



The Potential Corrosiveness of Soil Physico-Chemical Properties on Pipelines

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Authors' contributions

This work was carried out in collaboration among all authors. Authors EAOE, EF and UVO designed the study, performed the statistical analysis and wrote the protocol. Author EF wrote the first draft of the manuscript. Author NPT managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The study was conducted to determine the potential corrosiveness of selected soil physicochemical properties on pipelines.

Study Design: Soil samples were randomly collected around five pipeline locations with control from a farmland.

Duration of Study: The study lasted for three months.

Methodology: Standard methods were adopted in the collection of samples and the determination of the physicochemical properties of the samples.

Results: Metallic pipelines undergo more regular corrosion because they are used in environments like soil where they are chemically unstable. Soil physicochemical properties such as soil moisture, texture, pH and temperature, sulphate, chloride, redox potential and resistivity were determined. The pH of the five soil samples was acidic (pH =4.0 – 6.5), The highest moisture content was 22.88% while the lowest was 9.84%. The soil samples the potential of being corrosive to the buried galvanized-steel and cast-iron pipes. Delta Steel Company (DSC) roundabout had the highest

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sulphate content of 724.13 mg/kg while the lowest was Oleh with 156.14 mg/kg. The highest percentage of Total Organic Carbon was 0.52% and the lowest was 0.40%.

Conclusion: Besides pipeline vandalization, pipeline corrosion may likely be one of the major causes of oil spillage in localized underground pipelines within the region. There is, therefore, an urgent need for computerized sensors to assist in the monitoring of underground pipeline integrity in Nigeria.

Keywords: Pipelines; corrosiveness; soil; physico - chemical properties.

1. INTRODUCTION

The soil is a complex environment which is influenced by an array of underground factors. These factors influence soil degradation activities. The electrochemical nature, soil type and soil texture are part of the major properties that affect the corroding ability of any soil sample [1,2].

Naturally, all types of materials stand the chance of corroding. However, metals undergo more regular corrosion because we use them in environments like soil where they are chemically unstable. Nearly all metals, except copper and the precious metals (gold, silver, platinum, etc.) are processed from minerals which are inherently unstable in their environments [3]. Industries experience large economic losses due to failure of metallic structures that constitute facilities such as bridges, concretes, pipelines etc [4,5,6].

Millions of tons of metals are found partially or completely buried underground due to engineering projects [7]. Since these projects are inevitable in our societies, therefore, the need for corrosion control is critical. The method of corrosion control is subject of economic importance, technical variables and the demand for safety [8,9,10]. Material selection and system design, corrosion mitigation/prevention, corrosion assessment and pipeline inspection and monitoring are the four components involved in corrosion control activities [11,9].

The physicochemical properties of soil are imperative in the study of pipeline corrosion. Soil properties play a vital role in influencing soil reaction with various substances. Soil corrosiveness is chiefly responsible for the failure of buried pipelines [12,13,14,15,16,17,18,19]. Clay, silt, loamy and sandy soil or fine and coarse soil are various classifications of soil based on the sizes of their inorganic contents [20]. These soil classes go a long way to influencing the pH, moisture content, aeration, temperature, resistivity, soil type, soil particles,

permeability, and the presence of sulphate-reducing bacteria in the soil.

Hou et al. [21] had reported 10% increase in the annual cost of pipeline replacement due to an average of 20 breaks/100 km/year in Australia. According to Belmonte et al. [22], pipelines are designed to have service life exceeding 50 years. However, this is not the case as we see our pipelines age very fast due to internal and external damages of protective coatings, poor repair and maintenance of the lines.

2. MATERIALS AND METHODS

2.1 Sample Collection

Soil samples were collected from five pipeline locations and farmland. Soil samples were obtained at a depth of 5 to 10 cm and at a distance of 1 cm from pipelines, from agricultural soil (100 meters away from pipeline areas). They were collected into airtight polyvinyl bags to ensure that there was no loss of moisture content. The coordinates were determined with the Global Positioning System (GPS). The sampling location and coordinates are represented in the Table 1.

The Plate 1 is dried soil samples collected from five pipeline locations in Delta state.

2.2 Determination of Moisture Content

The oven-drying method (ODM) was used to determine the moisture content of the soil. The percentage of moisture was calculated by the formula in equation 1

$$\% \text{ M.C} = \frac{(W_2 - W_3)}{(W_3 - W_1)} \times \frac{100}{1} \quad (1)$$

Where

W1 = Weight clean dried aluminium container
W2 = Weight of wet soil in the aluminium container

W3 = weight of soil in the container after drying
 M.C = Moisture content
 % = Percentage

The Inverse of Electrical Conductivity was used to derive Resistivity ($1/EC = R$)

2.3 pH, Redox Potential and Temperature

The electrometric method was used to determine the pH of the soil samples. Temperature and Redox potentials were determined by changing the metering mode of a Hanna temperature meter.

2.5 Total Organic Carbon (TOC) and Total Organic Matter (TOM)

The samples were prepared and titrated through standard procedures [24]. Thereafter the total organic matter (TOM) was determined by the formula in equation 2

2.4 Electric Conductivity (uS/cm) & Resistivity (Ω-m)

With the aid of a scientific conductivity meter, standard procedures according to the method used in [23] were used to determine the electrical conductivity and resistivity of the soil.

$$\% \text{ Organic Carbon} = \frac{(\text{Meq FeSO}_4 \text{ for blank} - \text{Meq FeSO}_4 \text{ for sample}) \times 0.003 F \times 100}{\text{Weight of air-dry soil}} \quad (2)$$

Where:

Correction factor (F) = 1.33

Meq = normality of solution × ml of solution used

Table 1. Global Positioning System (GPS) reading of the sampling location

Sample location	Global Processing System (GPS) Reading	
FUPRE Pipeline	5 ⁰ 34'12.4" N 5.570116	5 ⁰ 50'15.6" E 5.837659
Oleh community pipeline	5 ⁰ 27'17.2" N 5.454784	6 ⁰ 12'33.5" E 6.209304
Olomoro community pipeline	5 ⁰ 25'41.9" N 5.428303	6 ⁰ 09'24.1" E 6.156681
DSC pipeline	5 ⁰ 34'26.0" N 5.573884	5 ⁰ 48'39.9" E 5.811071
Ugbomoro pipeline	5 ⁰ 34'20.7" N 5.572422	5 ⁰ 49'44.0" E 5.828899
Iteregbi farmland (control sample)	5 ⁰ 34'33.2" N 5.575854	5 ⁰ 50'28.1" E 5.841139



Plate 1. Dehydrated soil sample for analysis of physicochemical properties

The total organic carbon was thereafter determined by the formula in equation 3

$$\% \text{ Organic Matter} = \% \text{ Organic Carbon} \times 1.729 \quad (3)$$

2.6 Sulphate (SO₄²⁻)

After preparation of soil samples according to standard procedures for determination of sulphate absorbance, absorbance due to sulphate was obtained by the formula in equation 4

$$Y = Mx + C \quad (4)$$

Where:

$$x = \frac{Y - C \times \text{Dilution Factor}}{M}$$

Y = Absorbance of Standard
 x = Concentration of Sample
 C = Intercept on the y-axis
 M = Gradient from the graph

2.7 Available Phosphate (PO₄²⁻)

5 g of air-dried and sieved soil sample was weighed into a 15 ml centrifuge tube and 20 ml of the extracting solutions (Ammonium Fluoride and Hydrochloric Acid) were added. It was shaken for 1 minute on a mechanical shaker and the suspension was centrifuged at 2,000 rpm for 15 minutes. Distilled water was added to the

solution to a volume of 40 ml. 5 ml of Antimony Molybdate was added to the solution, followed by adding 2 ml of stannous chloride. The blank solution was subjected to the same treatment as the sample. After about 10-20 minutes, the absorbance of both sample and blank solution were measured with UV-Visible spectrophotometer at a wavelength of 680 nm.

2.8 Particle Size (Mechanical Analysis)

The hydrometer method of Bouyoucos as described in [25] was used to determine the particle size of each soil sample. Then the percentage sand, clay and silt were determined using:

$$\text{Sand} = 100 - \{H_1 + 0.2 (T_1 - 68) - 2.0\}^2$$

$$\text{Clay} = \{H_2 + 0.2 (T_2 - 68) - 2\}^2$$

$$\text{Silt} = 100 - (\% \text{ sand} + \% \text{ clay})$$

Where:

0.2 (T₁ - 68) is constant and = Temperature and hydrometer correction

-2.0 is constant and = Salt correction to hydrometer reading.

2.9 Textural Class

The soil textural triangle and table method as illustrated in Fig. 1 was used to determine the particle size.

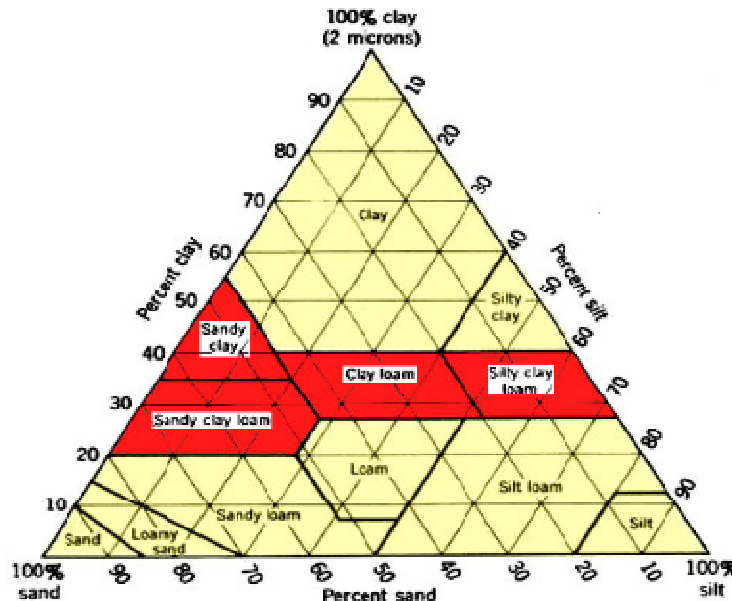


Fig. 1. Soil textural triangle sourced from [26,27]

Table 2. Textural components of different soils

Common names of soils (General texture)	Sand	Silt	Clay	Textural class
Sandy soils (Coarse texture)	86-100	0-14	0-10	Sandy
	70-86	0-30	0-15	Loamy sand
Loamy soils (Moderately coarse texture)	50-70	0-50	0-20	Sandy loam
Loamy soils (Medium texture)	23-52	28-50	7-27	Loam
	20-50	74-88	0-27	Silty loam
Loamy soils (Moderately fine texture)	0-20	88-100	0-12	Silt
	20-45	15-52	27-40	Clay loam
	45-80	0-28	20-35	Sandy clay loam
	0-20	40-73	27-40	Silty clay loam
Clayey soils (Fine texture)	45-65	0-20	35-55	Sandy clay
	0-20	40-60	40-60	Silty clay
	0-45	0-40	40-100	Clay

2.10 Chloride (Cl⁻) in Soil

In determining the chloride concentration in the soil sample, 20 g of each air-dried sample was measured into 250 ml of the conical flask. 100 ml of distilled water was added and samples were subjected to mechanical shaker for 30 minutes. The mixture was filtered and the filtrates of the samples were then made up to 100 ml with distilled water. Thereafter, the samples were titrated with K₂CrO₄ as an indicator, and with 0.014N AgNO₃. The mixture was titrated from yellow to reddish-brown colour. The end-points were observed and recorded. Thus, their concentrations were calculated using the formula in equation 5:

$$\text{Chloride (Cl}^-) = \frac{35.5 \times C_b \times V_b}{\text{Vol. of Sample}} \times 1000 \quad (5)$$

Where:

C_b = Concentration of AgNO₃ (Normality)

V_b = Volume of AgNO₃ (Consumed)

2.11 Determination of Total Nitrogen (NH₄-N) in Soil Using the Regular Macro-Kjeldahl Method

The total percentage of nitrogen was determined using the regular Macro-Kjeldahl method [28,29].

3. RESULTS AND DISCUSSION

The physicochemical parameters of the soil samples are provided in Table 3. Soil physicochemical properties are potential environmental factors that can affect the corrosion of pipes lines. Most of the factors represented in the results are not independent of

each other. From the table, the finding agrees with the results of [30] as soil resistivity has no linear relationship with moisture content. Soil moisture content usually has a direct relationship with soil aeration and aeration is largely influenced by rainfall and microbial activities.

The pH of the soil can pose potential effect on pipeline corrosion since the media under which the pipe is laid influence rate of corrosion. It is, however, important to state that pH does not operate independently of other physicochemical properties of the soil. From the result (Table 3) obtained the entire five samples had acidic pH (4.0 – 6.5) unlike the control with pH of 7.44. This study agrees with the finding of [31] who stated that soil pH at 7 has been confirmed to be the soil with the mildest level of corrosion on metallic pipelines. However, the soil within the ranges of 5 - 8.5 is not considered problematic to buried pipelines. It is important to note that there is a possible increase in the rate of corrosion with underground pipelines in acidified soil. The acidity of the soil within the sampled region may have been influenced by acid rainfall and acid-producing bacterial organism in the soil.

The result (Table 3 and Fig. 2) also showed that Ugbomoro had the highest moisture content of 22.88% (while Oleh had 9.84%. Increase in moisture content reduces the resistivity of soil and dry soil will certainly discourage the corrosion of metallic pipelines. The research also shows that clay soils have more moisture retaining capacity than sandy and rocky soils. Therefore, the soil samples are categorized to possess milder corrosiveness potential towards buried-galvanized steels and cast-iron pipelines within the respective localities.

Table 3. Results of the physicochemical parameter analysis of soil samples

Sample locations	Units	Fupre	Oleh	Olomoro	Ugbomoro	DSC roundabout	Iteregbi farmland (control sample)
Soil pH		4.74±0.1	4.46±0.11	4.53±0.1	4.83±1.08	6.05±1.08	7.44±1.08
Temperature	°C	29.05±1.12	29.1±1.2	28.5±0.5	27.6±0.9	28.8±0.06	28.65±1.07
Electrical conductivity	µS/cm	181.1±1.13	50.45±1.05	41.2±1.14	44.65±1.12	52.24±1.75	70.1±1.12
Electrical resistivity	Ω-n X 10 ⁻²	0.53±0.1	1.93±1.5	2.13±1.7	2.21±1.2	1.9±1.14	1.33±1.2
Redox potential	Mv	27.6±1.01	88.7±1.1	103.9±1.1	91.70±1.09	47.60±1.11	-29.8±1.1
Moisture content	%	14.38±1.13	9.84±1.1	12.36±1.02	22.88±1.1	13.7±1.05	10.58±1.2
Textural class		Loamy sand	Loamy sand	Loamy sand	Clay loam	Sandy	Loamy
Chloride	mg/kg	10.01±1.1	82.6±1.12	12.50±1.08	25.01±1.2	82.6±1.16	17.50±1.16
Total organic carbon	%	0.76±0.15	0.4±0.27	0.52±0.13	1.12±1.2	0.44±0.9	1.28±1.01
Total nitrogen	%	0.05±0.01	0.02±0.01	0.003±0.01	0.07±0.012	0.02±0.011	0.09±0.01
Sulphate	mg/kg	510.02±1.2	156.14±1.4	447.71±1.5	390.63±1.02	724.13±1.53	848.5±1.7
Phosphate	mg/kg	16.09±0.1	17.2±0.9	33.05±1	40.54±1	28.42±1.02	168.91±1.1

It was discovered that the soil sample from FUPRE had the lowest electrical resistivity (Fig. 3) and thus it is liken to have higher corrosive potential compared to the other soil. The soil samples were considered to be corrosive towards the buried-metallic materials because their redox potential value is less than 100 according to the classification

standards published by [32,33] From research, it has been observed that the lower the redox potential of the sample, the higher the corrosiveness of the soil to the buried pipeline. From Table 1, it is observed that the control had the lowest of -29.80 and Olomoro with 103Mv had the highest value.

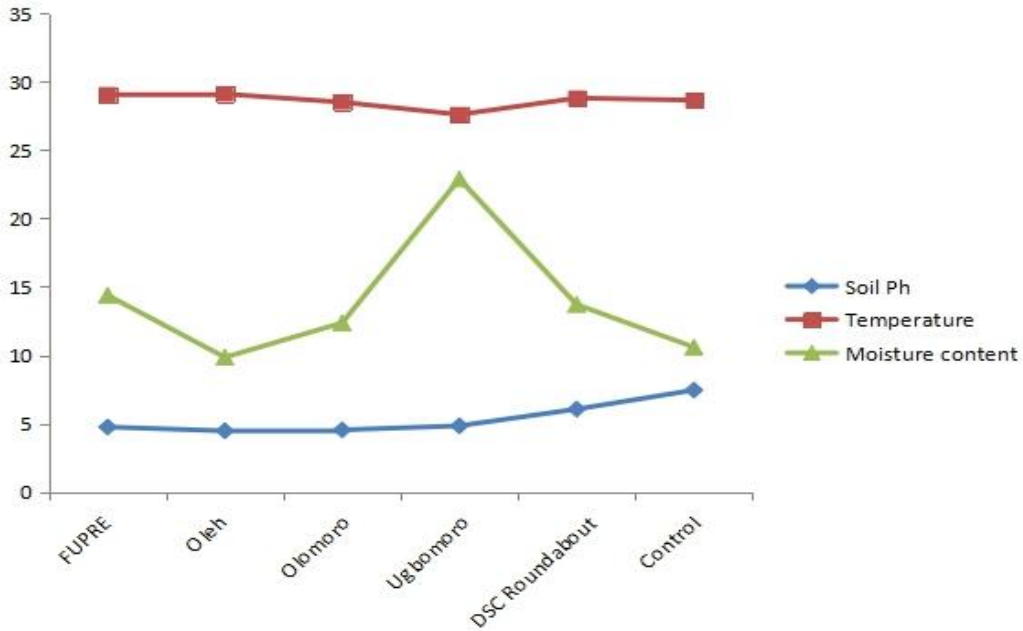


Fig. 2. Graphical representation of pH, temperature and moisture content

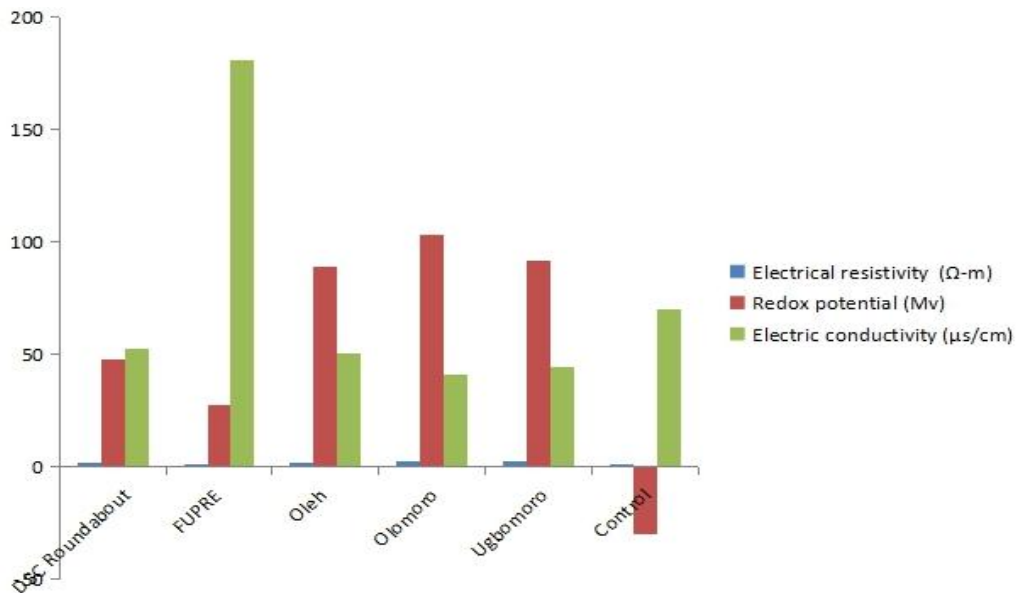


Fig. 3. A graphical representation of electrical conductivity, Redox potential and electrical resistivity

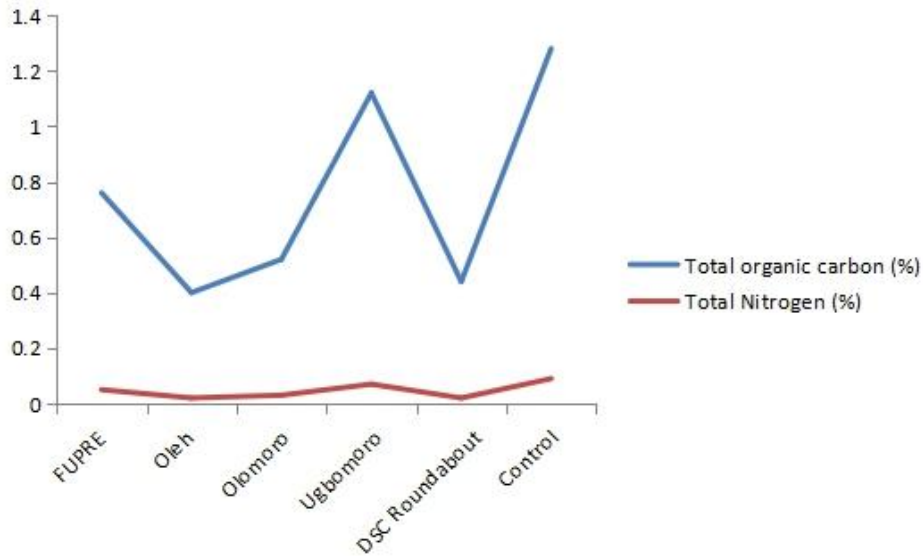


Fig. 4. A graphical representation of total organic carbon and total nitrogen in the soil samples

Among the soil samples, collected for this analysis, it was revealed that the majority of the soil samples contained greater than 200 mg/kg sulphate. Therefore it is considered to be corrosive for the buried galvanized-steel and cast-iron pipes. From Table 3, based on sulphate concentration, it is observed that the soil sample with the highest potential of corroding buried pipes is DSC roundabout with sulphate content of 724.13 mg/kg and the soil sample with the lowest corrosive ability was Oleh with 156.14 mg/kg.

In the terms of Total Organic Carbon; a measure of the carbon contained within the soil (organic matter such as plant and animal residue) as represented in Fig. 4 above, besides Itegbi farmland (control sample), Ugbomoro recorded the highest percentage of 0.52% and the lowest was Oleh with 0.40%. Research has shown that the percentage of the total organic carbon in soil is directly proportional to the rate of the corrosiveness of a particular soil. Therefore there is possibility of the organic carbon in the soil to react with water and other compounds to form weak acids which will eventually corrode the buried metal pipes.

4. CONCLUSION

Soil physic-chemical properties such as soil moisture, texture, pH and temperature, sulphate, chloride, redox potential and resistivity are important parameters that affect corrosion of buried pipelines. From the result of the studies, it

is imperative to say that in the absence of vandalization, good pipeline maintenance practice, corrosion is likely one of the major cause of oil spillage in the localised underground pipelines.

5. RECOMMENDATIONS

The need for modern security devices through computerized sensors in the checkmating of underground pipeline integrity can never be overemphasized. This measure will periodically help to check the integrity of buried pipes and ensure that the pipes are maintained before they are corroded. Periodic soil test and treatments should be done in localities with pipeline installation to extend the life span of the pipes.

DISCLAIMER

The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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