



Study on the Corrosive Nature of Soil Physico-Chemical Characteristics Toward Pipelines in Oil Producing Communities in Niger Delta of Nigeria

**Eunice Asiboroko Odesiri-Eruteyan^{a*}, Okorhi Folawe Beatrice^a
and Ogwuche Christiana Ene^b**

^a *Department of Environmental Management and Toxicology, Federal University of Petroleum Resources Effurun, Delta State, Nigeria.*

^b *Department of Chemistry, Federal University of Petroleum Resources Effurun, Delta State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: This research was carried out to investigate physicochemical characteristics of soils in oil producing areas of Delta State, Western Niger Delta region of Nigeria as they influence corrosion of buried pipelines in the region.

Study Design: Soil samples were collected along oil pipelines and at 500m away in three oil producing communities (Kokori, Otu-Jeremi and Okpai) in Delta State. Duration of Study: The study lasted for eighteen months.

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

Results: The soil characteristics could influence soil corrosiveness towards buried pipelines. Soil characteristics determined were texture, soil pH, moisture content, temperature, nitrogen content, redox potential, electrical conductivity, phosphorus, sulphate, sulphide and chloride content and total organic carbon. The pH of all the soil samples was acidic (pH=5.54±0.16-6.32±0.29), soil from Okpai pipeline area had the highest electrical conductivity, chloride content and silt content of 148.00±3.02 µS/CM, 23.32±2.67 mg/g and 39.96±4.26 % respectively. Sulphate content of the soil

*Corresponding author: E-mail: Odesiri.eunice@fupre.edu.ng, okorhi.beatrice@fupre.edu.ng;

samples was lower than 200ppm. The values were lower in soils along pipeline than soils in the farmland.

Conclusion: The soil samples have the potentials of being corrosive towards buried metal pipes. There is need for safe practices in the region.

Keywords: Corrosion; electrical conductivity; redox potential.

1. INTRODUCTION

Soil constitutes the most complex part of the environment known to cause metallic corrosion. Soil like any other part of the environment can be corrosive. This is an issue all over the world as many of our facilities that industries depend on are buried below the ground [1-4]. Depending on the soil, some soil types are more corrosive than others. Soil corrosive potential can be influenced by origin, location, climate, presence of living things and man's activities. The character and quantity of soluble salts combine with moisture content of the soil greatly influence the potential of the soil to transfer electric current [2,1]. Smooth grained soils like clays and silts are known to have higher corrosion potential since they usually have reduced hydraulic conductivity leading to build-up of acidic and basic materials which will not wash away rapidly. While granular soils like sands and gravels have high hydraulic conductivity, hence low corrosion potential leading to leaching of accumulated soils. Soils with smoother particles are known to have worst corrosives for underground facilities. Clay soil takes up more water since it has larger surface and strongly efficient in reduction of metals [2,1,5].

It is known that the surrounding environment as well as the physicochemical characteristics of materials greatly affects the material degradation rate [6]. Estimating the corrosiveness of soil is important for designing underground structures and for assessing the risk in engineering practice [7]. Although soil corrosion can cause structural failure and financial losses, it is imperative to have an indepth knowledge of the corrosive ability in a particular environment. It is important to take into account some mitigating measures during design and production process [1,4]. Generally, the following measurements determine corrosiveness of a soil including aeration, moisture content, temperature, soluble salt content, soil type, redox potential, soil resistivity and presence of microbes in the soil. One single factor should not be used to determine soil corrosiveness [1,8,4].

2. MATERIALS AND METHODS

2.1 Sample Collection

Soil samples were collected from a depth of 5 to 10cm and from a distance of 1cm from pipelines and flow stations, and from farmland soil (500meters far from pipeline location) for comparison. Soil samples were collected from oil-producing communities in Kokori (Erhieke Town), Otujeremi and Okpai with Global Positioning System (GPS) Reading of 05°38'58.2"N, 006°04'10.1"E, 05°34'45.4"N, 005°59'05.7"E for test and control samples respectively from Kokori community, 05°26'07.3"N, 005°52'56.8"E, 05°30'12"N, 005°49'18"E for test and control samples respectively from Out-Jeremi community and 05°40'03.7"N, 006°30'39.2"E, 05°40'06.4"N, 006°30'45.5"E for test and control samples respectively for Okpai community. Parameters analyzed were: soil texture, soil pH, moisture, temperature, nitrogen, phosphorus, redox potential, electrical conductivity, sulphate, chloride and total organic carbon. Soil samples were obtained from the locations in the months of January, July and December which included the dry and wet seasons. Soils were collected from the respective locations using a soil auger, air-dried and sieved to remove gravel, debris and chunks. The soils were thoroughly mixed to make them more homogenous and placed in labeled sterile polyethylene bags. Soil samples collected from the different locations were immediately taken to the laboratory.

2.2 Determination of Moisture Content

The moisture content was evaluated using oven-drying method by [9]. A clean aluminium container was dried and weighed (as W_1). A required quantity (50g) of wet/moist soil was weighed in the same container (as W_2). It was then placed in an oven for 24hours at 105°C. It was removed and allowed to cool and weighed with the same container (as W_3). The formula below was used in calculation:

$$\% \text{ Moisture Content} = \frac{\text{weight of wet soil} - \text{weight of dry soil}}{1} \times 100$$

Weight of dry soil

$$\% \text{ M.C} = \frac{(W2 - W3)}{(W3 - W1)} \times 100$$

2.3 pH, Redox Potential & Temperature

The pH, redox potential and temperature were determined in the soil by electrometric method. Hanna Temperature Meter was used for the reading. A 10g of air-dry soil was weighed into a beaker and 25ml of distilled water was added. This was kept in a shaker for 1hr for stirring. The meter was powered-on and the probe of the meter was inserted into a 1:2.5 soil/water suspension and the reading was taken and recorded, Temperature and redox potential were determined by moving the meter mode to temperature and redox potential [10,11,12].

2.4 Electric Conductivity (uS/cm)

Electrical Conductivity was determined using Scientific Conductivity Meter. 10g of air-dry soil (passed through 2mm sieve) weighed into a 50ml beaker. 25ml of distilled water was added and stirred. Then the electrode of the conductivity meter was inserted into the settled suspension, and the EC measurement value was taken [13].

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

Organic carbon was determined by the chronic acid wet digestion method of Walkley and Black (1934).

A 0.5g of soil sample that has passed through 60 mesh was treated with 10ml of 1M $K_2Cr_2O_7$ and 20ml of concentrated H_2SO_4 . The mixture was swirled gently until reagents were mixed, then more vigorously for 1 minute. It was allowed to cool for 30 minutes before the addition of 20ml of distilled water. 2.5ml of 0.5N of Ferrous ammonium sulphate were added and then titrated with 0.4N of potassium permanganate under bright light. The organic matter content was measured by heating air dried soils (1g) in a muffle furnace at $575^{\circ}C$ for 8 hours. The weight difference was taken as the organic matter content [14].

2.6 Sulphate (SO_4^{2-})

Sulphate was determined by KH_2PO_4 extraction method as adopted by [15]. A 5g of the sample (air-dry, passed 2mm sieve) was weighed into centrifuge tube or an Erlenmeyer flask. 25ml of the extracting solution was added and shaken for 30 minutes on a mechanical shaker. The suspension was centrifuged (but could be filtered through a Whatman No 42 filter paper). The filtrate was made up with distilled water to 50 ml. The sample was transferred into 100ml measuring cylinder, and 10ml of NaCl-HCl solution and 10ml of Glycerol-alcohol solution were added. The absorbance against blank at between 380-420nm was measured. Then, about 0.15g (a constant spoonful) of BaCl crystals was added, and shaken for 15minutes. The absorbance was measured after 30minutes. The absorbance due to sulphate was obtained by difference, using this formular:

$$Y = MX + C$$

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

Where:

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

2.7 Available Phosphate (PO_4^{2-})

Phosphate was determined by spectrophotometric method as adopted by [12]. 5g of air-dried soil/sediment sample (passed a 2mm sieve) was weighed into a 15ml centrifuge tube and 20ml 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 2,000rpm for 15 minutes. The solution was filtered and made up with distilled water to 40 ml. 5ml of Antimony Molybdate was added to the solution, followed by adding 2ml 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 680nm [16].

2.8 Particle Size (Mechanical Analysis)

Particle size distributions were determined in soil by the hydrometer method of Bouyoucos [17] as

described by [18]. 50g of fine textured soil was weighed and placed in the baffled cup. The cup was filled to half full with distilled water and 10ml of calogen (sodium hexametaphosphate) was added. The cup was placed on stirrer and stirred until soil aggregates were broken down (10minutes). The suspension was transferred to a Bouyoucos cylinder and was filled to the lower mark with distilled water while the hydrometer was in suspension. Then the first reading on hydrometer was taken and recorded at 5 seconds after the cylinder was set down. The hydrometer was removed and the temperature of the suspension using thermometer was taken and recorded. The suspension was allowed to stay for 3hours then the second reading was taken for hydrometer and temperature. Then, the percentage of sand, clay and silt were determined using:

$$\begin{aligned} \text{Sand} &= 100 - \{H_1 + 0.2(T_1 - 68) - 2.0\}^2 \\ \text{Clay} &= \{H_2 + 0.2(T_2 - 68) - 2\}^2 \\ \text{Silt} &= 100 - (\% \text{ sand} + \% \text{ clay}) \end{aligned}$$

Where $0.2(T_1 - 68)$ is constant = Temperature and hydrometer correction. -2.0 is constant = Salt correction to hydrometer reading.

2.9 Textural Class

This was determined in soil using textural table, in consideration of particle size as depicted.

2.10 Chloride (Cl) in Soil

Chloride concentration was ascertained by argentometric method as described by [2] and [19].

A 20g of air-dried sample was quantitatively measured into a 250-ml of conical flask, followed by the addition of 100ml of distilled water shake for 30 minutes inside mechanical shaker, filtered then make up to 100ml with distilled water, using K_2CrO_4 indicator, and titrated with 0.014N $AgNO_3$. The mixture was titrated from yellow to reddish colour. A colour change from yellow to reddish brown at the end-point was observed, recorded and calculated as:

$$\text{Chloride (Cl)} = \frac{35.5 \times C_b \times V_b}{\text{Vol. of}}$$

Sample Where: C_b = Concentration of $AgNO_3$ (Normality) V_b = Volume of $AgNO_3$ (Consumed).

2.11 Determination of Total Nitrogen (nh₄-n) in Soil using regular Macro-Kjeldahl Method

Total nitrogen was determined by the Kjeldahl's method [20], as described by [21] and also adopted by [22]. A 5.0g of soil sample was weighed into 500ml Macro Kjeldahl flask. 20 ml of distilled water was added. The flask was swirled for a few minutes, and allowed to stand for 30 minutes. A 1g of the K_2SO_4 - HgO mixture and 10g of K_2SO_4 were added. Then 30ml of concentrated H_2SO_4 was also added through a pipette. The flask cautiously heated at low heat on the digestion stand. When the water had been removed and frothing had ceased, more heat was applied until the digest cleared. Then the mixture boiled for 5 hours. The heating was regulated during this boiling so that the H_2SO_4 would condense about half way up the neck of the flask. The flask was allowed to cool and about 100ml of water was slowly added to the flask. The digest was carefully transferred into another clean Macro Kjeldahl flask (750ml). All sand particles in the original digestion flask were retained. The sand residue was washed with 50ml of distilled water 4 times and the aliquot was transferred into the same flask. 50ml H_3BO_3 indicator solution was added into 500ml Erlenmeyer flask which was then placed under the condenser of the distillation apparatus. A 750ml Macro Kjeldahl flask was attached to the distillation apparatus. About 150ml of 10N NaOH was added through the distillation flask opening the funnel stopcock. After which distillation commenced. The condenser was kept cool (below 30⁰C) to allow sufficient cold water to flow through and to regulate heat in order to minimize frothing and prevent suck-back. A 150ml distillate was collected and distillation was stopped. The NH_4 -N in the distillate was determined by titrating with 0.01N standard HCl (or H_2SO_4) using 25ml burette graduated at 0.1ml intervals. The colour change at the endpoint was from green to pink. The percentage of Nitrogen (% N) content in the soil was calculated.

Table 1. Soil Table (Textural Soil Classification)

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
	0-20	88-100	0-12	Silt
Loamy soils (Moderately fine texture)	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
0-20		40-60	40-60	Silty clay
0-45		0-40	40-100	Clay

3. RESULTS AND DISCUSION

Chemical and physical characteristics of soil samples collected from six different locations, both along pipelines and farmland are presented in Table 2.

The physicochemical properties of the soil showed that the pH of the soil samples was acidic in nature (5.54-6.32) and did not differ significantly with location. The observed pH values of the soils are similar to the values obtained by [23], [6]. This acidic range is a usual feature of soils of Niger Delta as reported by [23,5]. The low pH in these locations is influenced greatly by production of acidic metabolites, microbiological activities pollutants discharged into the environments and acidic rain as a result of gas flaring in the region. The acidic nature of the soil samples can influence corrosion towards buried pipelines based on US standards for test proceedings and procedures and also shown in the US table of criteria for assessing ground corrosion potential of Solid bar soil nails [24]. Soils with $\text{pH} < 4.5$ or $\text{pH} > 10$ have Strong Corrosion Potential (Aggressive). While soils with $5.5 < \text{pH} < 10$ have Mild to no Corrosion Potential (Non-Aggressive). Highly acidic soils clearly indicate a high corrosion risk to buried facilities. pH combines with the aerobic situations in the soil environment can influence the character of microbial activity that have a huge effect on corrosion rates as revealed by [2,1,25] Therefore, based on the pH values of the soil samples, the soil from these communities may be mildly corrosive towards buried pipeline.

The temperature of all the soil samples analyzed was moderately high. The result revealed that the soil samples can influence corrosion. The study revealed temperature that is consistent with temperature of the region and a usual characteristic of Niger Delta region soil [25]. This is also identical to the report of [26]. Temperature influences soil resistivity and also corrosion potential. When soil temperature decreases (approaches 0°C) resistivity of the soil increases with equivalent reduction in corrosion potential of the soil [1]. Mean redox potential values were higher in soil samples along pipelines than in farmland and all the values were lower than 100Mv. This indicates low redox potential. Redox potential is an act of measuring how a soil environment is reduced or oxidized. Reduced situations mean less redox potential and less than 100mv. This indicates that there is low or absence of oxygen. Oxidized situations mean elevated redox potential higher than about 100mv, which indicates that there is presence of oxygen. Redox potential determines the stability of metallic structure. Soil with low redox potential is anaerobic and will not promote rusting of metals. That is, there is absence of oxygen which is required for iron to rust. Anaerobic soil samples are devoid of oxygen which is necessary for production of passive oxide layers on the surface of the metallic materials [2,1,25]. Thus, this low redox potential in the soil samples in this region may result into anaerobic condition and hence promote proliferation of sulphate reducing bacteria which have contributed immersely to the corrosion problem.

Table 2. The Physico-Chemical Characteristics of Soil Samples in the Oil Exploration and Exploitation areas of Delta State

Parameter	Source of Soil Samples					
	Kokori		Jeremi		Okpai	
	Pipeline Area	Farm Land	Pipeline Area	Farm Land	Pipeline Area	Farm Land
Ph	5.81±0.21	6.32±0.29	5.54±0.16	5.63±0.17	5.55±0.15	5.81±0.11
Temperature (°C)	25.35±2.15	25.62±1.22	26.44±3.24	26.64±1.24	28.75±2.15	28.80±2.10
Electrical Conductivity (µS/CM)	104.00±9.00	55.00±6.00	113.50±14.50	51.00±7.00	148.00±12.00	135.00±11.00
Redox Potential (mV)	91.88±6.78	88.32±4.82	92.57±8.23	80.49±3.11	91.53±4.07	89.60±5.02
Moisture Content (%)	19.63±1.13 ^a	15.79±1.18	17.29±2.26	11.92±1.37	22.39±1.01	15.23±1.78
Chloride Content (mg/kg)	14.60±1.10	7.00±1.52	11.36±0.03	7.49±2.15	23.32±2.67	9.09±0.78
Sulphide (mg/kg)	4.42±1.01	0.12±0.01	4.06±1.03	0.10±0.01	6.20±1.11	0.22±0.01
Sulphate (mg/kg)	11.69±1.58	8.19±1.50	13.26±1.18	11.64±1.71	14.55±1.34	10.07±1.00
Phosphate (%)	1.22±0.87	3.20±0.20	0.98±0.75	2.15±1.13	1.30±0.72	5.20±1.19
Total Organic Carbon (%)	0.44±0.13	0.73±0.03	0.25±0.20	0.97±0.16	0.27±0.18	1.10±0.18
Total Nitrogen (%)	0.03±0.01	0.03±0.01	0.02±0.01	0.05±0.01	0.23±0.21	0.07±0.01
Silt (%)	8.01±0.41	4.04±0.84	5.60±0.30	4.05±0.08	39.96±4.26	7.55±0.35
Clay (%)	17.19±2.49	11.48±1.58	14.66±0.46	4.00±0.20	42.05±2.25	3.78±0.58
Sand (%)	76.21±5.51	86.33±6.43	81.07±5.57	92.76±6.68	18.87±1.37	88.77±4.25
Texture (%)	Loamy Sand	Loamy Sand	Loamy Sand	Sandy Loam	Clayey Loam	Sandy Loam

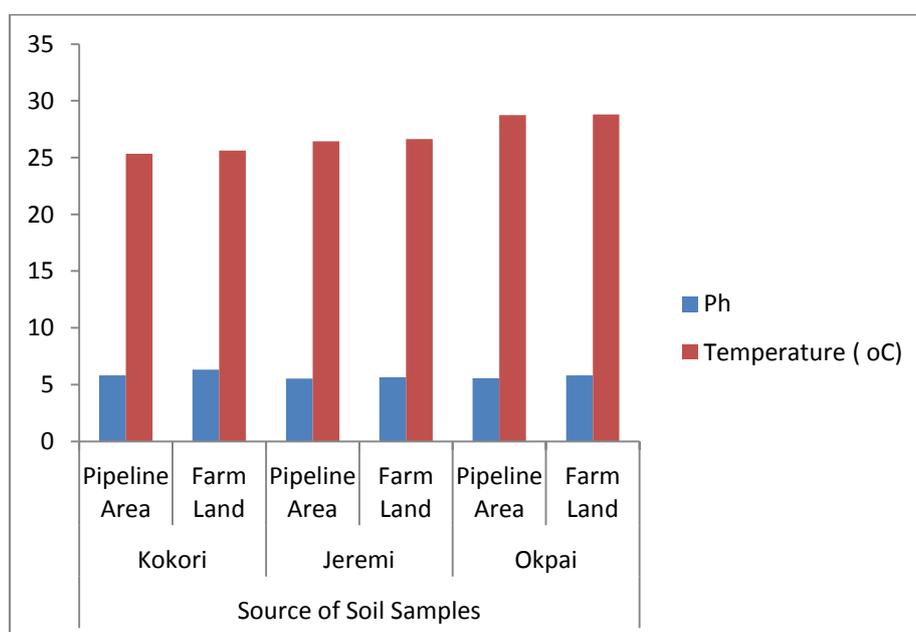


Fig.1. Graphical Representation of Temperature and pH

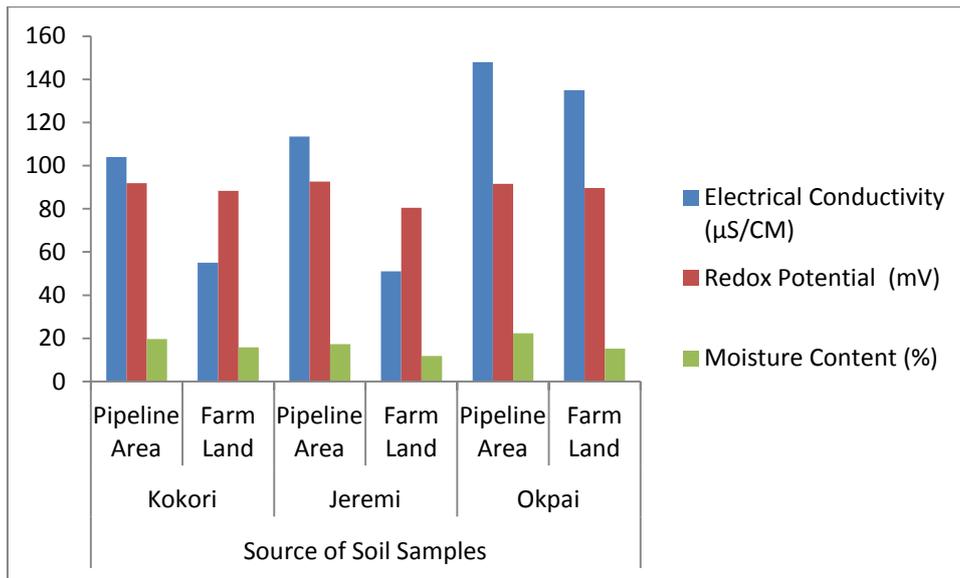


Fig.2. Graphical Representation of Electrical Conductivity, Redox potential and Moisture content

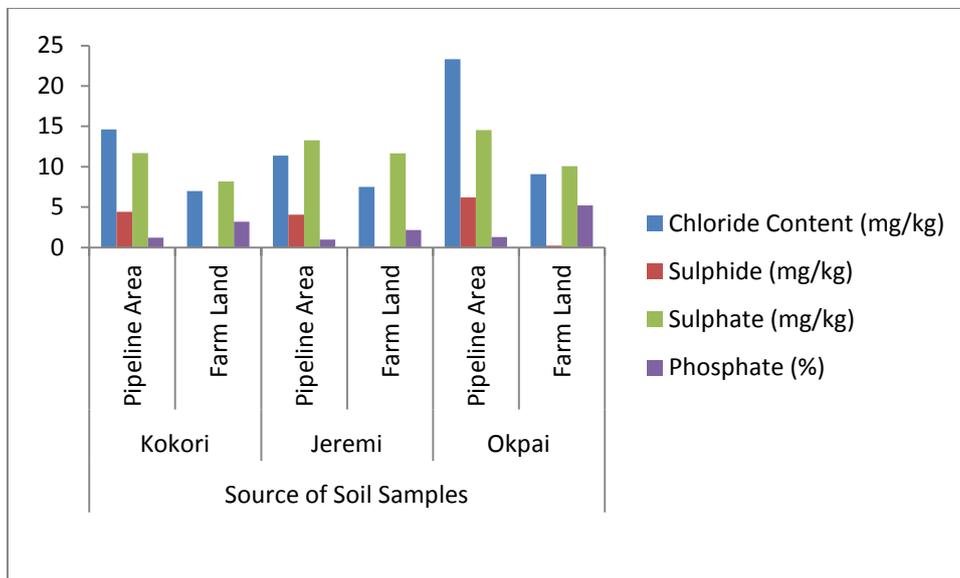


Fig.3. Graphical Representation of chloride content, sulphide, sulphate and phosphate in kilogram and percentage

As a result, the situation is most appropriate for the proliferation of sulphate reducing bacteria which can convert sulphides into sulphuric acid. This is also indicative of corrosive environment in all the locations based on classification standards as reported by [12], [4] [15] [20]. They revealed that soils with redox potential greater than 400mv are Less Corrosive, 200– 400mv are Mildly Corrosive, 100 -200 are Moderately Corrosive and less than 100mv are Corrosive (C). Thus, from the redox potential of the soil

samples which was lower than 100mv, all the soil samples were therefore slightly corrosive towards buried pipelines.

The moisture content values of the soils were moderate, higher in soils along pipelines than farmland soils. The values were within the range obtained by [27]. The moderate moisture content may be due to fluctuation and the season of the year, since there are wet and dry seasons in the region.

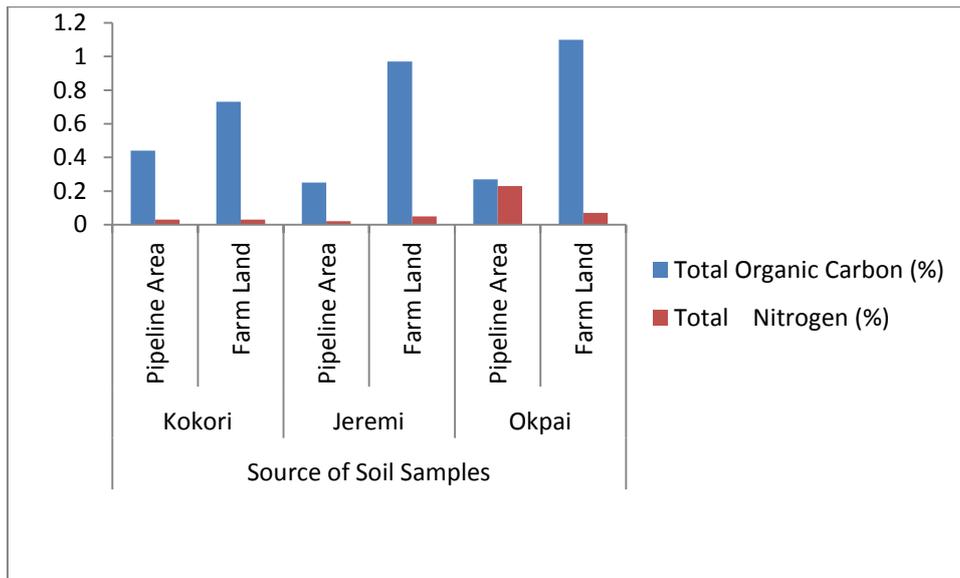


Fig.4. Graphical Representation of Moisture content and Total Nitrogen

This result showed the moisture content of the soil samples ranging from 15.23-22.39%. Moisture is basically one of the major factors of soil corrosion of buried metals. Corrosion occurs only if the soil is not completely dry. High moisture content reduces resistivity of soils, and hence increases corrosion capability [1]. The moisture content of the soil samples is presumed to be slightly to averagely corrosive based on usual European standards for evaluating soil corrosion capability. They reported that soils having moisture content lower than 20% are dry, hence slightly corrosive. The moisture content of the soil sample from Okpai pipeline area was 22% which may be considered to be mildly corrosive. Sulphate content of the soil samples was lower than 200ppm. The values were lower in soils along pipeline than soils in the farmland. Low sulphate content in the soils could be attributed to rapid conversion to sulphide by sulphate reducing bacteria since the environment is anaerobic. High sulphate content in soil is predominantly dangerous for buried structural materials. Sulphate is involved straightway in the electrochemical reactions that occur during corrosion process. It assists in pit initiation and also to accelerate the soil conductivity. Sulphates presence in the soil samples poses a significant risk for metals since sulphates can easily be reduced to highly corrosive products such as sulphides by anaerobic sulphates reducing bacteria. It has also been reported that sulphate reducing bacteria were isolated from these soil samples, this is indicative of corrosiveness. The

soil contains lower than 200ppm of sulphate is assumed to be mildly corrosive. The sulphate content of all soil samples was less than 200ppm, this shows that all the soil samples are corrosive based on classification standards as given by [4] [28] [10]. Chloride content of the soil along pipeline in Okpai was significantly different from the farmland soils. The mean values of chloride of soils along pipeline in all the locations were higher than farmland soils. Chloride ions are generally harmful because they damage the stable layers of protection that normally form on the soil surfaces of many metals thereby revealing unprotected metals to corrosion furthermore. Chloride ions can cause swelling crack and break apart buried structural materials. Chlorides ion promotes pitting corrosion and they tend to decrease the soil resistivity. Understanding the chloride levels can provide an insight into appropriate design of buried structural materials [2] [1] [26]. The chloride level of all the samples was observed to be below 100ppm and therefore considered to be low. This result showed that the soil samples are considered mildly corrosive based classification standards as reported by [12].

The texture of the different soil samples ranged from loamy sand soil to sandy loam and clayey loam soils. Locations had a notable influence on the different soil samples' particle sizes. Some types of soil are more corrosive than others. Fine-grained soil such as clays and silts are known to have a higher corrosion capability.

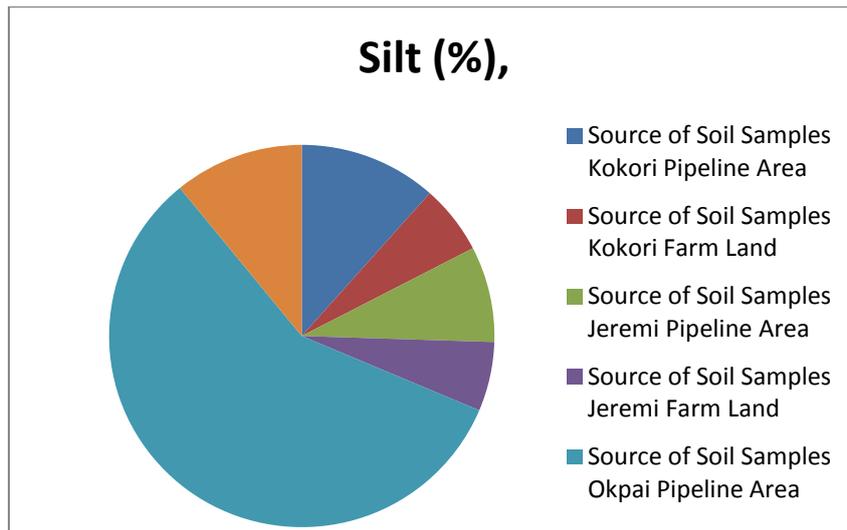


Fig.5. Graphical Representation of the percentage of silt and their various sources

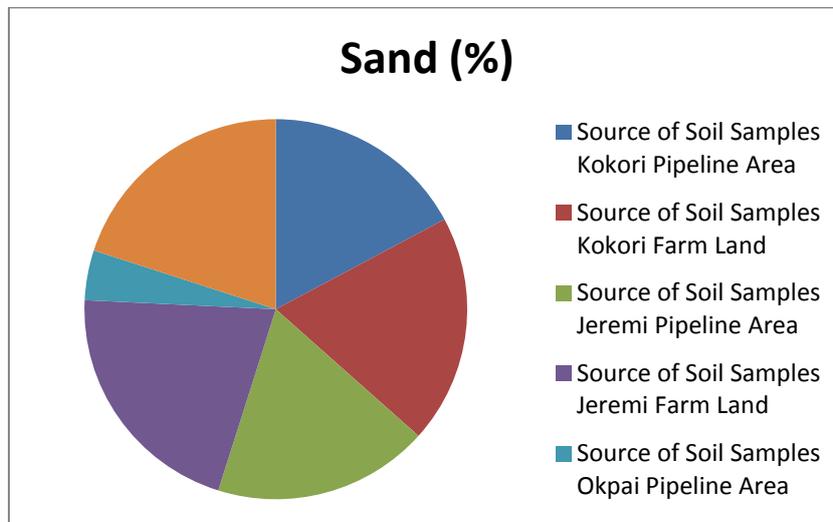


Fig 6.Graphical Representation of the percentage of sand and their source

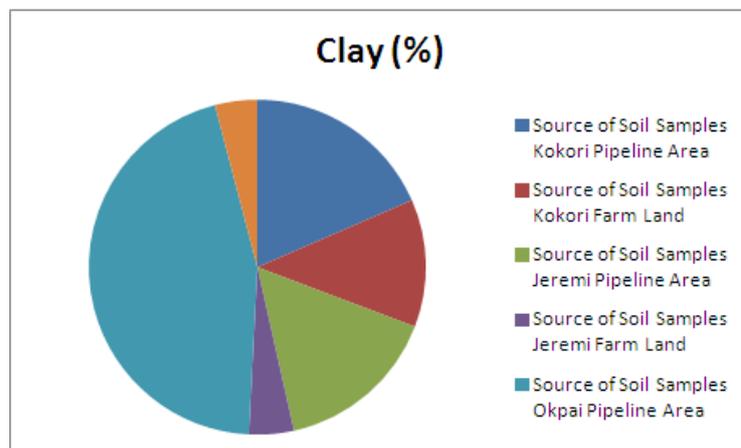


Fig. 7.Graphical Representation of the percentage of clay and their sources

While, granular soils such as sands and gravels are known to have less corrosion capability. All the soil samples in this region are sandy loam, loamy sand and clay loam [29-33]. Therefore, they are mildly to severely corrosive. Sandy soil is non corrosive, loamy soil is mildly corrosive, clayey soil is very corrosive and peat/muck soil is highly corrosive. Soil samples in this region can be corrosive [34-39].

The TOC levels of the soil samples fell within the range for Niger Delta soils as previously revealed by [40]. Total Organic Carbon (TOC) refers to the amount of carbon found in the soil. It is a measure of the carbon present in soil organic matter such as plant and animal residues. In terms of corrosion of buried pipes, organic carbon has a role to play [41-44]. Carbon combines with water and other compounds to produce weak acids which corrode buried metal as shown [45]. The phosphate, total nitrogen and total organic carbon contents of the soil samples were low. This was also similar to previous reports [25] [27]. Basically, these parameters altogether determine corrosiveness of a soil and a single parameter should not be used.

4. CONCLUSION

This study revealed that the soil samples physical and chemical characteristics could predispose metals or buried pipelines in the region to corrosion. Again, the physicochemical characteristics of the soil and that of the materials could influence the corrosion of the buried pipes.

5. RECOMMENDATIONS

Safe and environmentally friendly practices and cost effective mitigation measures should be carried out when laying down of underground facilities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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