

Soil Corrosivity Assessment in the Pre-Design of Sub-Surface Water Pipe Distributary Network in Yenagoa, South-South Nigeria Using Electrical Resistivity

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Abstract Investigation of the degree of corrosivity of the sub-soil in Yenagoa with a view to aiding pre-design of subsurface steel pipe network was conducted. Fifteen (15) Vertical Electrical Sounding using Schlumberger array was done at an average station interval of 2km. Resistivity data was processed using Interpex and IP2 win software's. The degree of corrosivity of the soil was assigned based on the modelled resistivity value of each geologic layer with respect to depth in the study area. The soil aggressiveness in the area was categorized into very highly corrosivity (less than 50 Ohms), high corrosivity (50-100 Ohms), low corrosivity (100-200 Ohms) and greater than (200 Ohms) negligible corrosivity. The geoelectrical results show four subsurface layers with respect to their resistivity, depth and corrosivity; Layer one (1) 32.000Ωm with a thickness that ranged between 0.37m and 1.57m, the top soil which is interpreted as having very highly corrosivity. Layer two (2) which had a resistivity of 115.441 Ωm and a thickness that ranged between 0.8m and 32.8m, was categorized as having low corrosivity; Layer three (3) had a resistivity of 244.268 Ωm with a thickness that ranged between 4.1m and 48.7m, categorized as having a negligible corrosivity, and layer four (4) with a resistivity of 1709.56 Ωm and a thickness of 6.2m to 48.5m had negligible corrosivity. Soil aggressiveness of the layer resistivity indicated very high corrosivity to a depth 2m from the ground level and abrupt decline in corrosivity as depth increased, as such; the top layer was characterized as having very high corrosivity. Water piping networks are usually done within 2m of the top soil, which is zone of "very high corrosivity". This should be taken into consideration during pipe network design, as it will guide in the determination of the type of subsurface steel pipes to be used to forestall economic waste and health risks associated with rupture of corroded pipes.

Keywords Soil Corrossivity, Resistivity, Subsurface pipe network, Yenagoa

1. Introduction

The application of geophysics in the investigation of the corrosivity of the earth material prior to sub-surface pipe laying has become a standard practice in recent times. Environmental Impact Assessment (EIA) requires knowledge of subsurface distribution of resistivity in construction projects that would involve burial of steel pipes and cables, and other sub-surface network of piping (Agunloye, 1984). The electrical resistivity method is highly significant in in-situ determination of the degree of corrosiveness of soils, its application is hinged on 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, permeability,

temperature, grain size, degree of grain cementation, concentration of saturating fluids, conductivity of matrix and soil porosity. Low resistivity in soil can be directly related to a high corrosivity/aggressiveness index of the soil material (Agunloye, 1984; Othman, 2005; Adesida et al, 2002; Gopal 2010).

This research investigates soil corrosivity across Yenagoa Metropolis which falls within longitude 5° 20.0' - 4° 50.0' N and latitude 6° 10.0' E - 6° 40.0' E. Resistivity survey using Schlumberger array was carried out at Igbogene, Okaki, Agudama, Akenfa, Etegwe, Opolo, Biogbolo, Kpansia, Azikoro, Ox-Bow lake, Swali, Ogu, Ovom, Okaka, Okutukutu (VES stations 1 – 15 respectively) with a view to delineating the subsurface geologic layers and determining their degrees of corrosivity. The significance of the research study is to highlight the extent and degree of corrosivity of the underlying soil material within a depth interval of 0 – 2m, as this zone or depth would host the proposed subsurface water pipe network distribution in Yenagoa. Corrosion and eventual rupture of subsurface pipes would lead to the

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contamination of the transported water; this could pose a health risk to the teeming populace utilizing such water.

2. Study Area Description

The study area fall under the Niger Delta sedimentary basin of Southern Nigeria, bordering the Atlantic Ocean (fig. 1). Although the stratigraphy of the Niger Delta clastic wedge has been documented during oil exploration and production, most stratigraphic schemes remain proprietary to the major oil companies operating concessions in the Niger Delta Basin. Stratigraphic evolution of the Tertiary Niger Delta and underlying Cretaceous strata is described by Short

and Stauble, (1967). The three major lithostratigraphic units defined in the subsurface of the Niger Delta, these are the Akata, Agbada and Benin Formations (Evamy et al., 1978; Doust and Omatsola, 1990). Decrease in age basin ward, reflecting the overall regression of depositional environments within the Niger Delta clastic wedge. Stratigraphic equivalent units to these three formations are exposed in southern Nigeria. The formations reflect a gross coarsening-upward progradational clastic wedge (Short and Stauble, 1967), deposited in marine, deltaic, and fluvial environments. Yenagoa lies within the low deltaic and freshwater swamps.

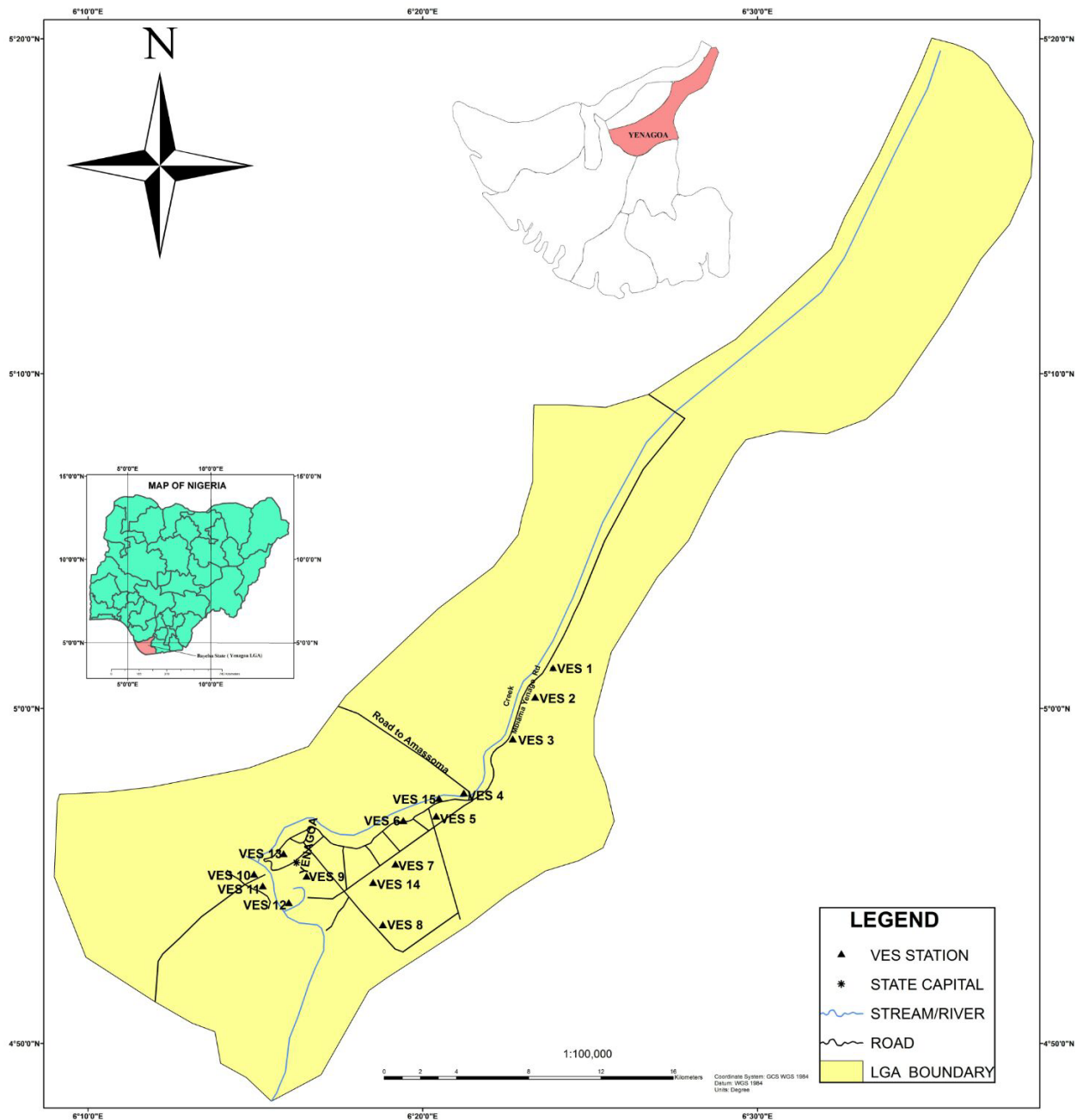


Figure 1. Location map of study area

3. Materials and Methods

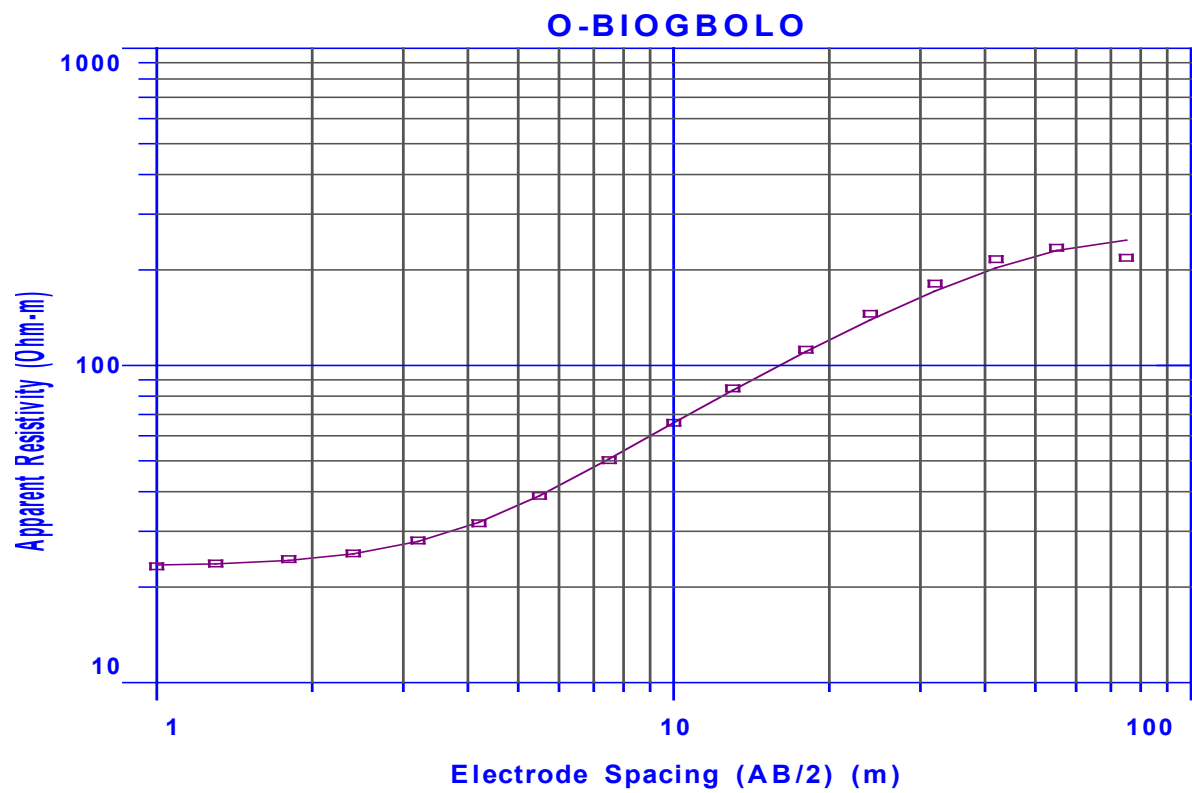
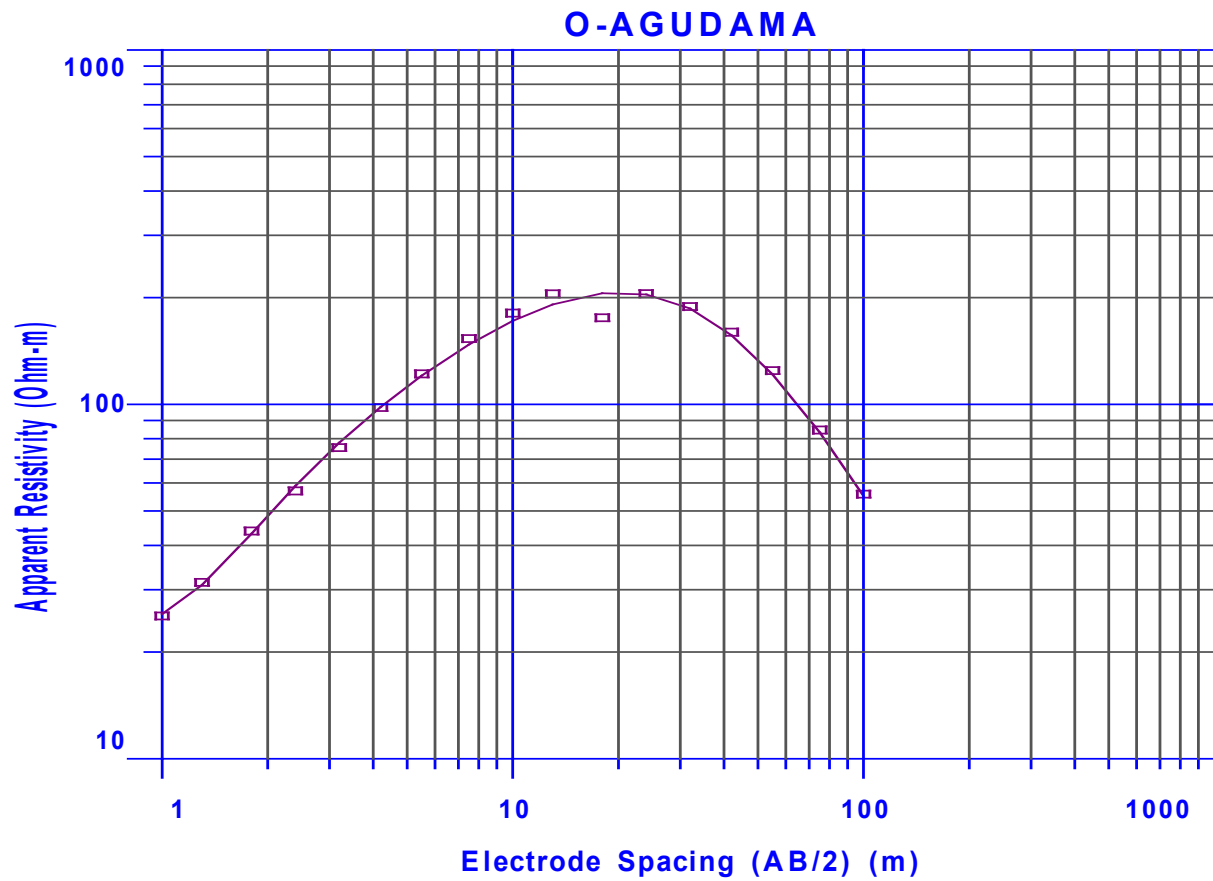
Resistivity was measured by injecting a well-defined signal current into the ground through the two current electrodes (C1, C2). The resulting voltage change (potential difference or drop in potential) is measured between the potential electrodes (P1, P2). This arrangement measures the mean resistivity between the voltage electrodes (P1, P2) up to a depth equal to about 1/3 of the distance between C1 and C2 (total electrode spread) and a width equal to about 2/3 of the distance C1 and C2 (Reynolds 1998). As the electrode spread (C1, C2) increases, depth of the probe increases. The potential-drop-ratio method is a variation on this procedure used for determining resistivity. Vertical Electrical Soundings (VES) was carried out in the study area. The Schlumberger array was used for the VES survey with maximum electrode spacing AB varies between 2 and 300m.

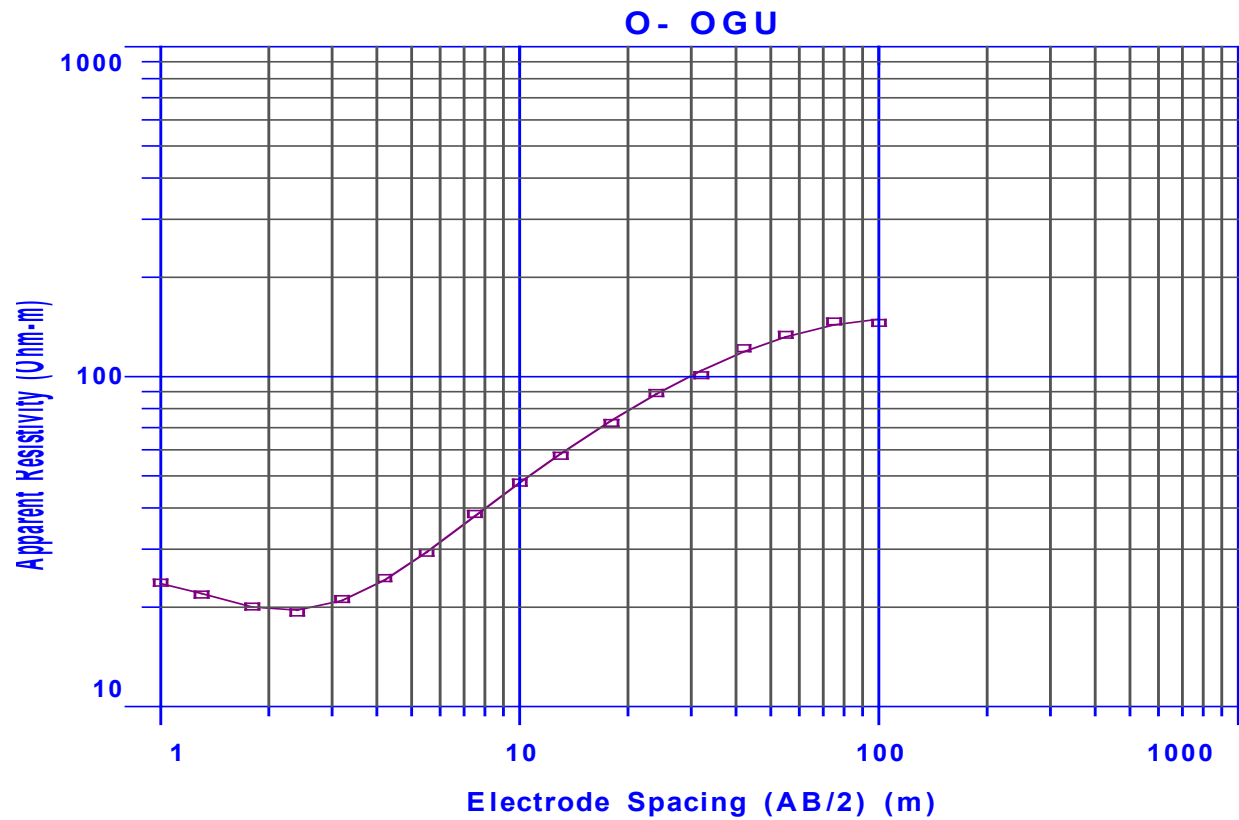
The study area was geo- referenced by using Garmin Global Positioning System (GPS). A total of fifteen (15) VES points were acquired with an average station spacing of 3 kilometers. The instrument used was an Abem Terrameter SAS 3000, a digital self averaging instrument for DC resistivity work. A portable 12 V battery was used as the power source while four stainless metal stakes were used as electrodes. A critical explanation of how the method works can be found in the literature Loke, 1997. Some precautions taken in the field to ensure high resolution data included shielding resistivity meter from direct sunlight and other heat sources to maintain its optimal, temperature, firm grounding of electrodes, tight coupling of cables to electrodes, prevention of cross-talking of cables, good clearance of electrodes and cables from water logged areas.

Table 1. Summary of VES model parameters and corrosion status

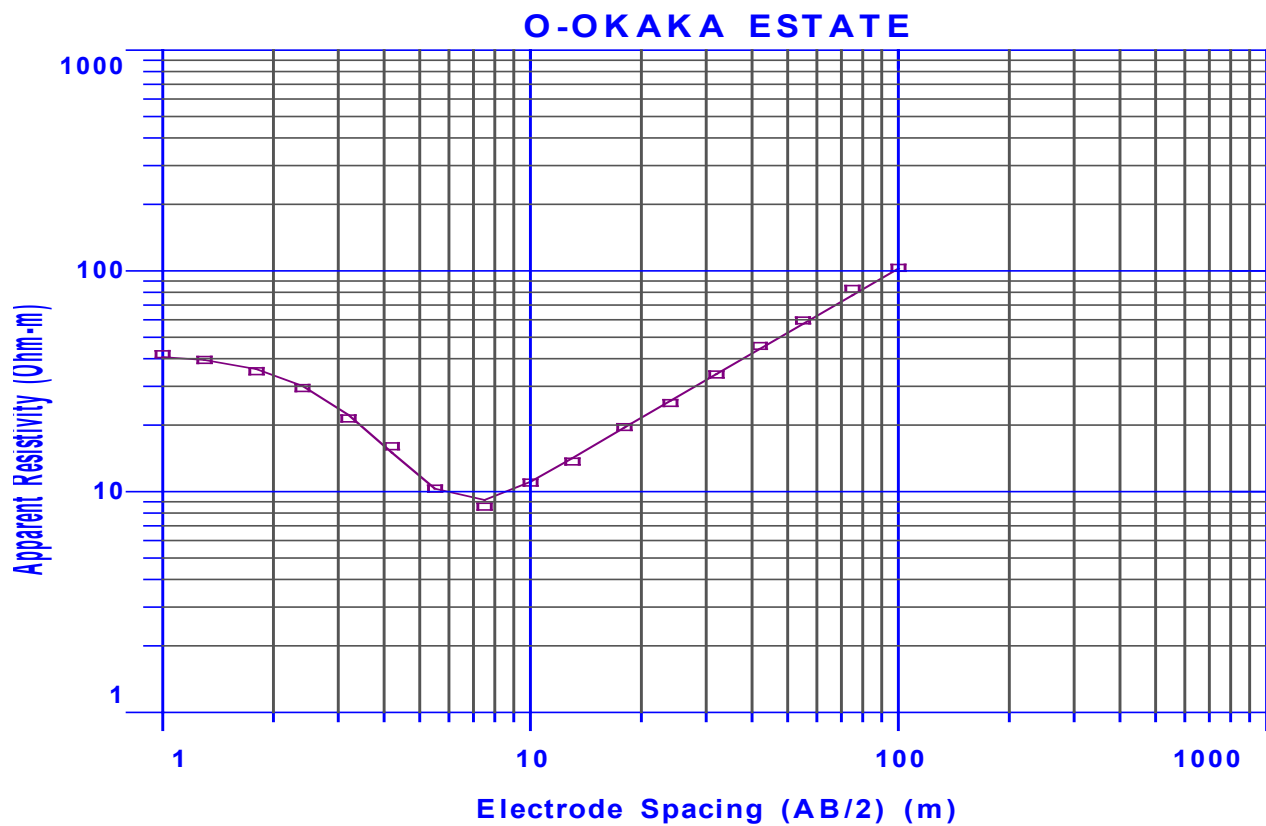
Station No	Layer No	Resistivity (Ω m)	Thickness (m)	Depth (m)	Lithology	Curve type	Corrosive status
1.	1.	25.605	0.7795	0.7795	Top soil	KQ	Very high
	2.	337.33	11.697	12.477	Sandy clay		Negligible
	3.	77.001	38.842	51.319	Clay		High
	4.	14.220					
2.	1.	57.501	0.7444	0.7444	Top soil	HKHA	High
	2.	19.485	0.8060	1.5505	Clay		Very high
	3.	138.24	4.0838	5.6343	Sandy clay		Low
	4.	26.386	6.2195	11.854	Clay		Very
	5.	825.86	38.441	50.295	Sand		Negligible
	6.	4284.4					
3.	1.	23.487	0.7307	0.7307	Top soil	AK	Very high
	2.	23.904	2.5559	3.2867	Clay		Very high
	3.	736.93	31.217	34.504	Clayey sand		Negligible
	4.	16.615					
4.	1.	16.575	0.6411	0.6411	Top soil	HA	Very high
	2.	5.1045	4.3359	4.9770	Clay		Very high
	3.	186.35	26.933	31.910	Sandy clay		Low
	4.	3963.2					
5.	1.	48.855	0.8762	0.8762	Top soil	KH	Very high
	2.	359.97	19.854	20.730	Clayey sand		Negligible
	3.	88.364	32.946	53.676	Clay		high
	4.	2494.2					
6.	1.	15.195	1.0444	1.0444	Top soil	AA	Very high
	2.	52.224	1.8776	2.9220	Clay		High
	3.	198.36	48.700	51.622	Sandy clay		Low
	4.	3336.0					
7	1.	41.879	0.7234	0.72348	Top soil	KH	Very high

Station No	Layer No	Resistivity (Ω m)	Thickness (m)	Depth (m)	Lithology	Curve type	Corrosive status
	2.	615.75	9.4800	10.203	Clayey sand		Negligible
	3.	81.549	29.995	40.198	Clay		High
	4.	11334.					
8.	1.	36.735	0.6125	0.61257	Top soil	HK	Very high
	2.	12.647	1.8775	2.4901	Clay		Very high
	3.	207.44	23.922	26.412	Sandy clay		Negligible
	4.	7.0535					
9.	1.	17.405	0.5043	0.50434	Top soil	HKQ	Very high
	2.	15.888	2.0837	2.5880	Clay		Very high
	3.	535.75	25.027	27.615	Clayey sand		Negligible
	4.	13.163	48.564	76.179	Clay		Very high
	5.	7.0261					
10.	1.	19.581	1.5192	1.5192	Top soil	A	Very high
	2.	220.25	32.827	34.346	Sandy clay		Negligible
	3.	8628.0					
11	1.	23.587	0.4617	0.46179	Top soil	HK	Very high
	2.	16.432	2.3906	2.8524	Clay		Very high
	3.	195.55	48.275	51.128	Sandy clay		Low
	4.	123.96					
12.	1.	40.727	1.5726	1.5726	Top soil	HA	Very high
	2.	2.4354	2.0745	3.6471	Clay		Very high
	3.	489.60	32.849	36.496	Clayey sand		Negligible
	4.	3992.9					
13.	1.	28.968	0.3745	0.37456	Top soil	HAA	Very high
	2.	17.179	1.6299	2.0045	Clay		Very high
	3.	57.877	10.101	12.105	Clay		High
	4.	234.36	39.998	52.103	Sandy clay		Negligible
	5.	1073.7					
14.	1.	44.020	0.6583	0.65833	Top soil	HA	Very high
	2.	21.485	2.6126	3.2709	Clay		Very high
	3.	195.09	25.850	29.121	Sand		Low
	4.	243.66					
15.	1.	22.568	0.7195	0.71953	Top soil	HK	Very high
	2.	20.541	1.5052	2.2247	Clay		Very high
	3.	475.93	26.918	29.142	Sandy clay		Negligible
	4.	87.399					

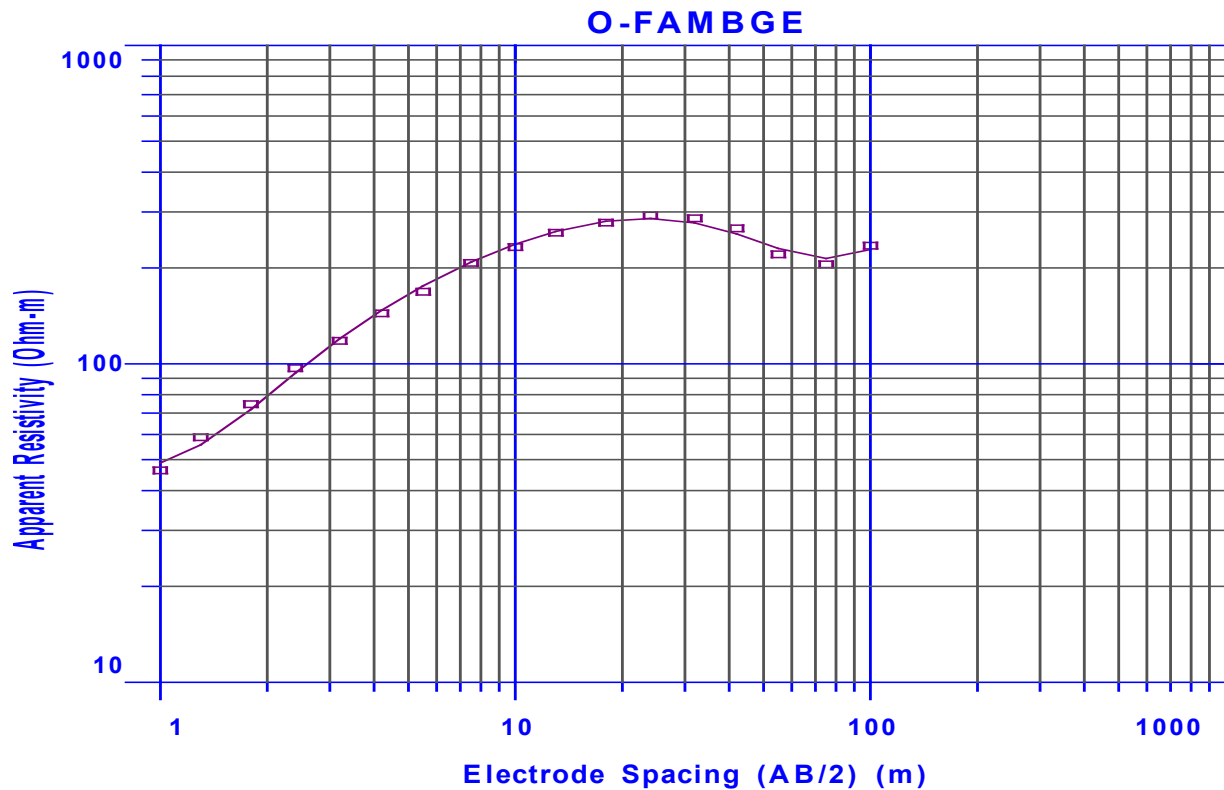




(c)



(d)



(e)

Figure 2. (a, b, c, d and e) KQ, AK, HAA, HA and KH modeled geo-electric curve types respectively

4. Result and Discussions

Modeling of data by IP2Win and Interpex softwares generated the modeled resistivity, thicknesses and depths of the study area. The interpretation and classification of the subsurface strata on the basis of the relationship between resistivity and corrosivity was done using guidelines proposed by Gopal (2010) and Peck et al (1953) as in tables 2 and 3 below.

Table 2. Classification of soil corrosiveness in terms of resistivity (Gopal, 2010)

Resistivity (Ω)	Corrosive probability
>200	Negligible
100–200	Low
50–100	High
<50	Very high

Table 3. Classification of soil type in terms of resistivity (Peck et al., 1953)

Apparent Resistivity (Ω m)	Lithology
<100	Clay
100-350	Sandy clay
350-750	Clayey sand
>750	Sand/Laterite/Bedrock

Summary of the interpreted curves can be seen in (Table 1). The curve types identified were KQ, HK, HA, AK,

AA, HKQ, A, HAA, HA, KH and HK (examples in fig 2-a, b, c and d), these suggested lithological variations in the area. The curves suggested that the area was mostly underlain by four geoelectric layers of various lithologies, however there were few cases of three, five and a single instance of six geo-electric layers in the study area (Table 1).

The hydrostratigraphic section in the study area consisted of a top layer composed of soils, sandy silt and clays with some humus. This surface layer had a thickness that ranged between 0.37m and 1.57m with layer resistivity varying between 15.19 Ω m and 57.5 Ω m, the resistivity of this layer depended majorly on the soil moisture content. Using the corrosivity table 2, about 9 VES points, which was 60% showed that this layer had very high corrosivity and 5 VES points showed the layer as high corrosivity. The second layer was basically a silty clay unit with about eleven VES points to show that, its thickness ranged between 0.8m and 32.8m and the resistivity also ranged from 2.4 Ω m and 615 Ω m. This layer also showed high corrosivity with the resistivity of majority of the VES points to show that, but this same layer under VES (1, 5, 7 and 10) was negligibly corrosive. The third layer, mostly referred to as the aquiferous layer had a thickness that ranged between 4.1m and 48.7m while its resistivity ranged between 57.9 Ω m and 8628 Ω m, it consisted of fine-medium-coarse sand with intercalation of clay, this was why the resistivity of 6 VES's (2,4,6,8,11 and 15) indicated that this layer is mainly composed of clayey sands. This layer had negligible corrosivity. The fourth layer in the

area sampled composed of more clay (VES 2 and 9), with VES 2 indicating sandy clay, the thickness of this layer was between 6.2m to 48.5m while its resistivity is between $13.4\Omega\text{m}$ to $58\Omega\text{m}$, this showed the layer to be of high corrosivity. The fifth layer seen on VES 2 had a thickness of 38.4m and a resistivity of $828\Omega\text{m}$, this layer was basically composed of sand, hence, it was categorized as having negligible corrosivity.

5. Conclusions

The study established the use of electrical resistivity method to investigate soil corrosivity in Yenagoa. The geo-electrical sections delineated four distinct layers. A top soil which was interpreted as having very high corrosivity, the second layer was interpreted as a low corrosive layer; the third and forth layers had negligible corrosivity. Soil corrosiveness of the modeled resistivity showed a very high corrosivity within a depth interval of 0-2m, with a progressive decrease in soil corrosiveness as depth increased. Considering the fact that pipe network distribution in Yenagoa was proposed to be at a depth of not more than 2m from ground level (top soil) which falls squarely within the “very high corrosivity” zone, corrosion resistant pipes are strongly recommended to forestall problems associated with rupture of corroded pipes.

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