Journal of Geography, Environment and Earth Science International

25(5): 46-56, 2021; Article no.JGEESI.66723
ISSN: 2454-7352

Geoelectrical and Physicochemical Evaluation of Soil Corrosivity on Metallic Pipelines: A Case Study

Ismaila Abiodun Akinlabi[1*] and Moshood Lekan Olaiya[1]

[1]*Department of Earth Sciences, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Author IAA designed the study, managed the literature searches and wrote the first draft of the manuscript. Author MLO acquired the field data and carried out the initial analyses. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2021/v25i530287
Editor(s):
(1) Prof. Anthony R. Lupo, University of Missouri, USA.
Reviewers:
(1) Ana Márcia Barbosa da Silva Antunes, University of São Paulo, Brazil.
(2) Adhimar Flávio Oliveira, Universidade Federal de Itajubá, Brazil.
Complete Peer review History: http://www.sdiarticle4.com/review-history/66723

Original Research Article

Received 08 February 2021
Accepted 13 April 2021
Published 02 July 2021

ABSTRACT

Geoelectrical sounding and physicochemical analyses were conducted on the topsoil underlying Osupa area in Ogbomoso, south western Nigeria to evaluate the soil corrosivity on the metallic water pipelines across the area. Schlumberger electrical resistivity soundings were conducted at 24 stations with electrode spacing varied from 1 to 100 m. The resistivity data were interpreted by using partial curve matching and computer-aided 1D inversion. Physicochemical analyses were also conducted on soil samples collected from about 1 m depth in test pits dug at points coincident with the sounding stations, following the BS/AWWA/ANSI Standards for Corrosivity testing to determine the soil pH, redox potential, moisture content and chloride content. The soil corrosivity was evaluated based on soil resistivity alone and the combined effect of soil pH and resistivity. The studied soils have resistivity ranging from 10 Ωm to 492 Ωm and thickness varying from 0.5 m to 4.6 m. The pH, moisture content, redox potential and chloride content range from 4.22 to 8.41, 14.33% to 29.09%, +50 mV to +97 mV and 102 ppm to 196 ppm respectively. The corrosivity intensity, based on the combined effect of soil pH and resistivity is essentially Medium-to- Medium-High being Medium at 10 locations, Medium-High at 8 locations, and High, Medium-Low, and Low

**Corresponding author: E-mail: akinlabiodun@gmail.com;*

at 2 locations each. More reliable information can be obtained about soil corrosivity toward buried metallic structures if the combined effect of the soil parameters affecting soil corrosion is considered.

Keywords: Metallic pipeline; resistivity; soil pH; combined effect; soil corrosivity.

1. INTRODUCTION

Pipelines for transporting water, crude oil or natural gas, are known to be undergoing corrosion induced by the hosting soil environment all over the world. Corrosion is a major cause of the failure of underground pipelines. It is the oxidation and electrochemical breakdown of the structure of pipes used to convey liquid or gas from production to distribution. It occurs naturally as a gradual and continuous attack on metallic materials in the presence of moisture and oxygen, resulting in the formation of oxides of the metal with subsequent loss of strength, ductility and other mechanical properties [1].

Water pipelines are usually buried in soils within the top 1 m, for safety and security. It is important to investigate the soil environment in which the pipes will be laid for corrosivity, to forestall failure of the pipelines attributable to corrosion-induced rupture and leakage, with consequent environmental degradation and financial burden, considering the costs of replacement and rehabilitation [2-5].

Soils and their inherent properties are key factors influencing corrosion of underground metallic pipes. The rate at which metallic pipes rupture depends on the corrosivity of the hosting soil environment. The major soil properties that influence external corrosion of metallic pipelines buried in soil include resistivity, moisture content, pH, redox potential, and chloride and sulphide contents [6]. They are naturally occurring and play an active role in the process by which the surface of a metallic pipe structure is oxidized or reduced by chemical or electrochemical reaction within the soil environment.

The water pipes buried in the topsoil of the study area have corroded over time, making it impossible to supply potable water to the use of the teeming population. Evaluation of corrosivity of the hosting soil environment is key in the investigation of metallic pipeline failure [7-9]. Since there is no prior information about corrosion characteristics of the soils of the study area on buried metal pipes, it has become necessary to determine the soil corrosivity to guide in the choice of pipes for the rehabilitation programme to restore the pipelines.

Geoelectrical method and physicochemical analyses were therefore employed to evaluate the corrosivity of topsoil on underground metallic water pipes around Osupa area, Ogbomoso, south western Nigeria. The objectives are to determine the resistivity values and physicochemical properties of the topsoil across the study area, determine the intensity of corrosion based on resistivity values alone and combined effect of soil parameter which affect soil corrosivity toward metallic pipes in the study area.

The study area is located within Latitudes 08°7.56'N - 08°8.13'N and Longitudes 04°14.18'E - 04°14.60'E (Fig. 1) with elevation ranging from 370m to 373mabove sea level. It lies within the Precambrian basement complex of south western Nigeria [10] and is underlain by quartzite, which occurs with quartz schist as quartzite-quartz schist complex (Fig. 2).

2. MATERIALS AND METHODS

The study was carried out by using geoelectrical method and physicochemical analyses. The geoelectrical method employed the Schlumberger vertical electrical sounding to determine apparent resistivities at twenty-four stations across the study area with the aid of an ABEM 1000 resistivity meter and its accessories. The current electrode spacing (AB/2) varied from 1 to 100 m. The field layout is shown in Fig. 3. The apparent resistivity data were interpreted using partial curve matching and computer assisted 1D inversion algorithm [11].

The physicochemical analyses entailed laboratory tests conducted on soil samples collected from about 1 m depth in the topsoil to determine soil parameters such as pH, redox potential, temperature, moisture content, resistivity and chloride ion (Cl^-) content following the American and British Standards [6,12]. The soil samples were collected at points coincident with the sounding stations beneath which resistivities of the topsoil were measured. The topsoils at different parts of the study area were then classified in terms of corrosivity intensity based on their resistivity values [13-16] as presented in Table 1 and Table 2, and the corrosive soil load function of pH and resistivity according to European Standard [17] shown in Table 3.

3. RESULTS AND DISCUSSION

The results of the resistivity survey and physicochemical analyses on the soil samples are presented in Table 4. The resistivity of the topsoil ranges from 10 Ωm to 492 Ωm while its thickness varies from 0.5 m to 4.6 m. The topsoil is predominantly clay with resistivity values mostly less than 100 Ωm. Clayey soils tend to have low resistivity and are corrosive toward buried metallic structure. The finer the particles of soil are, the more corrosive it is toward buried metallic structures. Soil resistivity plays a significant role in the evaluation of soil corrosivity since corrosion is an electrochemical reaction [18,19,20]. It may thus be used to theoretically classify the intensity of soil corrosivity.

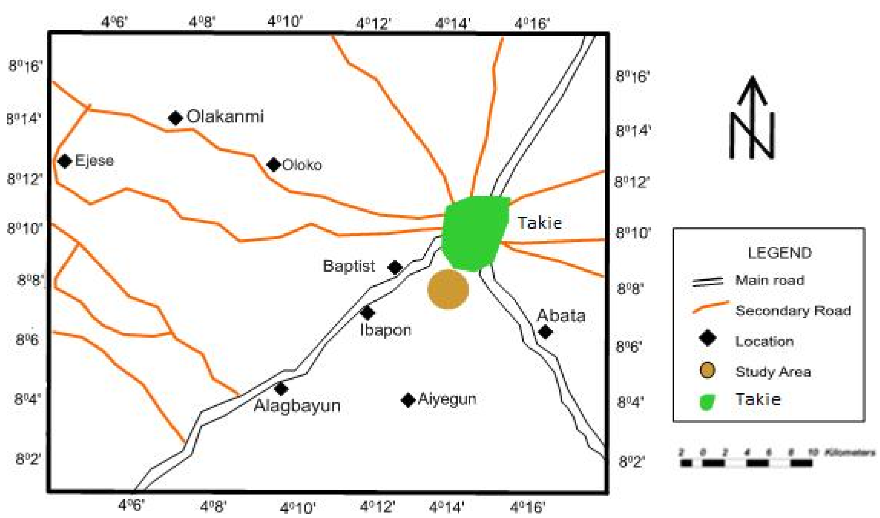

Fig. 1. Location map of the study area

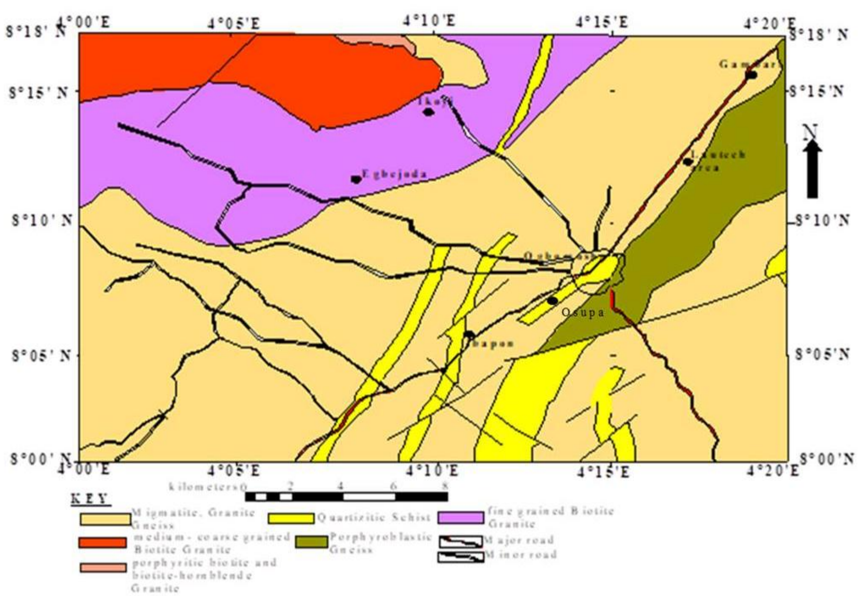

Fig. 2. Geological map showing the study area

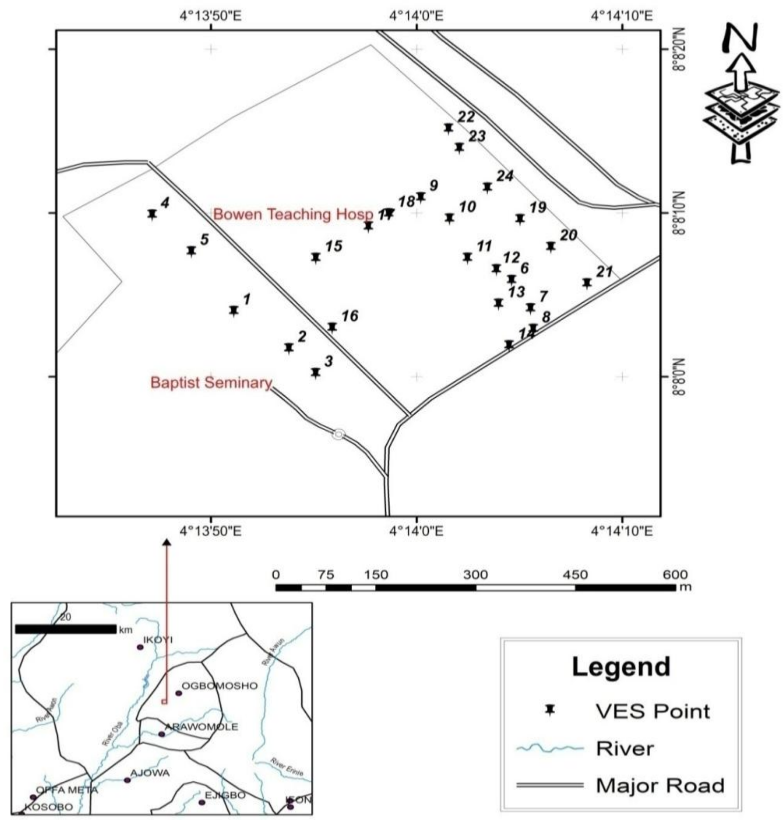

Fig. 3. Field layout showing the VES and Sampling points

Soils having resistivity below 200 Ωm are generally considered to be corrosive [13-16]. Since the majority (87.5%) of the topsoil resistivity is in this class, the topsoil beneath the study area is mainly corrosive and may have contributed to the deterioration of the buried metallic water pipes. In addition, since soil corrosion reactions are associated with ionic current flow, low soil resistivity enhances corrosion of buried metallic pipes while high soil resistivity inhibits it [21,22].

The moisture content of the studied soil ranges from 14.33% to 29.09% characteristic of moist soils with fair drainage [6]. Low moisture content generally suggests high resistivity and low soil corrosivity [8,23,24]. An increase in soil moisture content lowers soil resistivity and favours corrosion of metallic structures.

The soil pH varies from 4.22 to 8.41 which lie within the common range of 4 to 10 [7]. While the pH values for samples 1-3 and 16-21 range from 4.22 to 6.20 and suggest acidic soil, samples 4, 9-11, 14, 15 and 22-24 have pH ranging from 6.93 to7.37 indicating neutral soils. The pH range of 7.83-8.41 for samples 5-8, 12, 13 is characteristic of basic environment. Corrosion of buried steel and iron pipes are known to be enhanced considerably by acidic soil environments [19,20].

Redox potential (ORP) is the relative potential of an electrochemical reaction under equilibrium conditions. It is used to describe a soil's overall reducing or oxidizing capacity. In well-oxidized/aerobic environment, redox potential may be as high as +300 mV to +500 mV while it may be below +100 mV or even negative in a reduced/anaerobic environment [25]. The values for the study area range from +50 mV to +97 mV indicating low concentration of oxygen and reduced soil environment which can support corrosion of metallic pipes in the presence of sulphate-reducing bacteria [26,27].

The studied soils have Chloride content ranging from 102 ppm to 196 ppm and can be said to be corrosive [14-16]. The contribution of Chloride

(Cl^-) is very significant to soil corrosivity as increase in the chloride content in soil tends to enhance ionic current flow associated with corrosion reactions, reduce the soil resistivity, and consequently increase the soil corrosivity on buried metallic pipes [28,29].

Soil corrosion of buried metallic structures is a complex phenomenon since it is not a consequence of a single parameter, but a combination of different factors characteristic of the local soil conditions that influence deterioration [30]. The soil parameters are affected and influenced by one another directly and/or indirectly. Soil resistivity generally decreases with increasing moisture content and concentration of ionic species while chloride content is inversely related to pH. Moisture content, chloride content, temperature and pH thus contribute to the overall soil resistivity. Redox potential (E_h) and pH are related since most redox processes consume or release hydrogen ions (H^+). E_h decreases with increasing soil pH. Soils with high moisture content, high electrical conductivity (i.e., low electrical resistivity), high acidity and high dissolved salts will be most corrosive [22].

Considering the interrelationship between the soil parameters that affect corrosion of buried metallic structures, an assessment of soil corrosivity based on consideration of only one out of the many variables involved can be misleading. If pH data are combined with soil resistivity data, more reliable information can be obtained about the degree of soil corrosivity toward buried metallic pipes. The European Standard EN 12501-2: 2003 [17] provides a qualitative assessment of soil corrosivity taking into account the contribution of pH and resistivity.

Table 1. Classification of soil corrosivity in terms of resistivity [based on [13])

Soil Resistivity [Ωm]	Soil Corrosivity
<10	Very strongly corrosive (VSC)
10–60	Moderately corrosive (MC)
60–180	Slightly corrosive (SC)
> 180	Practically noncorrosive (PNC)

Table 2. Rating of soil corrosivity intensity based on soil resistivity (adapted from [14,15,16])

Soil Resistivity [Ωm]	Soil Corrosivity
>200	Essentially Non Corrosive
100-200	Mildly Corrosive
50–100	Moderately Corrosive
30-50	Corrosive
10-30	Highly Corrosive
<10	Extremely Corrosive

Table 3. Corrosive soil load function of pH and resistivity (based on European Standard [17])

pH	Resistivity in Ωcm	Resistivity in Ωm	Soil Corrosivity
< 3.5	Any	Any	High
3.5 – 4.5	< 4500	< 45	High
	>4500	> 45	Medium-High
4.5 – 5.5	< 4500	< 45	High
	4500 – 5000	45 -50	Medium-High
	> 5000	> 50	Medium
5.5 – 6.0	< 1000	< 10	High
	1000 – 5000	10 -50	Medium-High
	5000 – 10000	50 -100	Medium
	> 10000	> 100	Medium-Low
6.0 – 9.5	< 1000	< 10	High
	1000 – 3000	10 -30	Medium-High
	3000 – 10000	30 -100	Medium
	10000 – 20000	100 -200	Medium-Low
	> 20000	> 200	Low

Table 4. Soil parameters of topsoil from the study area

Sample/ VES No.	Resistivity [Ωm]	Moisture content [%]	pH	Redox Potential [mV]	Cl^- [ppm]
1	33	27.94	6.20	70	103
2	29	26.38	4.22	68	106
3	42	29.09	5.78	73	102
4	28	21.38	7.16	76	123
5	22	25.42	8.35	80	133
6	18	19.82	7.93	81	165
7	25	15.54	8.37	97	168
8	27	22.63	8.41	82	162
9	138	24.06	6.98	74	196
10	56	24.20	7.00	83	190
11	42	24.71	6.94	78	194
12	37	23.86	8.04	50	145
13	44	14.69	7.83	65	137
14	40	18.14	7.37	67	154
15	262	14.58	6.93	80	104
16	85	18.83	6.11	95	116
17	430	15.96	6.09	84	132
18	492	17.55	5.88	91	110
19	16	15.62	4.72	63	122
20	52	14.33	4.86	86	136
21	10	19.18	5.45	59	127
22	57	23.13	7.00	70	145
23	28	22.45	7.34	82	147
24	56	22.92	7.05	93	143

The corrosivity rating of the soils of the study area based resistivity alone [13-16] and corrosive soil load function of pH and resistivity according to European Standard EN 12501-2: 2003 [17] are presented in Table 5. The ranking by Baeckman and Schwenk [13], based on resistivity alone, reveals that most of the studied soils (19 out of 24 samples) are Moderately corrosive, while samples 9 and 16 are Slightly corrosive, and samples 15, 17 and 18 are Practically Noncorrosive.

The European Standard EN 12501-2: 2003, based on combined effect of soil pH and resistivity ranks samples 2-8 and 23 as Medium-High compared to the Moderately corrosive rank by Baeckman and Schwenk [13] and Highly corrosive/Corrosive rank by Robinson [14], NACE [15] and Escalante [16]. Samples 19 and 21 are ranked as High; samples 9 and 18 are Medium-Low while samples 15 and 17 are Low. Only 10 samples, comprising samples 1, 10-14, 16, 20, 22 and 24 are ranked as Medium out of the 19 samples in the equivalent Moderately corrosive rank by Baeckman and Schwenk [13], including the Corrosive samples 1, and 11-14 of Robinson [14], NACE [15] and Escalante [16]. The corrosivity of the studied soils based on combined effect of soil pH and resistivity is essentially Medium-to-Medium-High being Medium at 10 locations, Medium-High at 8 locations, and High, Medium-Low and Low at 2 locations each.

The rankings are presented in the corrosivity map in Figs. 4-6 all of which show increase in corrosivity from west to east across the study area with a middle belt of medium corrosivity widest and most pronounced in Fig. 6 in which the combined effect of soil resistivity and pH has been considered. The soil corrosivity is Medium-High to the north, east and south of the middle belt, and Medium-Low to Low westward. The identification of zones of different corrosion intensity/severity is expected to guide in the selection of safe pipeline paths and appropriate methods of corrosion control for the rehabilitation programme and subsequent maintenance schemes.

Table 5. Soil Corrosivity rating based on only resistivity and combined effect of pH and resistivity

Sample No.	ρ[Ωm]	pH	Corrosivity rating		
			Baekmann & Schenwenk 1975*	**Robinson'93*,NACE'93*& Escalante '95***	**European EN 12501-2:2003****
1	33	6.20	Moderately Corrosive	Corrosive	Medium
2	29	4.22	Moderately Corrosive	Highly corrosive	Medium-High
3	42	5.78	Moderately Corrosive	Corrosive	Medium-High
4	28	7.16	Moderately Corrosive	Highly corrosive	Medium-High
5	22	8.35	Moderately Corrosive	Highly corrosive	Medium-High
6	18	7.93	Moderately Corrosive	Highly corrosive	Medium-High
7	25	8.37	Moderately Corrosive	Highly corrosive	Medium-High
8	27	8.41	Moderately Corrosive	Highly corrosive	Medium-High
9	138	6.98	Slightly Corrosive	Mildly corrosive	Medium-Low
10	56	7.00	Moderately Corrosive	Moderately corrosive	Medium
11	42	6.94	Moderately Corrosive	Corrosive	Medium
12	37	8.04	Moderately Corrosive	Corrosive	Medium
13	44	7.83	Moderately Corrosive	Corrosive	Medium
14	40	7.37	Moderately Corrosive	Corrosive	Medium
15	262	6.93	Practically Noncorrosive	Essentially Noncorrosive	Low
16	85	6.11	Slightly Corrosive	Moderately corrosive	Medium
17	430	6.09	Practically Noncorrosive	Essentially Noncorrosive	Low
18	492	5.88	Practically Noncorrosive	Essentially Noncorrosive	Medium-Low
19	16	4.72	Moderately Corrosive	Highly corrosive	High
20	52	4.86	Moderately Corrosive	Moderately corrosive	Medium
21	10	5.45	Moderately Corrosive	Highly corrosive	High
22	57	7.00	Moderately Corrosive	Moderately corrosive	Medium
23	28	7.34	Moderately Corrosive	Highly corrosive	Medium-High
24	56	7.05	Moderately Corrosive	Moderately corrosive	Medium

*ρ = soil resistivity. *Based on soil resistivity alone. **Based on combined effect of soil pH and resistivity*

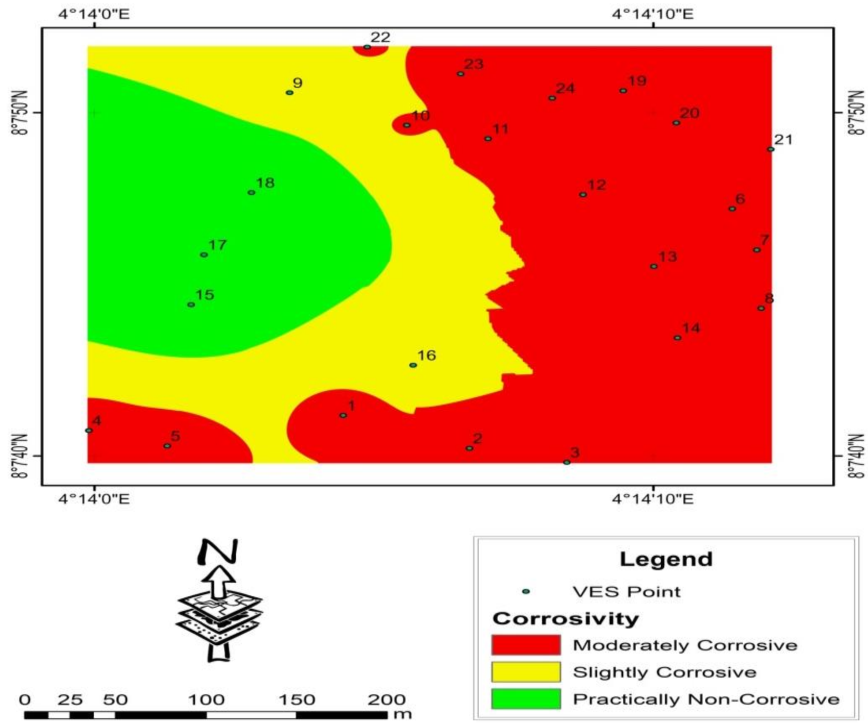

Fig. 4. Corrosivity map of the study area based on resistivity alone in accordance with [13]

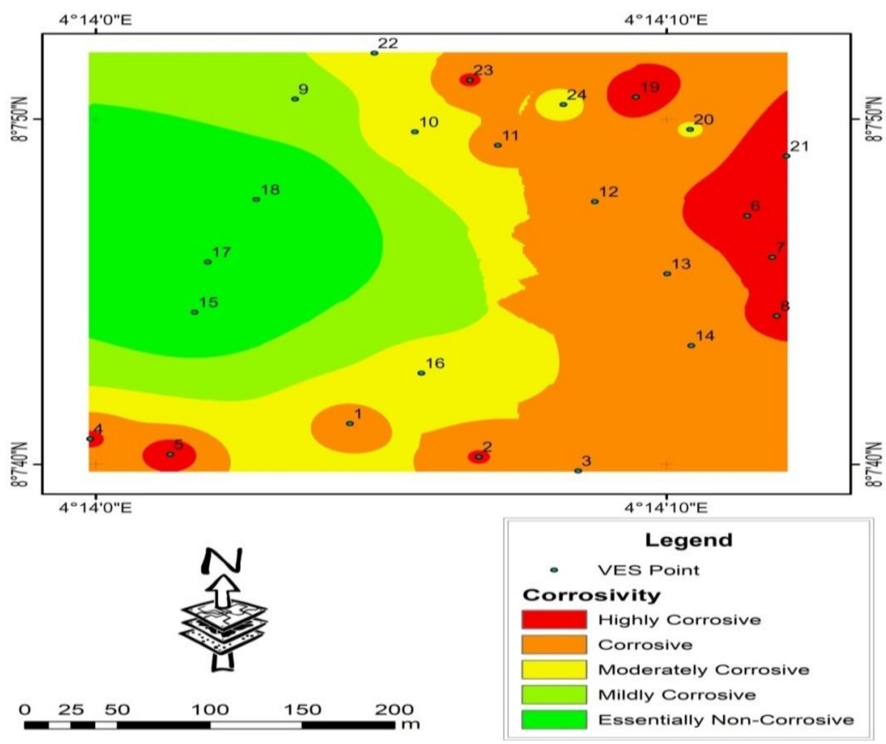

Fig. 5. Corrosivity map of the study area based on resistivity alone in accordance with [14-16]

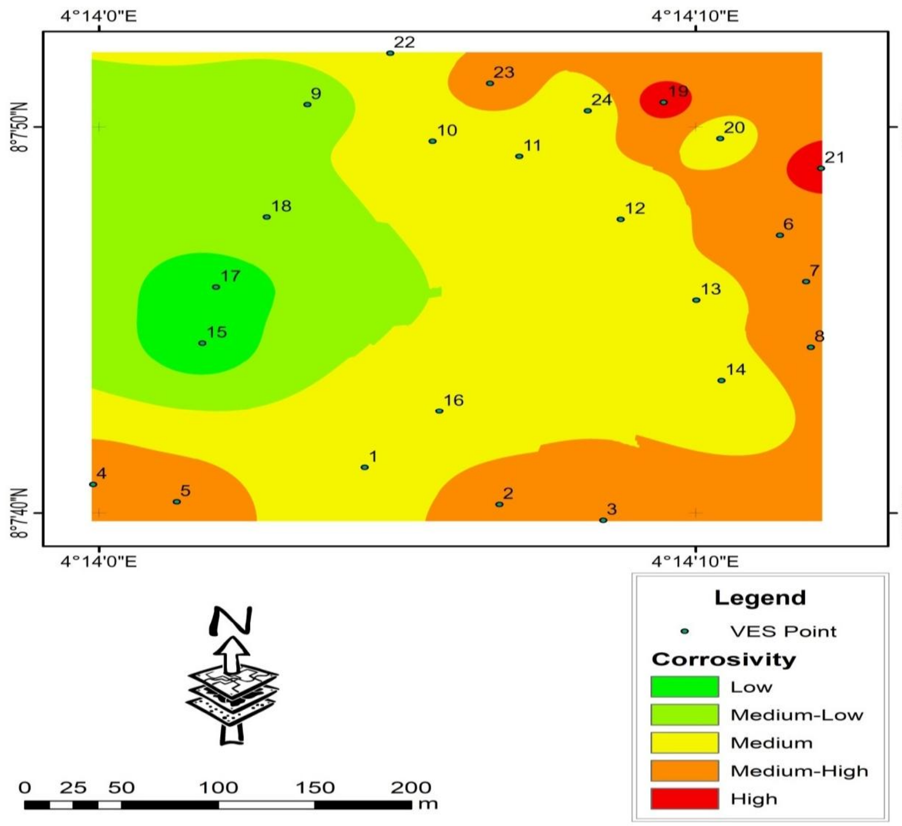

Fig. 6. Corrosivity map of the study area based on combined effect of pH and resistivity [17]

4. CONCLUSIONS

In this study, the results from geoelectrical sounding and physicochemical analyses for assessing the corrosivity of topsoil on underground metallic pipelines have been presented. It has been shown that the consideration of resistivity values alone may not be effective in the evaluation of soil corrosivity on buried metallic structures. The European Standard EN 12501-2: 2003, based on combined effect of soil pH and resistivity reveals that the soil corrosivity is mainly medium to medium-high compared to the moderately corrosive rank by Baeckman and Schwenk [13] and moderately corrosive/corrosive/highly corrosive rank by Robinson [14], NACE [15] and Escalante [16] which are based on resistivity values alone.

More reliable information can be obtained if the combined effect of the various soil parameters affecting soil corrosion is considered. The identification of zones of different corrosion intensity is expected to guide in the selection of safe pipeline paths and appropriate methods of corrosion control for rehabilitation programme and subsequent maintenance schemes.

ACKNOWLEDGEMENT

The authors gratefully appreciate the assistance of Mr H. A. Mustapha in producing the corrosivity maps, and the useful comments of the anonymous reviewers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ekine AS, Emujakporue GO. Investigation of Corrosion of Buried Oil Pipeline by the Electrical Geophysical Methods. J. Appl. Sci. Environ. Manage. 2010;14(1): 63–65.
2. Okoroafor C. Cathodic protection in the saving of national asset. J. Corr. Sci Tech. 2004;1.1(Special Edition):1-6.

3. Scheweitzer PA. Corrosion engineering handbook: Fundamentals of metallic corrosion, 2nd ed. Taylor and Francis Group: Abingdon, UK. 2006;1400.
4. Anyanwu SI, Nwosu HU, Reginald AE, Eseonu O. Correlation between soil properties and external corrosion growth rate of carbon steel. International Journal of Engineering and Science (IJES). 2014; 3(10):38-47.
5. Ameh ES, Ikpeseni SC, Lawal LS. A review of field corrosion control and monitoring techniques of the upsteam oil and gas pipelines. Nigerian Journal of Technological Development. 2017;14(2): 67–73.
6. American Water Works Association. AWWA Specification C-105. Standards for Determining Corrosivity of Soils; 1999.
7. Benmoussat A, Hadjel M. Corrosion Behaviour of Low Carbon Line Pipe Steel in Soil Environment. Eurasian Chem. Tech. Journal. 2005;7:147-156.
8. Rim-rukeh A, Owatefe JK. Investigation of soil corrosivity in the corrosion of low carbon steel pipe in soil environment. J. Appl. Sci. Res. 2006;2(8):466-469.
9. Ferreira CAM, Ponciano JA, Vaitsman DS, Pérez V. Evaluation of the corrosivity of soil through its chemical composition. Sci. Total Environ. 2007;338:250-255.
10. Rahaman MA. Review of geology of South Western Nigeria. In: Geology of Nigeria. 2nd Edition, (Kogbe CA ed.), Rock view Nig. Ltd, Jos, Nigeria; 1989.
11. Vander-Velpen BPA. Win resist version 1.0. Resistivity depth sounding interpretation software, ITC, delft, the Netherland; 2004.
12. BS 1377-3. Methods of test for soils for civil engineering purposes-part 3: Chemical and electrochemical tests. British Standards Institution, London. 2018;43.
13. Baeckman WV, Schwenk W. Handbook of cathodic protection: The theory and practice of electrochemical corrosion protection techniques. Portucullis Press Survey. 1975;396.
14. Robinson W. Testing soil for corrosiveness. Materials Performance. 1993;32(4):52-58.
15. NACE. Underground corrosion. National association of corrosion engineering publication. Corrosion/93 Symposium; 1993.
16. Escalante E. In: Corrosion tests and standards: Application and interpretation, ASTM, Philadelphia. 1995;137-142.
17. EN 12501-2: 2003. Protection of metallic materials against corrosion. Corrosion likelihood in soil. Part 2: low alloyed and unalloyed ferrous materials, European standard store: Pilsen, Czech Republic; 2003.
18. Roberge PR. Handbook of corrosion engineering, McGraw-Hill, Collumbus, OH, USA; 2000.
19. Doyle G, Seica MV, Grabinsky MWF. The role of soil in the external corrosion of cast iron water mains in Toronto, Canada. Canadian Geotechnical Journal. 2003;40 (2):225-236.
20. Bradford SA. Corrosion Controls, 2nd Ed., New York: Springer. 2017;141.
21. Uhlig HH, Revie RW. Corrosion and corrosion control: an introduction to corrosion science and engineering, 4th Edition, John Wiley and Sons. New York. 2008;458.
22. Jones DA. In: Principles and prevention of corrosion. 2nd Edition, Pearson education. 2017;572.
23. Yahaya N, Lim KS, Noor NM, Othman SR, Abdullah A. Effects of clay and moisture content on soil-corrosion dynamics. Malaysian Journal of Civil Engineering. 2011;23(1):24-32.
24. Pereira RFC, Oliveira ESD, Lima MAGA, Cezar Brazil SLD. Corrosion of galvanized steel under different soil moisture contents. Mater. Res. 2015;18:563-568.
25. Søndergaard M. Encyclopedia of Inland Waters. (Gene E. Likens eds). Elsevier Inc. 2009;2250.
26. Li SY, Kim YG, Jeon KS, Kho YT, Kang T. Microbiologically influenced corrosion of carbon steel exposed to anaerobic soil. Corrosion. 2001;57:815-828.
27. Fiedler S, Veparskas M, Richardson JI. Soil redox potential: importance, field measurements and observation. In: Advances in agronomy, Sparks DI, Ed., Academic Press, Cambridge, U.K. 2007; 94:1-54.
28. Arzola S, Palomar-Pardave ME, Genesca J. Effect of resistivity on the corrosion mechanism of mild steel in sodium sulfate solutions. J. Appl. Electrochem. 2003;33: 1233-1237.
29. Bahattarai J. Study on the corrosive nature of soil toward the buried structure. Scientific World. 2013;11(11):43-47.

30. Ariba-Rodriguez L, Villanueva-Balsera J, Ortega-Farnandez F, and Rodriguez-Perez F. Methods to Evaluate Corrosion in Buried Steel Structures: A Review. Metals. 2018; 8:334.
DOI: 10.3390/met8050334, p.1-21.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/66723