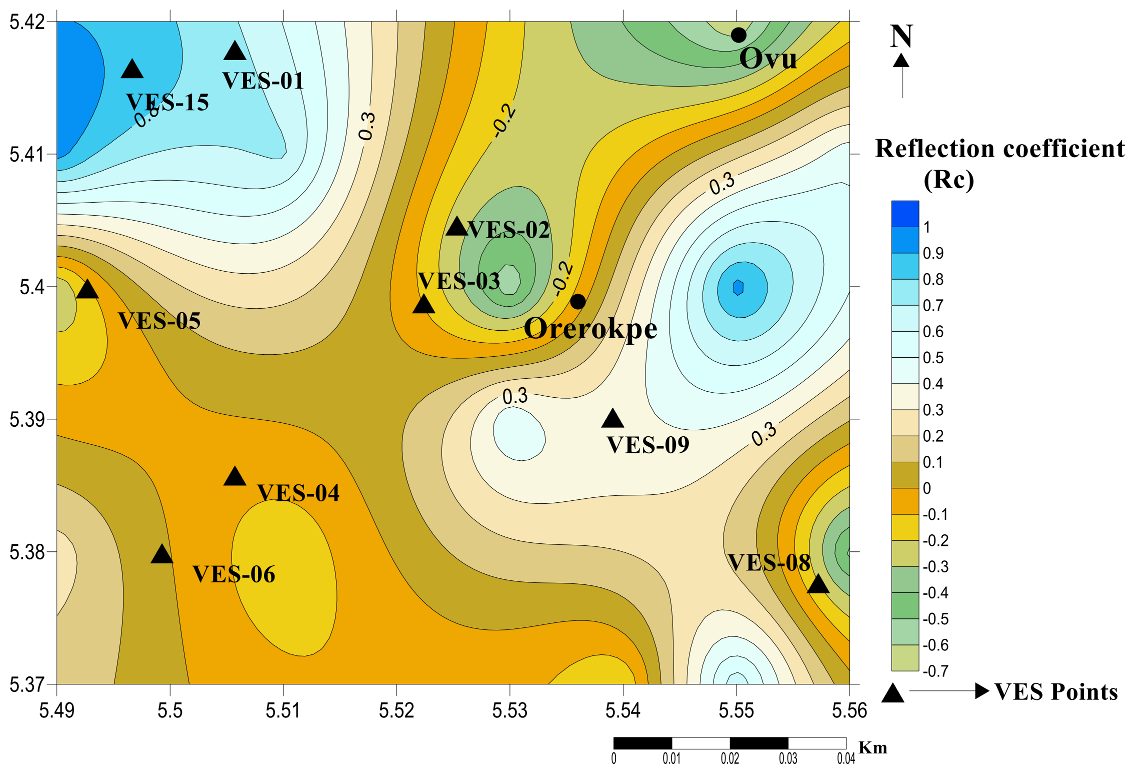

Fig. 5. Spatial distribution of reflection coefficient (Rc) within the study area.

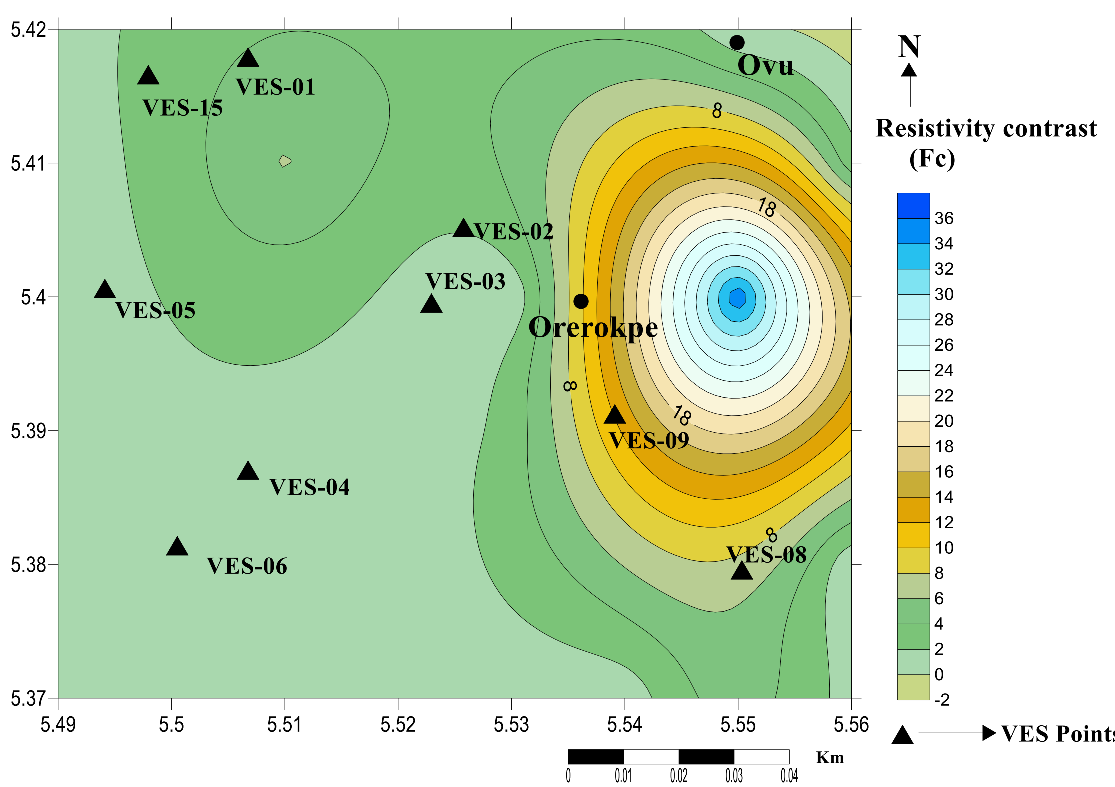

Fig. 6. Spatial distribution of Resistivity Contrast (Fc) within the study area.

Similarly, resistivity contrast (Fc) provides information on the area of water-bearing potential; low resistivity contrast values indicate high groundwater potentials (Adenihim et al., 2013).

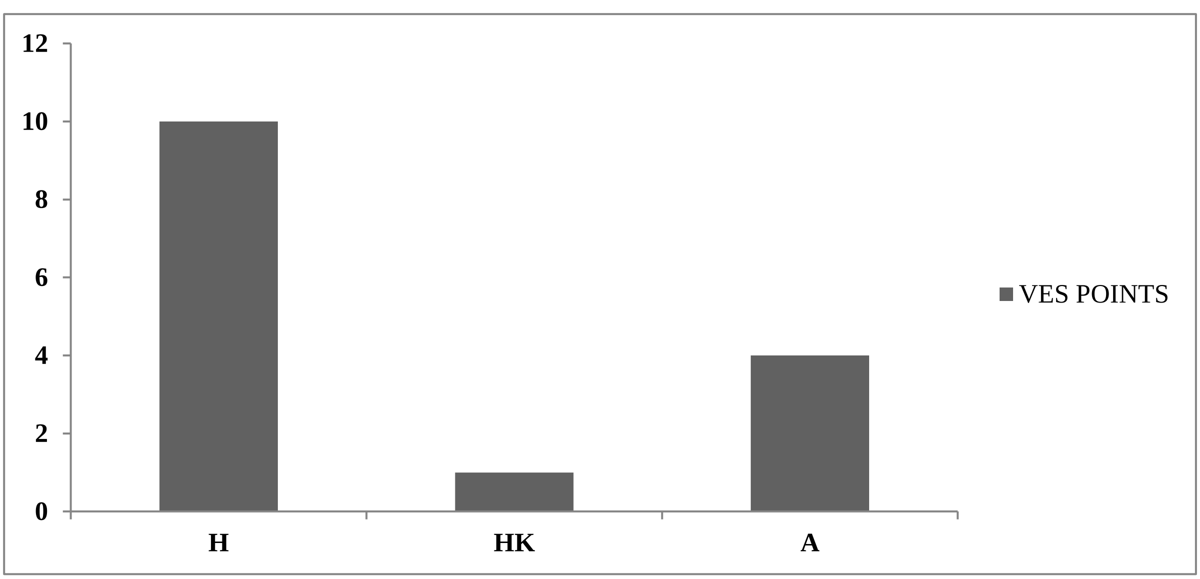

Fig. 7. Plot of VES points against Curve Type

As indicated in Table 2 and Fig. 6, the resistivity contrast values in this study vary from 0.17 to 35.79, with an average value of 0.57, indicating that the study area showed a good trace of groundwater potential. This is in line with the findings of [46], who concluded that the shallow aquifer beneath Orerokpe has a moderate to high output potential.

The H, HK, and A curves, as shown in Figs. 2a, 2b, and 2c and 7 define the qualitative interpretation findings of computer-modeled data curves. The prevalent curve in the study area was discovered to be curved H. The variation in curve type can be related to the variability of the geology of the research area, according to [4, 7]. The previous scholar that worked within the Niger Delta basin suggested the H curve is the dominant curve that is found within the basin, although to some instinct it combines with other curves types such as A, K, and Q. [16, 38, 46, 51-53].

4. CONCLUSION

This paper employed the electrical resistivity sounding method to assess the study area's aquifer vulnerability and groundwater potential. The VES findings revealed that geoelectric layers range from three to four layers, with H curves being the most prevalent curve type in the study area. The difference in curve type is related to lithological differences beneath the earth's surface. T values range from 822.26 to 32009.8 Ω/m^2, with high T values indicating that the study area has a good prospect for groundwater exploration. Based on the estimated values obtained from Rc and Fc, the study area appears to have groundwater potential that can be exploited. Results obtained from longitudinal conductance, the research area is classified as low to moderate in terms of surface contamination protection. It was observed that large percentages of water-bearing units are considered prone to contamination.

Recommendations

Based on the findings obtained from the study, the following are recommended:

i. The inhabitants of the study area should be educated on the danger of their actions in respect to the way sewage is disposed of and its impact on groundwater.
ii. Motorized or manual borehole should be drilled far away from septic tanks
iii. Human activities that can lead to oil spillage should be reduced to the barest minimum, in order to reduce surface to groundwater contamination.

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