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Original Article

Characterization of Sub-Soil Corrosion Potential Using Electrical Resistivity Method across the Niger Delta University Campus, Bayelsa State, Southern Nigeria

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Abstract - *Investigation of sub-soil corrosion potential was done on the Niger Delta University campus, Bayelsa State of Nigeria using the Vertical Electrical Sounding method. Six (6) VES stations spanning the area of interest were occupied, and data was acquired using the Schlumberger array configuration. The acquired VES data was modelled using the IP2WIN inversion software to generate geo-electric models. Geo-electric parameters were obtained from the models for the individual layers delineated by the VES profile. The geo-electric model from the 6 (six) VES stations investigated revealed 6 (six) distinct geo-electric layers, all with similar layer resistivity trends of $\rho1 > \rho2 > \rho3 < \rho4 > \rho5 < \rho6$ characteristic of the QHKH curve type across the area. Geologic interpretation based on the resistivity values obtained from the geo-electric model was done to characterize the various materials delineated. Classification of soil corrosiveness in terms of resistivity was then carried out to show the corrosion potential of each geologic layer. Results revealed a topsoil having negligible corrosion potential across the study area, and the second layer was interpreted as having a low corrosion potential in VES 1,2,3,4,6 and a high corrosion potential in VES station 5. The third layer had high to very high corrosion potential across all VES stations. The fourth and sixth layers had negligible corrosion potential across the area investigated, while the fifth layer had a low corrosion potential across the area under study. Results obtained show that geologic units are fairly laterally continuous across the area, although they vary in thicknesses due to differential compaction.*

Keywords - *Amassoma, Corrosiveness, Electrical, Resistivity, Sub-soil Characterization.*

1. Introduction

The electrical resistivity method in geophysics investigates the ability of earth materials to resist or conduct electrical current through it; as such, the electrical method can be used to characterize the resistivity or conductivity of earth materials [1, 2]. The electrical resistivity of a geologic material depends primarily on the salt concentration of the pore fluid, sediment particle size, porosity and, in some cases, permeability of the material [3]. It is an active source method that has its basis in Ohms law, which relates Resistance, Current Flow and Potential Difference in a material. The method involves artificially introducing an electrical current into the ground through a pair of electrodes, usually referred to as current electrodes, and measuring the potential difference between the pair by two other electrode pairs, known as potential electrodes, in the vicinity of the current flow [4]. In principle, the electrical resistivity method provides information on the earth's surface about variations of electrical properties of the sub-soil materials as the spacing between the current and potential electrodes is progressively increased about a fixed center or moved along a profile path. The internal distribution of the physical characteristics of the underlying rock materials, thus, has an impact on the measurements of resistance observed on the earth's surface during field investigations [5]. In practically all geological terrains, the characterization of subsurface geology has been effectively accomplished through the use of the electrical resistivity method owing to variations in the resistivity properties of various earth materials [6-8].

Corrosion is a progressive chemical attack and degradation that transforms metallic materials into oxides, salts, or compounds [9-11]. A very important factor required for corrosion to occur is moisture content; it is the amount of water or fluid a geologic material can hold, and it has a direct relationship to the conductivity of a geologic material. An increase in the conductivity of earth material would, thus, mean an increase in the potential for the material to be prone to corrosion. Since there is a known inverse relationship between conductivity and resistivity, an inverse relationship between soil corrosiveness and resistivity would thus exist.

This implies that as the resistivity of earth material decreases, the corrosiveness of the earth material increases [12].

Over the years, soil resistivity estimation has become a very effective tool for determining the corrosion potential of earth materials [13-15]. Electrical resistivity measurements are particularly useful for characterizing soil properties because they are non-invasive, cost-effective, and fast compared to other geophysical methods. Corrosion is a major problem in developing communities of the Niger Delta, and this is made worse by the high saline concentration of shallow pore fluids in geologic materials in the Niger Delta region, which is home to a vast network of metallic infrastructures which includes utilities and hydrocarbon resource transport pipelines.

A significant number of metallic infrastructures in contact with the earth within the Niger Delta University campus, such as buildings, water distribution pipes and water tank stands, have been observed to be undergoing extensive corrosion. This not only compromises the structural integrity of these assets but also poses potential health, safety, and environmental hazards that will have massive financial implications for the institution as time progresses. As such, this study aims to assess soil corrosiveness across the Niger Delta University campus using the electrical resistivity method, which will serve as a yardstick during developmental planning within the institution.

2. Materials and Methods

2.1. Geology of Study Area

The area under investigation is the Niger Delta University campus, which is located in the Amassoma community in Southern Ijaw Local Government Area of Bayelsa State in Southern Nigeria [Figure 1]. It lies within Latitudes 4'58"30°N 4'59"30°N and Longitudes 6'6"0° E - 6'6"50° E. The study area is the low-lying coastal Niger Delta region. It is accessible by a major road linking the community to the capital city of Yenagoa and a series of other minor road networks linking surrounding communities. A network drains it of numerous swamps and creeks, all emptying into the Amassoma River, which is a major tributary of the River Nun, one of the two major arms of the River Niger.

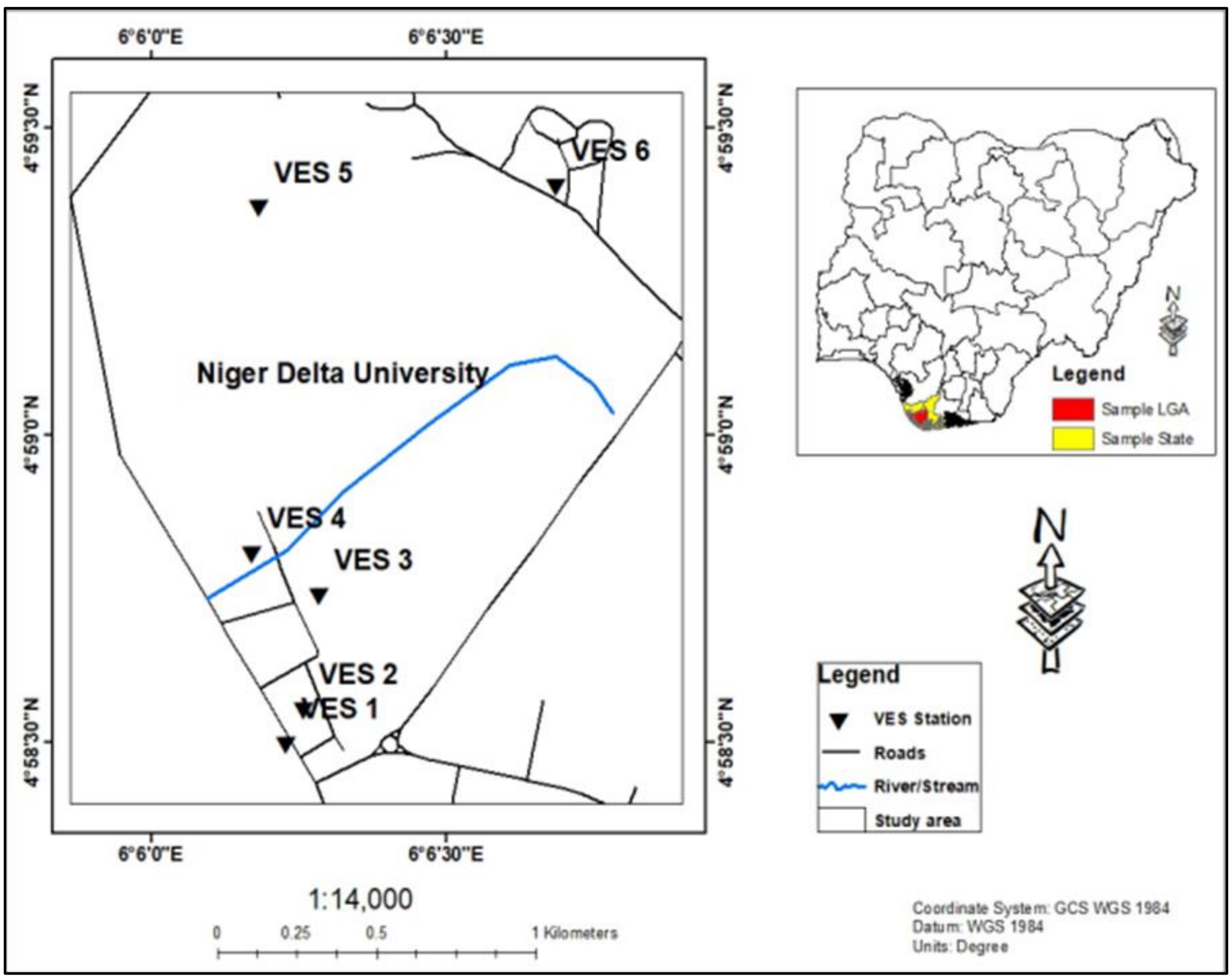

Fig. 1 Location map of study area showing VES stations

The Niger Delta basin is a sedimentary basin with an estimated area of about 70 000 sq km, and it has an average sedimentary thickness of 12 km at its thickest parts [16,17]. The basin is bound by the Benin flank on the Northwestern axis; to the east, it is bordered by the Calabar Flank and is bound by the Atlantic Ocean to the south [18].

Sediments of the Niger Delta basin take their source from a failed arm of a triple junction "RRR" fault system, which occurred when the South American tectonic plate and the African plate pulled apart due to centrifugal forces in the mantle in the Late Jurrasic, thus, opening up the African plate for the Atlantic Ocean to transgress into the continent [19,20]. There are three stratigraphic units in the Niger Delta basin; from the base, we have the Akata Formation, which is characterized by a marine depositional environment comprising dark grey shales.

Above the Akata, we have the Agbada Formation, comprised of a sequence of sandstones and shales associated with the transitional or deltaic depositional environment; the youngest stratigraphic unit lying above the Agbada Formation is the Benin Formation, which is comprised chiefly of sandstones with some intercalations of shales characteristic of a continental depositional environment [21-25].

2.2. Study Design

The principle of the Electrical Resistivity method in geophysics is hinged on how various types of earth materials respond to the flow of electric current through them. It involves introducing an electrical current into the ground via current electrodes. Using two potential electrodes, we record the resultant potential difference between them, giving us a way to measure the electrical impedance of the subsurface geology. The apparent resistivity measured is then a function of the measured impedance and the geometry of the electrode array. The apparent resistivity measured is then a function of the measured impedance and the geometry of the electrode array. An extensive theoretical background of the Electrical Resistivity method can be found in [1,6,26,27].

In this study, a total of six (6) Vertical Electrical Soundings (VES) stations were occupied across the area under study using the ABEM SAS 3000, a self-averaging Digital Resistivity Meter. The Schlumberger configuration was employed in this study because it is fast and less likely to be influenced by lateral sub-surface variations. The field procedure was carried out by introducing electrical current to the ground through two current 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 centre point of the electrode array remained fixed, but the spacing of the current and potential electrodes was increased to match the sounding programme for sampling varying depth levels. A product of the resistance measured and a Geometric Factor, which was determined by the electrode configuration in the field, gave the Apparent Resistivity.

The computed Apparent Resistivity data were inverted using a computer-aided 1-D inversion modelling software known as IP2Win to generate geo-electric profiles and parameters for each VES point sampled. Models were constrained with secondary lithological information obtained from boreholes in the vicinity of the study area and literature.

The positions and surface elevations of the investigated points were also recorded during the survey with a GPS receiver. The geo-electric parameters obtained from the 6 VES stations were then subjected to interpretation and classification on the basis of lithology and corrosiveness as proposed by [28] and [29], as presented in Tables 1 and 2 below.

3. Results and Discussion

Results of the modeled curve type and layer parameters generated from obtained field data of the Six (6) VES points investigated in this study are presented in Figure 2 and Tables 3 - 8 below.

Table 1. Classification of soil type in terms of resistivity [28]

APPARENT RESISTIVITY	LITHOLOGY
<100	Clay
100-350	Sandy Clay
351-750	Clayey Sand
>750	Sand/laterite/bedrock

Table 2. Classification of soil corrosiveness in terms of resistivity [29]

APPARENT RESISTIVITY	CORROSIVE PROBABILITY
>200	Negligible
101 – 200	Low
50 – 100	High
<50	Very high

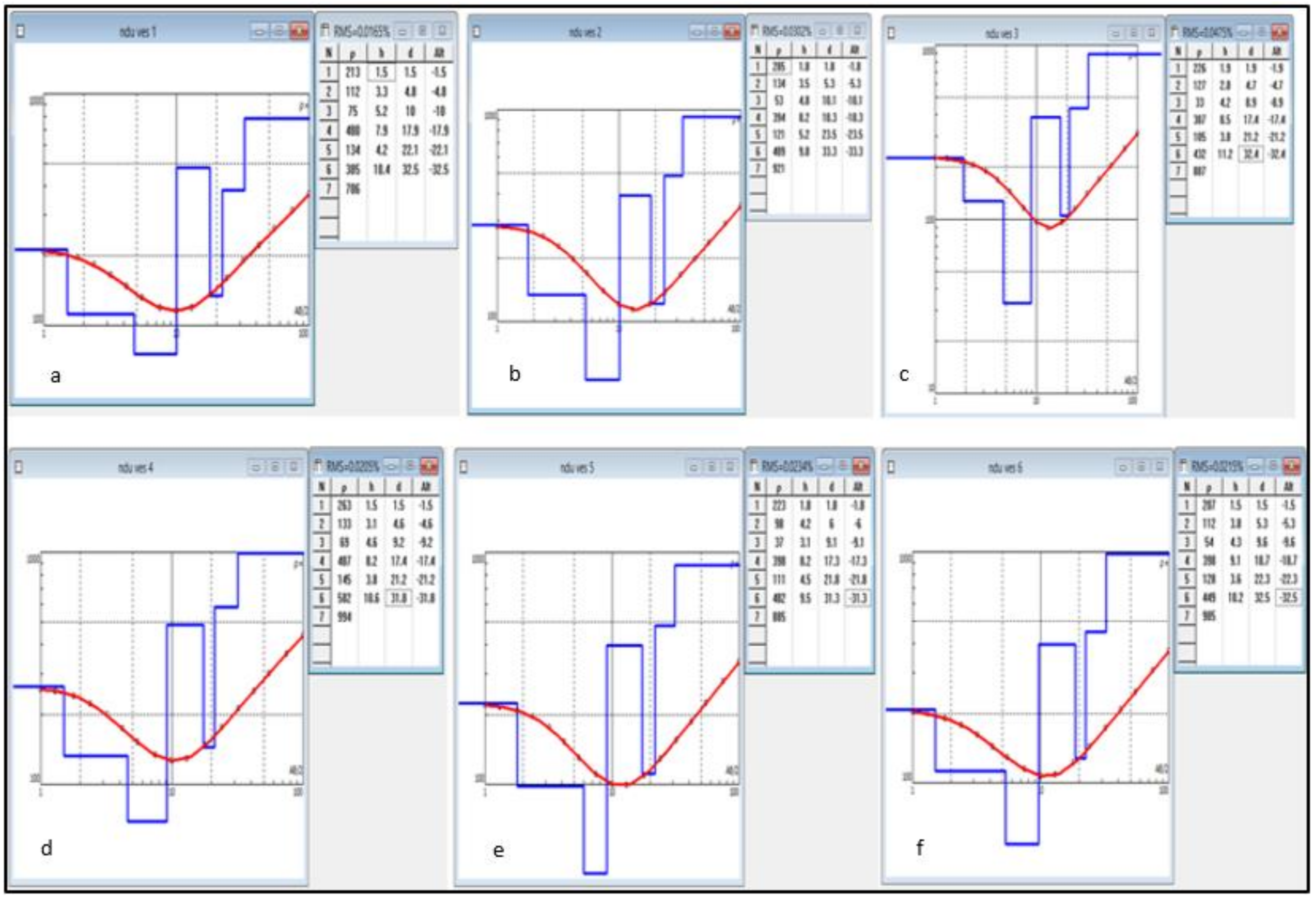

Fig. 2 (a – f) Geo-electric curves and parameters obtained from models of VES 1 - 6 investigated

3.1. VES 1

The result of this VES shows a total of six geo-electric layers with a resistivity trend of ρ1> ρ2> ρ3< ρ4> ρ5< ρ6 representative of a QHKH type, as presented in Figure 2a and Table 3.

Interpretation of the geo-electric section shows a resistive top soil to a thickness of 1.5 m with a resistivity of 213 Ωm. This layer has negligible corrosivity, implying that the topsoil is suitable for the installation of metallic material. The second layer is composed of silty clay with a resistivity of 112 Ωm. It has a thickness of 3.3 m and extends to a depth of 4.8 m (15 ft.); this layer has a low corrosiveness and, therefore, is partially suitable for the installation of metallic materials. The third layer comprises clay with a resistivity of 75 Ωm thickness of 5.2 m extending to a depth of 10 m. This layer is highly corrosive and is not suitable for the installation of metallic material. The fourth layer is composed of sandstone, with a resistivity of 400 Ωm and a thickness of 7.9 m extending to a depth of 17.9 m; this layer has negligible corrosivity and therefore is suitable for installation of metallic material. The fifth layer is composed of sandy clay with a resistivity of 134 Ωm, a thickness of 4.2 m extending to a depth of 22.1 m. This layer has a low corrosivity effect and is, therefore, partially suitable for the installation of metallic material. The sixth layer is composed of sandstone with a resistivity of 305 Ωm thickness of 10.4 m extending to a depth of 32.5 m. This layer has a negligible corrosivity effect and, therefore, is suitable for the installation of metallic material.

Table 3. Geo-electric layer parameters of VES station 1 model

VES NO.	LAYERS	RESISTIVITY (Ωm)	THICKNESS(m)	DEPTH(m)	CURVE-TYPE	LITHOLOGY	CORROSIVITY
	1	213	1.5	1.5		Topsoil	Negligible
	2	112	3.3	4.8		Sandy clay	Low
1	3	75	5.2	10	QHKH	Clay	High
	4	400	7.9	17.9		Sandstone	Negligible
	5	134	4.2	22.1		Sandy clay	Low
	6	305	10.4	32.5		Sandstone	Negligible

Table 4. Geo-electric layer parameters of VES station 2 model

VES NO.	LAYERS	RESISTIVITY (Ωm)	THICKNESS(m)	DEPTH(m)	CURVE-TYPE	LITHOLOGY	CORROSIVITY
2	1	285	1.8	1.8	QHKH	Topsoil	Negligible
	2	134	3.5	5.3		Sandy clay	Low
	3	53	4.8	10.1		Clay	High
	4	394	8.2	18.3		Sandstone	Negligible
	5	121	5.2	23.5		Sandy clay	Low
	6	489	9.8	33.3		Sandstone	Negligible

3.2. VES 2

This VES profile presented in Table 4 shows a total of six geo-electric layers. The curve at this station shows a trend in resistivity of ρ1> ρ2> ρ3< ρ4> ρ5< ρ6 associated with the QHKH geo-electric curve type shown in Figure 2b.

The top soil has a thickness of 1.8 m with a resistivity value of 285 Ωm, typical of clayey sand. The corrosiveness of this layer is negligible, so it is suitable for metallic installations. The second layer is composed of sandy clay with a resistivity of 134 Ωm. It has a thickness of 3.5 m and extends to a depth of 5.3 m. This layer is low in corrosiveness and, therefore, would not readily cause corrosion in metallic installations. The third layer comprises clay with a resistivity of 53 Ωm, a thickness of 4.8 m extending to a depth of 10.1 m. This layer is highly corrosive and would cause wear of metallic installations. The fourth layer is composed of sandstone, with a resistivity of 394 Ωm. It has a thickness of 8.2 m, extending to a depth of 18.3 m. This layer has negligible corrosiveness, so it is suitable for installations with metallic materials. The fifth layer is composed of sandy clay with a resistivity of 121 Ωm. It is 5.2 m thick, extending to a depth of 23.5 m. This layer is low in corrosiveness, and therefore, it is partially suitable for the installation of metallic material. The sixth layer is composed of sandstone with a resistivity of 489 Ωm. It has a thickness of 9.8 m, extending to a depth of 33.3 m. This layer has negligible corrosiveness. Thus, metallic materials used are not likely to undergo corrosion.

3.3. VES 3

A total of seven geo-electric layers was delineated by this VES profile with resistivity ranging from 33 Ωm to 432 Ωm, as presented in Table 5. A resistivity tends across the layers in the form of ρ1> ρ2> ρ3< ρ4> ρ5< ρ6 from the top to the bottom, which is a representation of the QHKH curve type shown in Figure 2c.

Table 5. Geo-electric layer parameters of VES station 3 model

VES NO.	LAYERS	RESISTIVITY (Ωm)	THICKNESS(m)	DEPTH(m)	CURVE-TYPE	LITHOLOGY	CORROSIVITY
3	1	226	1.9	1.9	QHKH	Topsoil	Negligible
	2	127	2.8	4.7		Sandy clay	Low
	3	33	4.2	8.9		Clay	Very high
	4	387	8.5	17.4		Sandstone	Negligible
	5	105	3.8	21.2		Sandy clay	Low
	6	432	11.2	32.4		Sandstone	Negligible

The top soil was resistive with a resistivity of 226 Ωm a thickness of 1.9 m. This layer was characterized as having negligible corrosiveness and is suitable for metallic infrastructure. The second layer, with a resistivity of 127 Ωm associated with sandy clay, has a thickness of 2.8 m extending to a depth of 4.7 m. This layer is characterized as a low corrosive layer partially capable of causing wear to metallic materials.

The third layer comprises clay with a resistivity of 33 Ωm and thickness of 4.2 m, extending to a depth of 8.9 m. This layer has a very high corrosion potential and, as such, would cause corrosion of metallic infrastructure.

The fourth layer has a resistivity of 387 Ωm associated with sandstones. It has a thickness of 8.5 m, extending to a depth of 17.4 m. Sandstones have negligible corrosivity and are, therefore, suitable for the installation of metallic material. The fifth layer is composed of sandy clay with a resistivity of 105 Ωm thickness of 3.8 m extending to a depth of 21.2 m.

This layer has a low corrosive effect, although it would eventually cause corrosion in the long term. The sixth layer has a resistivity of 432 Ωm associated with sandstones. It has a thickness of 11.2 m, going to a depth of 32.4. This layer has a negligible corrosive effect and is therefore recommended for the metallic infrastructure.

3.4. VES 4

This VES profile revealed a total of six geo-electric layers, as presented in Table 6. The observed resistivity trend from the top layer was ρ1> ρ2> ρ3< ρ4> ρ5< ρ6, which is associated with the QHKH curve type shown in Figure 2c.

Table 6. Geo-electric layer parameters of VES station 4 model

VES NO.	LAYERS	RESISTIVITY (Ωm)	THICKNESS(m)	DEPTH(m)	CURVE-TYPE	LITHOLOGY	CORROSIVITY
4	1	263	1.5	1.5	QHKH	Top soil	Negligible
	2	133	3.1	4.6		Sandy clay	Low
	3	69	4.6	9.2		Clay	High
	4	487	8.2	17.4		Sandstone	Negligible
	5	145	3.8	21.2		Sandy clay	Low
	6	582	10.6	31.8		Sandstone	Negligible

The top soil with a resistivity of 268 Ωm and thickness of 1.5 m was delineated. This layer is of negligible corrosivity and, therefore, is suitable for installation using metallic material. The second layer had a resistivity of 133 Ωm associated with sandy clay. It has a thickness of 3.1 m and extends to a depth of 4.6 m. This layer has low corrosive potential; thus, it may be recommended for temporary metallic installations. The third layer had a resistivity of 69 Ωm, characteristic of clays, with a thickness of 4.6 m extending to a depth of 9.2 m. Clays are associated with a high corrosion potential, so they are unsuitable for installations using metallic materials. The fourth layer had a resistivity of 487 Ωm associated with sandstones. It has a thickness of 8.2 m, extending to a depth of 17.4 m. This layer has negligible corrosiveness and, therefore, is suitable for the installation of metallic infrastructure. The fifth layer delineated has a resistivity of 145 Ωm, characterized as sandy clay. It has a thickness of 3.8 m, extending to a depth of 21.2 m. This layer has a low corrosive potential and is, therefore, partially suitable for the installation of metallic infrastructure. The sixth layer has a resistivity of 582 Ωm. It is composed of sandstone. This layer has a thickness of 10.6m, extending to a depth of 31.8 m. It has negligible corrosion potential and is, therefore, suitable for installations using metallic materials.

3.5. VES 5

This VES profile presented in Table 7 cuts across six geo-electric layers with a resistivity trend of $\rho 1 > \rho 2 > \rho 3 < \rho 4 > \rho 5 < \rho 6$ characteristic of the QHKH curve type shown in Figure 2d.

Table 7. Geo-electric layer parameters of VES station 5 model

VES NO.	LAYERS	RESISTIVITY (Ωm)	THICKNESS(m)	DEPTH(m)	CURVE-TYPE	LITHOLOGY	CORROSIVITY
5	1	223	1.8	1.8	QHKH	Top soil	Negligible
	2	98	4.2	6		Clay	High
	3	37	3.1	9.1		Clay	Very high
	4	398	8.2	17.3		Sandstone	Negligible
	5	111	4.5	21.8		Sandy clay	Low
	6	482	9.5	31.3		Sandstone	Negligible

The geo-electric parameters shows a resistive topsoil with a resistivity of 223 Ωm and a thickness of 1.8 m. This layer has negligible corrosiveness potential and is thus suitable for installations using metallic material. The second layer has a resistivity of 98 Ωm associated with clays. It has a thickness of 4.2 m and extends to a depth of 6 m.

Clays have a high corrosiveness potential, as such, this layer is not suitable for installation or infrastructures using metallic materials because they would gradually wear out due to corrosion. The third layer has a very low resistivity of 37 Ωm, characteristic of pure clays. It is 3.1 m thick, extending to a depth of 9.1 m.

This layer has a very high potential to cause corrosion. It is, therefore, not suitable for installations using metallic materials. The fourth layer has a resistivity of 398 Ωm associated with sandstone; it has a thickness of 8.2 m extending to a depth of 17.3 m. Sandstones are generally known to have negligible corrosivity potential; thus, they are suitable for installations or infrastructure using metallic materials. The fifth layer delineated by this profile has a resistivity of 111, Ωm is characteristic of sandy clay; it has a thickness of 4.5 m extending to a depth of 21.8 m.

This layer has a low corrosivity potential and, therefore, is partially suitable for the installation of metallic material. The sixth layer has a resistivity of 482 Ωm associated with sandstone and a thickness of 9.5 m extending to a depth of 31.3 m. This layer is negligibly corrosive and, therefore, is suitable for installations using metal-based materials.

3.6. VES 6

This geo-electric profile delineated a total of six layers, as presented in Table 8. The resistivity trend of $\rho 1 > \rho 2 > \rho 3 < \rho 4 > \rho 5 < \rho 6$ associated with the QHKH curve type was observed as shown in Figure 2e.

Table 8. Geo-electric layer parameters of VES station 6 model

VES NO.	LAYERS	RESISTIVITY (Ωm)	THICKNESS(m)	DEPTH(m)	CURVE-TYPE	LITHOLOGY	CORROSIVITY
6	1	207	1.5	1.5	QHKH	Top soil	Negligible
	2	112	3.8	5.3		Sandy clay	Low
	3	54	4.3	9.6		Clay	High
	4	398	9.1	18.7		Sandstone	Negligible
	5	128	3.6	22.3		Sandy clay	Low
	6	449	10.2	32.5		Sandstone	Negligible

The topsoil has a resistivity of 207 Ωm with a thickness of 1.5 m; this layer is of negligible corrosive potential. It is suitable for installations using metallic-based materials. The second layer has a resistivity of 112 Ωm, consistent with sandy clay; it has a thickness of 3.8 m and extends to a depth of 5.3 m. Sandy clay has low corrosiveness potential and, therefore, is partially suitable for the installation of metal-based materials. The third layer has a resistivity of 54 Ωm associated with clays, it has a thickness of 4.3 m extending to a depth of 9.6 m. Clays are known to be highly corrosive, and they cause wear and tear on metal-based materials. The fourth layer has a resistivity of 398 Ωm, consistent with sandstone. It has a thickness of 9.1 m, extending to a depth of 18.7 m. This layer has negligibly corrosion potential. The fifth layer has a resistivity of 128 Ωm associated with sandy clay. It is 3.6 m thick, extending to a depth of 22.3 m. This layer has low corrosion potential, so it is partially suitable for installations using metal-based materials. The sixth layer has a resistivity of 449 Ωm, consistent with sandstone. It has a thickness of 10.2 m, which goes to a depth of 32.5 m. Sandstone has negligible corrosiveness potential; therefore, it is suitable for installations or infrastructure using metal-based materials.

4. Conclusion

The Vertical Electrical Sounding method was successfully employed to investigate sub-soil corrosion potential in the Niger Delta University campus. Six VES stations spanning the area of interest were occupied, and data was acquired using the Schlumberger array configuration. Results from the geo-electric models obtained from the six VES stations occupied revealed six distinct geo-electric layers, all with a similar layer resistivity trend of $\rho1> \rho2> \rho3< \rho4> \rho5< \rho6$ characteristic of the QHKH curve type. Results revealed that the top soil had negligible corrosion potential across the study area, and the second layer was interpreted as having a low corrosion potential in VES 1,2,3,4,6 and a high corrosion potential in VES station 5.

The third layer had high to very high corrosion potential across all VES stations. The fourth and sixth layers both had negligible corrosion potential across the area investigated, while the fifth layer had a low corrosion potential across the area under study. From the results obtained, it can be concluded that the geologic units are fairly laterally continuous across the area, although they vary in thickness due to differential compaction. During the planning and design phase of construction, the corrosion potential of the individual geologic layers must be taken into account in determining the type of material to be used to forestall economic wastage and environmental hazards that may arise due to the corrosion of metal-based construction materials and subsequent failure of infrastructures across the campus.

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