

## Analysis of Steel-Corrosive Chemical Species in Nigerian Defence Academy Soil in Kaduna Metropolis Using X-Ray Fluorescence and Diffraction Techniques

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### Abstract

*Corrosive actions of soils at various locations can be quite deleterious to underground engineering structures with high costs and liability. The commonly used chemical parameters for evaluating corrosion potential of soil to steel are pH level, water, oxygen, sulfate, chloride, sulfide, and nitrate contents as can be assessed by the presence and quantities of ions such as hydroxyl ( $\text{OH}^-$ ), hydrogen ( $\text{H}^+$ ), oxygen ( $\text{O}^{2-}$ ), sulphate ( $\text{SO}_4^{2-}$ ), chloride ( $\text{Cl}^-$ ), sulphide ( $\text{S}^{2-}$ ), and nitrate ( $\text{NO}_3^-$ ). The paper stemmed from a desire to understand the corrosivity extent of soil at Afaka campus of Nigerian Defence Academy (NDA) to underground steel components or structures which have kept growing in number around the campus for about 12 years. Soil samples were collected at 150 different depth and surface locations of the campus covering an area of about 80 hectares and thoroughly mixed to have a representative sample. Portions of the representative samples were separately analyzed using the X-ray fluorescence (XRF), and diffraction (XRD) techniques. The analyses indicated that on average, the soil has low corrosivity to steel due to non-presence of critical corrosive chemical species to steel in the soil. The only chemical specie that was observed capable of causing steel corrosion in the soil is sulfur dioxide, and even then, its composition in the soil was seen to be minimal.*

**Keywords:** Soil environmental corrosivity, Location variation, Underground steel structures, Costs and liability, Afaka campus soil, Evaluation

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### 1. Introduction

Corrosion stems from material interaction with the environment. It is an insidious material degradation process that poses serious challenges in usage of materials in engineering, jeopardizes safety, and hinders technological progress. Environment is any physical thing other than a vacuum that is in contact with engineering material. Corrosive environments can vary greatly in aggressiveness and include various types of soils, atmospheres, waters such as seas and rivers, industrial chemicals or solutions, animal and human wastes and fluids from their bodies, micro-organisms, etc. (Guma *et al.*, 2017 & 2020).

Soil as a corrosive environment constitutes much of the earth and a bulk of engineering systems are in service contact with it. Soil is made up of many various components such as minerals, rock, sand, clay, silt, air, water, and organic material which are matter from dead organisms. No two soils are exactly alike; and extremes of

variation in structure, composition, and corrosive activity are found in different types of soils. There are many different types of soils with unique characteristics like; color, texture, structure and mineral contents at various depths and different locations on earth. There are also up to six layers of soil downwards to the centre of the earth named as O, A, E, B, C and R horizons with different characteristics. The degrees of variations in soil characteristics affect soil corrosivity levels to metallic materials to various extents (Schoonover and Crim, 2015).

Soil particles are generally known to be covered with thin surface film of moisture with dissolved salts and gases. The total volume of soil consists of solid particles and pores filled with moisture and air. Soils with a high proportion of sand are known to have very limited storage capacity for water whereas clays are excellent in retaining water. Variation in soil properties as a result of differences in moisture content, oxygen

content/Redox potential, permeability/texture, temperature, and resistivity can set up differential corrosion cells and influence soil corrosion to critically high degrees at some locations around the world. Other soil variables that can equally influence soil corrosivity to various degrees are discharge characteristics, presence of aggressive ions, microbiological activity, stray currents, electrochemical potential fields, agricultural chemical activities, and spillage of corrosive substances and pollution. It is well-established that soils with high moisture content, high electrical conductivity, high acidity, and high dissolved salts are most corrosive (Baker and Fessler, 2009; Beavers and Thomson, 2008; Guma *et al.*, 2015).

High costs and liability can arise due to corrosive actions of soils that engineering structures are in associated service contact with. For example, studies by the Federal Highway Administration of the United States showed that the total direct cost of corrosion in the United States alone from 1999 to 2001 was about \$276 billion per year, which was about 3.1% of the nation's gross domestic product (GDP) per year (Koch *et al.*, 2002). The study also showed that major contribution to this value was from corrosion occurring in the ground. These included drinking water and sewer systems, highway bridges and buildings, gas and liquid transmission pipelines and storage facilities (Koch *et al.*, 2002). Unprotected pipelines, buildings, and other engineering structures erected on corrosive soils usually have shorter life span. If corrosion of such constructions is not considered, their service lives may be severely overestimated and public safety may be at risk. The frequent collapse and other problems associated with buildings and critical underground engineering structures such as steel pipelines due to corrosion is a serious concern to engineers, governments and the general populace in many countries including Nigeria. The adverse effects are colossal loss of lives and properties (Achebe *et al.*, 2012; Ekine and Emujakporue, 2010; Ekoh *et al.*, 2012; Oyedele *et al.*, 2012).

Corrosion of steel as a prime construction material accounts to about 90% of all corrosion problems in the whole world. Steel is used to make a wide range of equipment and metallic structures that are commonly employed in soil and atmospheric environments (Fontana, 1987; Guma *et al.*, 2017). The type of soil affects the corrosion rate of steel much more than any variation in the steel material or its method of manufacture. Carbon

steel has very low corrosion resistance but is the type used in very large quantity in amounts up to 85% of all steels for underground or soil-based structures such as bridges, domestic and industrial and organizational building systems, etc.; due to its low cost and good mechanical strength and fabrication properties. The general average corrosion rates of carbon steel are well understood in the typical soil conditions, but for the design engineer, the precise localized rates or micro-environment conditions must be well understood for him/her to have confidence in the ultimate durability of designed structures or systems that are in service contact with soil (Fontana, 1987; Guma *et al.*, 2017). The rate of steel corrosion in soil is related to factors such as soil moisture, particle-size distribution, sulfate-reducing bacteria quantity, acidity, and electrical conductivity of the soil. The commonly used chemical parameters for evaluating corrosion potential of soil to steel are pH level; and water, oxygen, sulfate, chloride, and sulfide contents as can be assessed by the presence and quantities of ions such as hydroxyl ( $OH^-$ ), hydrogen ( $H^+$ ), oxygen ( $O^{2-}$ ), sulphate ( $SO_4^{2-}$ ), chloride ( $Cl^-$ ), sulphide ( $S^{2-}$ ), and nitrate ( $NO_3^-$ ). Soils usually have a pH range of 5-8. In this range, pH is generally not considered to be a dominant variable affecting corrosion rates. More acidic soils represent serious corrosion risk to common structural materials such as steel, cast iron and zinc coatings (Gasem, 2014; Guma *et al.*, 2015; Oyedele *et al.*, 2012).

Since 2008, when the NDA campus was moved from its old site at Ribadu campus to the new and permanent site at Afaka, a lot of construction work has been ongoing at high pace thereat. Many high-rise buildings, military training facilities, fluid pipes, underground storage tanks, etc. have continued to be constructed or erected in or on the soil at the new campus. In all these constructions, carbon steel has been in much use in the form of components or as whole structures. Although proper engineering designs with regard to corrosion problems were well considered in the constructions, their corrosion can still be inevitable without best maintenance practices with available practicable safe-guarding information (Guma *et al.*, 2017). It is therefore important to be knowledgeable about reliable information for use in corrosion management and control of steel components in ground based structural systems that must be exposed for several years in service to NDA soil at Afaka campus.

The commonly used techniques of assessing soil corrosivity level are through measurements and analyses of electrical resistivity, and number and quantities of corrosive chemical species present in the soil (Guma *et al.*, 2015). Discrimination of analyzed chemical composition to have knowledge of the types and quantities of aggressive chemical species in soil is a versatile and reliable approach to corrosion prevention or control by methods such as environmental modification, inhibitive treatment, and coating.

XRF analysis is a simple fast technique of chemical analyses of solids and liquids including geological materials such as minerals and soils. XRF analysis has advantages of safe sample preparation without chemical waste, low cost of facility ownership, analysis at the production site, no need for daily re-calibration, and non-destructive analysis. On the other hand, XRD analysis is one of the most versatile and widely used analytical techniques for characterizing chemical compositions of different materials including minerals and soils. The advantages of XRD analysis are fast identification of materials with high accuracy, easy sample preparation, and computer-aided material identification of chemical species with large library of known structural information (Guma *et al.*, 2012; Potts, 1987).

The aim of this paper is to present a conducted survey of average chemical composition of soil at Afaka campus of NDA in Kaduna metropolis up to a depth of about 1.5m using separately, XRF and XRD analyses and the discriminated information which provides an understanding of corrosivity potential of the soil to steel components or structures.

## 2. Materials and methods

### 2.1 Soil collection for analyses

About 0.5kg of soil was collected at 150 different surface locations of at least 20m apart and various depth levels of up to 1.5m within the land of NDA permanent site at Afaka in Kaduna metropolis covering an area of about 80 hectares and mixed thoroughly to have a representative soil sample. The soil was collected within six days during the July-September annual period of peak rainfall in Kaduna metropolis using farmers on the land with remunerations.

### 2.2 XRF and XRD analysis

#### 2.2.1 XRF analysis

The XRF analysis of the representative soil sample was analyzed with the soil in green form at the National Steel Raw Material Research and Development Council, Malali, Kaduna using an XRF spectrometer made by Skyray Instruments USA Inc. The spectrometer was used to generate and focus high energy X-rays on the soil sample placed appropriately in the sample holder of the facility through the X-ray tube of the spectrometer as shown in Fig. 1. The rays ionized the different compositional chemical species in the sample and made each of them to emit secondary X-rays of distinct wavelengths and energy level characteristics as shown in Fig. 2. The distinct energy level characteristics were automatically processed with relevant integral computer software of the spectrometer. The computer had a library of information on such wavelengths and energy characteristics stored in its memory for various chemical elements and groups so outputted identified chemical groups present in the samples with their percentage compositions. This was done 10 times with different samples of the representative soil sample. Out of the 10 samples, one of the samples whose outputted analyzed results were similar or deviated minimally from one another was chosen as the XRF analyzed result for the soil.



Fig. 1: X-ray tube of the spectrometer

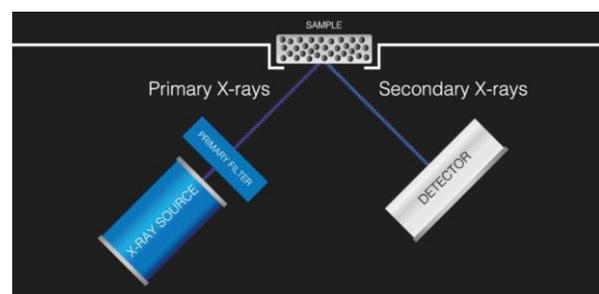


Fig. 2: Arrangement for XRF analysis of the test samples

### 2.2.2 XRD analysis

The XRD of the representative sample of the Afaka soil was taken at room temperature using the Japanese-made Shimadzu-1200 model diffractometer at the National Steel Raw Material Research and Development Council, Malali, Kaduna, with counter monochromatic Cu-K $\alpha$  radiation (from a Cu tube) of wavelength-0.15406nm in accordance with Guma *et al.* (2012). The voltage and current settings were 40kV and 30mA, respectively. The soil was examined in a continuous mode over the angle range of the goniometer from 2 theta ( $2\theta$ ) = 0 to 60°. The scanning speed, sampling pitch and preset time were  $2\theta = 7^\circ/\text{min}$ , 0.02 degrees and 0.17seconds, respectively. With these, the diffractogram, reference peak intensities, reference high and low intensity peaks, the performed search/match and accept information, and the analyzed chemical compositions of the soil were produced with the diffractometer's integral computer accessory. Like the XRF, the XRD analysis was conducted 10 times with different samples of the representative soil sample. Out of the 10 samples, one of the samples whose outputted analyzed results were similar or deviated minimally from one another was chosen as the XRD analyzed result for the soil.

### 3. Results and discussion

Results of the X-ray fluorescence (XRF) analysis are presented in Table. 1, while that of X-ray diffraction (XRD) analysis is presented in Fig. 3 and Tables 2 and 3. According to the XRF analysis results shown in Table 1, it can be observed that the average soil at Afaka campus of NDA contains 16 chemical elements and 16 oxides of different percentage compositions. The elements in the soil are Si, Al, Fe, Mo, Ca, Sn, K, Na, Ti, Mg, Zr, S, Mn, Cr, V, and P in combined forms as oxides. Out of these elements, Si has the highest content in the soil to the tune of 42.39%. This is followed by the other elements in that order to the least in content P (0.69%). Generally, most normal soils contain some known element types in various percentage ranges such as 1 to 5% (Fe), 1 to 30% (Al), about 28% (Si), about 0.25% (Ca), 0.1 to 2% (K), 0.001 to 0.005% (Cr), 0.002 to 0.3% (Mn), 0.02 to 2.4% (Ti), 0.0005 to 0.106% (Zr), and 0.0018 to 0.0115% (V). The content levels can however be much higher at some locations around the globe depending on geological factors, pollution level, agricultural usage, and types of vegetative growths (Vodyanitski, 2016). It can

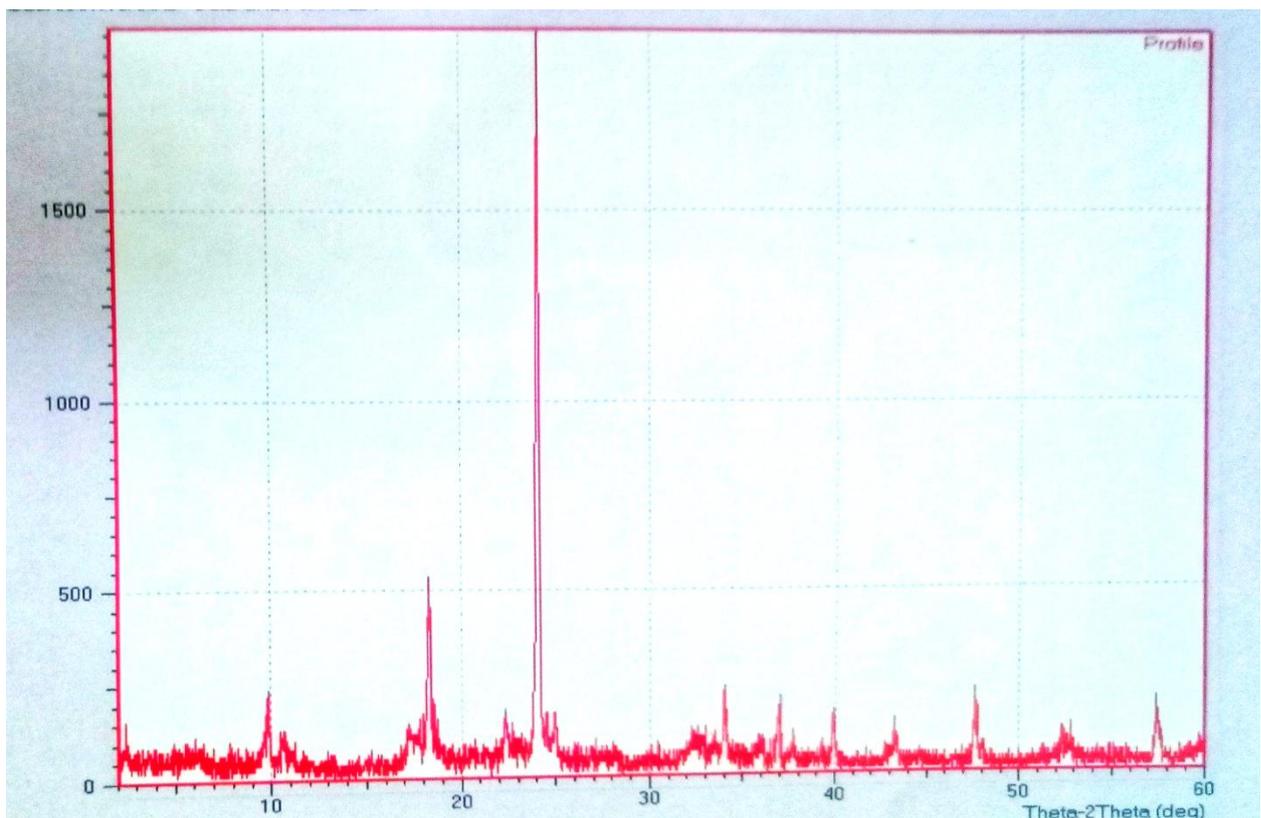
therefore be seen from Table 1 that the analyzed soil at Afaka campus of NDA is distinctive in composition from average normal soil by elemental contents except for Al and Si. Out of the 16 oxides, SiO<sub>2</sub> had the highest content of 40.60% followed by Al<sub>2</sub>O<sub>3</sub> (21.64%) and least by PbO<sub>2</sub> (0.76%). Out of the 16 oxides, only SO<sub>2</sub> is known to be inimical to corrosion of steel; the other oxides are generally not known for posing notable corrosion problems to steel (Gasem, 2014). SO<sub>2</sub> is corrosive to steel because it can react with any water constituent and oxygen in the soil to form corrosive sulphuric acid. Sulphuric acid is highly corrosive to steel and can damage the material (Guma and Daniel, 2019). Even then the percentage of SO<sub>2</sub> in the soil is seen to be very small (1.32%) for the formation of any notable quantity of sulphuric acid that can corrode steel material in the soil.

From the XRD analysis results presented in Fig. 3 and Tables 2 and 3, it is observable that the average soil contains 15 chemical compounds of different compositions which are essentially potassium, aluminum, iron, sodium, and calcium inorganic salts or alkali or oxides. All these compounds are also not known for posing any significant corrosion problems to steel (Gasem, 2014). The differences in the XRF and XRD analyzed results are however due to differences in designed capabilities of the XRF and XRD analytical techniques to analyze chemical elements. However, the XRF and XRD results complement one another, and point to the same conclusion that the NDA soil at Afaka campus can have very low corrosivity to steel components or structures in the soil. The corrosivity conclusion drawn here with the XRF and XRD analyses of NDA soil at Afaka campus is in moderate agreement with results of the work of Guma and Oguchi (2011) on the corrosivity level of a section of river in Kaduna to mild steel. Guma and Oguchi (2011) found that the river section is generally more or less moderate in corrosivity to mild steel with average corrosion penetration rate of 0.082mm/yr in spite of possible effects of the river pollution by human activities. Also, the drawn corrosivity conclusion here is in fair agreement with the work of Guma *et al.* (2015) on soil corrosivity levels of the whole Kaduna metropolitan area during annual period of peak rainfall (August to October) using electrical resistivity method. By their results, Guma *et al.* (2015) showed that the whole Kaduna metropolitan area has randomly variable soil corrosivity spectrum that is mildly corrosive on average and

generally decreases downwards from aggressive at depths of less than about 0.5m to slightly corrosive around the depth of 4.5m.

**Table 1:** Chemical elements detected in the soil in Wt% by XRF analysis

Element symbol	Atomic conc.	Weight conc.	Oxide symbol	Stoich. wt conc.
Si	42.39	33.73	SiO <sub>2</sub>	40.60
Al	26.88	20.54	Al <sub>2</sub> O <sub>3</sub>	21.84
Fe	7.38	11.67	Fe <sub>2</sub> O <sub>3</sub>	9.39
Mo	3.97	10.78	MoO <sub>3</sub>	9.10
Ca	5.16	5.85	CaO	4.61
Sn	1.10	3.70	SnO <sub>2</sub>	2.65
K	2.09	2.31	K <sub>2</sub> O	1.57
Na	3.22	2.10	Na <sub>2</sub> O	1.59
Ti	1.54	2.09	TiO <sub>2</sub>	1.97
Mg	1.88	1.30	MgO	1.21
Zr	0.50	1.28	ZrO <sub>2</sub>	0.98
S	1.28	1.16	SO <sub>2</sub>	1.31
Mn	0.66	1.03	MnO	0.75
Cr	0.65	0.96	Cr <sub>2</sub> O <sub>3</sub>	0.79
V	0.61	0.88	V <sub>2</sub> O <sub>5</sub>	0.89
P	0.69	0.61	P <sub>2</sub> O <sub>5</sub>	0.78



**Fig. 3:** The diffractogram obtained with XRD analysis of the soil

**Table. 2:** Search match results for the diffractogram

<b>Congest 3 Peak</b>	<b>Peaks 2Theta</b>	<b>D</b>	<b>I/II</b>	<b>FWHM</b>	<b>Intensity</b>	<b>Integrated</b>
no.	(deg)	(Å)		(deg)	(Counts)	(Counts)
7	24.0839	3.69222	100	0.16400	195	1614
3	18.3014	4.84369	21	0.17880	40	444
6	23.860	3.72636	12	0.10660	23	184

Data List

Peak no.	2Theta (deg)	D (Å)	I/II	FWHM (deg)	Intensity (Counts)	Integrated (Counts)
1	9.8400	8.98155	7	0.12000	14	171
2	10.5433	8.38395	4	0.11330	8	101
3	18.3014	4.84369	21	0.17880	40	444
4	22.3233	3.97928	6	0.14000	12	120
5	22.730	3.90899	3	0.08000	6	44
6	23.8600	3.72636	12	0.10660	23	184
7	24.0839	3.69222	100	0.16400	195	1614
8	24.5000	3.63045	4	0.20000	8	101
9	24.9500	3.56598	6	0.14000	11	104
10	28.0633	3.17705	3	0.08670	6	42
11	32.3658	2.76386	4	0.07830	7	64
12	33.9740	2.63662	12	0.10800	23	131
13	34.1200	2.62567	4	0.09000	7	49
14	35.8700	2.50148	4	0.10000	7	84
15	35.9166	2.43293	9	0.12670	18	164
16	37.7100	2.38354	3	0.12000	6	59
17	39.8750	2.25898	8	0.13000	15	134
18	43.225	2.09146	5	0.11500	10	103
19	47.5931	1.90909	11	0.12230	22	161
20	52.3150	1.74735	5	0.11000	9	65
21	52.7950	1.73258	3	0.11000	6	47
22	57.4250	1.60341	9	0.19000	15	191

**Table 3:** XRD analysed chemical composition of the soil by computer search match results

No.	Card	Chemical Formula and Name, and (Mineral name)	S	L D <sub>x</sub>	D Wt%	R
1	25-0645	Mg <sub>3</sub> (Si <sub>2-x</sub> O <sub>5</sub> ) (OH) 4-4x = Magnesium Silicate Hydroxide ( Chrysotile)	0.268	0.571(8/18)	0.586	0.335
2	10-0495	KMg <sub>3</sub> (Si <sub>3</sub> Al)O <sub>10</sub> (OH) <sub>2</sub> = Potassium Magnesium Aluminum Silicate Hydr	0.430	0.417(10/26)	0.782	0.326
3	10-0492	KMg <sub>3</sub> (Si <sub>3</sub> Al) O <sub>10</sub> (OH) 20.346 = PotassiumY Magnesium Aluminum Silicate Hydr	0.766	0.417(10/26)	0.766	0.319
4	29-1016	KMg <sub>2</sub> Al <sub>3</sub> (Si <sub>10</sub> Al <sub>2</sub> ) O <sub>30</sub> = Potassium Magnesium Aluminum Silicate (Os)	0.181	0.364(12/33)	0.739	0.269
5	10-0357	(Na, K) (Si <sub>3</sub> Al) O <sub>8</sub> = Potassium Magnesium Aluminum Silicate (Sanid)	0.324	0.412(7/17)	0.631	0.260
6	33-0664	Fe <sub>2</sub> O <sub>3</sub> = Iron Oxide (Hematite, Syn )	0.389	0.364(4/42)	0.693	0.252
7	29-1488	Al <sub>2</sub> Si <sub>2</sub> O <sub>5</sub> (OH) <sub>4</sub> = Aluminum Silicate Hydroxide (Kaolinite-1)	0.116	0.286(4/21)	0.807	0.231
8	26-0911	(K,H <sub>3</sub> O) Al <sub>2</sub> Si <sub>3</sub> AlO <sub>10</sub> (OH) <sub>2</sub> = Potassium Aluminum Silicate Hydroxide	0.559	0.412(7/18)	0.518	0.213
9	6-0263	KA1 <sub>2</sub> (Si <sub>3</sub> Al) O <sub>10</sub> (OH, F) <sub>2</sub> = Potassium Aluminum Silicate Hydroxide	0.438	0.357(15/42)	0.595	0.212
10	50-1606	(Mg, Fe) 3Si <sub>2</sub> O <sub>5</sub> (OH) <sub>4</sub> = Magnesium Iron Silicate Hydroxide ( Lizard)	0.290	0.325(13/42)	0.631	0.205
11	49-1057	K-Mg-Al-SiO <sub>2</sub> - H <sub>2</sub> O = Potassium Iron Magnesium Aluminum Silicate	0.274	0.364(4/22)	0.556	0.202
12	16-0613	Mgx (Mg, Fe) <sub>3</sub> (Si, Al) 4O <sub>10</sub> (OH) <sub>2</sub> . 4H <sub>2</sub> O = Magnesium Iron Aluminum Silicate Hydroxide	0.237	0.310(9/32)	0.651	0.202
13	19-1184	NaAlSi <sub>3</sub> O <sub>8</sub> = Sodium Aluminum Silicate Hydroxide (Albite, ordered)	0.318	0.310(13/42)	0.615	0.190
14	13-0135	CaO <sub>2</sub> (Al, Mg) 2Si <sub>4</sub> O <sub>10</sub> (OH) <sub>2</sub> .4H <sub>2</sub> O = Calcium Magnesium Aluminum Silicate Hydrox	0.375	0.308(4/17)	0.600	0.185
15	23-1405	NaCa <sub>2</sub> Mg <sub>5</sub> AlSi <sub>7</sub> O <sub>22</sub> (OH) <sub>2</sub> = Sodium Calcium Magnesium Aluminum Silicate	0.212	0.261(6/23)	0.694	0.181

#### 4. Conclusions

A survey of average chemical species in NDA soil at its Afaka campus in Kaduna metropolis up to a depth of about 1.5m has been conducted using XRF and XRD analyses. The analyses indicate that the soil can have very low corrosivity to steel components or structures in service contact with it due to non-presence of significant steel-corrosive chemical species in the soil. Most of the chemical species found in the soil were oxides, and inorganic salts and alkali which are generally not known to pose notable corrosion problem to steel. The only chemical specie that was found capable of posing corrosion problem to steel components in the soil is sulphur dioxide, even then its analyzed

composition in the soil was found to be minimal. This paper is therefore a contribution towards providing applicable comprehensive public information for any rethinking or strategy in averting practical corrosion problems with steel components in soil-based constructions at Afaka campus of NDA for longevity of the constructions and the desired service safety from them.

#### References

Achebe, C.H., Nneke, C.C. and Anisiji, O.E. (2012) Analysis of Oil Pipeline Failures the Oil and Gas Industries in the Niger Delta of Nigeria. Proc. International Multi-conference of

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Using X-Ray Fluorescence and Diffraction Techniques

- Engineers and Computer Scientists Vol. II, March, 2012, Hong Kong.
- Baker, M.B. and Fessler, R.R. (2009) Pipeline Corrosion. Final Report Submitted to U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration, Office of Pipeline Safety Integrity Management Program, Under Delivery Order DTRS56-02-D-70036.
- Beavers, J.A. and Thompson, N.G. (2008) External Corrosion of Oil and Natural Gas Pipelines. ASM Handbook, Vol 13C, Corrosion: Environment and Industries.
- Koch, G.H., Brongers, M.P.H., Thompson, N.G.Y., Virmani, Y.P. and Payer, J.H. (2002) Corrosion Costs and Preventive Strategies in the United States. CC Technologies Laboratories, Inc Publication No. FHWA-Rd-01-156
- Ekine, A.S. and Emujakporue, G.O. (2010) Investigation of corrosion of buried Oil pipeline by the electrical geophysical methods. Journal of Applied Science and Environmental Management 14(1): 63-65.
- Ekoh, J.E., Akpabio, E.J. and Etukudo, U.I. (2012) Cathodic Protection of Buried Pipelines in Niger Delta. Environmental Research Journal 6(4): 304-307.
- Fontana, M.G. (1987) Corrosion Engineering, 3rd Edn., McGraw-Hill Book Company, New York, 32- 34.
- Gasem, Z.M. (2014) Cathodic Protection ME 472-061 Corrosion Engineering 1 ME, KFUPM. [www.scibd.com/doc/131766374/cthdic-protection](http://www.scibd.com/doc/131766374/cthdic-protection). Accessed 19/07/2019.
- Guma, T.N., Ajayi, E.O. and Mohammed, M.H. (2020) Standard Techniques of Stress Corrosion Cracking Testing: A Review. Journal of Newviews in Engineering and Technology (JNET), 2(1): 58-72.
- Guma, T.N. and Daniel, K.O. (2019) Effects of some Amine Treatments on Corrosion of Mild Steel in Acidic Chloride Environment. International Journal of Emerging Technology and Advanced Engineering, 9(8): 39-49.
- Guma, T.N. and Oguchi, C.I.C. (2011) Field Test Assessment of Corrosivity of River Kaduna to Mild Steel. PeCOP Journal of Science, Engineering and Technology, 4(1): 40-50.
- Guma, T.N., Atiku, S.A. and Abdullahi, A.A. (2017) Corrosion Management and Control: Entrepreneurial Opportunities and Challenges in Nigeria. International Journal of Engineering Research and Application, 7(10): 14-23.
- Guma, T.N., Madakson, P.B., Yawas, D.S., and Aku S.Y. (2012) X-ray Diffraction Analysis of the Microscopies of some Corrosion-Protective Bitumen Coatings. International Journal of Modern Engineering Research, 2(6): 4387-4395.
- Guma, T.N., Mohammed, S.U., and Tanimu, A.J. (2015). A Field Survey of Soil Corrosivity Level of Kaduna Metropolitan area through Electrical Resistivity Method. International Journal of Scientific Engineering, 3(12): 5-10
- Guma, T.N., Mohammed, S.U., and Tanimu, A.J. (2016). An Experimental Investigation of Galvanic Anode Specifications for Suitable Cathodic Corrosion Protection of Low Carbon Steel in Kaduna Metropolitan Soil. American Journal of Engineering Research, 5(2): 72-76.
- Oyedele, K.F., Meshida, E.A. and Obidike, C.C. (2012) Assessment of Coastal Soil Resistivity Using Resistivity Tomography at Lekki, Lagos. International Journal of Science and Advanced Technology, 2(6): 77-81.
- Potts, P.J. (1987) X-ray fluorescence analysis: principles and practice of wavelength - A Handbook of Silicate Rock Analysis, 226-285.
- Schoonover, J.E. and Crim, J.F. (2015) An Introduction to Soil Concepts and the Role of Soils in Watershed Management. Journal of Contemporary Water Research and Education, 254(1): 21-47.
- Vodyanitski, Y.N. (2016) Standards for Contents of Heavy Metals in Soils of some States. Annals of Agrarian Soils, 14(3): 257-263.