Geoelectric and Geochemical Assessment of Sub-Soil Corrosivity and Competence for Civil Infrastructures at Utue-Ogume, Delta State, Nigeria

Thompson Chinedum Irunkwor

thompson.irunkwor@unidel.edu.ng

University of Delta, Agbor, Delta State, Nigeria https://orcid.org/0000-0002-8858-7082

Collins Ogorm Molua

University of Delta, Agbor, Delta State, Nigeria

Chuks Okobia

University of Delta, Agbor, Delta State, Nigeria

Dandy Dumbiri Nmorsi

University of Delta, Agbor, Delta State, Nigeria

Nkonyeasua Abanjo

University of Delta, Agbor, Delta State, Nigeria

Monday Edobor

University of Delta, Agbor, Delta State, Nigeria

Chinyere Ngozika Eze

University of Nigeria, Nsukka

Research Article

Keywords: Soil Competence, Soil Corrosivity, Geochemical Parameters, Vertical Electrical Sounding

Posted Date: December 5th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-5572060/v1

Additional Declarations: The authors declare potential competing interests as follows: The authors declare that they have no competing interests with respect to the research authorship and/or publication of this article.

Abstract

The corrosive nature of sub-soil to aggressive attack on buried metallic pipes and concrete, and its competence to withstand overburden stress from civil engineering infrastructures at Otue-Ogume, an oil producing community in Delta State was here assessed with geo-electric and geochemical methods. Nine Vertical Electrical Sounding (VES) was carried out with Mini-Res Resistivity Meter using the Schlumberger array. Soil samples were also collected with hand auger at varying depths of 0-1m, 1-2m and 2-3m at each of the nine VES stations for geochemical analysis. The VES data was processed with IPI2WIN software and delineated six to eight geo-electric layers of lateritic topsoil, clayey sand, sandy clay, Fine-medium grained sand, medium-coarse grained sand, coarse grained sand, sandy clay and clay. The soil resistivity, thickness and depth ranged respectively from 53.04Ωm to 4535Ωm, 0.6m to 79.2m and 0.6m to 134.8m. The geochemical parameters (pH, Cl^-, and So_4^{2-}) were lower than the permissible standards, although the Cl^- and $So4^{2-}$ concentration could be potentially high with time due to seasonal fluctuations which can trigger the corrosion dynamics of the soil. The subsurface soil layers were characterized as essentially non-corrosive, moderately corrosive and mildly corrosive to concrete and metallic pipes. The subsurface soils were also characterized as highly competent, competent and moderately competent confirming that it can withstand erecting of massive buildings or civil engineering infrastructures to depth of 2m. Treatment of the moderately and mildly corrosive sub-soil layers is strongly advised before crude oil and gas transmission pipes is buried to that depth.

1 Introduction

Soil materials has its values and importance in the construction, mining and oil and gas industries as it acts as foundation for most civil engineering construction works as well as bed for laying pipelines for transportation of water from source to households, and for conveying processed crude oil and gas from production source to distribution terminals. For safety and security purpose, the United States Department of Transportation’s Pipeline and Hazardous Materials Safety Administration (USPHMSA) and the American Petroleum Institute (API) Standard 1104 recommended burying oil and gas pipelines at a minimum depth of 1.0m to protect it from external threats such as seismic activities, agricultural work and construction activities [1, 2]. Water pipelines and foundation footings for civil engineering structures is also recommended to be layed to a minimum depth of 1.0m [3–6]. However, the most worrisome issue about buried pipelines and other civil engineering buried metal works is the lifespan and their integrity to withstand the aggressive corrosive attack that is activated by soil chemical composition which eventually result in pipelines rupture and soil strength weakness/failure. This gives credence to the findings of [7–9] that corrosion is one of the causes of ruptures in pipelines with average occurrence time of 0.2 years and the most common type of damage is identified as an external corrosion.

The rupture of metallic pipes conveying water and crude oil and gas as well as the collapse of civil infrastructures has become a serious environmental concern in recent times in Nigeria where there have been statistically high reported cases of crude oil/gas spillages and building collapse resulting in loss of life and adverse effect on the environment. [10] and [11] opined in [12] that the corrosive nature of the soil materials hosting metallic pipes and civil engineering infrastructures weakens the soil strength (competence) and makes it aggressive to buried metallic steel pipes due to the buildup of corrosion cells leading to severe corrosion failure. Corrosion is induced by material-environment contact and often results in material deterioration, putting safety at risk and posing substantial problems in materials and engineering [13–15]. Therefore soils that are in contact with materials used for engineering construction can cause corrosion to steel or even concrete used for reinforcement resulting in structural failure arising from the soil corrosive nature [16, 17]. Factors such as soil resistivity, soil pH, soil soluble ion contents of chlorides and sulphates, soil moisture contents and the rates of microbes in the soil among others influences corrosion and they can be empirically measured to determine soil corrosivity [9].

Detailed information about the soil corrosivity of an area is very necessary in engineering and agricultural activities, and for steel pipes that are used for water reticulation purposes. Due to the inverse relationship between soil corrosivity (conductivity) and soil resistivity, a robust knowledge of the subsurface resistivity distribution of an area is thus necessary in order to assist in the prevention of corrosion of underground steel pipes, metallic cables and other piping and tubing networks buried underground. A lower resistivity signature of the soil implies higher conductive and corrosive environment since corrosion is an electrochemical reaction. Therefore low soil resistivity enhances corrosion of buried metallic pipes while high soil resistivity inhibits it [18–20].

A critical knowledge about the competence of soil in an area is very important as it provides information on the capability of the soil to withstand stress and strain from overburden engineering structures such as buildings, overhead bridges, Overhead water reservoir facilities, and road construction. The determination of soil competence for foundation studies normally assists civil engineers in the design of the foundations of civil engineering structures [21, 22]. A detailed and excellent knowledge about soil competence in an area would also assist in curbing the environmental menace caused by frequent collapse of buildings and other civil infrastructures.

The relationship between soil corrosivity and soil physicochemical (Geochemical) parameters is so very complex that the soil corrosivity appraised by these parameters is often unreliable [9], [23, 24]. Arising from this shortcoming, electrical resistivity (Geo-electric) geophysical method is employed to corroborate with the geochemical (physicochemical) parameter analysis for the investigation of soil corrosivity as it relates to the electrical properties of soils with depth for lithologic subsurface characterization in order to understand the nature of soil against corrosion of metallic pipes and concrete, and to know the strength of the soil structure for civil engineering construction purposes. The application of electrical resistivity in the investigation of soil corrosivity and soil competence in foundation studies have been used by several authors like [12], [17], [25–32]. None of these authors' works involved the application of an integrated approach of geophysical and geochemical investigation for soil corrosivity and competence.

The study area, Utue- Ogume is a rapidly growing and an expanding region due to the establishment of a tertiary institution (Novena University), and the oil exploration activities by Energia Nigeria Limited. As an oil producing community, the Delta State government is presently constructing a Multi-billion Naira gas processing plant in the area, which upon completion is expected to provide 700,000 metric tonnes of processed gas daily aimed at improving power supply in the region and in the State capital at Asaba [33]. This study is necessary in order to have a good knowledge of the soil aggressiveness to concrete materials and buried metallic pipes. Therefore a comprehensive investigation about the corrosivity and competence of the soil to civil engineering metal construction works and infrastructures is crucial to avert a potential unnecessary environmental menace of building collapse incidences and pollution of arable farmlands, surface water bodies and groundwater aquifers occasioned by the crude oil/gas rupture of buried metallic steel pipeline for conveying crude oil/gas and water reticulation purposes in the area. This study aim at assessing the geoelectric and geochemical properties of subsurface layers in order to evaluate the soil corrosive nature and its competence to withstand overburden stress from civil infrastructures at Utue-Ogume community of Delta State in order to prevent the occurrence of disasters of these civil infrastructures for sustainable development in the reduction of loss of life, economic damage, and environmental degradation. This study is extremely important because the area under investigation is in the Niger Delta region which is an environmentally sensitive area due to the frequent large scale occurrences of oil spillages arising from ruptured pipelines and causing environmental pollution that has affected flora and fauna.

2 Materials and Methods

2.1 Study Area

Utue-Ogume community located in Ndokwa West Local Government Area (LGA) of Delta State Nigeria lies within Latitude 5^0 44’ 57.94” and 5^0 44’ 59.64” North of the Equator and Longitude 6^0 12’ 22.28” and 6^0 12’ 23.95” East of the Greenwich Meridian (Fig. 1). It sits astride the *Benin Formation* which is often referred to as the coastal plain sands (Qp) of the Pliocene – Pleistocene and Alluvium of the upper Quaternary (Recent sediments). The sedimentary *Formation* of the area consists of silty clayey sands, sandy clay, sands and gravels and it is flat lying in topography whose sediments are partly marine and fluvial in origin.

[34] reported that Ndokwa West LGA where Utue-Ogume is located has three distinct landforms namely: the combined Ase River, River Niger flood plain that occupies the eastern portion of the area and stretches from Aboh to Umuzezi; the Sombreiro-Warri that runs diagonally across the area from Abbi to Umuzezi; and the low ridged plain that extends from Obiaruku through Umuaja to Nsukwa. The area is drained by four main river systems viz: The Adofi River at the North which flows South and swings North eastwards to join the dominant Ase River System whose network in combination with the River Niger drains the eastern portion of the area. The head waters of the River Ethiope and Okumeshi River (Warri River) drains the North West portion of the area. The average annual rainfall is about 2600mm with a mean temperature of 31.2^0C [35].

2.2 Data Acquisition

This study employed the random soil sampling method to collect soil samples, and the geophysical data acquisition technique to gain insight into the subsurface soil condition.

2.2.1 Geophysical Data acquisition

Electrical resistivity geophysical technique using the vertical electrical sounding (VES) was adopted to collect data about subsurface resistivity of the soil layers. The technique is non-destructive it involves injecting electric current into the subsurface through two current electrodes, AB and the potential difference created due to the passage of the electric current into the earth materials is measured across a pair of potential electrodes, MN. The subsurface data was acquired with the *Mini-res Resistivity Meter* adopting the Schlumberger array. The *Mini-res Resistivity Meter* is a signal averaging system that is of high sensitivity with the potential of automatically taking consecutive readings and the results are averaged continuously and displayed as resistance automatically.

A total of Nine VES was randomly run in the NE-SW and NW-SE direction with the Schlumberger array using a maximum current electrode spread (AB/2) of 300m. The Schlumberger array was utilized due to its advantage of being faster, more economical to use and less sensitive to lateral variation. At each VES station where measurements were made, a reading of resistance R of the volume of the earth material within the electrical space of the electrode configuration was obtained. The measured resistance values (R) were converted into apparent resistivity (ρ_a) by multiplying with a geometric factor (K), such that:

$$\rho a = \pi R \frac{[(AB/2)^2-(MN/2)^2]}{MN} = \pi RK \quad \ldots \quad 1$$

Where K is the geometric factor and is given by:

$$\frac{(AB/2)^2-(MN/2)^2}{MN} \quad \ldots \quad 2$$

Sounding curves were generated with the obtained apparent resistivity values and were interpreted qualitatively and quantitatively. The quantitative interpretation of the curve was done by partial curve matching and computer iteration methods utilizing the 1-D inversion IPI2WIN software to obtain geoelectric section of the one-dimensional resistivity model for the area with minimal root mean square error of the order of 3%. The IPI2WIN software uses least-squares optimization technique where a starting model is adjusted successively until a minimum reduction is obtained in the difference between the field data and the model output. The software further converts the resulting apparent resistivities as a function of spacing in the field to true resistivities as a function of depth such that the obtained true resistivities represents the best average bulk resistivity for the given layer.

2.2.2 Soil Samples Collection

At each VES station, about 2kg of soil samples was randomly collected at 2m apart to a varying depth of 0-1m, 1-2m and 2-3m using a stainless steel soil hand auger and a spatula. The soil hand auger was first cleaned with acid, detergent and rinsed with tap water before it was used to drill or bore to a depth of 3m. The representative soil samples were collected at regular intervals of 1.0m from the bored holes to a depth of 3m. Each of the soil samples so randomly collected at 2m apart at each VES station and to a varying depth of 1.0m, 2.0m and 3.0m were thoroughly mixed together to give a composite sample at each depth. Thus, a total of nine composite soil samples were collected at the nine VES stations for analysis of geochemical (physicochemical) parameters. The nine soil samples were each stored in a labeled air-tight polythene bags and were taken to the soil test division of Benin-Owena River Basin Development Authority laboratory located at the University of Benin (UNIBEN) main campus where they were dried at 105^{o}C for 48 hours, thereafter sieved with < 2mm stainless sieves to remove large debris, plant roots and gravel size materials. The sieved samples were further grinded with pestle and mortar to get it homogenized and then kept in desiccators before chemically digested. The sieved samples were digested with a strong acid to dissolve the samples and their inorganic contents in solution before subjecting them to physicochemical parameters analysis. The concentration levels of chloride ion, sulphate ion and organic matter were determined.

The soil pH was determined in-situ electronically using the glass method with a standard caliberated pH meter. The procedure involved weighing 0.02kg (2g) of soil samples (that was collected at the varying depths) in a beaker and 100ml of water was added, then stirred gently and allowed to stand for 30 minutes before introducing the pH meter into the soil-water suspension for 60 seconds. Readings were taken thereafter. The soil pH was taken in-situ because soil chemistry is sensitive to environmental changes [36, 37].

3 Results and discussion

3.1 Layer Lithology

The number of subsurface layers at each VES data station was identified from the results of the geoelectric curves. The area consists of HK curve types (Fig. 2). The obtained VES curves delineated six to eight geoelectric heterogeneous layers of lateritic topsoil, clayey sand, sandy clay, Fine to medium grained sand, medium to coarse grained sand, coarse grained sand, sandy clay and clay (Table 1). The resistivity, thickness and depth of the area varied respectively from 53.04Ωm (VES 9) to 4,535Ωm (VES 3), 0.6m (VES 1 and VES2) to 79.2m (VES 7), and 0.6m (VES 1 and VES 2) to 134.8m (VES 1).

3.2 Evaluation of Soil Corrosivity and Competence with Geochemical Parameters

The results of the geochemical (Physicochemical) parameters conducted to depth of 3meters are presented in Table 2 and were used to evaluate the soil corrosivity and competence in the area as followings:

(i) Soil pH

The Soil pH values ranged from 6.2 to 8.7 with a mean value of 7.5 indicating that the soil in the area is slightly acidic to strongly alkaline when compared to the [38] classification (Table 3). Comparing the soil pH range to the corrosivity ratings by [39] the soil in the area can be classified into moderately corrosive, mildly corrosive (acidic environment) and negligible degree of corrosivity (Table 4).

(ii) Chloride Concentration

The chloride concentration in the soil ranged from 8.5ppm to 83.8ppm with a mean value of 26.33ppm (Table 2). These values of chloride concentration in the soil are below the permissible standard of 200ppm by [40] and [41] hence has no serious corrosive effect on buried metals. However, in a moderately to mildly acidic environment the soil level of chloride becomes mildly corrosive since the chloride concentration level is below 500ppm (Table 4).

Although the area is characterized by low chloride value, its presence in the soil can potentially harm or affect buried metallic pipe fittings as it will tend to decrease the soil resistivity of the area with time if not properly contained or treated.

(iii) Sulphate Concentration

The sulphate concentration in the soil varied from 126.8ppm to 276.9ppm with a mean concentration value of 203.79ppm. These range of sulphate concentration values in the soil were observed to be lower (Table 2) than the recommended permissible limit of 1000ppm [40, 41]. However, although the sulphate concentration values are lower than permissible standard for soil, a comparison of the sulphate concentration values to the corrosivity rating by [39] as highlighted in Table 2 and Table 4 revealed that the sulphate concentration in the soil to a depth of 3m at all the VES stations are in the classification of mild to moderate corrosivity. Therefore the soil at that depth is a potential threat to buried metallic pipes with time if not properly contained or treated. 63% of the first and second subsoil layers in the area were characterized as negligible corrosivity while 26% and 11% of the third subsoil layers in the area were respectively characterized as mildly corrosive and moderately corrosive when rated with geochemical parameter values (Table 4 and Fig. 3).

(iv) Organic Matter Content

It was observed from the laboratory result that there was no organic matter content in the area (Table 2) implying absence of any trace of crude oil pollution within the area at the time of investigation. The absence of organic matter encourages burying of pipes since the soil would not be aggressive to buried metallic pipes in the area, but such metallic pipes and any civil engineering metallic works or concrete should be buried to depth not beyond 2m.

(v) Evaluation of Soil Corrosivity with Resistivity Data

Since corrosive soils are aggressive to concrete, water reticulation pipes and crude oil/gas buried pipelines, the corrosive nature of the soil was investigated to depth of 3m. This depth was chosen because the minimum recommended depth of burial for water pipelines, crude oil and gas pipelines, and foundation footings of civil engineering structures is to approximately 1.0 meters (3 feet) [1], [3–5]. The first, second and third layer resistivity values at the nine VES stations which was to a depth of over 2m was used to investigate the soil corrosivity in the study area. The inferred lithology obtained while drilling with the hand auger was assigned to the first, second and third layer resistivity and was compared to the corrosivity rating by [42] and [43] (Table 5). The soils in this area can therefore be classified into essentially non-corrosive and mildly corrosive (Table 6). This classification is in agreement with the geochemical parameters classification (Table 2) of mildly, moderately and negligible corrosivity. The essentially non-corrosive nature of the soil to a depth range of 1m to 2m was observed in the first and second resistivity layers at all the VES stations (VES 1to VES 9). However, a corrosivity classification inversion to mildly corrosive nature of the soil was observed from depth 2m and above in the third resistivity layer at VES 2 to VES 9. Hence, the use of steel pipes to transport crude oil and gas and for water pipelines reticulation should be buried to a restricted depth of 1.0m which is the layer of non-corrosive soil. Civil infrastructure foundation footings should also be done to a depth of 1.0m of essentially non-corrosive soil since the soil materials at this depth would not be aggressive to concrete foundation footings or metallic engineering works in the area. Care should also be taken not to bury crude oil/gas pipelines, water pipelines and foundation footings of civil infrastructures to a depth beyond 2m as it would respectively result in crude oil/gas and water pipelines leakage as well as in the collapse of civil infrastructures. The soil beyond 2m depth would aggressively attack buried metallic pipes and concrete. The non-corrosive and mildly corrosive nature of the soils at the nine VES locations is highlighted in Table 6 and Fig. 4.

Table 1
Lithologic Delineation and Curve types of the 1D Inversion Model from the VES Stations

VES Location	Layer	Resistivity(Ωm)	Thickness(m)	Depth(m)	Lithology
VES 1	1	3236	0.6	0.6	Top Soil
	2	1310	0.6197	1.22	Clayey Sand
	3	224.6	1.26	2.48	Sandy Clay
	4	786	8.376	10.86	Fine to Medium grained Sand
	5	4452	10.58	21.44	Medium to Coarse grained Sand
	6	1499	45.93	67.37	Coarse grained Sand
	7	873.8	67.44	134.8	Sandy Clay
	8	267.2	-	-	Clay
VES 2	1	1620	0.6	0.6	Top Soil
	2	1263	0.6827	1.283	Clayey Sand
	3	142.3	1.197	2.48	Sandy Clay
	4	668.1	8.376	10.86	Fine to Medium grained Sand
	5	5840	10.58	21.44	Medium to Coarse grained Sand
	6	1276	43.25	64.69	Coarse grained Sand
	7	790.3	55.84	120.5	Sandy Clay
	8	239.6	-	-	Clay
VES 3	1	941.7	0.7044	0.7044	Top Soil
	2	4186	0.5782	1.283	Sandy Clay
	3	193.6	9.573	10.86	Fine to Medium grained Sand
	4	4535	10.58	21.44	Medium to Coarse grained Sand
	5	1083	34.52	55.95	Coarse grained Sand
	6	248.7	-	-	Sandy Clay/Clay
VES 4	1	625	0.704	0.704	Top Soil

	2	3008	0.578	1.28	Sandy Clay
	3	145	9.57	10.9	Fine to Medium grained Sand
	4	3325	10.6	21.4	Medium to Coarse grained Sand
	5	1020	41.7	63.1	Coarse grained Sand
	6	167	-	-	Sandy Clay/Clay
VES 5	1	869	1.02	1.02	Top Soil
	2	1392	0.618	1.64	Sandy Clay
	3	131	9.22	10.9	Fine to Medium grained Sand
	4	2978	10.6	21.4	Medium to Coarse grained Sand
	5	942	64.6	86.1	Coarse grained Sand
	6	167	-	-	Sandy Clay/Clay
VES 6	1	697	0.739	0.739	Top Soil
	2	1158	0.858	1.6	Sandy Clay
	3	190	8.5	10.1	Fine to Medium grained Sand
	4	4075	11.3	21.4	Medium to Coarse grained Sand
	5	1340	60	81.5	Coarse grained Sand
	6	273	-	-	Sandy Clay/Clay
VES 7	1	392	0.776	0.776	Top Soil
	2	1169	0.821	1.6	Sandy Clay
	3	166	8.5	10.1	Fine to Medium grained Sand
	4	4718	16.7	26.8	Medium to Coarse grained Sand
	5	1629	79.2	106	Coarse grained Sand
	6	94.3	-	-	Sandy Clay/Clay
VES 8	1	359	0.8227	0.8227	Top Soil
	2	1158	0.7746	1.597	Sandy Clay

	3	195.24	7.212	8.809	Fine to Medium grained Sand
	4	3555	17.98	26.79	Medium to Coarse grained Sand
	5	1010	75.18	102	Coarse grained Sand
	6	183.1	-	-	Sandy Clay/Clay
VES 9	1	1286.8	1.146	1.146	Top Soil
	2	1158	0.6319	1.778	Sandy Clay
	3	179.12	7.031	8.809	Fine to Medium grained Sand
	4	2551	13.23	22.04	Medium to Coarse grained Sand
	5	924.9	70.45	92.49	Coarse grained Sand
	6	53.04	-	-	Sandy Clay/Clay

Table 2
Soil Corrosivity Rating of Geochemical Parameters using pH Values in the Study Area

VES Stations	Depth of Sample Collection (m)	pH Values	Cl^- (ppm)	SO_4^{2-} (ppm)	Organic Matter (%)	Corosivity Rating
VES 1	0–1	7.6	9.2	127.8	ND	Negligible Corrosive
	1–2	7.6	9.2	133.5	ND	Negligible Corrosive
	2–3	6.7	15.4	140.6	ND	Mild Corrosive
VES 2	0–1	8.7	8.8	130.6	ND	Negligible Corrosive
	1–2	8.5	8.9	129.4	ND	Negligible Corrosive
	2–3	6.8	15.7	137.2	ND	Mild Corrosive
VES 3	0–1	8.3	9.5	126.8	ND	Negligible Corrosive
	1–2	7.9	10.3	138.4	ND	Negligible Corrosive
	2–3	6.4	22.6	142.5	ND	Moderate Corrosive
VES 4	0–1	7.9	11.9	189.6	ND	Negligible Corrosive
	1–2	7.7	11.7	222.7	ND	Negligible Corrosive
	2–3	6.8	38.6	256.7	ND	Mild Corrosive
VES 5	0–1	8.2	27.6	228.3	ND	Negligible Corrosive
	1–2	7.8	28.1	253.6	ND	Negligible Corrosive
	2–3	6.6	45.2	264.2	ND	Mild Corrosive
VES 6	0–1	8.5	44.3	236.7	ND	Negligible Corrosive
	1–2	8.2	45.6	249.3	ND	Negligible Corrosive
	2–3	7.1	83.8	273.1	ND	Mild Corrosive

• ND Means Not Detected

VES 7	0–1	8.4	27.2	188.8	ND	Negligible Corrosive
	1–2	8.1	52.5	195.4	ND	Negligible Corrosive
	2–3	6.6	78.9	259.2	ND	Mild Corrosive
VES 8	0–1	7.6	12.7	185.3	ND	Negligible Corrosive
	1–2	7.5	13.4	228.8	ND	Mild Corrosive
	2–3	6.3	33.6	273.4	ND	Moderate Corrosive
VES 9	0–1	8.3	8.5	266.5	ND	Negligible Corrosive
	1–2	7.6	11.9	247.2	ND	Negligible Corrosive
	2–3	6.2	25.8	276.9	ND	Moderate Corrosive
Range	0–3	6.2–8.7	8.5–83.8	126.8-276.9		
Mean		7.5	26.33	203.79		
Permissible Standard FAO (1992), USDA (2014)		7	200	1000		

• ND Means Not Detected

Table 3
Soil pH Classification [38]

pH Values	Soil Classification
<3.5	Ultra Acidic
3.5–4.4	Extremely Acidic
4.5-5.0	Very Strongly Acidic
5.1–5.5	Strongly Acidic
5.6-6.0	Moderately Acidic
6.1–6.5	Slightly Acidic
6.6–7.3	Neutral
7.4–7.8	Slightly Alkaline
7.9–8.4	Moderately Alkaline
8.5-9.0	Strongly Alkaline
> 9.0	Very Strongly Alkaline

Table 4
Soil Corrosivity Rating as a function of Soil Geochemical (Physicochemical) Parameters [39]

Water Soluble Chloride Concentration (ppm)	Water Soluble Sulphate Concentration (ppm)	pH Level	Degree of Corrosivity
Over 5,000	Over 10,000	-	Very Severe
1,500–5000	1,500 – 10,000	< 5.5	Severe
500-1,500	150-1,500	5.5–6.5	Moderate
Below 500	-	6.5–7.5	Mild
-	0-150	> 7.5	Negligible

Table 5
Soil Corrosivity Rating [43], [47–50]

Soil Resistivity (Ωm)	Soil Corrosivity Rating
> 200	Essentially Non-Corrosive
100–200	Mildly Corrosive
50–100	Moderately Corrosive
30–50	Corrosive
10–30	Highly Corrosive
< 10	Extremely Corrosive

(vi) Evaluation of Soil Competence with Resistivity Data

The first, second and third layer resistivity values to a depth of over 2m at the nine VES locations was used to investigate the competence or ability/capacity of the sub-soil to withstand overburden stress and strain from civil engineering infrastructures (such as buildings, bridges and overhead water reservoirs) and other anthropogenic activities. The lithology of the layers and the degree of competence corresponding to it was assigned to each first, second and third layer resistivity for each VES station using the classification ratings in by [44] and [45] as shown in Table 7.

The soils in the area can be classified into highly competent, competent and moderately competent when compared to the classification rating by [44]. The competent nature of the soil in all the locations is highlighted in Table 6.

On the basis of subsoil resistivity values and inferred lithology at the VES stations, the study revealed that 67% of the first and second subsoil layers at VES 1 to VES 9 was rated essentially non-corrosive, 3% of the third subsoil layer at VES 1 was also rated essential non-corrosive, while 30% of the third subsoil layer at VES 2 to VES 9 was rated as mildly corrosive. Again, 15% of the first subsoil layer at VES 4, VES 6, VES 7 and VES 8 was rated competent in the area. 19% of the first sub-subsurface layers at VES 1, VES 2, VES 3, VES 5 and VES 9 was also rated highly competent to withstand overburden stress from civil engineering infrastructures. Moreover, 33% of the second subsoil layer at VES 1 to VES 9 was rated highly competent to withstand overburden stress while 33% of the third subsoil layer was rated moderately competent at VES 1 to VES 9. These are highlighted in Fig. 5. It was observed that the subsurface layers of competent and highly competent soils are characterized by high resistivity values which also correspond to essentially non-corrosive soil having almost neutral pH values, low chloride and sulphate values to a depth range of 0.6m to 1.7m. This layer and depth is good for erecting massive civil engineering infrastructures and would withstand the structures overburden weight on the soil thereby avert collapse of such structures. While the subsurface layers of moderate competent soil are characterized by lower resistivity values than those of competent soils and correspond to mildly corrosive soils of pH values between 6.5–7.5, and low chloride and sulphate values. Nevertheless, the chloride and sulphate concentrations have the potential of becoming higher since chloride and sulphate concentrations in soils are subject to seasonal fluctuations; thus an expected potentially higher concentration level of chloride and sulphate in the soil material in the area can trigger the corrosion dynamic of the soil [46].

Table 6
Degree of Soil Corrosivity and Competence at the VES Stations in the Study Area

VES Stations	Layer	Resistivity (Ωm)	Depth (m)	Inferred Lithology	Corrosivity Rating	Competence Rating
VES 1	1	3236	0.60	Lateritic Topsoil	Essentially Non-Corrosive	Highly Competent
	2	1310	1.220	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	224.6	2.480	Sandy Clay	Essentially Non-Corrosive	Moderately Competent
VES 2	1	1620	0.60	Lateritic Topsoil	Essentially Non-Corrosive	Highly Competent
	2	1263	1.283	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	142.3	2.480	Sandy Clay	Mildly Corrosive	Moderately Competent
VES 3	1	941.7	0.704	Lateritic Topsoil	Essentially Non-Corrosive	Highly Competent
	2	4186	1.283	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	193.6	10.86	Sandy Clay	Mildly Corrosive	Moderately Competent
VES 4	1	625	0.740	Lateritic Topsoil	Essentially Non-Corrosive	Competent
	2	3008	1.280	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	145	10.90	Sandy Clay	Mildly Corrosive	Moderately Competent
VES 5	1	869	1.020	Lateritic Topsoil	Essentially Non-Corrosive	Highly Competent
	2	1392	1.640	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	131	10.90	Sandy Clay	Mildly Corrosive	Moderately Competent
VES 6	1	697	0.739	Lateritic Topsoil	Essentially Non-Corrosive	Competent
	2	1158	1.60	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	190	10.10	Sandy Clay	Mildly Corrosive	Moderately

						Competent
VES 7	1	392	0.776	Lateritic Topsoil	Essentially Non-Corrosive	Competent
	2	1169	1.60	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	166	10.10	Sandy Clay	Mildly Corrosive	Moderately Competent
VES 8	1	359	0.823	Lateritic Topsoil	Essentially Non-Corrosive	Competent
	2	1158	1.597	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	195.24	8.809	Sandy Clay	Mildly Corrosive	Moderately Competent
VES 9	1	1286.8	1.146	Lateritic Topsoil	Essentially Non-Corrosive	Highly Competent
	2	1158	1.778	Clayey Sand	Essentially Non-Corrosive	Highly Competent
	3	179.12	8.809	Sandy Clay	Mildly Corrosive	Moderately Competent

Table 7
Sub-soil competence Rating using Resistivity Values [44]

Soil Resistivity (Ωm)	Lithology	Competence Rating
< 100	Clay	Incompetent
100–350	Sandy Clay	Moderately Competent
350–750	Clayey Sand	Competent
> 750	Sand/Laterite/Crystalline Rock	Highly Competent

4 Conclusion

Integrated use of electrical resistivity and geochemical (physicochemical) parameters has been employed to investigate the corrosivity and competence of soil to civil engineering infrastructures at Utue-Ogume community. The geochemical parameters was carried out to corroborate with electrical resistivity geophysical investigation and the findings classified the soil in the area as essentially non-corrosive to moderately/mildly corrosive within a subsurface depth range of 0-3meters. The study also finds that the subsurface soils to a depth of 1.0m in this area are essentially non-corrosive to civil infrastructures and engineering subsurface metal works such as buried crude oil/gas pipelines and metallic pipes used for water reticulation purposes. It is important to note that the subsurface layers of mildly corrosive soils with pH values ranging from 6.5 to 7.5 and low chloride and sulphate concentrations could potentially become higher to characterize the layer as highly corrosive with time because [46] alluded that chloride and sulphate concentration levels in soils are subject to seasonal fluctuations which can trigger the corrosion dynamics of the soil. The soils are also competent within a depth range of 1.0m to 2.0m for erecting massive civil buildings or civil engineering infrastructures in all the surveyed locations as this would help to avert building collapse in the area. However, it is recommended that geotechnical studies on the soils of this area be carried out so as to ascertain other engineering properties of the soil material. It is also advised to adopt liming or fly ash soil stabilization method, cathodic protection method, barrier protection with membranes, liners and coating method as well as chemical treatment of the soil with corrosion inhibitors method for treatment of the moderately and mildly corrosive soil layers before transmission pipes can be buried to that depth of the layer.

Declarations

Acknowledgements

Not applicable.

Author contributions

All authors contributed equally to the preparation of this manuscript. Thompson Chinedum Irunkwor developed the research framework and prepared the manuscript. Chuks Okobia, Dandy Dumbiri Nmorsi and Nkonyeasua Abanjo performed the experimental setup and analyzed the results. Collins Ogorm Molua, Monday Edobor and Ngozi Chinyere Eze further analyzed the results and improved on the theoretical aspects of this paper. All authors revised and approved the manuscript.

Funding

There is no funding available for this research.

Data Availability

All data supporting this research are included in the article. However, it can be further provided on demand from the corresponding author.

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Competing Interests: The authors declare that they have no competing interests with respect to the research authorship and/or publication of this article.

References

1. United States Department of Transportation's Pipeline and Hazardous Materials Safety Administration (USDTPHMSA) (2022) PHMSA Regulatory Requirements for Pipeline Operations in Marine Environments. Retrieved online from https://www.cdmcs.org. Accessed on 12th August, 2024
2. American Petroleum Institute (API) (2001) API 1104 Standard for Welding Pipelines and Related Facilities. 49CFR 195.214(a). Retrieved online from https://www.law.resource.org. Accessed on 12th August, 2024
3. American Water Works Association (AWWA) (1999) AWWA Specification C-105. Standards for Determining Corrosivity of Soils
4. American Water Works Association (AWWA) (2002) PVC Pipe-Design and Installation. AWWA Manual of Water Supply Practices-M23. 2nd Edition: Denver, CO80235, USA
5. United States Environmental Protection Agency (USEPA) (2002) Deteriorating Buried Infrastructure Management Challenges and Strategies. Washington DC20004. United States
6. International Building Code (IBC) (2021) Soils and Foundations. Retrieved online from https://codes.iccsafe.org; https://www.mybuilder.com. Accessed on 10th August, 2024
7. Sosa E, Alvarez-Ramirez J (2009) Time Correlations in the Dynamics of Hazardous Material Pipelines incidents. J Hazard Mater, 1204–1209
8. Noor NM, Yahaya N, Din MM, Nor SHM (2009) Prediction of Corroding Pipelines Remaining Lifetime Using Semi-Probabilistic Approach. Malaysian J Civil Eng 22(2):204–220
9. Noor NM, Othman SR, Yahaya N, Sing LK, Abdullah A (2012) Qualitative Assessment of Chloride and Sulphate Influence on Soil Corrosivity. Adv Mater Res 446(449):3462–3466
10. Bayowa OG, Olayiwola NS (2015) Electrical Resistivity Investigation for topsoil thickness, competence and corrosivity evaluation: A Case Study from Ladoke Akintola University of Technology, Ogbomoso, Nigeria. *2nd International Conference on Geological and Civil Engineering. IPCBEE 80(2015): 52–56. IACSIT Press, Singapore*
11. Edeye E, Eteh DR (2021) Geoelectric Investigation of Corrosivity and Competence Soils Using geospatial Technology: A Case Study in Part of Yenagoa, Bayelsa State, Nigeria. Int J Earth Environ Sci 2:1–7
12. Onyeanwuna UB, Akakuru OC, Opara AI, Onyekuru SO, Ibeneme SI, Ofoh IJ, Aigbadon GO, Isreal H (2024) Application of Geological and Geo-electric Methods in the Assessment of Corrosivity, Competence, and Vulnerability of Soils around Southeastern Nigeria. Int J Phys Sci 19(1):58–79
13. Mars GF (1987) *Corrosion Engineering*. 3rd Edition. New York: McGraw Hill Book
14. Ekine AS, Emujakporue GO (2010) Investigation of Corrosion of Buried Oil Pipeline by the Electrical Geophysical Methods. J Appl Sci Environ Manage 14(1):63–65
15. Guma TN, Mohammed SU, Tanimu AJ (2015) A field Survey of Soil Corrosivity level of Kaduna Metropolitan Area through Electrical Resistivity Method. Int J Sci Eng Res 3:5–10

16. National Association of Corrosion Engineering (NACE) (1993) Corrosion/93 Symposium
17. Agoha CC, Ebekuo CA, Mgbeojedo TI, Onwubuariri CN, Njoku JO, Ofoh IJ, Nwokeabia CN, Ibeneme SI, Anuforo DN (2024) Investigation of Soil Corrosivity, Competence and Comprehensive Aquifer Evaluation of Orlu and Environs, Southeastern Nigeria. Sustainable Water Resour Manage 10(138):1–16
18. Uhlig HH, Revie RW (2008) Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering. 4th Edition, New York: John Wiley and Sons. P. 458
19. Jones DA (2017) In: Principles and Prevention of Corrosion. 2nd Edition. Pearson Education
20. Akinlabi IA, Olaiya ML (2021) Geoelectric and Physicochemical Evaluation of Soil Corrosivity on Metallic Pipelines: A Case Study. J Geogr Environ Earth Sci 25(5):46–56
21. Akintorinwa OJ, Adeusi FA (2009) Integration of Geophysical and Geotechnical Investigations for a proposed Lecture Room Complex at the Federal University of Technology, Akure, Southwestern Nigeria. Ozean J Appl Sci 2:241–254
22. Ofomola MO, Iserhien-Emekeme RE, Okocha FO, Adeoye TO (2018) Evaluation of Subsoil Competence for Foundation Studies at Site III of the Delta State University, Nigeria. *Journal of Geophysics and engineering*, 15(2018): 638–657
23. Kasahara K, Adachi H, Kajiyama F (1981) Corrosion of Buried Steel Pipes Driven by Macro-Galvanic Cells. 8th International Congress on Metallic Corrosion (ICMC). DECHEMA, Mainz, Germany, p 1832
24. Li MC, Han Z, Lin HC, Cao CN (2001) A New Probe for the Investigation of Soil Corrosivity. Corrosion 57(10):913–917
25. Akintorinwa OJ, Ojo JS, Olorunfemi MO (2010) Geophysical Investigation of Pavement Failure in Basement Complex Terrain of Southwestern Nigeria. Pac J Sci Technol 11:649–663
26. Fatoba JO, Alo JO, Fakeye AA (2010) Geoelectric Imaging for Foundation Failure Investigation at Olabisi Onabanjo University Main Campus, Ago-Iwoye, Southwestern Nigeria. J Appl Sci Res 6:2192–2198
27. Okolie EC (2011) Geo-electric Investigation of Treasured Formation Strata and Groundwater Potential in Ogume, Delta State, Nigeria. Int J Phys Sci 6(5):1152–1160
28. Akintorinwa OJ, Abiola O (2011) Subsoil Evaluation for pre-foundation Study Using Geophysical and Geochemical approach. J Emerg Trends Eng Appl Sci 2:858–863
29. Oyedele KF, Oladele S, Onoh C (2012) Geo-assessment of Subsurface Conditions in Magodo Brook Estate, Lagos, Nigeria. Int J Adv Sci Technol Res 4:731–741
30. Coker JO, Makinde V, Mustapha AO, Adesodun JK (2013) Electrical Resistivity Imaging for Foundation Failure Investigation at Remo Secondary School, Sagamu, Southwestern Nigeria. Int Sci Invest J 2:40–50
31. Ofomola MO, Adiat KAN, Olagunju GM, Ako BD (2009) Integrated Geophysical Methods for Post-Foundation Studies, Obanla Staff Quarters of the Federal University of Technology, Akure, Nigeria. Pac J Sci Technol 10:93–111

32. Ayanninuola OS, Msughter UD, Ofoegbu CO, Uko ED (2023) Characteristics of Soils for Civil Engineering Foundations in Part of North Central Nigeria, Using Electrical Resistivity Method. Nigerian J Technological Dev 20(2):23–34
33. Amaize E (2020) New Gas Plant in Delta to Provide 700,000 Metric Tonnes Daily. Retrieved online from https://www.vanguardngr.com/2020/08/new-gas-plant-in-delta-to-provide-700000-metric-tonnes-daily/. Accessed on 14th August, 2024
34. Akpoborie IA (2011) Aspects of the Hydrology of the Western Niger Delta Wetlands: Groundwater Conditions in Neogene (recent) Deposits of the Ndokwa Area. *In Proceedings of the Environmental Management Conference, Federal University of Agriculture, Abeokuta, Nigeria*
35. Nigerian Meterorological Agency (NMA) (2003) Warri Meterorological Bulletin, In: National Meteorological Report
36. Meindinyo RK, Agbalagba EO (2012) Radioactivity Concentration and Heavy Metal Assessment of Soil and Water, in and around Imirigin Oilfield, Bayelsa State, Nigeria. J Environ Chem Ecotoxicol 4(2):29–34
37. Irunkwor TC, Ngerebara OD (2018) Soil Physico-chemical Characteristics and Metallic Corrosion in Parts of the Niger Delta. Int J Eng Appl Sci 5(3):63–66
38. United States Department of Agriculture (USDA) (1993) Natural Resources Conservation Service Handbook 18. *Soil Survey Manual, Chap. 3, Selected Chemical Properties*. Retrieved online from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/chemical/?cid=nrcs142p2_053863. Accessed on 12th April, 2024
39. Davenport GC, Rinne EE, Zamora AM (1981) Geotechnical Investigations for Corrosive Soils. *United Nations Assisstance Mission UNAM) Proceedings*
40. Food and Agriculture Organization (FAO) (1992) The State of Food and Agriculture 1992. Food and Agriculture of the United Nations
41. United States Department of Agriculture (USDA) (2014) Natural Resources Conservation Service Handbook 18. *Soil Quality Indicators manual*. Retrieved online fromhttps://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/health/chemical/?cid=nrcs142p2_053863. Accessed on 12th April, 2024
42. Bhandari PP, Dahal KP, Bahattarai J (2013) The Corrosivity of Soils Collected from Araniko Highway and Sanothimi Areas of Bhaktapur Nepal. J Institutional Sci Technol 18(1):71–77
43. Oki OA, Egai AO, Akana TS (2016) Soil Corrosivity Assessment in the Pre-design of Sub-surface Water Pipe Distributary Network in Yenegoa, South-South Nigeria Using Elecrical Resistivity. Geosciences 6(1):13–20
44. Idornigie AI, Olorunfemi MO (2006) Electrical Resistivity Determination of Subsurface Layers, Subsoil Competence and Soil Corrosivity at an Engineering Site Location in Akungba-Akoko, Southwestern Nigeria. Ife J Sci 8:22–32
45. Ojo JS, Olorunfemi MO, Akintorinwa OJ, Bayode S, Omosuyi GO, Akinluyi FO (2015) Subsoil Competence Characterization of Akure Metropolis, Southwestern Nigeria. J Geogr Environ Earth Sci

Int 3(1):1–14

46. Texas Department of Transportation (TxDOT) (2005) Guidelines for Treatment of Sulfate-Rich Soils and Bases in Pavement Structures. Retrieved online from https://www.ftp.dot.state.tx.us/pub/txdot-info/cmd/tech/sulfates.pdf. Accessed on 12th August, 2024
47. Robinson W (1993) Testing Soil for Corrosiveness. Mater Performance 32(4):52–58
48. Escalante E (1995) In Corrosion Tests and Standards: Application and Interpretation, ASTM, Philadelphia. Pp. 137–142
49. Gopal M (2010) Corrosion Potential Assessment: The Geology of South-Western Nigeria. Geological Survey of Nigeria, pp 31–87
50. Bahattarai J (2013) Study on the Corrosive Nature of Soil Toward the Burial Structure. Sci World 11(11):43–47

Figures

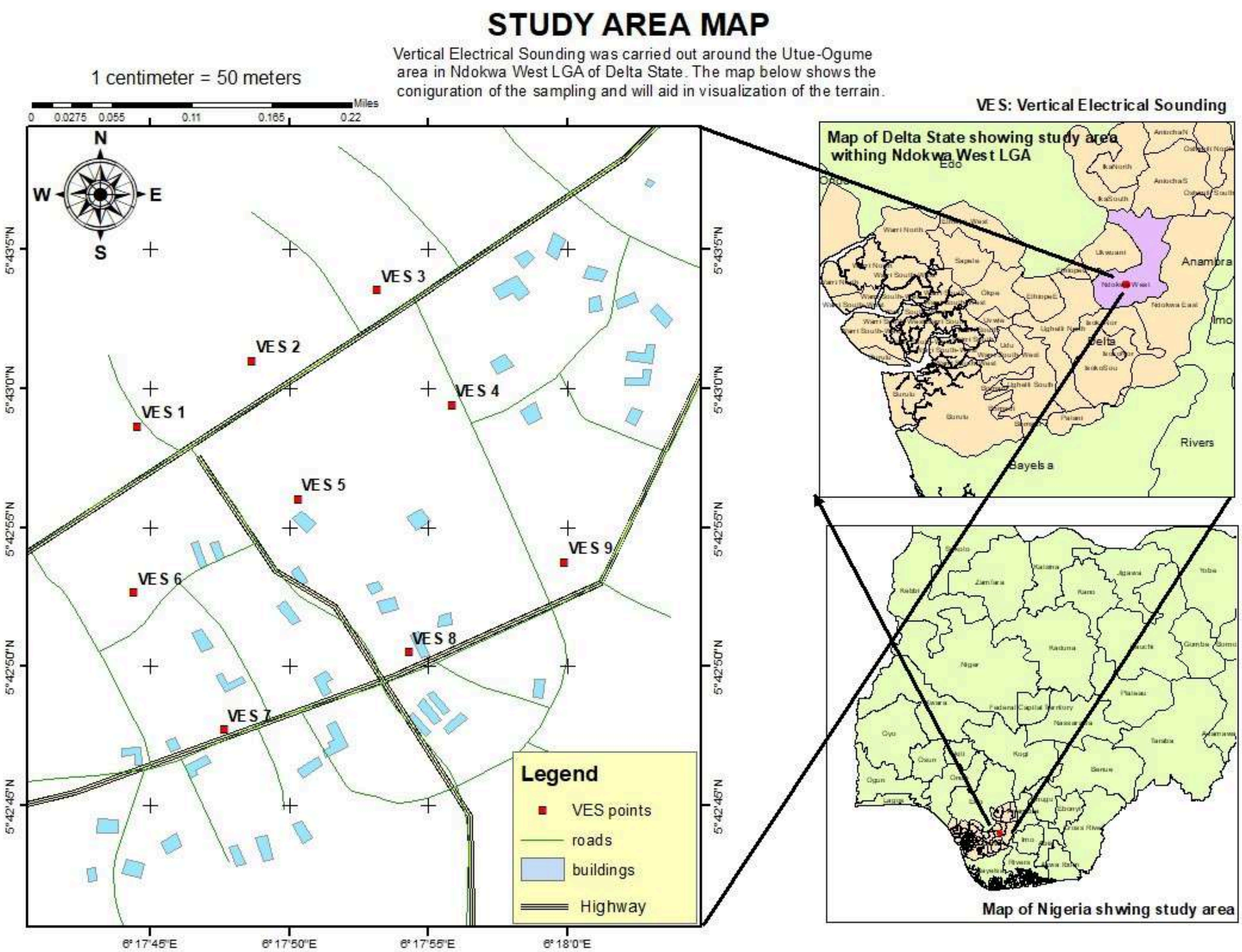

Figure 1

Map of Delta State Showing the Study Area and VES Sampling Points

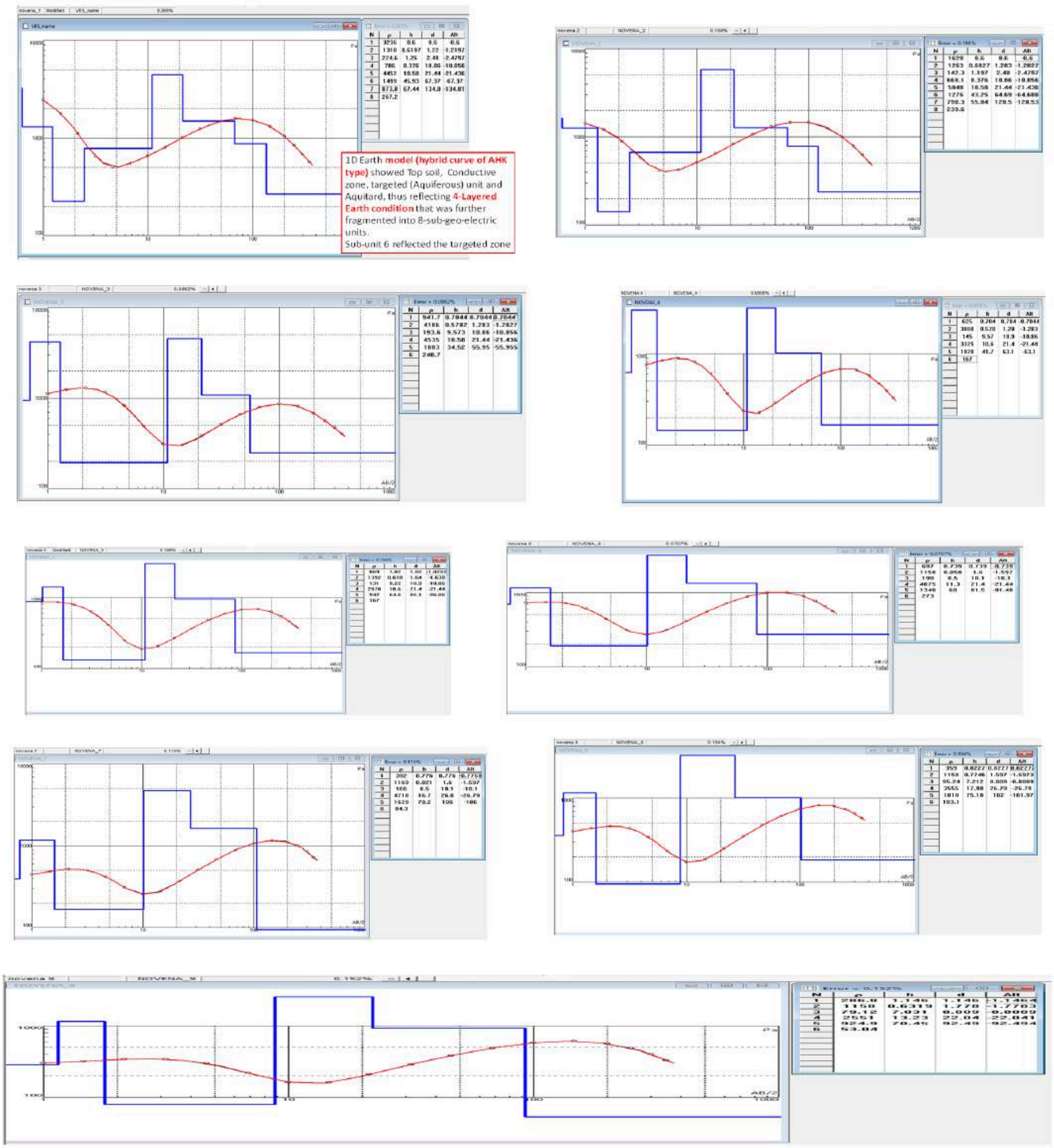

Figure 2

VES Field Curves of the 1-D Resistivity Model

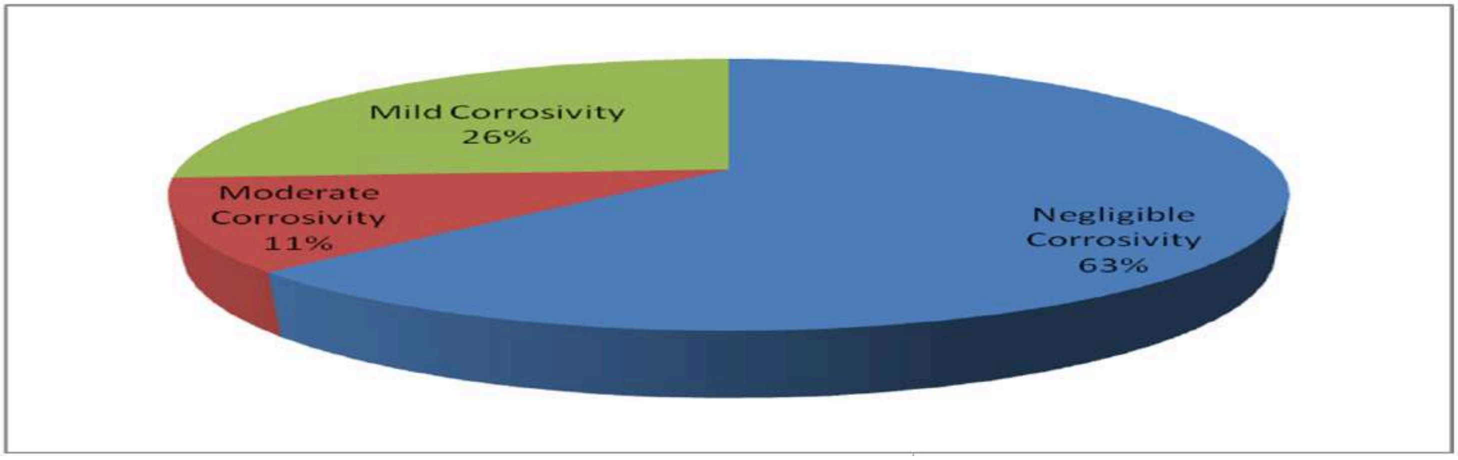

Figure 3

Percentage of Subsoil Corrosivity Rating with Geochemical Parameters

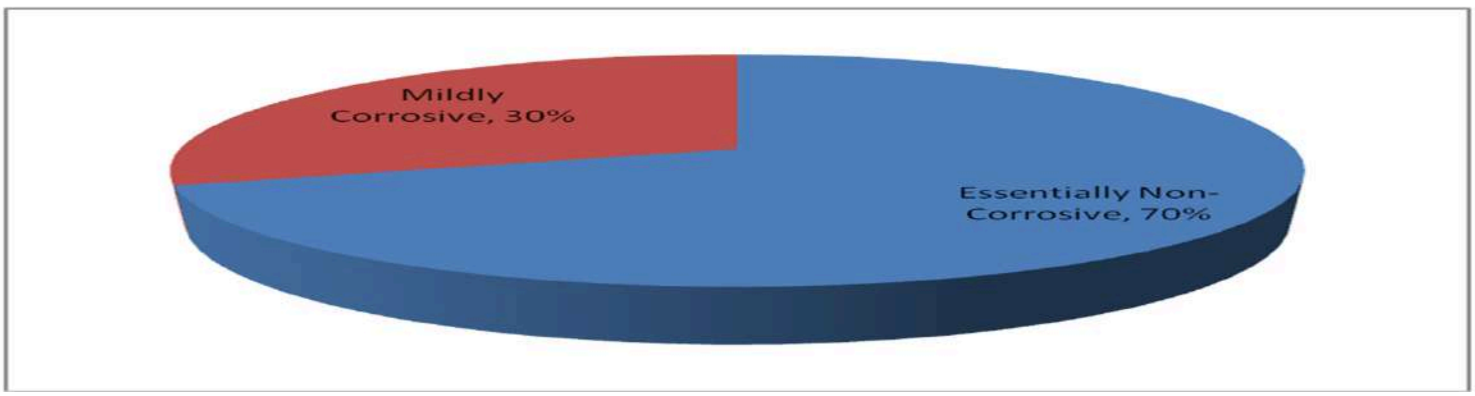

Figure 4

Percentage of Subsoil Corrosivity Rating with Resistivity Data

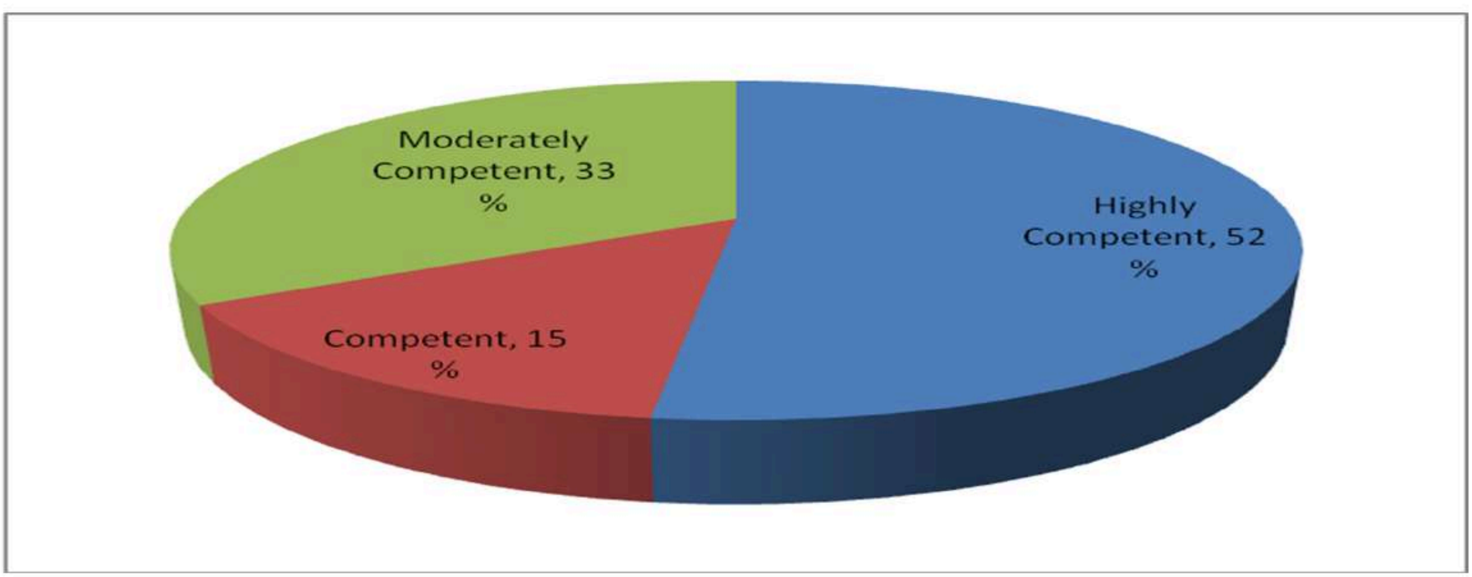

Figure 5

Percentage of Subsoil Competence Rating with Resistivity Data