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Original Research Article

Soil Resistivity Measurement for Corrosivity Assessment using Barnes Method

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ABSTRACT

Corrosion attacks are frequently responsible for most material's failures and its effect on underground metallic materials is a very widespread problem. In order to avoid unpleasant corrosion of pipes and steel structures, the electrical resistivity technique using Barnes method was utilised at PZ Cussons Ikorodu, Lagos State, Nigeria. Electrical resistivity survey (Wenner array method) was carried out with a resistivity meter in which four electrodes were deployed at each of the fifteen electrical resistivity test (ERT) locations. The pattern of distribution of resistivity based on geophysical analysis reflects four groups. Group 1 has resistivity values less than 50 ohm-m. Group 2 accommodates resistivity values between 50 and 100 ohm-m. Group 3 has resistivity values between 100 and 200 ohm-m. Group 4 houses resistivity values above 200 ohm-m. The general trend of the geophysical analysis in Group 4 revealed that resistivity values are high and therefore do not pose a corrosive risk to proposed metal pipes and steel structures at the aforementioned depths. In contrast, groups 1-3 which are predominant, have resistivity values that are less than 200 ohm-m which correspond to low to very high corrosive probability. The analysis revealed that mitigation measure should be considered via good cathodic protection for these groups where resistivity values are considered low at various depths within the study area. Therefore, proposed metal pipes and steel structures should be buried between depth intervals 1.50–4.50 m in the area under investigation.

1. INTRODUCTION

The corrosion of buried steel structures in soil are influenced by redox potential, resistivity, soluble ion content, pH, moisture content, rates of microbes in soil and many more (Lim *et al.,* 2013). Hence soil corrosivity can be evaluated by the empirical determination of the aforementioned factors. The complexity of electrochemical process in soil may influence steel pipes to corrode due to the presence of different soil electrolytes (Escalante, 1995). The relationship among physicochemical parameters and soil corrosiveness is very intricate; therefore, the soil corrosiveness evaluated by these parameters is often undependable (Li, 2003; Sosa and Alvarez-Ramirez, 2009). Materials such as metals and their alloys (e.g. steel) that can undergo corrosion to lose their strength, ductility and other mechanical properties (Ekine and Emujakporue, 2010). During soil corrosion, several chemical actions and reactions occur between the buried steel structures and its immediate environment, the host soil (Ozegin *et al.,* 2011). Unfortunately, site engineers sometimes fail to incorporate pre-development geophysical investigations in their job schedule for reasons of cost and other logistic considerations despite their necessity (Olorunfemi *et al.,* 2000; Olorunfemi *et al,* 2004).

Steel structures and metallic pipes buried in the subsurface soil materials of low electrical resistivity values are predisposed to corrosion attack (Lim *et al*., 2013). The corrosivity of soils is nearly inversely proportional to their resistivity; that is low resistivity, means a high probability of corrosion (Andrew *et al*., 2005). Soil resistivity is a function of soil moisture and the concentration of ionic soluble salt; hence it is considered to be the most comprehensive indicator of soil's corrosivity.

Many factors are correlated to soil resistivity such as salinity and nutrients (Rhoades *et al.,* 1999), water content and preferential direction of water flow (Michot *et al.,* 2003), texture-related properties such as sand, clay, depth to clay pans or sand layers (Corwin and Lesch, 2003), bulk density (Corwin and Lesch, 2005), and measured soil properties such as organic matter (Fedotov *et al.,* 2005). Understanding the resistivity of the soil structure is a key to monitoring the level of soil corrosion (Mbamalu and Edeko, 2004).

In this study area, metal pipes and other steel structures are expected to be buried which might corrode if immersed in a low resistivity soil thereby resulting into material failure. Hence, soil corrosion assessment of the study area becomes necessary in order to safeguard underground metallic materials and other infrastructural assets that are of great importance. This has necessitated the application of electrical resistivity technique using Barnes method for soil corrosivity assessment.

2. MATERIALS AND METHODS

2.1. Location and Geology of Study Area

The study area, Ikorodu, Sagamu road, Lagos State, is in Wetland region of Lagos, Southwestern Nigeria which is bound to the west by the Republic of Benin, to the east and north by Ogun state and to the South by the Atlantic Ocean. It is accessible through Ikorodu-Sagamu road. The study area is underlain by the sedimentary rocks of Dahomey Basin (Figure 1). The Dahomey Basin is an extensive sedimentary basin stretching from eastern Ghana, Togo and the Republic of Benin to the western part of Nigeria, up to the Benin hinge line. According to the works of Jones and Hockey (1964), Reyment (1965), Ogbe (1972), Kogbe (1976), Omatsola and Adegoke (1981) and Adekeye (2005), the sediments recognized in the Nigerian part of the basin which dates back to Quaternary and recent Oligocence to Pleistocene in age belonging to the Abeokuta Group (comprising of Ise, Afowo and Araromi Formations), the Ewekoro, Akinbo, Oshoshun, Ilaro Formations, the coastal plain sands and alluvium (Figure 2). The coastal plain sands together with the recent alluvium constitute the youngest sedimentary unit of the Dahomey Basin and underlain the cosmopolitan Lagos area which is a zone of coastal creeks and lagoons developed by barrier beaches associated with sand deposition. The local subsurface geology reveals two basic lithologies namely clay and sand deposits. These deposits may be interbedded in places with sandy clay or clayey sand and occasionally with vegetal remains and peat (Ayolabi and Peters, 2005; Akoteyo *et al*., 2011).

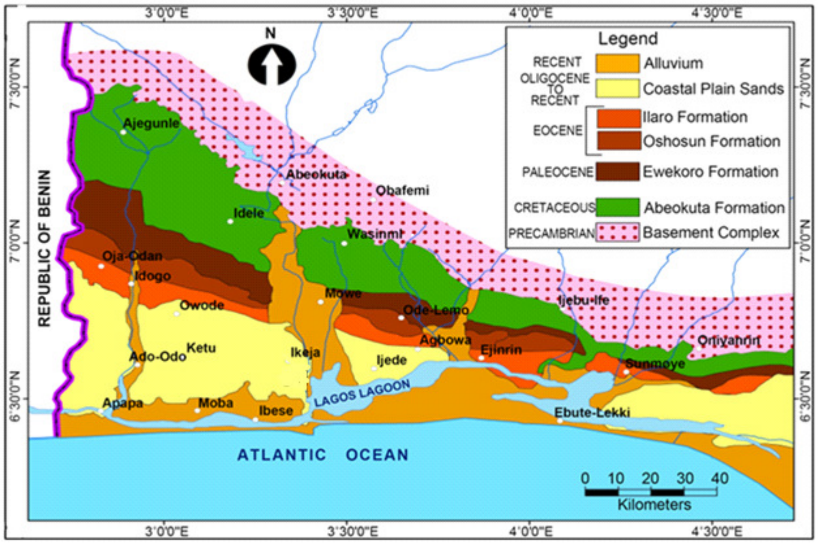
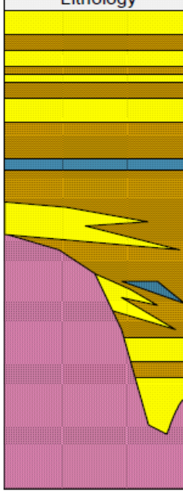


Figure 1: Geological map of Lagos State showing the study area (Modified after Billman, 1976)



Generalized Lithology	Formation	Age		Thickness (feet)	Comments
	Benin Fm., Coastal Plains Sands	Tertiary	Pleistocene - Oligocene	0 – 1600	coastal-plain clastics
	Oshosun – Ilaro – Ameki Fms.	Tertiary	Eocene	200 – 1000	fluvial and marine sands and clays
	Ewekoro Fm.	Tertiary	Paleocene	400 – 1000	marine shale, limestone
	Araromi Fm. Abeokuta Fm.	Cretaceous	Maastrichtian	500 – 1000	coastal sand, shale; marine shale
	Afowo Fm. Turonian Sst. Albian Sst.	Cretaceous	Campanian - Aptian	0 – 800	marine sandstone, shale, limestone
	Ise Fm.	Cretaceous	Barremian - Neocomian	0 – 6000+	continental and lacustrine rift-basin fill
	crystalline basement (undifferentiated)	Cambrian - Precambrian			metamorphic and igneous complex

Figure 2: Stratigraphic column of the eastern Dahomey Basin (MSMD, 2006)

2.2. Geophysical Investigation

Fifteen Electrical Resistivity Test (ERT) points (Figure 3) via Wenner array were acquired using a resistivity meter called PASI. The Wenner 4-Elecrode method using ASTM standard (ASTM, 2001) was used to determine the soil resistance at each location to depths of 0.75, 1.50, 2.25, 3.0 and 4.50 m in both North-South and East-West directions. The ASTM standard assumes that the electrode spacing (a) should equal the maximum depth of interest. The depths proposed were used for electrode spacing values for both approaches. Four steel rods were driven into the soil in a straight line at equal spacing. The location points were geo-referenced using handheld Garmin Etrex model Global Positioning System (GPS) for the longitude, latitude and elevation values.

L. Adeoti et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 703-712

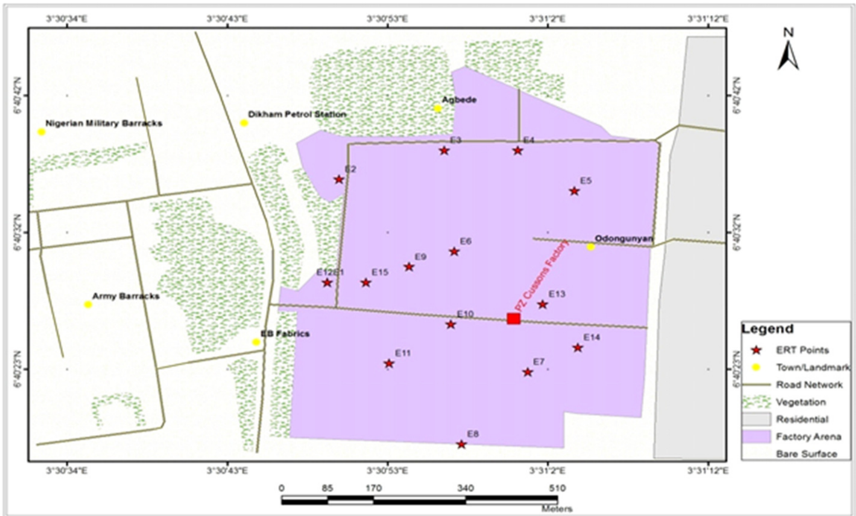


Figure 3: Base map of the study area

After the field survey, the resistance measurements were reduced to the apparent resistivity values using appropriate constants. The Barnes method was used for analyzing resistivity data (Equation 1) (Ronald, 2001). It assumes layer depth equals electrode spacing, and allows the computation of the lower layer apparent resistivity. The interpretation of corrosivity correlation to soil resistivity varies among corrosion engineers. However, Table 1 was used as a guide to correlate resistivity values with degree of corrosivity because of its general acceptance (Gopal, 2010).

$$\rho_{layer} = 2\pi a \frac{V}{I} = 2\pi a R_{layer} \tag{1}$$

Where:
ρ_{layer} is the layer resistivity
a is the electrode spacing = a_2-a_1
a_1 = upper electrode spacing
a_2= immediate underlying lower electrode spacing

$$R_{layer} = \frac{R_1 \times R_2}{R_1 - R_2} \tag{2}$$

Where:
R_1= Resistance of the upper layer
R_2= Resistance of the immediate underlying lower layer

Table 1: Classification of soil corrosiveness in terms of resistivity (Gopal, 2010)

Resistivity (Ohm-m)	Corrosive probability
>200	Negligible
100-200	Low
50-100	High
<50	Very high

3. RESULTS AND DISCUSSION

Soil resistivity values from the tests conducted at ERT 1 - ERT 15 in N-S and E-W directions at depths of 0.75, 1.50, 2.25, 3 and 4.50 m vary generally from 11 ohm-m to 279 ohm-m with an average of 154 ohm-m (Table 2). These resistivity values fall within very high to negligible corrosive probability when compared with the standard in Table 1. The pattern of distribution of resistivity values in N-S and E-W directions at depths of 0.75, 1.50, 2.25, 3 and 4.50 m reflects four groups. The Group 1 has resistivity values less than 50 ohm-m. Group 2 accommodates resistivity values between 50 and 100 ohm-m. Group 3 has resistivity values between 100 and 200 ohm-m. Group 4 houses resistivity values above 200 ohm-m.

Parts of ERT 2, ERT 4, ERT 6, ERT 9 and ERT 15 at various depths in Table 2 fall within Group 1. At depth interval 0.75-3.0 m in ERT 2, the resistivity values range from 26 to 41 ohm-m in N-S direction while at depth 0.75 m in ERT 2 in E-W direction, resistivity value is 34 ohm-m. The values of soil resistivity obtained at depth interval 3.0-4.5m range from 42 ohm-m to 49 ohm-m for ERT 4 in N-S direction. The resistivity value at depth 0.75 m is 11 ohm-m in N-S direction for ERT 6 while resistivity values at the same depth in ERT 9 oscillate between 39 and 49 ohm-m in both N-S and E-W directions. At depth interval 0.75-4.5 m in ERT 15, the resistivity values vary from 19 to 37 ohm-m in both N-S and E-W directions. These resistivity values are less than 50 ohm-m, thus fall within very high corrosive probability in accordance with the standard shown in Table 1. These areas are probable anodic points, where metal iron entered into the solution and gave out electrons. The Fe^{2+} given out combined with oxygen in the electrolyte to form rust (corrosion). These zones also correspond to areas of poorly aerated wet clays (soil) (Ekine and Emujakporue, 2010).

Parts of ERT 1 – ERT 7, ERT 9 – ERT 10 and ERT 12 at various depths in Table 2 constitute Group 2. At depth 1.5 m, ERT 1 has resistivity values ranging from 73 to 96 ohm-m in both N-S and E-W directions. The resistivity values vary between 51 and 99 ohm-m at depth interval 1.5-4.5 m in E-W direction for ERT 2 and ERT 10, while at the same depth interval, the soil resistivity values vary from 57 to 97 ohm-m for ERT 6, ERT 7 and ERT 9 in both N-S and E-W directions. The resistivity values at depth 4.5 m vary from 57 to 90 ohm-m in E-W direction for ERT 3 and ERT 12 but the resistivity values fall between 62 and 73 ohm-m both N-S and E-W directions for ERT 5. At depth interval 0.75-2.25 in ERT 4, resistivity values vary between 53 and 67 ohm-m in N-S direction while at depth interval 0.75-4.5 m in ERT 4, the resistivity values range from 50 to 72 ohm-m in E-W direction. The resistivity values at depth 0.75 m vary between 75 and 76 ohm-m for ERT 5 in both N-S and E-W directions. At depth 3.0 m for ERT 5, resistivity value is 98 ohm-m in N-S direction but for ERT 5 at depth 4.5 m, resistivity values oscillate between 62 and 73 ohm-m in both N-S and E-W directions. The resistivity values at depth interval 3.0-4.5 m in ERT 10 vary between 79 and 94 ohm-m in N-S direction. At depth interval 0.75-1.5 m in ERT 12, the resistivity values oscillate between 91 and 97 ohm-m in N-S direction. The resistivity interval in group 2 corresponds to high corrosive probability because all the resistivity values are between 50 and 100 ohm-m. These areas are interpreted as zones where chemical reaction (corrosion) is taking place in the subsurface (Ekine and Emujakporue, 2010).

L. Adeoti et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(2) 2018 pp. 703-712

Table 2: Soil resistivity results

ERT NO	Depth (m)	Resistivity (Ωm)		Layer (m)	Layer Resistivity (Ωm)	
		N-S	E-W		N-S	E-W
1	0.75	103	117	0.0-0.75	103	117
	1.5	73	96	0.75-1.5	57	82
	2.25	103	123	1.5-2.25	537	279
	3	119	126	2.25-3.0	217	137
	4.5	105	116	3.0-4.5	84	100
2	0.75	26	34	0.0-0.75	26	34
	1.5	27	51	0.75-1.5	29	102
	2.25	34	54	1.5-2.25	66	60
	3	41	52	2.25-3.0	124	50
	4.5	57	62	3.0-4.5	207	97
3	0.75	181	161	0.0-0.75	181	161
	1.5	187	154	0.75-1.5	308	147
	2.25	189	126	1.5-2.25	195	92
	3	171	104	2.25-3.0	134	68
	4.5	141	90	3.0-4.5	105	72
4	0.75	53	50	0.0-0.75	53	50
	1.5	67	72	0.75-1.5	90	124
	2.25	64	66	1.5-2.25	58	58
	3	49	53	2.25-3.0	29	33
	4.5	42	51	3.0-4.5	33	47
5	0.75	75	76	0.0-0.75	75	76
	1.5	113	110	0.75-1.5	231	202
	2.25	116	119	1.5-2.25	122	140
	3	98	102	2.25-3.0	67	71
	4.5	62	73	3.0-4.5	28	47
6	0.75	11	101	0.0-0.75	113	101
	1.5	81	71	0.75-1.5	63	54
	2.25	66	69	1.5-2.25	49	67
	3	72	60	2.25-3.0	93	43
	4.5	71	71	3.0-4.5	69	108
7	0.75	118	126	0.0-0.75	118	126
	1.5	86	97	0.75-1.5	67	79
	2.25	89	65	1.5-2.25	96	39
	3	96	68	2.25-3.0	126	78
	4.5	79	76	3.0-4.5	59	102
8	0.75	160	165	0.0-0.75	160	165
	1.5	203	183	0.75-1.5	277	204
	2.25	229	223	1.5-2.25	310	401
	3	239	224	2.25-3.0	277	227
	4.5	215	223	3.0-4.5	173	221

9	0.75	39	49	0.0-0.75	39	49
	1.5	63	57	0.75-1.5	164	67
	2.25	79	68	1.5-2.25	161	113
	3	89	75	2.25-3.0	138	113
	4.5	107	105	3.0-4.5	187	465
10	0.75	120	133	0.0-0.75	120	133
	1.5	124	99	0.75-1.5	129	79
	2.25	103	86	1.5-2.25	77	69
	3	94	57	2.25-3.0	75	28
	4.5	79	71	3.0-4.5	60	141
11	0.75	123	117	0.0-0.75	123	117
	1.5	227	194	0.75-1.5	1481	573
	2.25	240	270	1.5-2.25	272	1236
	3	245	279	2.25-3.0	260	310
	4.5	246	257	3.0-4.5	248	223
12	0.75	97	111	0.0-0.75	97	111
	1.5	91	114	0.75-1.5	87	118
	2.25	106	106	1.5-2.25	156	93
	3	119	107	2.25-3.0	186	112
	4.5	119	57	3.0-4.5	119	31
13	0.75	154	172	0.0-0.75	154	172
	1.5	100	100	0.75-1.5	87	70
	2.25	93	98	1.5-2.25	156	93
	3	109	109	2.25-3.0	186	171
	4.5	121	113	3.0-4.5	119	121
14	0.75	98	106	0.0-0.75	98	106
	1.5	101	103	0.75-1.5	103	100
	2.25	114	122	1.5-2.25	157	192
	3	126	143	2.25-3.0	183	308
	4.5	155	158	3.0-4.5	289	201
15	0.75	20	19	0.0-0.75	20	19
	1.5	23	22	0.75-1.5	26	25
	2.25	25	24	1.5-2.25	34	31
	3	28	28	2.25-3.0	42	60
	4.5	37	37	3.0-4.5	92	92

Parts of ERT 1, ERT 3, and ERT 5 – ERT 14 at various depths in Table 2 form Group 3. At depth 0.75 m, the soil resistivity values range from 103 to 172 ohm-m in both N-S and E-W directions for ERT 1, ERT 7, ERT 8 and ERT 13. However, soil resistivity values at the same depth vary between 101 and 133 ohm-m in E-W direction for ERT 6 and ERT 10 but for the ERT 11 at the same depth, the resistivity value is 123 ohm-m in N-S direction. At depth interval 0.75-3.0 m, the soil resistivity values vary between 104 and 189 ohm-m in both N-S and E-W directions for ERT 3 but the resistivity values range from 106 to 114 ohm-m for ERT 12 in E-W direction. However, the resistivity value at depth 4.5 m for ERT 3 in N-S direction is 141 ohm-m. The soil resistivity values at depth interval 0.75-2.25 m for ERT 10 range from 103 to124 ohm-m in N-S direction whereas at depth interval 0.75-1.5 m, the soil resistivity values vary from 117 to 194 ohm-m for ERT 11 in E-W direction. The soil resistivity values at depth interval 2.25-4.5 m for ERT 1 and ERT 13 in both N-S and E-W directions vary between 100 and 172 ohm-m while at the same interval in ERT 12, soil resistivity values at vary between 106 and 119 ohm-m in N-S direction. At depth interval 1.5 -2.25 m, the soil resistivity values at ERT 5 vary from 110 to 119 ohm-m in both N-S and E-W directions. However, soil resistivity value at depth 3 m for ERT 5 is 102 in E-W direction. At depth 1.5 m at ERT 8, the resistivity value is 183 ohm-m in E-W direction. The soil resistivity values at depth interval 1.5-4.5 m range from 101 to 155 ohm-m in N-S direction for ERT 14 but the resistivity values at depth ranging from 0.75 to 4.5 m fall between 103 and 158 ohm-m in E-W direction for ERT 14. These resistivity values correspond to low corrosive probability because the resistivity values fall between 100 and 200 ohm-m.

Parts of ERT 8 and ERT 11 at various depths in Table 2 form Group 4. The soil resistivity values at depth interval 1.5-4.5 m vary from 203 to 246 ohm-m for ERT 8and ERT 11 in N-S direction. At depths 2.25 – 4.5 m, soil resistivity values at ERT 8 and ERT 11 oscillate between 223 and 270 ohm-m E-W direction. The resistivity values in this group are above 200 ohm-m, hence fall within negligible corrosive probability.

4. CONCLUSION

Soil resistivity test via Wenner array of geophysical investigation was conducted at PZ Cussons, Ikorodu, Lagos, Nigeria to assess the characteristics of the underlying formations for soil corrosivity. Soil resistivity values from the tests conducted at ERT 1 - ERT 10 in N-S and E-W directions at depths of 0.75, 1.50, 2.25, 3 and 4.50 m vary generally from 11 ohm-m to 279 ohm-m with an average of 154 ohm-m. These resistivity values fall within very high to negligible corrosivity probability. The pattern of distribution of resistivity values in N-S and E-W directions at depths of 0.75, 1.50, 2.25, 3 and 4.50 m reflects four groups. Group 1 has resistivity values less than 50 ohm-m. Group 2 accommodates resistivity values between 50 and 100 ohm-m. Group 3 has resistivity values between 100 and 200 ohm-m. Group 4 has resistivity values above 200 ohm-m. The general trend of the geophysical analysis in group 4 reveals that resistivity values are high therefore, do not pose a corrosion risk to proposed metal pipes and steel structures at the aforementioned depths because resistivity values are higher than 200 ohm-m. In contrast, groups 1-3 are predominant and have resistivity values that are less than 200 ohm-m which correspond to low to very high corrosivity probability. The analysis revealed that mitigation measure should be considered via good cathodic protection for these groups where resistivity values are considered low at various depths within the study area. Therefore, proposed metal pipes and steel structures should be buried between depth intervals 1.50 – 4.50 m in the area under investigation.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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