



# INVESTIGATION OF SOIL CORROSIVITY IN KOLO AND ENVIRONS, BAYELSA STATE, NIGERIA

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**Abstract:** The impact of certain physicochemical parameters thought to affect soil corrosivity was investigated using the geoelectric sounding technique and laboratory analytical procedures in the Kolo area of Bayelsa State. Representative soil samples were taken from freshly drilled wells at a depth of 1.5metres. At the same time, vertical electrical soundings (VES) were methodically carried out using the Wenner electrode configuration at specific borehole locations. The samples were then analysed for electrical conductivity/resistivity, moisture content, pH, sulphate, carbonate, chloride, and oxidation-reduction potential. Values of the laboratory tests were used to calculate the corrosivity status of each soil sample. From the test results, the corrosivity of the soils falls within the “slightly corrosive” and “moderately corrosive” categories. In addition, the resistivity sounding identified four geoelectric layers: a topsoil (layer 1) of thickness ranging between 0.55 - 0.92m which overlies a layer with resistivity as low as 32Ohm-m and thickness ranging between 0.75 – 2.2m. The second layer is underlain by two successive layers with noticeably greater maximum resistivities (771 and 1936Ohm-m) and maximum thickness of 6.82 and 9.67m respectively. The geoelectric measurements were used to generate spatial distribution maps of the research area. The maps indicate that the central section of the area is highly corrosive to buried metallic facilities. On the other hand, the flanks to the east and west are relatively less corrosive, especially at a depth of 1.5m (layer 2). In addition, corrosivity increased from north to south with pockets of low and high resistivity values dotting the eastern and western flanks for layer 1. To avoid pipeline failures caused by soil

corrosion, it's crucial to implement sufficient protection and corrosion control measures. This is particularly important since most oil pipeline systems are buried within the relatively more corrosive second layer.

**Keywords:** Resistivity, Sounding, Physicochemical, Corrosivity, Wenner configuration

## I. INTRODUCTION

Almost all metals are susceptible to corrosion, which is the deterioration of a metal as a result of reactivity with its surroundings [1]. It is a known truth that any product buried in soil would eventually corrode and deteriorate back to its original state [2]. Preventing corrosion is almost impossible; fortunately, corrosion control is achievable [3]. Not only may corrosion directly affect pipeline networks, but it can also cause leaks and bursts that contaminate soils and groundwater. This can negatively impact the availability of drinkable water as well as the condition of agricultural land for many years to come. Fuel line ruptures and gas main leaks may result in fires and explosions that might be very dangerous, particularly in metropolitan areas.

The most common kind of soil corrosion is electrochemical, which causes corrosion pits to develop [4]. The redox (oxidation-reduction) processes that occur during corrosion, in which metallic substrates are transformed into other compounds within a cathode-anode system, depend on the typically excellent electrolytic characteristics of soil environments. The phenomena of soil-influenced corrosion is intricate and yet poorly understood because of the diverse dynamics and complexity of soil environments.

In recent years, it has become normal procedure to use geophysics to investigate the corrosivity of soils before

embedding pipelines therein. For a successful environmental impact assessment (EIA), it is necessary to understand the subsurface resistivity distribution for building projects that entail burying steel pipes and cables as well as other subsurface piping networks [5].

Due to various environmental variables like mineral composition, fluid content, water saturation, permeability, grain size, cementation level, fluid concentration, matrix conductivity, and soil porosity, the electrical resistivity of earth materials varies. By employing the electrical resistivity method, it is feasible to gauge the corrosiveness of soils in their natural setting. A potential link exists between low soil resistivity and a heightened corrosivity index of the soil material.[6].

According to [7], if the concentrations of sulfate and chloride in the soil are less than 200 and 100 mg/l, respectively, and the pH ranges from 5 to 9, with resistivity higher than 50 Ohm-m, the soil is commonly regarded as "mildly corrosive". The authors further stated that because anaerobic sulfate-reducing bacteria may easily convert sulfate above 200 mg/l in soils to highly corrosive sulfides, buried structural items can be seriously at risk of corrosion. The electrochemical characteristics of the soil mass, which are necessary for corrosional processes, are inextricably related to soil humidity and, by extension, soil wetness. These factors have a significant role in soil corrosion rates. Iron corrodes by an oxidative reaction in water even in the absence of oxygen [8]. Another physicochemical factor that indicates the changes in  $Fe^{2+}$  pitting, is the soil pH [9]. [10], in their paper showed that pH measurements boosted the correlation coefficient of resistivity based study for soil corrosivity investigation.

The petroleum and water sectors, and to a lesser degree the roadways sector, seem to have been the driving forces behind

the majority of corrosion investigations that have been documented in the literature. Given that cable design has often reduced this danger and there is a dearth of public information to the contrary, it seems that subsurface corrosional processes have minimal effect on the electrical and telecommunications industries. In addition, the application of cathodic protection have significantly decreased the effect of corrosion on electricity pylons [11].

In the Niger Delta, oil spills are a common occurrence and a significant cause of environmental deterioration. This cannot be ignored with a casual glance since it has led to serious conflict between the local populace and the international oil corporations doing business in the region. Over the last three decades, the study communities have had a notable number of environmental threats, with corrosion being a contributing factor in some situations. The current investigation consequently uses geoelectric method together with standard laboratory analytical procedures to explore the physicochemical parameters of soil that are associated with soil corrosivity.

## II. LOCATION OF STUDY

The research area is located between latitudes  $4^{\circ}45'0''N$  -  $4^{\circ}55'0''N$  and longitudes  $6^{\circ}15'0''E$  -  $6^{\circ}25'0''E$  (Figure 1). Major oil producing corporations in Nigeria own a network of petroleum pipelines inside this area. The Mbiama-Yenagoa road leads northward into the region, while the Nembe and Brass Rivers go southward. A network of pipeline installations is a common feature in zone of study well head sites, and accessibility is via an existing network of motorable roads connecting the different villages.

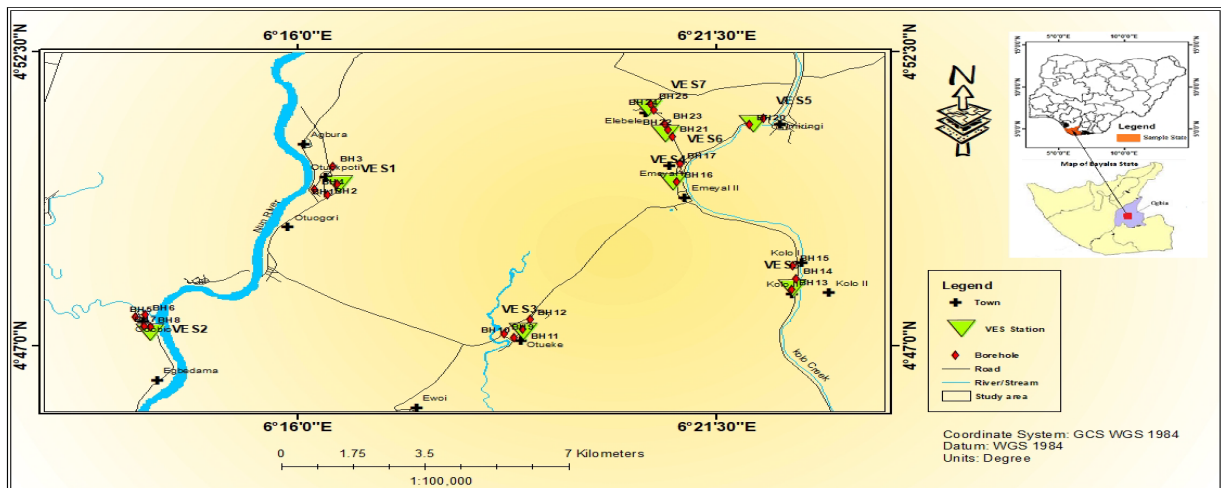


Fig. 1: Borehole/sample points



**III. METHODS OF STUDY**

The study methods include:

- (a) Sample collection and laboratory testing
- (b) Geoelectrical survey

**A. Sample collection and laboratory testing**

The soil samples were taken at a 1.5-meter depth below the surface. Given that oil pipelines are normally buried between 0.91 and 1.83 meters below the surface, the depth of 1.5 meters was selected. Using a hand auger, the soil samples were extracted from the boreholes. In order to ensure that the moisture content remained constant during the laboratory moisture content examination, each sample was placed within an airtight waterproof bag. To prevent any kind of artificial contamination, sampling was done in the field without the use of any preservatives. Using a Horiba U-10 digital meter, the sediment samples' pH and electrical conductivity were determined. In accordance with conventional protocols, an electrode was submerged in a 1:2 soil-water solution that had been shaken and allowed to equilibrate for around an hour in order to measure conductivity. Using a digital potentiometer, the samples' oxidation-reduction potential (ORP) was measured in accordance with the guidelines provided in reference [12]. Following the instructions in reference [13], the weight loss method was used to determine the moisture content (MC) of the soil samples. The methods used to measure the concentrations of carbonate, sulfate, and chloride were silver nitrate titration, turbidimetric technique, and thiocyanate titration, respectively.

**B. Geoelectrical survey**

The respective positions of the boreholes and VES are shown in figure 1. Data acquisition was conducted using the ABEM terrameter (SAS) 1000, which is equipped with an automated signal averaging microprocessor and a liquid crystal digital readout. The electrical resistance within the area was assessed employing the Wenner four-pin electrode setup [14]. Measurements were taken along two perpendicular axes (x, y) at each central point of the VES. Subsequently, the mean value was computed and documented. The method for determining the layer resistivities is:

$$\rho = 2\pi a \Delta V / I \tag{1}$$

In this equation, I denotes current, a stands for electrode spacing,  $\rho$  for apparent resistivity, and  $\Delta V$  for potential difference. You may rewrite equation (1) as follows:

$$\rho(xy) = 2\pi a R(xy) \tag{2}$$

Where R(resistance) =  $\Delta V / I$

The IP2win interpretation program was used to ascertain the resistivity, thickness, and depth of the geological strata based on the field geoelectric data that was obtained.

**IV. RESULTS AND DISCUSSIONS**

Table 1 and Figure 2 provide the results of the geoelectric results derived via vertical electrical sounding and laboratory testing respectively.

Table 1: Results of geoelectric survey

VES No.	Layer thickness (m)				Layer resistivity (Ohm-m)				
	$h_1$	$h_2$	$h_3$	$h_4$	$\rho_1$	$\rho_2$	$\rho_3$	$\rho_4$	$\rho_5$
1	0.86	1.79	2.25	4.65	234	81	346	1406	2820
2	0.75	1.18	6.82	7.74	146	215	771	1936	3387
3	0.92	1.5	2.4	5.9	114	53	451	279	165
4	0.55	1.72	3.33	9.67	83	157	30	307	1128
5	0.84	0.78	3.5	9.2	76	42	118	512	2453
6	0.79	1.25	2.16	8.4	388	135	517	1683	4864
7	0.65	1.58	4.06	7.2	172	32	278	644	1297
8	0.62	1.1	2.2	8.73	304	128	42	584	1765

**A. Soil moisture content**

The tested soil samples had moisture contents ranging from 23.2 to 42.5%. Just four out of the twenty-four samples showed moisture levels exceeding forty percent, while the remaining twenty samples had moisture content ranging between twenty and forty percent. The ones with higher moisture were labeled highly corrosive, whereas those with lower moisture were categorized as mildly corrosive towards

buried-galvanized steel and cast-iron components, all based on their moisture content.

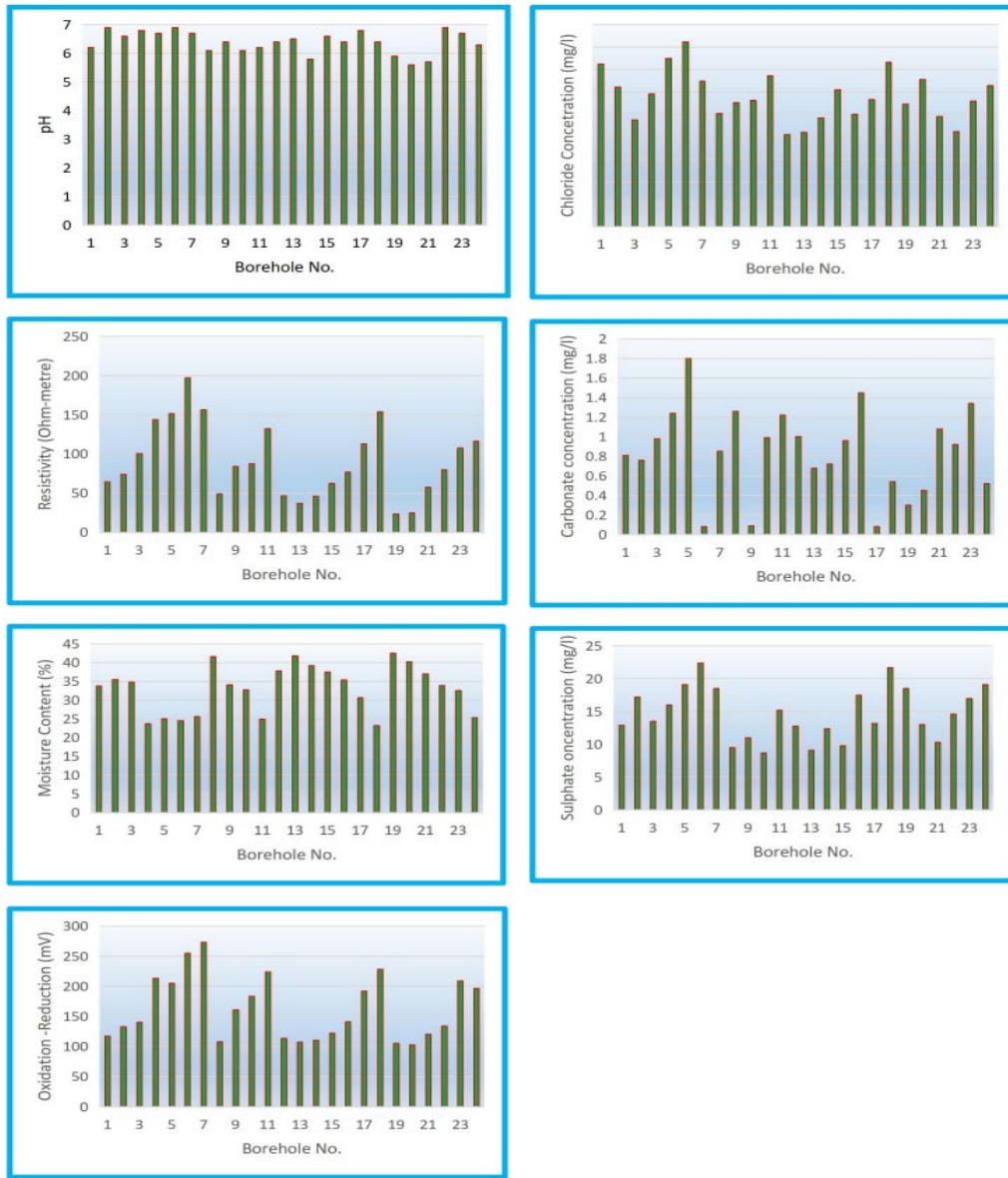


Figure 2: Results of soil physicochemical parameters

### B. Soil pH

The soil samples that were examined had pH values between 5.6 and 6.9, which means they ranged from mildly acidic to moderately acidic. 50% of the other samples had pH values between 6.0 and 6.5, which is mildly corrosive, or pH values between 6.6 and 6.9, which is inconsequential. Four samples, with pH values between 5.6 and 5.9, were classified as highly corrosive. Depending on the soil's redox potential, iron may either corrode slowly or be immune within the pH range of 4-

8.5 [15]. On the other hand, it has been proposed that near neutral pH levels allow the soil to support the growth of sulfate reducing bacteria (SRB), while low pH levels prevent the formation of the passive corrosion protective layer, resulting in increased corrosion rates [16].

### C. Sulphates, Chlorides and Carbonates

Anions that are very aggressive, including sulphates ( $\text{SO}_4^{2-}$ ) and chlorides (Cl), are often the source of corrosion pitting.

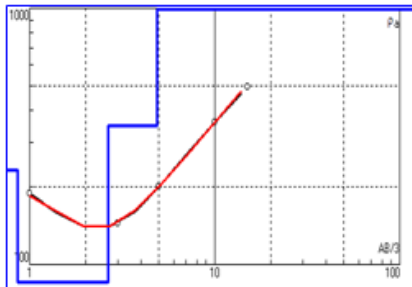


Sulfuric acid arises from the oxidation of pyrite ( $\text{FeS}_2$ ) through chemical and biological processes. This acid is known to be highly corrosive to metallic objects and carries the risk of contaminating both ground and surface waters. Specifically, chloride ions can induce pitting corrosion of passive films, leading to the degradation of buried metal assets. However, given that the levels of sulfates and chlorides in the soil samples analyzed in the research area are

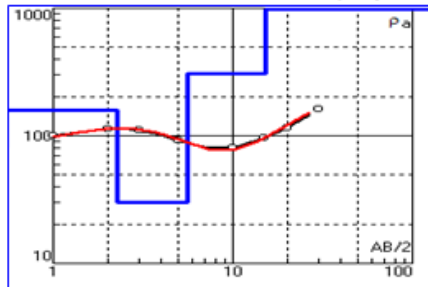
significantly below 100 and 200 mg/l, respectively, it is believed that their contribution to the overall corrosive nature of the soil samples is minimal. The findings also demonstrate that the amounts of carbonate ( $\text{CO}_3^{2-}$ ) in the tested soil samples are very low, seldom exceeding 1.5 mg/l. This might be explained by the heavy rainfall, which causes bases like carbonates to leach out of the soil in huge amounts and replaces colloidal complexes with hydrogen ions ( $\text{H}^+$ ) [17].

Table 2: Relationship between soil resistivity, chloride and sulfate and soil corrosivity

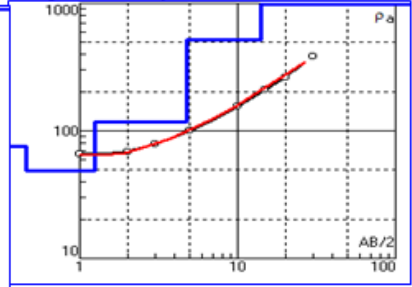
Soil parameter	Soil corrosive rate
Soil resistivity (Ohm-cm)	
>200	Non-corrosive
100 – 200	Mildly corrosive
50 – 100	Moderately corrosive
30 – 50	Corrosive
10 – 30	Highly corrosive
< 10	Extremely corrosive
Chloride (ppm)	
< 100	Non-corrosive
< 1000	Mildly corrosive
> 1000	Corrosive
Sulphate (ppm)	
< 100	Non-corrosive
< 1000	Mildly corrosive
> 1000	Corrosive



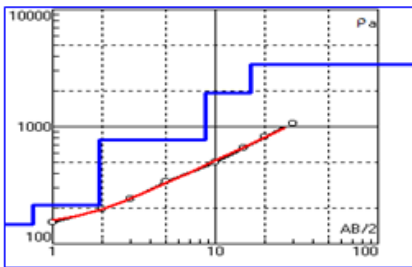
VES 1



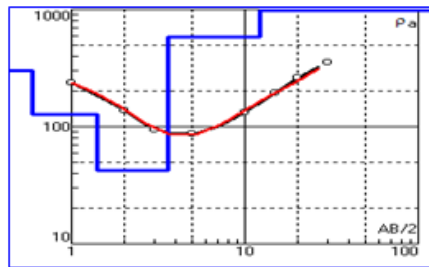
VES 4



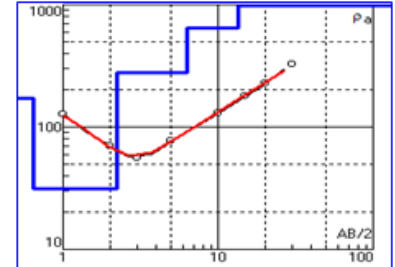
VES 7



VES 2



VES 5



VES 8

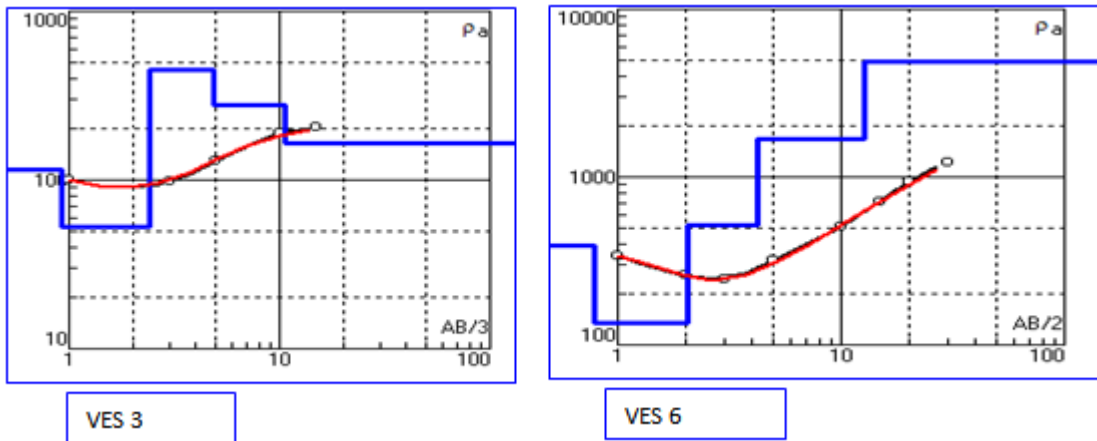


Figure 3: Modelled geoelectric curves

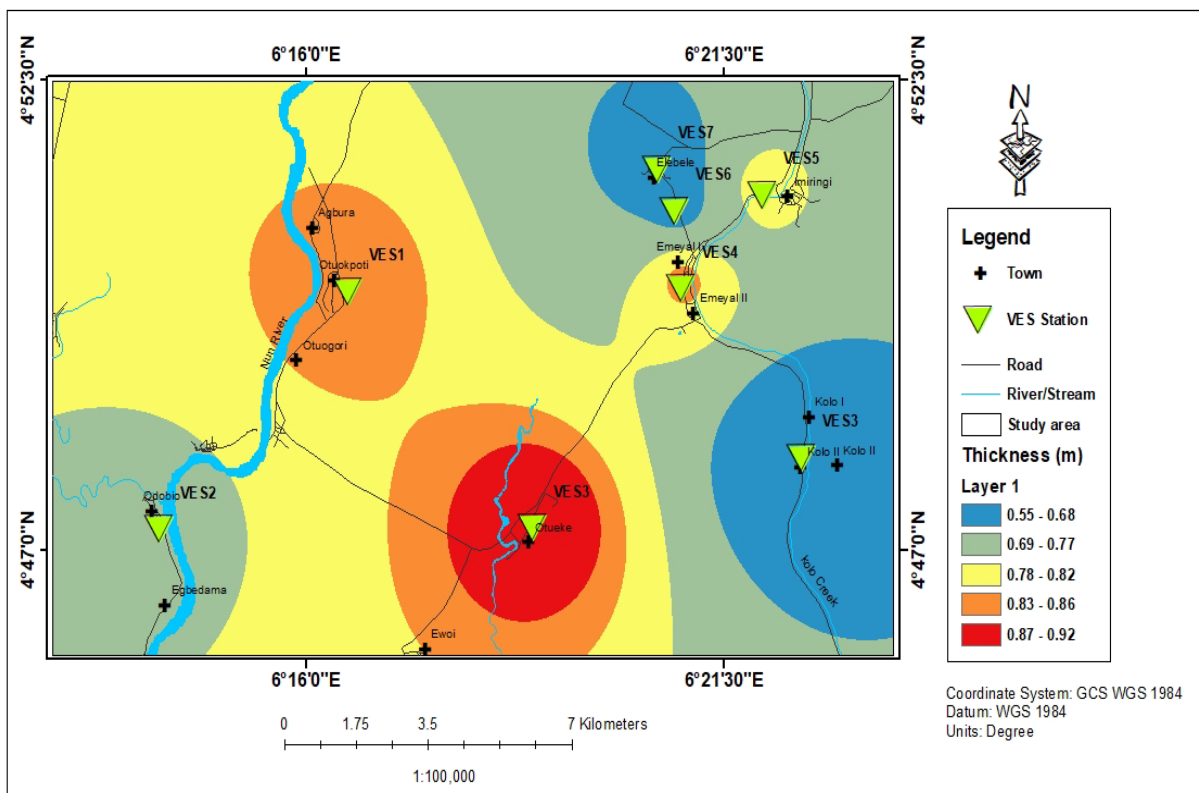


Figure 4: Thickness variation of Layer 1 across study area

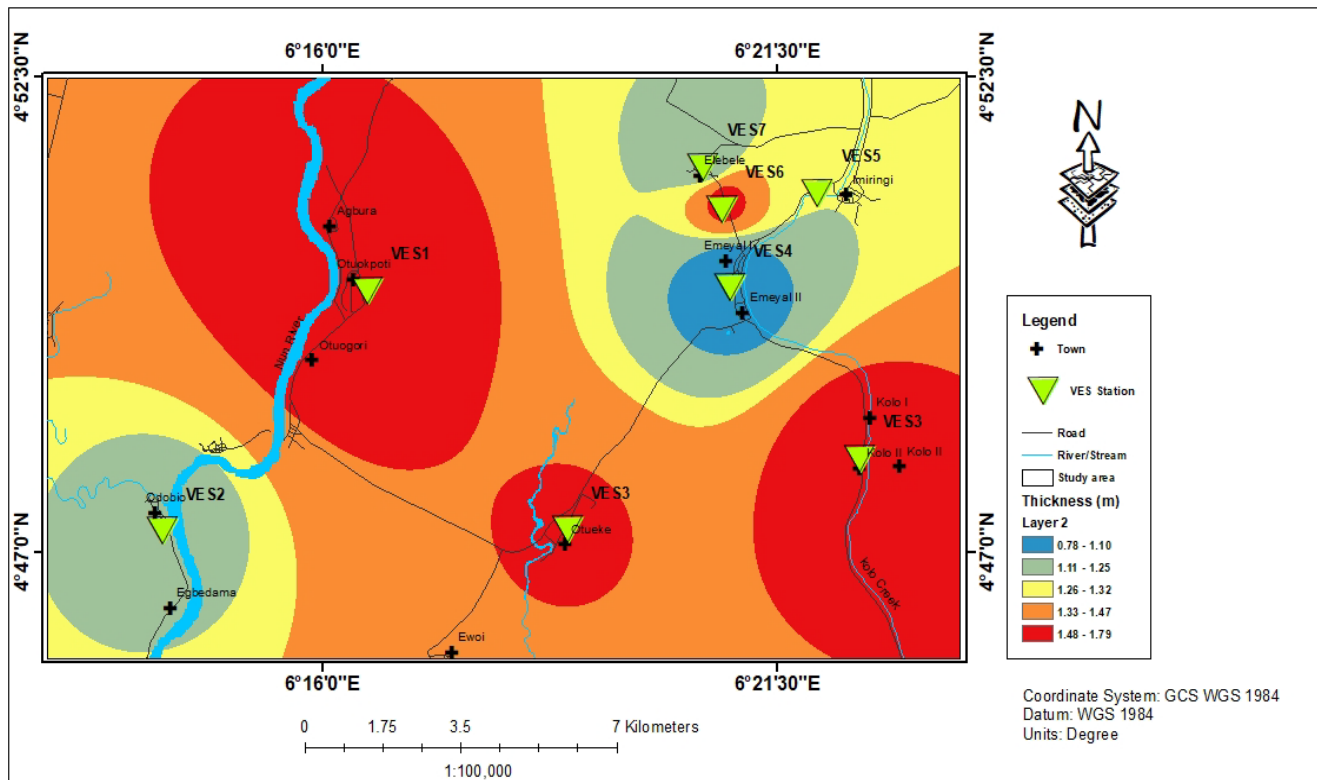


Figure 5: Thickness variation of Layer 2 across study area

#### D. Soil resistivity

The ability of soil to conduct corrosion currents is assessed by its resistivity. This study employed two techniques (sounding and laboratory analysis) to ascertain this property. The values for resistivity obtained from laboratory testing ranged from 23.6 to 197.2 Ohm-m for twenty-four samples, whereas processed data for the eight soundings carried out yielded results between 42 and 215 Ohm-m for the depth of 1.5m. Despite the marginal differences in measured resistivities, both methods revealed that values for specific sample/sounding sites predominantly fell within the same range of corrosivity ratings. Table 1 and figure 2 attest to the similarity of the corrosivity ratings. Figure 2 depict four distinct subsurface layers with resistivity values typically increasing with depth as represented in figures 4 to 7. This

suggests that metallic underground installations may exhibit lower susceptibility to soil corrosion at greater depths. In addition, the sounding data reveals a predominately low resistivity layer within the target depth of 1.5 meters, occurring between 0.75 and 2.2 meters. The underlying layer, with resistivity ranging from 30 to 771 Ohm-m at depths of 2.2 to 5.54 meters, is presumed to be less prone to corrosive effects. The physicochemical data as seen in figure 2 reveal that 25% of the soil samples had values of resistivity below 50 Ohm-m, 33% between 50 and 100 Ohm-m, and approximately 42% had resistivities between 100 and 200 Ohm-m. From the foregoing, the tested soil types are respectively categorized as corrosive, moderately corrosive, and mildly corrosive, respectively.

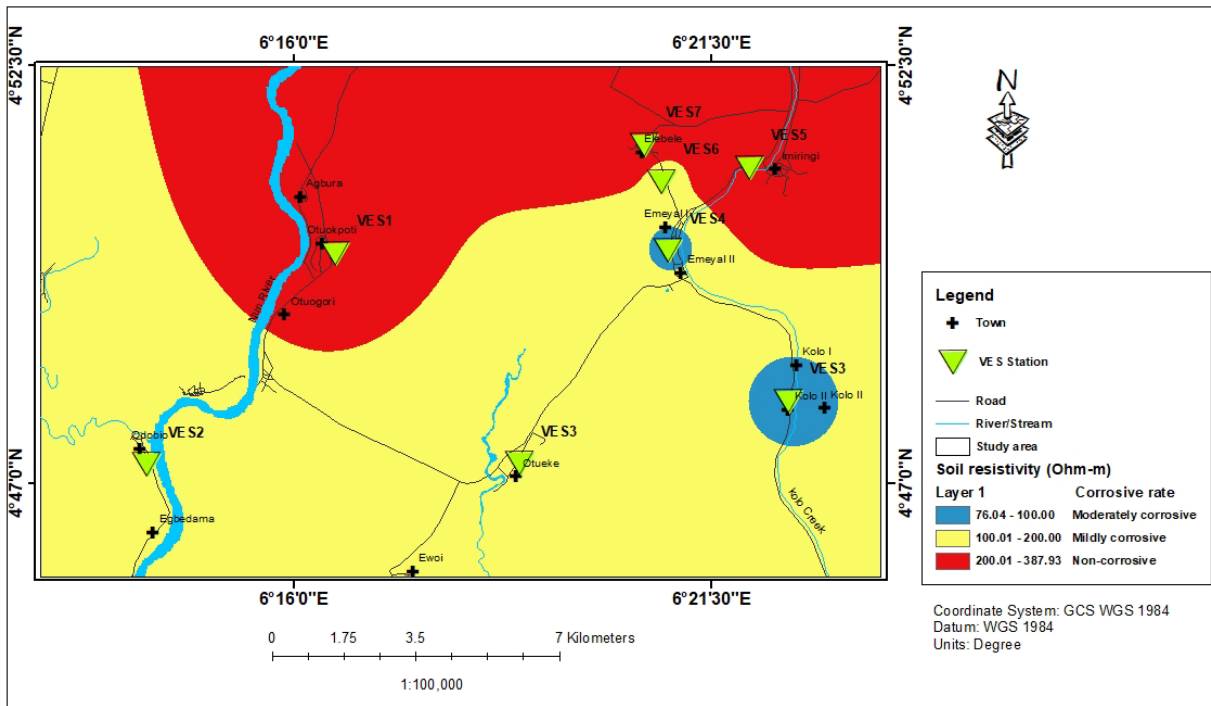


Figure 6: Soil corrosivity for layer 1 in the study area

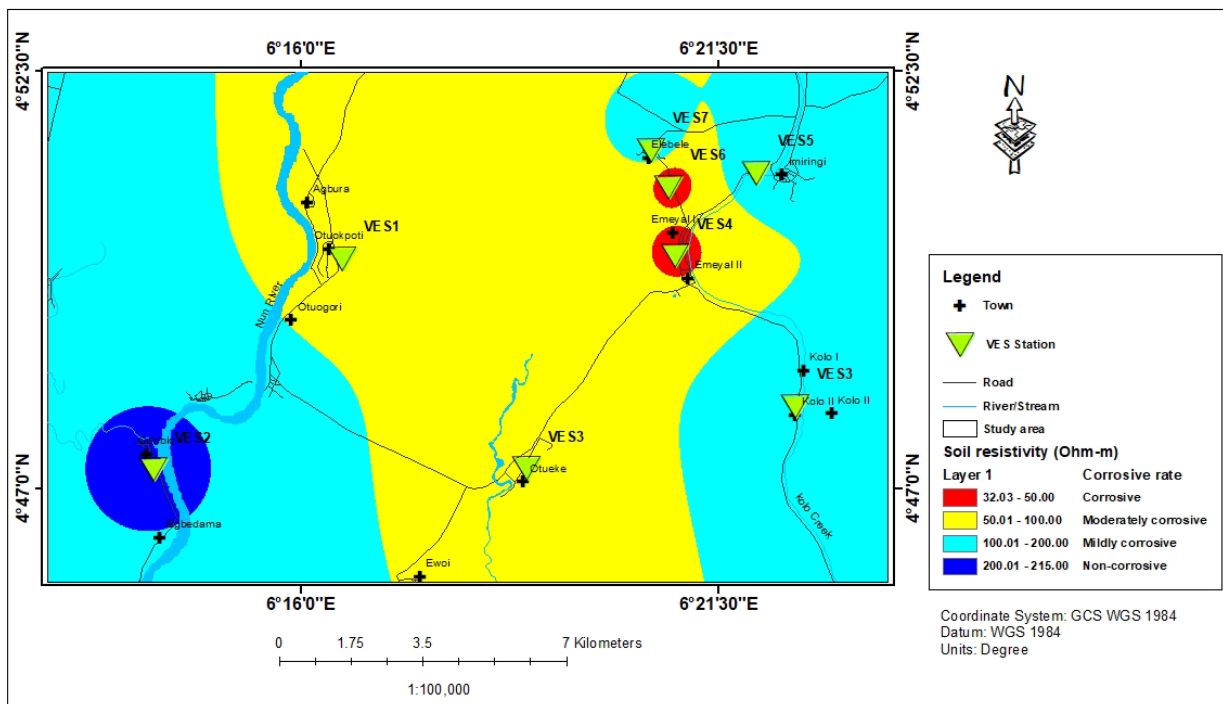


Figure 7: Soil corrosivity for layer 2 in the study area





**E. Oxidation-reduction potential**

The value of the oxidation-reduction potential (ORP) of a given soil is another parameter that is essentially determined to understand why soil erodes underground structural components, especially, iron pipes. Low oxygen soils with an ORP of less than 100 mV often inhibit the production of mild oxide layers on the facility’s surface since oxygen is required for the reaction to continue [18]. Moreover, the ORP of a certain soil may be used to determine if sulphate reducing

bacteria (SRB), a major cause of corrosion, are present in the soil. Since low oxygen levels in the soil increase the sulfide content of the soil by converting sulphate to sulfide, low ORP is optimal for SRB formation. According to the study's distribution of ORP values, seven soil samples were classified as moderately corrosive because their ORP values fell between 100 and 200 mV, whereas seventeen soil samples were classified as mildly corrosive because their ORP values fell between 200 and 400 mV [19].

Table 3: Corrosivity rating based on oxidation-reduction potential of soils [19]

Oxidation-reduction potential (mV)	Soil corrosivity
>400	Non-corrosive
201 - 400	Mildly corrosive
100 - 200	Moderately corrosive
< 100	Severely corrosive

**F. Corrosivity rating**

Soil corrosivity is the product of a number of contributing physicochemical components. It is vital to identify the contributing factors and then evaluate the aggregate for each sample that was analysed. Analysis of the integrated results presented in Table 1 to 3 and figure 2, shows that 11 samples were classified as highly corrosive, while 13 samples fell into the moderately corrosive group, according to the final findings. Corrosivity contour maps showing the variation in layer thickness and corrosivity of the layers from both the field and lab research is shown in Figures 4 - 7. From the figures, the central section of the research area is potentially the most corrosive to buried metals, while the flanks to the east and west are relatively the least corrosive for the target depth of 1.5m (layer 2). Additionally, corrosivity in the research region increased from north to south with pockets of low and high resistivity values dotting the eastern and western flanks for layer 1 (0.55m -0.92m).

between 0.55 - 0.92 m and has resistivity between 83 - 388 ohm-m. The second layer (resistivity as low as 32 Ohm-m and thickness ranging between 0.75 – 2.2m) is underlain by two successive layers with noticeably greater maximum resistivities (771 and 1936 Ohm-m) and maximum thickness of 6.82 and 9.67m respectively. Since most oil pipeline networks are contained within the relatively more corrosive second geoelectric layer (0.75 to 2.2 m), it is crucial to implement adequate preventive and corrosion control measures to avoid pipe failures caused by corrosion effects.

**V. CONCLUSION**

The physicochemical elements that influence soil corrosivity are interconnected and cannot be considered in isolation. In this paper, various factors that impact soil corrosivity have been systematically evaluated. Laboratory tests conducted in the study indicate that out of the 24 samples analyzed, 13 were mildly corrosive, while 11 were moderately corrosive. The sounding results identified four distinct geoelectric layers. Resistivity values obtained from the laboratory investigation and the sounding were found to be strongly correlated. The geoelectrical results further reveal that the corrosivity of the research area decreases from north to south in the top layer, with the eastern and western regions exhibiting lower corrosivity rating values. The top layer thickness ranges

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