IJST EXPLORE International Journal of Science and Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-7318

International Journal of Science and Technology Volume 3 No. 2, February, 2014

Shallow Resistivity Measurements for Subsoil Corrosivity Evaluation in Port Harcourt Metropolis, Nigeria

Ngah, S.A., Abam, T.K.S.
Institute of Geosciences and Space Technology,
Rivers State University of Science and Technology. P. M. B. 5080, Nkpolu-Oroworukwo, Port Harcourt, Nigeria

ABSTRACT

Variations in electrical resistivity, a diagnostic physical property of geologic materials, have been investigated in Port Harcourt Metropolis using Schlumberger electrode configuration. The aim of the survey was to assess the corrosivity of the subsoil environment with a view to deciding on the components to be installed underground and the appropriate protection measures to be taken against corrosion to achieve expected design life. Depth to groundwater level in the area is shallow necessitating that groundwater be protected from pollution resulting from corrosion. Two geo-electric resistivity layers were distinguished to a depth of 40m based on characteristic resistivity ranges and were interpreted in terms of soil type, water level and lithology. The upper layer with resistivity values between 11 – 53 ohm-m has a thickness of between 5 - 13m. The lower layer has higher resistivity values; 68 – 875 ohm-m. The resistivity values of the upper layer fall within corrosive – moderately corrosive, while the lower layer falls within moderately corrosive – slightly corrosive in the BS Soil Electrical Resistivity Classification. Shallow installations will suffer corrosion from aggressive subsoil if appropriate measures are not taken to protect them. Groundwater quality will be a major casualty of corrosion of unprotected buried steel pipes since groundwater table is shallow to near-surface.

Keywords: *Resistivity, corrosion, subsurface installations, Port Harcourt, Nigeria.*

I. INTRODUCTION

Electrical resistivity is a fundamental and diagnostic physical property of geologic materials and can be determined by a wide variety of techniques. Electrical resistivity survey methods developed in the early 1900s became very much more widely used since 1970s due primarily to the availability of computers to process and analyse the usually large data, (Reynolds, 1998). Its initial use was mainly for hydrogeological, mining and geotechnical investigations. With increase in environmental awareness and control, its use has now been extended to environmental studies especially to determine the subsurface resistivity distribution in areas requiring subsurface installation of corrosible components. Environmental Impacts Assessment, EIA, requires knowledge of subsurface distribution of resistivity in construction projects that would involve burial of steel pipes and cables. This becomes more pertinent in areas of shallow groundwater conditions like the Niger Delta where this study was carried out.

The use of electrical resistivity surveys in environmental studies derive from the fact that the electrical resistivity of earth materials depends on environmental parameters such as mineral and fluid content, degree of water saturation in the rock/soil, the amount and concentration of saturating fluids, the conductivity of matrix, porosity, permeability, temperature, grain size and degree of grain cementation. The survey gives a picture of the subsurface resistivity distribution and suggests the level of aggressiveness of subsoil environment which can result in corrosion of buried steel components. Knowledge of this will aid proper handling of corrosion problem and increase the design life of steel components and structures. Knowing the range of corrosivity, choices can be made on the kinds of materials for subsurface installation and need and methods of protecting subsurface installations from aggressive sub-soil environment.

In this study, shallow resistivity measurements were made at locations where it was intended to carry out subsurface installations. The aim was to assess the corrosivity of the subsoil environment with a view to deciding on the components to be installed and the appropriate protection against corrosion to achieve expected design life. Extant environmental laws require that groundwater be protected from pollution resulting from corrosion.

II. PHYSIOGRAPHY AND HYDROGEOLOGY

The survey was carried out at three locations in Port Harcourt, capital of Rivers State, Nigeria, (Figure 1). Port Harcourt itself is located between latitudes 04^{o} 43'N and 05^{o}00'N and longitudes 06^{o}45'E and 07^{o}06'E occupying an area of over 420km^{2} in the Niger Delta, (Iloeje, 1992). The metropolis comprises Port Harcourt Local Government Area, (PHALGA) and parts of Obio-Akpor Local Government Area. The geomorphological setting uniquely constrained the spatial spread of Port Harcourt city as a continuous landmass. It is generally low-lying with elevation between 8 -17m above mean sea level and slopes unperceptively towards the Atlantic Ocean. The drainage pattern is largely controlled by the Bonny River and its tributaries and creeks which together drain various outcrops of relatively higher land which are largely surrounded by mangrove swamps, (Bell-Gam 2002). Rainfall is high in Port Harcourt with annual mean of 240cm. the rainfall exhibits double maxima regime with peaks in July and September. The area falls within the humid tropics with humidity of 63- 79%, (Korean Report, 1980).

The physiography conforms to the geomorphic features of the Niger Delta governed by several factors which influence transport and ultimate deposition of the sediment load, shape and growth of the delta. The Niger Delta comprises five geomorphic sub-environments; the undulating lowlands of the coastal plain sands, the flood plain of the lower Niger with extensive sand deposits, the meander belts consisting of wooded freshwater swamps, the mangrove swamps and estuary complexes and the beach ridges. These sub-environments are zones where a vast amount of sediments are deposited by rivers in their search for lines of flow, (Osakumi and Abam 2004).

Port Harcourt is located within the quaternary coastal plain of the lower Niger with extensive alluvium deposits. The lithology consists of massive, highly porous and permeable freshwater bearing sands and sandstones with minor clay beds that form the main source of water supply to the city. Alluvium forms the surface blanket for the coastal plain sands, (Hospers 1971). They are sufficiently recharged by precipitation and surface water bodies. Static water levels are generally shallow, varying between 2 and 8m and getting closer to the surface near the coast. Groundwater flow is generally in the NE-SW trend in line with the regional trend in the basin, (Ehirim and Ebeniro 2006) Water quality increases with depth with the thick sequence of sands forming the major aquifers in the area while the clays form the aquitards. The water table in the area shows appreciable seasonal fluctuations, rising with the rains and declining during dry season.

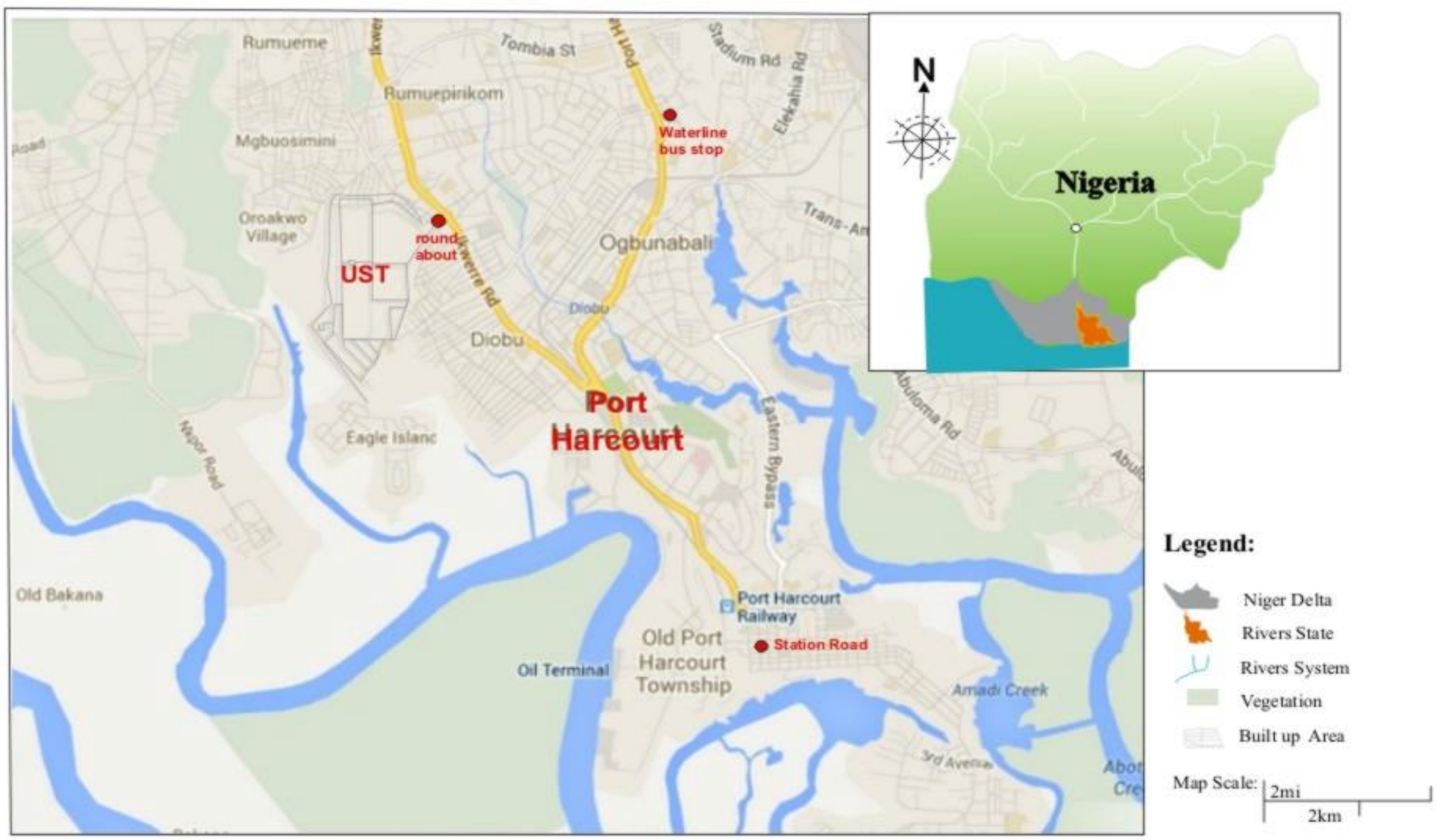

Fig. 1.1: Map of Nigeria showing Rivers State and Port Harcourt the Study Location

III. MATERIALS AND METHODS

Resistivity was measured by injecting a well-defined signal current into the ground through the two current electrodes (C_1, C_2). The resulting voltage change (potential difference or drop in potential) is measured between the potential electrodes, P_1, P_2. This arrangement measures the mean resistivity between the voltage electrodes (P_1, P_2) up to a depth (ID) equal to about 1/3 of the distance between C_1 and C_2 (total electrode spread) and a width equal to about 2/3 of the distance C_1 and C_2. (Reynolds

1998). As the electrode spread (C_1, C_2) increases, depth of the probe increases. The potential-drop-ratio method is a variation on this procedure used for determining resistivity.

All resistivity techniques require the measurement of ground resistance (R) which is converted to apparent resistivity (**ρ_a**) by multiplying with a geometric factor (K), a term that describes the geometry of the electrode configuration such that:

$$\rho_a = \pi.R.a\,(b/a + b^2/a^2) \qquad (1)$$

$$\rho_a = KR \qquad (2)$$

where R = resistance value read on the resistivity meter (Ω)

K = geometric factor

a = distance between both inner electrodes (m)

b = distance between inner and outer electrodes (m)

ρ_a = average resistivity (Ωm) of an equivalent soil layer which is equal to 75% of the distance between the inner and outer electrodes (0.756)

ABEM Terrameter (SAS) 1000C with a liquid crystal digital readout was used for data acquisition under a bright, sunny weather condition. Schlumberger array was adopted because of its economy of space and less physical movement of electrodes. Under this configuration, the potential electrodes (P_1, P_2) are placed at a fixed spacing (b) which is no more than one fifth of the current electrode half spacing, (a). The current electrodes are placed at progressively larger distances. When the measured voltages between P_1 and P_2 falls to very low values, the potential electrodes are spaced more widely apart (spacing b_2). The measurements are continued and the potential electrode separation increased again as necessary until VES is completed. Measurements were taken to a depth of approximately 40 meters at each location with a total electrode spread, C_1, C_2 of about 120m.

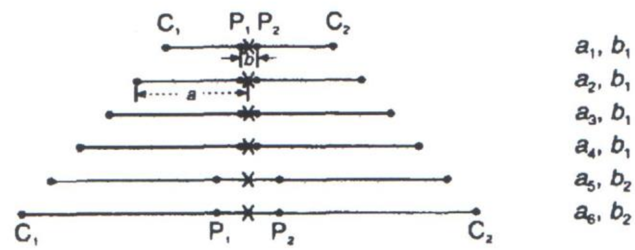

Figure 2. Expanded arrays for Schlumberger

These values were entered manually in a recording sheet and transferred to the computer on completion of each day's work after verifying for accuracy. Datasets were finally subjected to computer processing and analysis using mathematical methods and applying appropriate constants.

IV. RESULTS AND DISCUSSIONS

The results of the resistivity measurements are presented in tables 1, 2 and 3 for Station Bus Stop, Waterlines and RSUST Round About sites respectively.

Table 1. Subsoil Electrical Resistivity Measurement at Station Rd Bus Stop, (location 1)

CO ORDINATE Northings	Eastings	ELECTRODE SPACING C_1C_2 (m)	CONSTANT K	MEASURED RESISTANCE (ohm)	RESISTIVITY (Ωm)
		3	13.744	2.3947	32.912757
N 04⁰45'55.5"		4.5	31.416	0.86022	27.024672
E 007⁰01'04.8"		6	56.156	0.42148	23.668631
		9	126.842	0.241	30.568922
Elevation:11m		12	112.312	0.14019	15.745019
		15	175.929	4.9778	875.73938
		21	345.575	0.057852	19.992205
		30	351.858	5.7269	2015.0556
		45	793.643	0.060836	48.282066
		60	1412.146	0.057123	80.666016
		90	623.319	0.04633	28.878369
		120	1123.119	0.02695	30.268057
		150	1759.292	0.067564	118.8648

Table 2. Subsoil Electrical Resistivity Measurement at Water Lines, (location 2)

CO ORDINATE Northings Eastings	ELECTRODE SPACING $C1C_2$ (m)	CONSTANT K	MEASURED RESISTANCE (ohm)	RESISTIVITY (Ωm)
	3	13.744	4.6039	63.276002
N 04^{0}48'59.9"	4.5	31.416	0.55114	17.314614
E 007^{0}0'27.5"	6	56.156	0.59679	33.513339
	9	126.842	0.4185	53.083377
Elevation: 20m	12	112.312	0.3116	34.996419
	15	175.929	0.2651	46.638778
	21	345.575	0.13124	45.353263
	30	351.858	0.19354	68.098597
	45	793.643	0.031009	24.610076
	60	1412.146	0.14291	201.80978
	90	623.319	0.0251	15.645307
	120	1123.119	0.021852	24.542396

Table 3. Subsoil Electrical Resistivity Measurement at RUST Round about, (location 3)

	ELECTRODE SPACING C1C2(m)	CONSTANT K	MEASURED RESISTANCE (ohms)	RESISTIVITY
	3	13.744	11.424	157.01146
N 04^{0}48'19.2"	4.5	31.416	0.66889	21.013848
E 006^{0}59'19.6"	6	56.156	0.20144	11.312065
	9	126.842	0.1281	16.24846
Elevation: 13.1m	12	112.312	1.1466	128.77694
	15	175.929	0.36291	63.846393
	21	345.575	0.45756	158.1213
	30	351.858	0.22666	79.752134
	45	793.643	0.11845	94.007013
	60	1412.146	0.050874	71.841516
	90	623.319	0.057585	35.893825
	120	1123.119	0.078071	87.683023

A plot of apparent resistivity against depth was also made and shown as Figures 1, 2 and 3 respectively for Station Bus Stop, Waterlines and RSUST Round About sites.

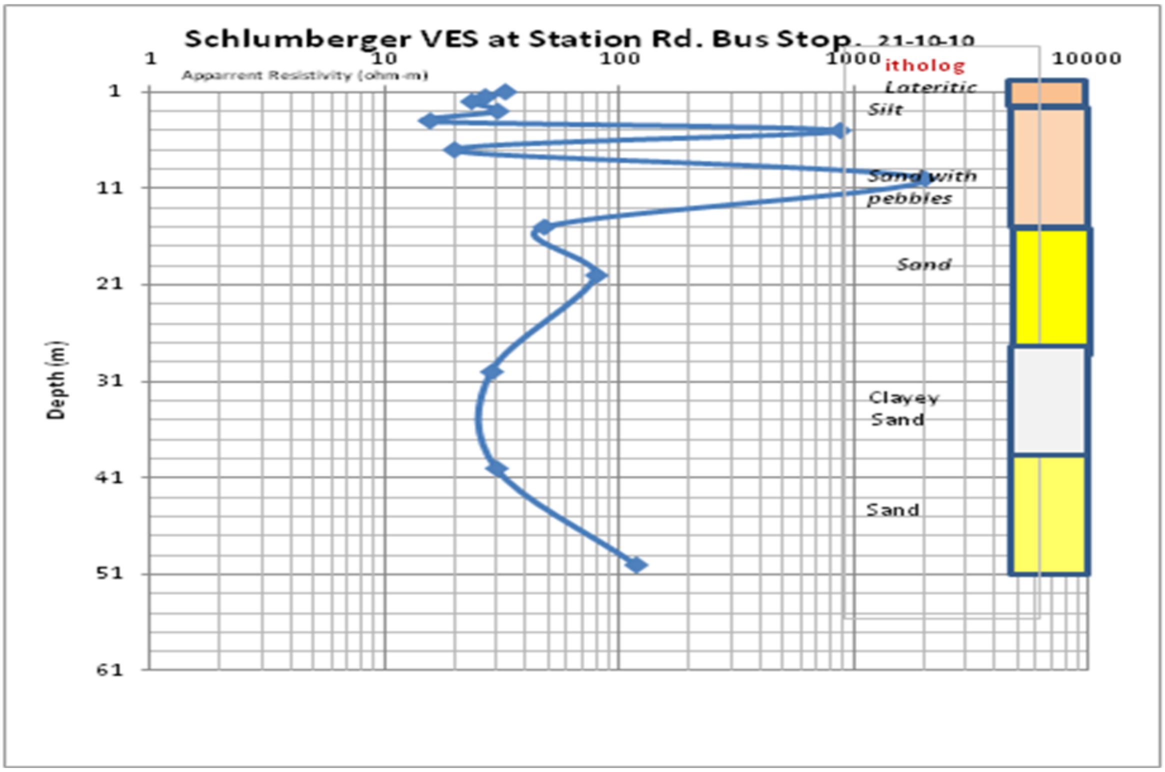

Figure 3. Apparent Resistivity/Geoelectric model at Station Road site, (location 1).

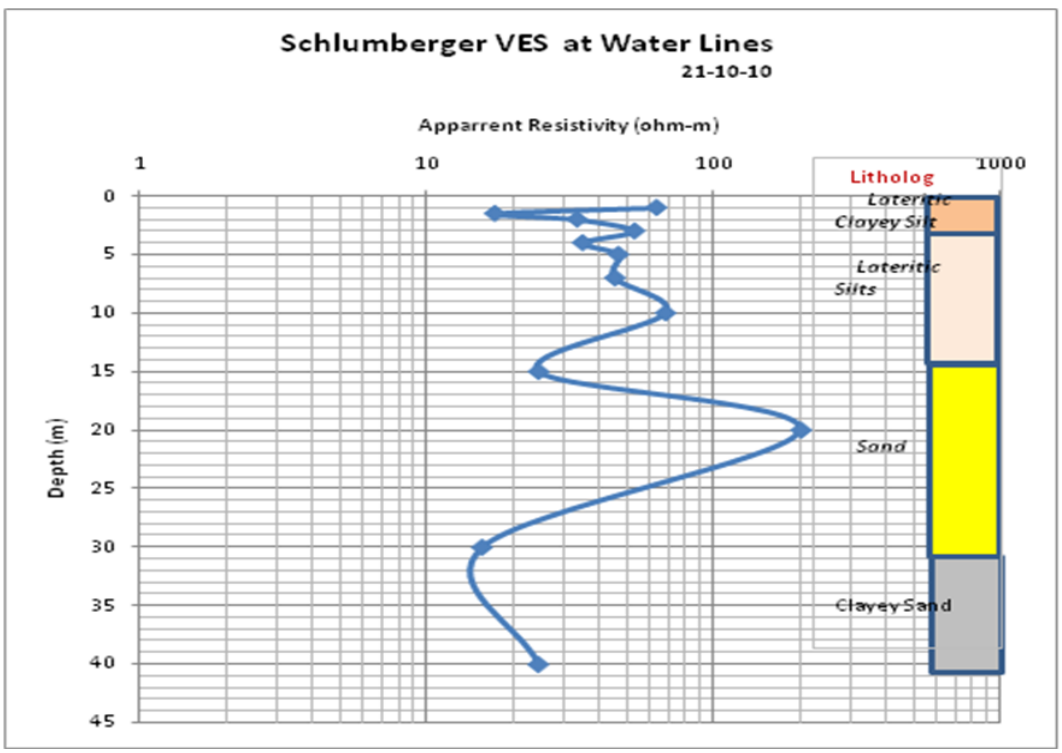

Figure 4. Apparent Resistivity/Geoelectric model at Water Lines site, (location 2).

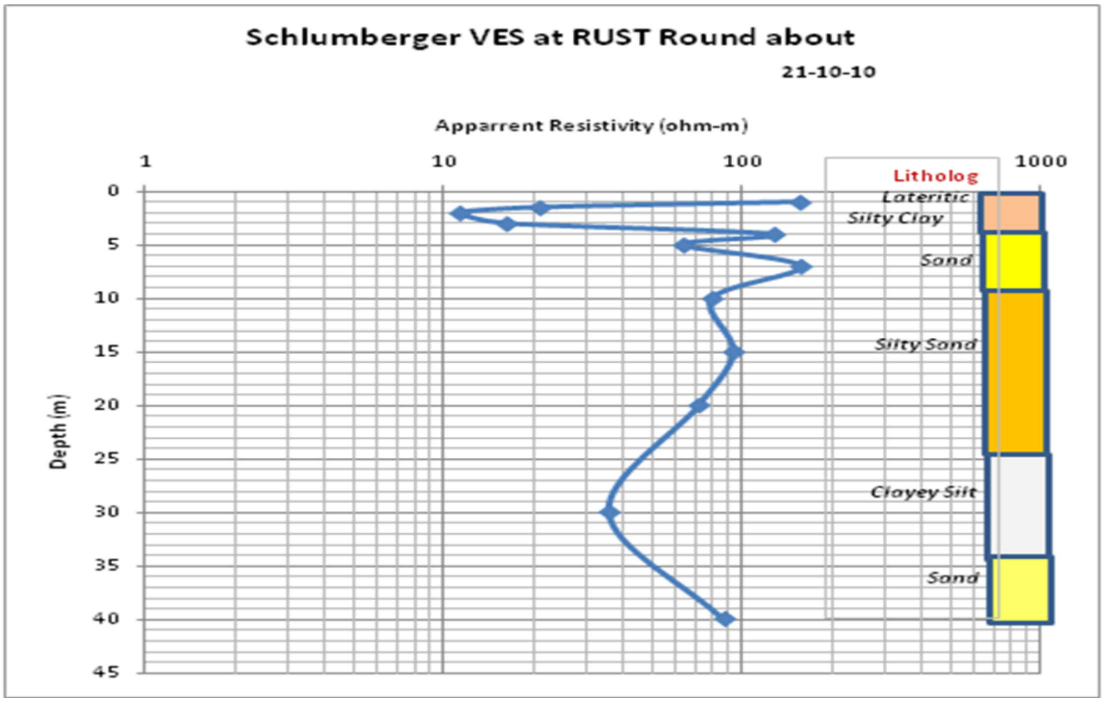

Figure 5. Apparent Resistivity/Geoelectric model at RSUST Round About, (location 3).

From the results, the area is seen to be characterized by two major geo-electric resistivity layers within the shallow subsurface sounded depth of 40m. The upper layer comprising lateritic to clayey silt has a resistivity range of 15–32Ωm and a thickness of about 8m at Station Bus Stop site.) At the Waterlines site, this layer has a resistivity range of 17–53Ωm and thickness of about 13m. It thins out at RSUST Round About site to about 5m with a resistivity of 11–21Ωm. The lower layer consists of silty sand to sand with occasional clay bands. The resistivity values are higher in this layer and ranges between 48 – 875Ωm at Station Bus Stop site. At the Waterlines site, the resistivity ranges between 68 – 201Ωm and 79 – 158Ωm at RUST Round About. Table 4 gives the Soil Electrical Resistivity Classification BS-1377.

Table 4: Soil Electrical Resistivity Classification (BS – 1377)

Soil Resistivity (ohm-m)	Soil Corrosivity
< 10	Severe
10 – 50	Corrosive
50 - 100	Moderately corrosive
>100	Slightly corrosive

The results were compared with the Soil Electrical Resistivity Classification Code, BS 1377, Table 4. The summary of resistivity ranges and corrosivity classes of the subsoil at each location is shown in Table 5.

Table 5. Summary of shallow layer Corrosivity classes in Port Harcourt Metropolis

Location	Layer Resistivity (ohm-m)	Approx. Thickness m	Corrosivity Class
Station Bus Stop	Layer1, 15 – 32 Layer 2, 48 - 875	8	Corrosive. Modrately to slightly corrosive
Waterlines	Layer1, 17 – 53	13	Corrosive to moderately

Junction	Layer 2, 68 – 211		Corrosive Moderately to slightly corrosive
RSUST Roundabout	Layer 1, 11 – 21 Layer 2, 79 - 158	5	Corrosive. Moderately Corrosive

From the tables, soil corrosivity in the area is high. The immediate near-surface (upper geo-electric layer) is corrosive at the three sites. However, the corrosivity is moderate in the lower layer at all the sites.

V. CONCLUSIONS

Shallow electrical resistivity measurements made at some representative locations in Port Harcourt Metropolis have shown that the area is characterized by two major geo-electric resistivity layers within the shallow (40m) of investigation. The upper layer is made up of lateritic to clayey silt and has a resistivity range of 15 – 32Ωm and a thickness of about 8m at Station Bus Stop site. At the Waterlines site, this layer has a resistivity range of 17 – 53Ωm and thickness of about 13m. It thins out at RSUST Round About site to about 5m with a resistivity of 11 – 21Ωm. The lower layer consists of silty sand to sand with occasional clay bands. The resistivity values in this layer are much higher; 48 – 875Ωm at Station Bus Stop site, 68 – 201Ωm at Waterlines site and 79 – 158Ωm at RUST Round About. The soil resistivity values fall within corrosive to moderately corrosive for the near-surface horizons while the lower layer moderately corrosive and slightly corrosive when placed against the British Standard. This soil resistivity conditions show the soil to be largely aggressive. Near surface installations are likely to suffer corrosion if appropriate measures are not taken to protect them. The corrosion will have an adverse impact on the environment especially groundwater quality since water level is generally shallow in the area. Anti-corrosion measures are imperative for subsurface installation of corrosible components in the area.

REFERENCES

[1]. Bell-Gam W.I. (200). Major Cities and their Regions: Port Harcourt. In: Atlas of Nigeria. Les Editions, J.A. Paris, France pp138 -139.

[2]. Hospers, J, 1971.. Geology of the Niger Delta. In: The Geology of East Atlantic Continental Margins of Africa. Great Britain, Inst. Sci. Report 70/16. pp 121 – 142.

[3]. Iloeje, N.P. (1992). A New Geography for West Africa. Longman Group Ltd, Nigeria.

[4]. Keller, G.V and Frischnecht, (1970). Electrical Methods in Geophysical Prospecting, 2nd Edition. Pergamon Press, New York NY, 517pp.

[5]. Korean Report (1980). Investigation of the possible flood protection measures in the Nun and Forcados Rivers area of the Niger Delta. Report submitted to Niger Delta Basin Development Authority. 105pp

[6]. Osakuni, M. U and Abam T.K.S (2004). Shallow resisitivity measurement for cathodic protection of pipelines in the Niger Delta. Environmental Geology Vol. 45. No.6. pp747-752

[7]. Reynolds, J.M. (1998). An introduction to Applied and Environmental Geophysics. John Wiley and Sons, London, 650pp.

[8]. Zohdy, A.A.R. (1989). A New method for the automatic interpretation of Schlumberger and Wenner Sounding Curves. Geophysics VIS p. 245-245.