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Investigation of Soil Physicochemical Effects on the Corrosion of Buried Iron Pipes

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Abstract:

Soil corrosivity was an active problem of water pipeline damaged by corrosion that affects the performance of pipe manufacturers. In Addis ababa, groundwater pipelines were facing breakage and like due to corrosion damage of the pipes. The population of nearly four million were facing a shortage of clean and continuous water supply. Maintenace and replacing old pipes with new ones increased additional cost and delay of water supply for the city. For this investigation of corrosion, causes were conducted which soil property is the one factor. Investigation of soil corrosivity for a given specific location before installation is important to design robust pipes that can serve for long life. Soil physicochemical behaviors of the soil parameters were pH, moisture content, and electrical resistivity for any type of soil. In addition, soil bulk density, total nitrogen, soil texture, and electrical conductivity were also the main factors to be studied. The laboratory result indicated that pH of 6.98-7.04, moisture content of 23.7-37.5%, and electrical conductivity of 0.105-313 ds/m were observed. Total nitrogen was small as 0.06-0.10 for a type of soil were class and loam soils. From the analysis of eight soil samples taken from different cities. The results show that the corrosivity behavior of buried iron pipes in the capital city of Ethiopia was moderately corrosive. As confirmed from various soil samples tested from corroded pipes at different depths of 40, 80, and 120 cm. The influence of soil corrosiveness factors initiates pits formation and propagates its width and depth on the surface of pipes.

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1. INTRODUCTION

Understanding corrosion damage mechanisms of pipelines are very important in the drinking water distribution system to predict the lifetime of pipes, to keep water quality, and to minimize health risks. Soil is the collection of naturally occurring minerals that directly contacts buried metallic structures [1]. In this regard, nothing gives comfort once the pipeline has been buried in the soil which means there is always a threat of pipe damage caused by corrosion especially among the water distribution system (WDS). Hence, identifying major soil corrosivity parameters and behaviors are very crucial to determine the rate of corrosion and to apply a controlling strategy at a specific location. The main concern of Water distribution system (WDS) owners is improving the effectiveness of the pipe network, keeping water quality, minimizing leakages, controlling pipes' corrosion, long years of service time, reducing the impacts of water pipes damage, etc. But the damage of buried iron water pipes due to water and soil attack is a common problem that creates considerable cost and challenging water supply owners, customers, and industries. The reoccurring of pipes leakage, maintenance, replacement, and water service interruption are frequent routine problems to the water distribution bodies. When the corrosivity status of the soil is understood, it can give much information including the design of suitable environmental adaptability materials' selection, manufacturing processing, changing pipelines path, and avoiding pipe materials producing in large mass quantity before testing the relation of pipe with soil interaction. Soil corrosion was a known problem for a long time ago which has been attacking metallic products and it was considered as one of the main influential factors which consequences damaging of buried pipelines [2]. The authors stated that soil corrosion is being destructive mechanism due to the reaction of buried materials with the environment that degrades pipelines and affects cyclic and static strength. The growth of corrosion causes pipelines to leak or break which consequences seriously to environmental, human, and financial losses. Corrosion attacks all types of manufacturing products including water pipes, spare parts, cars, ships, airplanes, machinery, etc. through the chemical reaction between a material and its environment during the exposure time. It is a costly problem damaging materials and becoming a worldwide issue and affecting the economy which was estimated at 3.4% of world GDP per year in 2013; [3].

The time of installation of water pipelines can be known but it is difficult to know when the exact time of failure unless observing pipes' break creating water loss. Pipe damage leads to maintenance and replacement activities depending on the pipe damage conditions. This is due to the gradual deterioration of the pipes from both sides of internal and external surfaces. Studying the interaction of pipe materials with that of physicochemical environmental contexts is a sensitive issue to determine corrosion rate, maintain water quality, and prediction of pipelines lifetime as well as asset management. The gradual degradation of materials due to underground corrosion leads to damage to the buried metallic structures. It has direct environmental and population health [4]. Soil is well known as corrosive to the buried structures, especially water pipes that are affected by soil environmental factors. Investigations of soil corrosivity are very important because any amount of kilometers of water pipelines and others are buried in the soil. Studying the corrosivity of soil for a given specific location has several advantages including the reduction of the frequent reoccurring maintenance and replacement works.

Water pipelines are exposed to water and soil during service time for several years is a great important issue to study corrosion damage (CD) of water pipes. Investigation of CD leads to identify corrosion rates which create favorable conditions to deal with the threats of health and economic impacts as well as to apply corrosion controlling mechanisms. The corrosion of water pipes in the soil is an unenviable phenomenon and inherently varies from place to place. The electrochemical process forms a variety of rust oxides on the surface of the pipe while reacting with soil environmental factors such as oxygen, moisture, salt content, sulfide, chloride, resistivity. The surface of the water pipe is challenging in water pipe external corrosion due to the reaction between the soil embedded around the pipe and the external surface of the structure. The paper focus to investigate soil parameters on how they are affecting the surface of the water pipe and in turn to analyze the corrosion resistance of buried pipes with soil environments to determine corrosion rate and the remaining service lifetime. This depends on the soil parameters such as soil pH is one of the most affecting soil parameters on the metallic structures. the literature stated soil pH corrosiveness values ranged from 1-5 is corrosive, 5-8.25 less corrosive and pH > 8.25 is corrosive [5].

1.1. Pipe-Soil-Interaction

Soil corrosion occurs due to the electrochemical process between soil and pipe which degrades buried iron pipes with the presence of moisture is acting as an electrolyte. The variety of coatings such as zinc and cathodic protection cannot stop the corrosivity of soil as it has been an evitable phenomenon to the buried pipes. The work of several scholars shows the identification of soil corrosivity status depends on the specific location and pipe materials suitability where the installation is performed. Corrosion damage of buried water pipe surfaces results from a chemical and electrochemical reaction with a function of time process at soil/pipe interface [6]. The effect of soil on the ferrous metals needs to be studied and predicted the service life before mass production of the items to be buried to create the chance of design modifications. Higher soil moisture content degrades under the chemical interaction of pipe, water, oxygen, and soil minerals able to create localized pitting and uniform corrosion around the pipes. Soil corrosively is a complicated situation due to variable characteristics of parameters including electrochemical situation, microorganism, temperature, and minerals of ions, cation, and anion in the soil reacting with pipe materials. The corrosivity of soil towards ferrous metals is a usual problem for the water distribution suppliers, sewerage, and oil and gas distribution system managers [7].

Corrosion of water pipelines has a great influence on the health of human beings causing gastric and liver problems through frequent taking water for a long time. This is due to water pipelines performance are influenced by the water and embedded soil environments and climate conditions [8]. Analyzing the amount of bicarbonate (HCO_3) in the soil that surrounded the pipe is very important because it enhances pipeline corrosion by forming FeO_3 and stress corrosion cracking (SCC) [9]. Soil environment that contains chloride, bicarbonate, dissolved CO_2, bacteria, soil type, sulfate, and temperature are factors influencing the ferrous pipe corrosion rate. Knowledge about soil contents is crucial to identify the main corrosion affecting parameters of buried water pipes. It is also possible to forecast the damage status of pipe corrosion within that specific soil environment. The effect of soil is not uniform around the pipe through the entire length due to soil moisture and mineral variations. Soil properties including resistivity, pH, moisture content, chloride, bulk density, bicarbonate, redox potential, and sulfate content were reported as basic soil properties [10].

1.2. Soil Corrosivity

It is difficult to generalize the corrosiveness of soil for a certain area by studying some samples due to a variety of parameters. Soil properties vary both from one site to another and the horizons of a given contour [11]. It needs extensive investigation both in wide area coverage and at different depths of the underground to conclude soil corrosiveness at some level. Hence, this study focused on the soil which is embedded around the pipes at the depth of 40, 80, and 120 cm. The service of the WDS can easily be stopped for a while when a pipe segment is damaged under different mechanisms such as corrosion, soil loads, and operational conditions. Through the time process, the frequent water pipe damage caused by soil corrosivity is a common problem for the buried pipes. It is an evitable phenomenon despite utilizing different coating materials. The corrosivity condition depends on the environmental specific location which needs to be studied the compatibility of materials and soil environments. The physicochemical characteristic of soil varies as the depth of soil increases due to the acidity of soil increments**.** A soil that contains acidic, aerated, or contaminated with sulfide, chloride, and other solutes, the zinc coating corrodes easily [12]. The age of buried galvanized steel corrosivity depends on the thickness of zinc coating. To reduce soil corrosivity on the pipes, cheap and non-conductive materials like gravel or sand utilization before buried the pipe will prolong the service of pipes [13].

There are a variety of water pipes damage possibilities and exposed to traverse, mechanical damage, and longitudinal cracks, stress corrosion cracking (SCC), operation condition, and environmental factors (soil and water) [14]. Soil corrosiveness attacks the surface of pipes due to moisture, microorganisms, minerals, and stray current. The related study of many scholars reveals that buried ferrous pipes damage condition depends on soil parameters including soil pH, sulfate, resistivity, chloride, and moisture [15]. The study conducted on the agricultural soil shows the resistivity ranges 90 -150, whereas clay contains 20 -200 m This indicates that clay soil is more corrosive to the buried ferrous pipes than loam soil. Corrosion of steel structures in the soil is a complex phenomenon due to several variables including pH, aeration, redox potential, moisture, soluble ionic species, resistivity, and microbiological activity [13, 16]. The types of pipe damage mechanisms create a loss of capital investment in the long term which covers total pipeline replacement cost and in the short-term pipe damage consequences maintenance and replacement cost. Pipe corrosion has a direct influence on human life [13]. Soil corrosion damage mechanisms of the structures of buried infrastructures that require design considerations such as materials selection and studying environmental impacts are very crucial to control corrosion. Buried ferrous pipes are predominantly affected by electrochemical corrosion due to the presence of soil moisture acting as an electrolyte which damages the pipes in the form of uniform corrosion around the pipes and pitting corrosion**.** Pipe damage is expressed in terms of water quality deterioration, thickness reduction, weight loss, and changing of the physical and mechanical properties of the pipes. The corrosion process leads to the breakage and leakage of the pipes eventually which creates threats of health and economic losses. This is due to corrosion pits have different shapes and sizes which can grow randomly on the pipe segment depending on time and environment**.**

The electrical conductivity (EC), soil pH, moisture, and soil type can attack the surface of buried water pipes. Other soil parameters including soil mineral content, chloride, and sulfide can attack buried pipe surfaces [17]. A similar study was conducted by Suganya *et al*., 2018 [18] shows the impact of soil corrosivity factors including chloride and moisture content in the laboratory with time function. The authors used the method of weight loss to determine moisture content and the result was increased under wet soil. This is due to soil types such as clay soil has a fine grain structure which leads to holding more moisture than sandy soil. Soil moisture having <20% shows high resistivity amount; in turn, it indicates low electrical conductivity (EC) [19]. The result was obtained based on the investigation of corroded galvanized steel under different soil moisture content [20]. They stated that galvanized pipe is best for water quality stability except for the potential release of zinc. Knowledge about the interaction of old ferrous pipes surface and water is very important in the water distribution system to keep the quality of water. Once the pipe surface begins to deteriorate; due to corrosion, the quality water gradually will change to red.

The external pipe corrosion is damaged by soil corrosiveness due to soil moistures with other parameters acting as an electrolyte which creates an electrochemical reaction. The external surface of buried water pipes and other metallic structures are exposed to soil corrosion which is a sensitive issue to be studied to manage corrosion damages. This study focused on soil corrosiveness for many reasons including investigating the corrosion process of buried pipe structures, determine corrosion rate, predict service life, and suggest a protective strategy. Several factors affect soil corrosiveness to the buried metallic pipelines but this study focused on the major soil parameters including soil pH, moisture content, electrical conductivity, resistivity, total nitrogen (%TN), bulk density, soil type, and texture. The results of this paper have many important applications including an understanding of water and soil behaviors with that of ferrous pipes, determining corrosion resistance of ferrous pipes surface, analyzing corrosion rate, controlling water quality, corrosion controlling with maintenance implementation, and predicting the service life of water pipes. The results obtained from the study are also helpful for corrosion controlling, keeping water quality, and correlating buried structures with soil corrosion behavior, decisions of the right time of pipe replacement, and forecasting the remaining pipes' service age.

The aim of this research was to fill the gap that no research published on the investigation of causes of corrosion for groundwater pipelines in Addis Ababa capital city of Ethiopia. Corrosion is a complicated problem due to a variety of factors including pipe design, materials used, weather conditions, soil, and water. This paper presents the results of a survey conducted on water pipelines corrosion status and damage mechanisms to predict the lifetime of buried drinking water pipelines. Factors of buried water pipes damage are identified due to soil and water parameters through service life. Identifying the main causes of corrosion damage of water pipelines is critical to predicting the long-term pipe damage during the lifetime of buried water pipes. In this study, 15 to 20 years old damaged galvanized steel water pipes were used as samples for the analyses.

2. MATERIALS AND METHODS

2.1. Soil Sample Preparation

The service age of buried water pipes depends on the corrosivity of water and soil parameters. The purpose of the soil test was to evaluate the main external corrosion factors of pipeline damage mechanisms and to evaluate the rate of corrosion. Soil types and compositions of soil inherently vary from place to place due to the variability of soil mineral composition [21]. To investigate soil corrosivity on galvanized and ductile iron pipes, eight soil samples were collected from different sites of the city that were contacting around the pipes. The depth was 40, 80, and 120 cm, and the time of soil samples collection was from August to September 2020 in the rainy season. The collected bulk soil samples were screened by removing foreign materials, dried in the air, and sizing the grains into smaller particles considering the procedures of [22]. Later, three of the samples were selected visually based on their physical properties, grain size, color (red, black, and brown), and moisture content [23]. The soil samples were put in a plastic bag and after separation of foreign materials (sublimation), the soil (in situ) was weighed using digital balance and the weight was reported as 1268, 2525, and 3590 grams to compare soil moisture content with that of laboratory result (dry condition). The soil samples were dried in the open air for seven days at room temperature and measured their weight to determine moisture content. The samples were then coded for easy identification of the result (Figure **1**).

Figure 1: Soil samples.

2.2. Methods

2.2.1. Measuring Soil Bulk Density

Soil bulk density (BD) describes how the compactness of the soil grains each other. It determines the porosity or aeration of the soil. The BD of soil was measured by weighing the dry soil powder on a beam balance of accuracy of 0.001g and calculating the volume of soil. The soil having more porosity lets oxygen move inside the soil which can create pipe corrosion reacting with soil moisture. Air-dried soil with uniform grain size (<2mm) was put in the cylinder and calculated its volume using Eqn. (1) and weighted. The bulk density (ρ) is then computed by using Eqn. (2) and taking the average density of three samples to minimize error. As the depth of soil increases, the concentration of oxygen and its free movement decreases which can create localized corrosion reacting with moisture and pipe materials. For this experiment, the mass of soil was 1370 g, and volume (v) equals 1092 cm^3.

$$v = \frac{1}{4}\pi d^2 h \quad (1)$$

$$\rho = \frac{m}{v} \quad (2)$$

2.2.2. Evaluating of Soil Moisture Content

The weight-loss method was used to determine soil moisture content based on the standard of ASTM D4959-07 [24, 25]. The soil samples were collected from the embedded buried pipes at depths of 40, 80, and 120 cm. The samples (in situ) were then weighted using digital balance having the accuracy of 10^{-3} g with a known weight of the container. The dried specimens were weighed with the container to determine the weight discrepancy and multiply by a hundred to get the value in terms of percentage Eqn.3 [25].

$$\text{Soil moisture } (Sm) = \frac{(W_s) - (D_s)}{(D_s)} \times 100 \quad (3)$$

Where: Ws is wet soil in (g) and Ds is dry soil in (g).

2.2.3. Measuring Soil pH

The pH of the soil was evaluated using Benchtop HI2210 pH meter Figure **2**, Germany after calibrated in the standard buffer solution. The test was conducted in the ratio of 1:1.25 soil-water suspension and following ASTM G51-95 (2012) standards [25, 26].

Figure 2: Benchtop HI2210 pH meter.

Figure 3: conductivity meter.

2.2.4. Determining Soil Electrical Conductivity

The electrical conductivity (EC) was determined in the prepared mixtures of 1:1.25 soil to water suspension using conductivity meter after calibrated by the standard conductivity reference solution considering ASTM G187-05 standards [27]. This experiment is effective to estimate the amount of salinity (salt content) of soil in deci-Siemens per meter (ds/m). Air-dried 50g soil having a grain size less than 2mm was put into a glass beaker and 100 ml of water was added into the graduated cylinder. The solution was stirred well using a glass rod and allowed to stay for 30 min. During this time, stirred suspension every 15 minutes to homogenize the soil and water mixture as well as to dissolve salt materials. Soil electrical conductivity (SEC) depends on texture, moisture content, dissolved electrolyte, and porosity [28].

2.2.5. Determining Soil Resistivity

Soil electrical conductivity (σ) and resistivity (ρ) have inverse correlation and hence computed the value of resistivity from the report of σ. Resistivity was calculated from the values of electrical conductivity Eqn. 4.

$$\rho = \frac{1}{\sigma} \tag{4}$$

2.2.6. Evaluating Soil Texture

It is one of the factors which affect soil corrosivity to the buried structures. Soil corrosivity level is categorized based on the soil type and grain size that allows the moisture-holding capacity in the soil described in increasing order as sand < loam < clay. Similar work shows, the grain sizes soil of soil is categorized as (4.76-0.074, 0.074-0.002, and < 0.002) mm for sand, silt, and clay respectively [1]. Various studies focused on the soil corrosivity and categorized the order of corrosiveness as sand-cay-loam < clay-loam < clay in increasing order of corrosivity [29, 30].

Soil texture (S_t) describes the compositions of soil and grain size distribution. It was determined based on the

Table 1: Soil Laboratory Test Procedures

Parameters	Laboratory Equipment	Sample wt.	Procedures
Soil pH	Benchtop HI2210 PH meter	10 g.	Preparing soil sample. Calibrate the pH meter. Mix and stir the soil-distilled water solution and allow it to stay for 30 min. Tem. 21.9 ^{O}C Take the reading
Electrical conductivity	Benchtop electrical conductivity meter 4310 (JANEWAY)	50 g	Preparing sol sample Calibrate the device Mix and stir the soil-distilled water solution and allow it to stay for 30 min. Tem. 22.10 ^{O}C. Take the reading
Total nitrogen (%TN)	Digestion unit and distillation unit -Titration, burette	10 g	Preparing sol sample Calibrate the device Chemicals used H_2SO4, Na_2SO_4, H_3BO_3 Allow staying for 2 days.
Soil texture	Soil hydrometer	50 g	Preparing sol sample Mix the soil with water and stirred it with a glass rod Sodium hexametaphosphate to disperse the soil coagulated Allowed to stay for 3 hours

ratio of the weight of the sample (w_s) and total weight (w_t) Eqn 5.

$$S_t = \frac{w_s}{w_t} \times 100 \quad (5)$$

3. RESULTS AND DISCUSSIONS

Broadly, the process of buried water pipes corrosion depends on the water and soil environmental conditions. Hence, this study focuses on the soil corrosivity on the ductile iron and galvanized water pipes and the investigations of water corrosion parameters to the iron pipes were conducted in the previous study which was published as parts of the main pending research. Soil corrosion is an evitable and serious issue for buried water pipes and other structures due to a variety of soil corrosivity factors but soil pH, resistivity, sulfide, chloride, and moisture content are predominantly influential parameters of the soil on the buried structures [31].

3.1. Studying Soil Moisture

Knowledge about soil physicochemical is crucial to identify the main corrosion affecting parameters of buried water pipes. From this point of view, it can be easily predicted the severity of pipe corrosion within that specific soil environment. The effect of soil is not uniform around the pipe through the entire length due to soil moisture and mineral variations. The annual rainfall of the city reaches up to 1200 mm which contributes to the higher content of soil moisture. This environmental effect contributes to the soil's corrosivity of moisture. Soil corrosiveness depends on the combined effect of soil properties including moisture content, pH level, aeration, temperature, soil texture, microorganisms, and mineral salts [32]. The nature of the soil is different from place to place throughout the world. Moisture content (MC) is one of the most influential soil corrosion parameters to the buried iron pipes. The corrosion behavior of soil on the buried water pipes was studied based on the moisture contents of the samples. The result of soil moisture content indicates the corrosivity values (23.7%, 30.8%, and 37.5% for moderately corrosive, less corrosive, and mildly corrosive respectively (Figure **4**). Soil moisture acts as an electrolyte underground to form metallic corrosion. Corrosion is the process of electrochemical reaction due to the migration of electrons. The process requires a lower energy state to release electrons to form corrosion (oxidation) [33].

The study conducted by Galai *et al*., 2019; Gupta *et al*., 1979) [34, 35] shows soil moisture content from 25-30% is aggressively cause by corrosion mechanisms to the buried iron pipes. Moisture is a condition for soil to be corrosive while dry soil is a poor electrolyte which means very less corrosive. A similar study conducted on the soil corrosivity of moisture content was determined as less corrosive (0-20%), mildly corrosive (20-40%), and moderately corrosive (40-60%). As the moisture content increases, soil corrosivity becomes aggressive. Soil corrosivity level is based on the moisture content categorized as less, mildly, and moderately corrosive in increasing order of corrosivity. Seasonal weather conditions have a great role in the recording of a high amount of moisture variations. For this study, moisture was evaluated in the city which is situated in highland having more annual rainfall up to 1200 mm which led to moist the soil for several months. A soil having an EC of more than 4ds/m is said to be saline means the salt content of the soil is higher

Table 2: Laboratory Results of Soil Physicochemical Analyses

Soil parameter	Soil sample code			Soil corrosivity condition
	#1	#2	#3	
Amount of resistivity (Ω.m)	42.74	31.95	95.24	High corrosive
PH	6.98	7.04	7.04	Normal
Electrical Conductivity (dS/m)	0.234	0.313	0.105	Corrosive
%Sand (wt/Wt)	50	46	46	Moderately corrosive
%Clay (Wt/Wt)	16	24	26	
% Silt (Wt/Wt)	34	30	30	
Soil textural class	Loam	Loam	Loam	
Total nitrogen (%TN)	0.06	0.10	0.10	Less corrosive
Dry soil bulk density (ρ)	1.25	1.22	1.23	corrosive

which is corrosive to the buried iron pipes due to consisting of soluble salts such as Mg, Ca, Na, SO_4, and Cl [36].

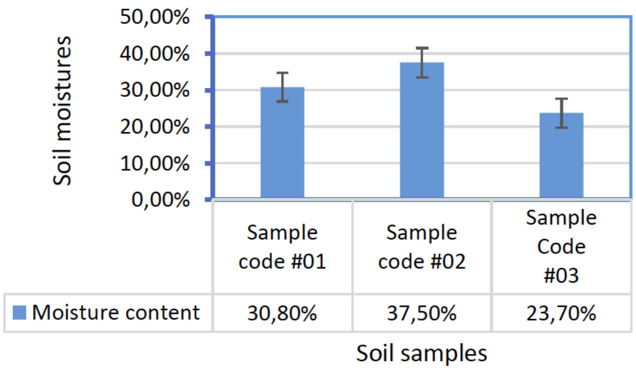

Figure 4: Soil moisture content.

3.2. Electrical Conductivity

The amount of soluble salt present in the soil solution was determined by electrical conductivity (EC). It is an indirect evaluation method of salt content [37]. A soil having an EC of more than 4ds/m at 25 °C is said to be saline means the salt content of the soil is higher due to the soil containing soluble salts such as Mg, Ca, Na, SO_4, and Cl indicate the presence of salt in the soil [38]. Table **2** shows that the summary of soil laboratory results which was focused on the major soil corrosivity including the value of soil electrical conductivity within the range (0.105 - 0.313 dS/m), resistivity (3195- 9524 Ω.cm), pH (6.98-7.04), soil textural class (loam), total nitrogen %TN 0.06-0.10 and the average bulk density was 1.23 g/cm^3 reported from the municipal water distribution system.

3.3. Studying Soil Resistivity

Soil corrosivity and resistivity have an inverse relationship which means higher resistivity has a low corrosivity condition. The rate of soil corrosivity was determined in the laboratory by determining the amount of resistivity. A soil that has low resistivity indicates more corrosive properties to the buried structures [39]. For example, dry soil contains low moisture levels that possess high resistivity and such type of soil property was identified as low corrosivity to the underground installed pipes [40]. Corrosion damage of buried pipes increases as soil conductivity increases. Soil conductivity has an inverse correlation to its resistivity. On the other hand, conductivity has a direct relation to moisture content. The presence of an electrical conductor and resistivity indicates soil corrosivity situations. As soil moisture content increases, resistivity decreases, and the rate of corrosivity to the buried structures increases. Higher resistivity value has lesser corrosivity potential whereas lower resistivity value causes more pipe corrosion damage.

Table 3: Pipe Corrosion Rate Based on Soil pH, Moisture, and Resistivity

Soil parameter	Parameter's condition	Corrosion rate
pH	Near neutral	Non-corrosive
Soil moisture	Increases	Increases
Soil resistivity	Decreases	Increases

The rate of corrosion in the soil is higher due to the presence of moisture that can create resistivity which increases the rate of pipe corrosion in the soil. A low value of resistivity indicates higher corrosive property. A soil that contains much amount of moisture has low resistivity whereas dry soil contains higher resistivity but low corrode. Studying the electrical resistivity of the soil helps to determine soil corrosivity and the suitability of pipes to be installed. Soil resistivity (ρ) is the resisting capacity of electricity in the soil. It varies according to the soil composition, temperature, and moisture content depth of soil. The result of soil resistivity (ρ) was determined by relating to the reciprocal electrical conductivity (σ) and computed by Eqn. (3). Based on the soil resistivity investigation, the result was reported as 42.74, 31.95, and 95.24 Ω.m respectively. The amount of soil electrical resistivity indicates the soil corrosivity perspective. Based on the investigation, the study of soil resistivity conditions on the buried iron pipes was identified as moderately to mildly corrosive potential. Soil resistivity and conductivity have an inverse relation. Soil that has high resistivity means low conductivity and belongs to less corrosive to the buried structures. Soil resistivity is affected by moisture content, soil type, bulk density [41, 42].

3.4. Soil Texture and its Compositions

Figure **5** depicts lab reports of soil grain sizes having three categories: sand, silt, and clay are mixed in nature and textural class (TC) identified as loom (L) soil. The result shows that the corrosivity level of loam soil is mildly corrosive which is lower than clay soil does. The term texture refers to the degree of fineness and uniformity of soil. Soil type is one of the causes of attacking pipe surface and consequently leads to failing to the buried structures. Table **2** shows the proportions

Table 4: Soil Corrosivity Status

Soil Parameter	Value	Soil corrosivity condition	Source of reference
Resistivity	0-500 ohm.cm	Extremely corrosive	ASTM soil corrosivity rates
	501-1000 ohm.cm	Extremely corrosive	
	1001-2000 ohm.cm	Severely corrosive	
	2001-5000 ohm.cm	Moderately corrosive	
	5001-10000 ohm.cm	Mildly corrosive	
	>10000 ohm.cm	Very Mildly corrosive	
Moisture content	0-20%	Less corrosive	
	20-40%	Mildly corrosive	
	40-60%	Moderately corrosive	

of soil composition (texture) consists of sand, silt, and clay with the amount of range from 44-50, 30-34, and 16-26 respectively. Based on the laboratory of soil type analysis, it belongs to loam soil and its corrosivity condition is identified as moderate corrosive to the iron pipes that are installed in the municipal. The composition of soil from three sites contains the average values of 47% sand, 31% silt, and 22% clay (Figure **5**).

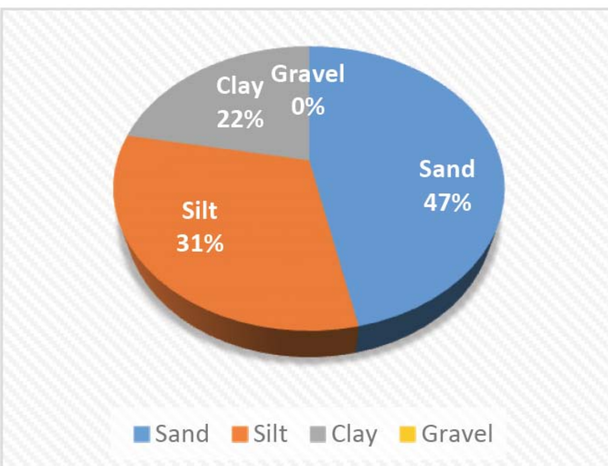

Figure 5: Average major soil compositions.

3.5. Pipe Surface-Soil pH Analysis

The purpose of soil pH testing was to determine the basicity or acidity of a soil solution to investigate the conditions of soil corrosivity. The amount of pH relates to the deterioration of buried pipes and assisting the formation of microorganisms at a higher level of pH > 8, **[**25]. The pH of the soil sample ranges from 6.98-7.04 which is near a neutral soil pH value. Such results of soil pH are categorized as "non-corrosive" to the buried cast iron and galvanized water pipes. Soil pH identification is very important to determine the corrosivity behavior of the soil where pipes are installed. A soil environment having a near-neutral pH value (7) is needed to prolong the life of buried iron pipes. According to several researchers' findings, soil pH ranges from 5-8.5 is a safe condition which is a negligible impact on ferrous underground pipes. The lab report of soil pH is shown in (Table **2**) indicates the range of 6.98-7.04 with a mean value of 7.02. For this reason, the nature of soil corrosivity was determined as less problem of soil corrosivity for buried ductile iron and galvanized water pipes in the municipal. The information observed from the field survey of real case pipes evaluation shows corrosion holes and pipe surface damage were found around the pipes at random locations (Figure **7**).

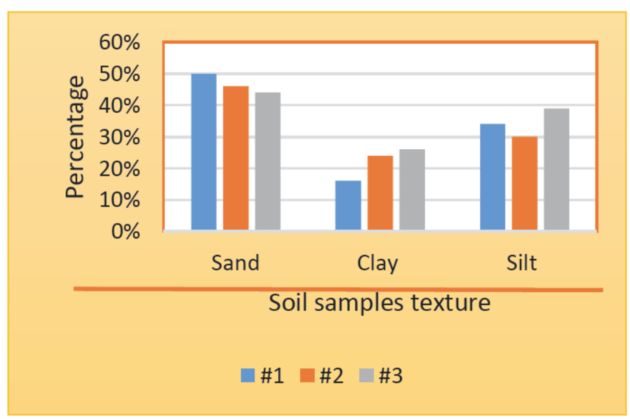

Figure 6: Soil samples texture.

As a result of soil samples depict in this study, the highest value of pH is 7.04, and the lowest value reported as 6.98 at 80 cm depth soil which was embedded in the pipe. The physicochemical properties of soil vary from place to place even as the depth increases within the same area, the result completely

Figure 7: Photograph of corrosion damaged buried water pipes.

differs. This shows the property of soil is complex due to a variety of soil layers and compositions in its nature. Based on the evaluation of pH, the corrosivity behavior of soil belongs to the range of “non-corrosive to less corrosive” level.

3.6. Investigating Total Nitrogen

Table **2** depicts the laboratory report of soil total nitrogen (%TN) within the range of 0.06-0.10. The result shows the minimum amount of nitrogen content in the soil due to more depth of the pipe (80-120 cm). This shows the number of nitrate decreases as the depth of soil increases and vice-versa. Topsoil contains much amount of humus which holds more amount of nitrate which can be corrosive to the buried iron pipes due to the presence of microorganisms in the soil. In general, Soil corrosivity is a complex phenomenon due to a variety of soil parameters including soil pH, moisture content, resistivity, oxygen content (aeration), texture, temperature, sulfate-reducing bacteria (SRB), chloride, sulfate, salt, minerals, microorganisms, electrical conductivity, soil type, etc. Total nitrogen (TN %) describes the presence of microbial remains, decayed plants, and different amounts of composition in the soil. Soil nitrogen includes the compound of ammonium (NH_4), nitrite (NO_2), and nitrate (NO_3)**.** The authors stated soil total nitrogen (%TN) content having within the range of 0.05-0.33% was observed as soil corrosivity.

4. CONCLUSION

Soil corrosion is a complicated phenomenon due to the inherent environmental variations which attack buried structures in different ways such as mechanical (soil load), chemical, and biological (corrosion insisting of microorganisms). Other deterioration mechanisms are related to the type of liquids and gas transportation through the pipes that react with the inner wall of the pipes in addition to the working conditions such as pressure and flow rates. Evaluation of soil corrosion condition has several advantages including protecting pipe corrosion damage and keeping water quality. The mechanisms of corrosion damage of buried structures are understood but the status of soil corrosivity is different from place to place due to the inherent environmental variations. The study focus on the investigations of soil corrosivity parameters on the buried ferrous water pipes of the city water distribution system to identify major corrosion factors of buried pipes. Based on the study, moisture content, resistivity, and total nitrogen (%TN), soil type, and texture were identified as the main corrosive factors to ductile iron and galvanized steel pipes. The laboratory report indicates 6.98-7.04 pH, 23.7-37.5% moisture content, 0.105-313 ds/m electrical conductivity, 0.06-0.10 total nitrogen, and soil textural class is being loamed soil. The soil analysis result shows that soil moisture content was identified as the major corrosion potential of other mechanisms. This is due to the presence of fine grain sizes in the soil components such as the percentages of clay and silt are being more in the soil. On the other hand, soil texture was reported as one of the factors of soil corrosivity to the buried iron pipes next to moisture content due to the capacity of fine soil grains holding water moisture. The electrical conductivity of soil is also identified as the main parameter of soil corrosivity due to conductivity behavior to the stray current. Another parameter of soil such as soil pH is categorized under slightly corrosive factors to the buried pipes.

In general, as a solution; soil corrosivity can be minimized by studying the environmental context of soil corrosivity primarily which can create the chance to correct during design, manufacturing phases, and testing of corrosion resistance of the pipes to produce environmentally adaptable water pipes and control of soil corrosion. Additionally, the authors propose two solutions: (1) water supply owners need to conduct a soil test before installation and (2) the use of less corrosive materials such as volcano red ash and gravel or sand around the pipes before buried is a good technique to control corrosion and prolong the service life of the pipes. The soil analysis result shows that the condition of soil corrosivity ranges from "less corrosive to mildly corrosive" to the buried iron pipes of the municipal. Eventually, the results obtained from the experimental analyses help to predict the remaining service life of buried water pipes, to change the path of the pipeline, and to take actions of corrosion controlling strategy.

CONflICTS OF INTEREST

The authors have been explored the science of corrosion and hence no conflict concerns with any individual or organization.

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