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A Field Survey of Soil Corrosivity Level of Kaduna Metropolitan Area through Electrical Resistivity Method

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Abstract: ***Soil resistivity-corrosivity is basic in the analysis of corrosion problems and design of corrective measures. It can differ widely at different geographical areas. This paper focuses on soil corrosivity level as it concerns critical underground engineering structures which in the past few decades have continued to be inevitably installed or erected as some technological means of development in Kaduna-a top populous, administrative, industrial, and military garrison city in Nigeria. The survey was conducted at 310 different underground locations up to 4.5m-depth during annual period of peak rainfall (August to October 2014) in the area through the ASTM G57-06 standard test method for field measurement of soil resistivity. Dispersion analysis of the obtained information was carried out using Microsoft Excel statistical facility. The analysis indicates that within the survey depths, the soil resistivity of the area is generally different at each location and increases downwards. The resistivity varies within the extremes of 31.9 Ohm-m at the depth of 0.5m to152.9 Ohm-m at the depth of 4.5m with overall mean value of 72.13481 Ohm-m, standard deviation of 33.78109 Ohm-m and coefficient of variation 46.83%. Translated into corrosivity, the analysis represent a stochastically variable soil corrosivity spectrum that is mildly corrosive on average and generally varies downwards underground from aggressive at depths of less than about 0.5m to slightly corrosive around 4.5m. The paper intends to provide some supplementary, readily available and applicable predictive information for strategic corrosion control in the area.***

Keywords: soils, corrosivity level, variation, underground engineering structures, effects, applicable information

1. Introduction

Corrosion stems from material interaction with the environment. It is an insidious material degradation process that jeopardizes safety, poses serious challenges in materials and engineering and hinders technological progress. Corrosion attacks are frequently responsible for most material failures or their service limitations by causing them to lose their cherished strength, ductility and other mechanical properties. High liability and costs can arise due to corrosive actions of soils that engineering structures are in associated 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 was about $279 billion per year, which is about 3.2 percent of the nation's present gross domestic product (GDP). 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 [1, 2, 3, 4, 5, 6, 7, 8 and 9].

Corrosion can be a problem for both metallic and concrete structures in contact with the ground. If corrosion is not considered, the service life of the project may be severely overestimated and public safety may be at risk. Unprotected pipelines, buildings, and other engineering structures erected on corrosive soils usually have shorter life span. The frequent collapse and other problems associated with critical underground engineering structures such as steel pipelines due to corrosion is a serious concern to engineers, governments and the general populace. The adverse effects are colossal loss of lives and properties [10 and 11]. For example, during the 20-year period from 1988 to 2007, corrosion was responsible for 18% of the significant incidents in pipelines carrying natural gas or hazardous liquids worldwide. On average there have been 52 significant corrosion incidents per year on pipelines in the United States alone. Those incidents resulted in 1.4% fatalities and 5.2% injuries per year, and caused about $25 million of property damage per year. The Nigerian geographical space also consists of engineering structures such as oil and gas pipelines which are based or buried underground. These structures are exposed to diverse climatic and soil conditions and are subject to various levels of location corrosion. For example, Achebe *et al* [6] reported a total of 137 pipeline failures across six states in the Niger Delta region of Nigeria alone in the period 1999-2005. Corrosion accounted 18% of these failures. It is therefore desirable to avoid corrosion of such critical engineering structures.

Control of corrosion is primarily an economic problem. Whether or not to apply a control method is usually determined by the cost savings involved. The method or methods utilized must be the optimum economic choice [3]. Corrosion control in any environment will not be proper and optimal without realistic information on the corrosivity level of the environment in the first place. Soil resistivity is a broad indicator of soil corrosivity level and basic in the analysis of corrosion problems. Soil resistivity-corrosivity can differ drastically at different geographical areas. For safety, durability and reliability of underground engineering structures, it is pertinent to estimate the degree of soil corrosivity/aggressivity of the relevant location prior to construction works and use the obtained information in the design and maintenance of the structures [10 and 11].

Kaduna is a top populous, industrial and military garrison city in Nigeria where several underground steel and concrete engineering structures worth billions of Nigerian Naira have continued to be inevitably installed or erected in the past few decades as some technological means of development. Corrosion problems with such assets are inevitable and must be avoided at minimal cost. In developing countries such as Nigeria, where the general level of corrosion-consciousness and counteractions are minimal some inevitable corrosion problems with such structures can exist and be technically corrected or not corrected, and incur loses with or without awareness. It is generally desirable that proper information on corrosivity levels of all critical environments where metallic and concrete engineering structures are applied should be readily available and consulted for their optimal corrosion control [12].

The aim of this paper is to supplement applicable predictive information on soil corrosivity level of Kaduna metropolis for early corrosion prevention strategies such as coating specifications and cathodic protection of metallic and concrete engineering structures that are or should be in associated contact with the ground within the area.

2. Methodology

2.1 Basis of Soil Resistivity-corrosivity

Research carried out in the field usually has the advantage of realism with a better chance that the results obtained from it can be generalized to real-world operational environment. For a realistic field survey and analysis of resistivity-corrosivity results for the metropolitan area, it is imperative to have general understanding of the basis on the subject beforehand. Generally, soil types and other factors that affect its resistivity and corrosivity are well established in the literatures. Soil covers much of the land on earth. It is made up of minerals (rock, sand, clay and silt), air, water, and organic material which are matter from dead organisms. There are many different types of soils with unique characteristics like; colour, texture, structure and mineral contents at various depths at different area locations. 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. 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 result of differences in moisture content, oxygen content/Redox potential, permeability/texture, temperature, resistivity, discharge characteristics, presence of aggressive ions such as chlorides, sulfate and sulfide; microbiological activity, stray currents, electrochemical potential fields, agricultural chemical activities, spillage of corrosive substances and pollution can set up differential corrosion cells. The levels and types of these variables, soil type and layer can result in critically high soil corrosivity levels at some locations around the world. It is well-established that soils with high moisture content, high electrical conductivity, high acidity, and high dissolved salts are most corrosive [9, 13 and 14].

The commonly used parameters for evaluating corrosion potential of soil are resistivity, pH, sulfate content, chloride content, Redox potential and sulfide content. 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. Soil resistivity is historically a broad indicator of soil corrosivity. Soil corrosivity resistivity generally decreases with increasing moisture content and the concentration of chemical species. Soil corrosivity is inversely related to soil resistivity so that low resistivity of soil indicates high probability of corrosion potential. It is typically indicative of soil corrosivity in alkaline soils and useful as a guide in acid soils. Although a high soil resistivity alone will not guarantee absence of serious corrosion, electrical resistivity is effective, suitable and most important parameter for assessment of soil corrosivity/aggressiveness level. It is also commonly used for the delineation of horizontal and vertical discontinuities in the electrical properties of the subsurface and also for the detection of three-dimensional bodies of anomalous electrical conductivity. Soil resistivity data has been the basis of any predictable grounding system design. It is basic in the analysis of soil corrosion problems and design of corrective measures such as cathodic protection and specification of protective coatings. In the electrical resistivity method, artificially generated currents are introduced into the ground, and in the presence of variations in the conductivity of subsurface layers, the current flow path is altered which affects the electric potential distribution, and the resulting potential differences are measured at the surface [10 and 15].

2.2 Study Area

Since soil corrosivity can vary greatly from location to location around the globe, it is imperative to provide more relevant information on the study area that can enable better appreciation of the significance of the survey and any peculiarities of results from it. Kaduna is located on the southern end of the high plains of Northern Nigeria, gridded by Latitude 100 40^{I}N and 100 60^{I}N and Longitude 70 10^{I}E and 70 35^{I}E. The metropolis is historically on three firm bases legs; Administrative Capital, Industrial Town and as Military Garrison. One principle of its master plan is the delineation of a ‘functional territory’ which was reclassified as ‘inner zone’ and an ‘outer zone’ to allow it function economically, socially and administratively as the capital within its natural city region and control of development within local daily sphere of influence. The city was the second most industrialized city after Lagos in Nigeria in the 1970’s, though this economic climate of Kaduna has got worse in the last two to three decades. It is still one of the top cities in the ranking of growing industrial and commercial activities in Nigeria. It is a noted centre for refining crude oil, automobile manufacturing, producing weapons, brewing and bottling, textile manufacturing, sand-casting, metal forging, civil engineering construction works, agricultural processing, metalworking, electric power distributing, warehousing, machinery manufacturing, steel working, treating water, etc. One of the three refineries in Nigeria is located in the metropolitan area of the city. The refinery has a production capacity of about 110,000 barrels per stream day. A number of pipelines pass underground through the area for feeding the refinery with raw stock and distributing its products to some away locations.

The city is located in a tropical continental climate with distinct wet and dry seasons and August to October as period of peak rain fall. The bed rock geology of the area is predominantly metamorphic rocks of the basement complex consisting of gneisses and older granites. The soils are typical red-brown to red-yellow tropical ferruginous soils with vegetation comprising of savannah grassland with scattered trees and woody shrubs. The population of the city experienced rapid growth from about 169125 in 1967 to a projected figure of 1371805 in 2009 from the 2006 population census. There is a river named after the city 'river Kaduna' which passes almost through the city centre and divides it in what is more or less called Kaduna North and Kaduna South. The river is invaluable to the people of the city in terms of cheap and dependable water supply for different domestic, commercial and industrial uses. Millions of litres of the river water is pump-supplied daily to industries and homes through underground steel pipes for household drinking, washing, bathing, cooking, sewage disposal; industrial and commercial cleaning, machinery and engine cooling, admixture preparations, food preparations, etc [12, 16 and 17]. There is a railway and road bridges across river Kaduna at four locations in the vicinity of the city as well as culverts, flyovers and culvert road bridges at several locations, water and chemical storing facilities, several low and high rise buildings and other engineered structures that are all based on the ground or in associated contact with the ground as well as being planned in the city metropolis.

2.3 Survey Procedure

The soil resistivity was determined using the SAS 300c resistivity meter according to ASTMG57-06 (2012) standard test method for field measurement of soil resistivity using the Wenner Four-Electrode method [18]. Using a hammer, four stainless steel probe electrodes each of length 0.46m long were driven into soil at each survey site in a straight line at equal distances (A) apart as shown in Figure 1.

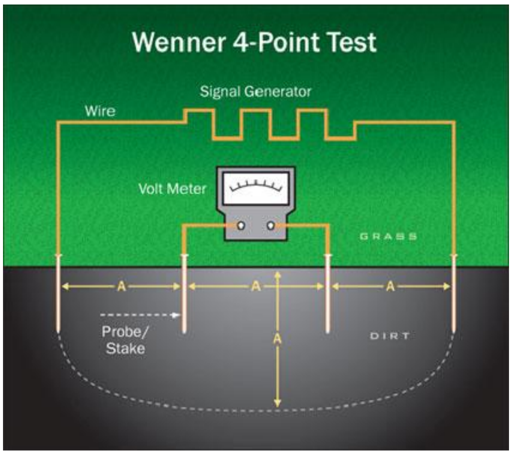

Figure 3.1: Set up for measurement of the soil resistivity according to the Wenner's Four Electrode Method [18 and19]

A metric tape was used to determine accuracy of the spacing 'A' between the electrodes. The two inner and outer electrodes were then connected by copper wire conductors as shown in Figure 3.1. A current (I) was passed to the outer electrodes while a voltage reading was taken within the two inside electrodes. With the reading, the Wenner resistance (R) was evaluated as,

$$R = \frac{V}{I} \quad 1$$

The soil resistivity (R_S) was determined as [15],

$$R_S = 2.\pi.A.R \quad 2$$

The survey was conducted up to underground depths of 4.5m during annual period of peak rainfall in the area (August to October 2014). Altogether, 310 different locations at soil depths of 0.5, 1.5, 2.5, 3.5 and 4.5m were surveyed so as to obtain a sufficiently suitable representative characteristic soil corrosivity level that an entire buried structure will experience in the metropolitan area. The depth in the soil was determined by the spacing between the electrodes in accordance to John Horward [20]. For each depth at a specified location, the test was conducted with 20 different straight line orientations of the electrodes within a circular band of about 10m in diameter. The results obtained for the 20 orientations were averaged to obtain a resistivity value for the depth at the location. Choice of locations for the survey was random and included marshlands, creeks, areas with poor drainage characteristic and variations in land topography, areas very close to river Kaduna and streams or streamlets, refuse dumping grounds, muddy areas, clay areas and bushy or unsettled areas that could have various effects on corrosivity level of the metropolitan soil.

3. Results and Discussions

Results of the survey were collated, tabulated and presented as shown in Table 1. Table 1 shows soil resistivity values at various underground locations up to 4.5m depth in the metropolitan area. From the results, it can be observed that the resistivity varies stochastically from location to location. The resistivity values are more or less comparable with one another at the same soil depth of the various locations than at different depths. Generally, the resistivity values increase downwards in the ground within the surveyed depths as can be seen from Table 1. This shows that generally the water table which can lower resistivity and increase corrosivity level according to Shreir [22] is below 4.5m for the metropolitan area. Dispersion analysis of the 310 surveyed depth locations in the area using Microsoft Excel statistical facility shows overall average resistivity values of 39.54177, 43.48919, 58.97762, 87.84097 and 129.3821Ohm-m; maximum resistivity values of 48.92, 59.01, 71.01, 95.91 and152.9 Ohm-m and minimum resistivity values of 31.9, 34.43, 45.43, 76.12 and 109.93 Ohm-m at soil depths of 0.5, 1.5, 2.5, 3.5 and 4.5m respectively in each case. The analysis also shows an overall mean resistivity value of 72.13481 Ohm-m for all the 310 survey locations of the area with a standard deviation of 33.78109 Ohm-m and coefficient of variation 46.83%. The highest resistivity value of 152.9 Ohm-m was obtained at Barnawa while the lowest value of 31.90 Ohm-m was at both Barkin Ruwa and Farin-gida with a range of 121 Ohm-m within which the whole soil resistivity spectrum of the area is spread. The range, mean value, standard deviation and other differences in values as can be observed in Table 1 indicate a great dispersion between the extremes of soil resistivity values at the depths of 0.5m and 4.5m of the different metropolitan soil locations.

The generally accepted corrosivity index for soils according to resistivity is: the soil is very corrosive if its resistivity is under 10 Ohm-m, aggressive if from 10-50 Ohm-m, mildly corrosive if from 50-100 Ohm-m, slightly corrosive if from 100-200 Ohm-m, progressively less corrosive if over 200 Ohm-m and not corrosive from 300-1000 Ohm-m [13, 23 and 24]. By using this resistivity-corrosivity relationship information commonly accepted by the engineering community, it can be observed from Table 1 that the entire metropolitan area is underlain by soil spectrum that is aggressive around the depth of 0.5m to slight corrosivity level at depth locations of about 4.5m and mildly corrosive on average. This indicates that, unprotected underground engineering structures in the area can be prone to aggressive corrosion. Within the 4.5m-depth of survey, the resistivity values indicate that the soil corrosivity level of the metropolitan area decreases downward in the ground.

Adepipe Oyewole [25] obtained high and low soil resistivity values between Izom and Sarki Pawa along Ajaokuta-Abuja gas pipeline system in Nigeria. His results showed that soil depths of 0.5, 1.0, 1.50, 2.0, 3.0 and 5.0m had low resistivity values of 311.143, 383.143, 386.571, 339.429, 301.714 and 345.714 ohm-m respectively while their high resistivity values were 6414.571, 10754.857, 11361.429, 12609.143, 14,124.00 and 17662.857 ohm-m respectively. From analysis of his results he concluded that it would be better to lay pipeline at a depth of 1-2m below the ground surface between Izom and Sarki Pawa because the resistivity represented a uniform soil composition and galvanic anodes for cathodic protection be located at 1m-depth. Oyedele Kayode Festus *et al* [11] assessed soil corrosivity at Lekki, Lagos. Their results showed that the geo-electric layers of the area in descending order consisted of top soil, sand, clay, silt-sand and coarse sand. The first layer had resistivity values from 128 to 272 Ohm-m, with thickness values that varied from 0.3 to 2.6m. The second layer had resistivity values that varied from 64 to 92 Ohm-m and thickness values that ranged between 13.7 to 45.4m. The third geo-electric layer had resistivity values that varied from 6 to 37 Ohm-m and thickness values that ranged from 12.0 to 18.0m. The fourth layer had resistivity values that varied from 40 to 86 Ohm-m and thickness values that ranged from 13.0 to 18.0mm. The last layer had reistivity values that varied from 88 to 261Ohm-m with no thickness value because the current terminated there. From their analysis of their results, they concluded that the Lekki area was underlain by none corrosive to very corrosive geo-earth materials. John Tarilonye Afa and Felix Opuama Ngobia [26] showed that resistivity values obtained from February and September which are two seasons of extreme weather conditions; that is dry and rainy seasons in Brass, Ogbia and Amassoma in Nigeria at three different depths within 0.5 to 1.5m varied from 18-90, 22-180 and 21-242 ohm-m respectively.

From test results of these three researchers and our study, it can be observed that soil corrosivity levels of Kaduna metropolitan area, Izom to Sarki Pawa, Lekki, Brass, Ogbia and Amassoma areas differ widely from one another at comparable soil depths. The pattern of variation of resistivity and corrosivity level with increasing depth in the ground however appears more or less similar.

From all our results and the foregoing analysis, it is inferable that engineering structures such as pipelines can be laid around the depth of 4.5m in the metropolitan soil if minimal protection and corrosion risks are desired. This will however be more costly in terms of labour and maintenance compared to less depth. To lay structures in the soil at depths of less than 4.5m particularly less than 0.5m, more protection through suitable methods such as cathodic protection and use of suitable protective coatings or their combinations need to be provided on the basis of soil of aggressive corrosivity of about 31.9 Ohm-m resistivity.

4. Conclusion

A Soil resistivity survey at 310 different depth locations up to 4.5m within the metropolitan area of Kaduna-a top populous, administrative and military garrison city in Nigeria was properly conducted. The soil resistivity of the area has been found to be generally random at each location, increases with underground depth and varies within the extremes of 31.9 Ohm-m at the depth of 0.5m to152.9 Ohm-m at the depth of 4.5m with overall mean value of 72.13481 Ohm-m, standard deviation of 33.78109 Ohm-m and coefficient of variation 46.83%. Resistivity-corrosivity analysis show that the soil corrosivity spectrum of the area is also randomly variable, mildly corrosive on average, aggressive at depths of less than about 0.5m and generally varies downwards underground to slightly corrosive soil at the depth of about 4.5m. Adequate protection with suitable methods such as cathodic protection and suitable protective coatings or their combinations can be provided to engineering structures concerned with the metropolitan soil on the basis of soil of aggressive corrosivity of about 31.9 Ohm-m resistivity. The paper is hereby posited as supplementary readily available applicable predictive information for research interest, consultation, consideration or rethinking for early corrosion prevention, inspection and maintenance of critical engineering structures or systems that are to be buried or already buried within the metropolitan area.

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Table 1: Result of Average Soil Resistivity Survey of Kaduna Metropolitan Area at some Specified Depth Locations by Tanimu [21]

Location	Average corrosivity level at specified depths (Ohm-m)				
	0.5m	1.5m	2.5m	3.5m	4.5m
Abakpa	35.20	49.83	60.32	91.19	140.90
Afaka	35.13	49.70	60.98	91.82	131.80
Airforce village	39.97	49.20	60.22	90.69	129.07
Askolai	33.98	45.15	62.01	92.81	123.19
Badarwa	38.90	40.49	67.54	90.42	132.87
Badiko East	38.97	41.46	64.32	89.92	128.30
Badiko West	38.09	43.43	67.54	89.42	127.21
Barnawa	43.89	44.43	61.32	91.82	152.90
Barkin Ruwa	31.90	34.43	45.43	90.70	109.93
C. market area	33.01	49.25	61.73	92.07	129.28
Doka	48.17	57.40	65.32	91.42	136.81
Dosa	43.89	50.43	67.54	89.04	127.82
Farin-gida	31.90	43.30	64.01	94.97	135.80
Farin-gida Ext	32.91	44.63	65.40	95.91	137.01
Gonin-gora	34.29	47.79	68.96	90.75	120.67
Hayin Banki	33.70	44.58	60.73	91.09	122.28
Hayin Rafonguza	33.90	42.43	64.32	91.44	127.80
Janruwa	32.94	45.04	67.54	89.42	129.83
Janruwa Ext.	33.81	44.14	66.43	91.53	121.83
Kurmin-Mashi	33.90	44.83	67.32	89.04	119.92
Kabala Doki	41.69	52.41	71.02	91.98	128.18
Kabala Constain	44.27	58.43	67.92	91.98	122.68
Kadpoly area	45.60	59.01	68.30	92.42	127.80
Kad. State Univ.	33.15	43.18	65.02	88.01	118.35
Kakuri	43.20	44.12	61.03	92.42	142.87
Kamanzo	42.97	43.71	60.69	90.02	135.19
Kanawa	42.89	43.43	60.07	87.31	131.29
Kawo	41.90	41.88	58.72	84.75	130.06
Kawo Ext.	40.97	40.45	54.34	83.69	128.80
Kotoko	43.01	43.60	60.32	84.92	130.80
Kudenda	40.03	39.87	53.91	83.02	129.23
Mahuta	40.79	42.01	55.31	85.41	131.80
Mahuta Ext.	39.91	41.67	54.73	84.92	130.93
Malali	40.12	39.73	53.02	82.37	128.74
Mando	43.84	44.15	61.02	91.17	136.23
Maraban Rido	39.69	40.43	54.27	83.45	129.39
NAF base	37.08	37.61	50.32	80.42	121.83
Nat. Eye C. area	38.21	38.15	54.32	91.14	137.86
Narayi	43.69	44.81	61.43	92.79	139.16
Narayi High Cost	36.19	39.10	48.63	89.14	125.34
Nasarawa	40.70	40.95	55.07	84.51	130.09
NDA new site	38.29	37.65	53.31	81.07	124.15
NDA old Site	40.87	39.13	54.09	85.71	127.19
NNPC	38.18	44.49	63.12	87.77	130.07
Panteka areas	37.31	38.23	51.85	79.34	121.89
Rigachikun	39.27	45.21	64.09	89.45	131.67
Rigachikun Ext.	38.91	44.29	63.25	89.01	130.93
Rigasa	36.45	37.23	50.11	78.31	120.02
Sabon Tasha	36.77	42.57	63.28	87.93	130.29
Trade fair area	35.08	39.94	61.65	84.81	128.93
Trikania	37.96	39.22	52.83	76.95	123.61
Tudun Nupawa	34.18	37.85	58.10	82.37	127.74
Tudun Wada	47.94	43.18	64.12	89.21	131.19
Ungwan Borou	48.92	44.03	67.10	91.82	141.31
Ungwan Gwari	38.21	40.46	53.91	77.14	124.44
Ungwan Muazu	47.54	42.06	63.72	87.33	129.16
Ungwan Mua.Ext.	45.81	42.26	65.15	88.93	133.16
Ungwan Pama	46.83	42.63	63.91	88.42	131.10
Ungwan Rimi	37.27	38.69	51.96	76.12	123.02
Ungwan Romi	43.90	40.94	54.12	85.98	127.80
Ungwan Shanu	48.60	43.93	65.34	90.42	132.10
Ungwan Sunday	44.95	41.70	62.59	86.74	130.08