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Subsurface Investigation Using Electrical Resistivity and Standard Penetration Test as Guide for Gas Pipeline Installation in Lekki Peninsula, Lagos

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ABSTRACT

The study focuses on the assessment of corrosives probability and cathodic protection potentials of the subsurface layers using Vertical Electrical Sounding (VES) and Standard Penetration Tests (SPT) with a view to ascertaining the suitability of the subsoil information for the installation of gas pipelines. A total of fifteen (15) VES points were carried out using Schlumberger electrode array along three traverses. N_{SPT} -values were obtained at every 1.5m within the four boreholes drilling within the study area. The geo-electric sections produced from the interpreted data reveal three to five geo-electric layers which correspond to top soil, sand, and saline sand. A sand formation with very high resistivity indicates that this layer is not likely to cause corrosion of the buried pipelines as such it gives very good cathodic protection to the pipelines buried within this layer. The saline sand layer, a geo-material is associated with low resistivity which might be due to salt water intrusion, has very high potentiality to corrosion and very poor cathodic protection. It implies that any pipeline buried within this layer would be highly prone to corrosion. The results of the four borehole logs correspond with the depth soundings technique. The study underlines that the results of the N_{SPT} – values of soil samples fall between 15 and 50 which are indicative of medium to dense sand. These values further reveal the competence of the soil strength for engineering purposes. However, the analysis shows the soil type in each layer within geo-electric section is not consistent because it oscillates between sand and saline sand due to their differences in resistivity. Thus, the proposed pipeline infrastructure /facilities to be installed within the study area due to systems design or other factors should be adequately supported with good cathodic protection systems. This study has shown the effectiveness of carrying out geophysical and geotechnical studies prior to burying of pipelines.

KEYWORDS: Schlumberger array, Geo-electrical layer, Corrosive, Cathodic protection, pipelines, N_{SPT} –values

INTRODUCTION

Pipelines play an extremely important role in Nigeria in particular and throughout the world in general as an efficient and safety means of transporting crude oil and natural gas from producing fields to refineries and processing plants liquids over long distances to the consumers. A buried operating pipeline is rather unobtrusive and rarely makes its presence known except at valves, pumping stations or terminals (Beaver and Thompson, 2006). Pipeline corrosion is a growing problem in the oil and gas industry. The gradual chemical attack and degradation of metallic materials due to corrosion results in the conversion of metallic materials into oxides, salts or other compounds (Ekine and Emujakporue, 2010). Corrosion is a natural process by which a corrosion-current is formed with a flow of electrons from high potential anode to a lower potential cathode material leading to weakening of the strength, ductility and other mechanical properties of pipeline facilities. This often results in the failure of pipeline when allowed to continue without urgent attention given to it. Sometimes, the aftermaths of pipeline failure are potential explosion, human and economic risk and environmental disaster (Okoroafor, 2004).

The environmental factors that influence corrosion and subsequent failure of underground pipelines are the conditions of the soil which might be due to the moisture contents, pH of the soil, the presence of microbes and soil types to name a few (Levin, 1992 and Chukwu et al., 2008). Another cause of external corrosion of earth buried pipelines is linked with the soil resistivity which gives a better prediction of soil corrosiveness than any other soil properties (Andrew et al., 2005). Therefore, soil resistivity measurement is imperative in the investigation of external corrosion of buried pipelines (Okiwelu et al., 2011). Soil resistivity is a function of soil moisture and the concentrations of ionic soluble salts and is considered to be most comprehensive indicator of a soil's corrosiveness. Environmental concerns which are consequences of the pipelines failure usually manifested as leakage cannot be ignored. The damages due to this leakage are minimal compared with the environmental damages that would accompany the ugly incident if little or no attention is given. The failures by these pipeline infrastructures due to corrosion are one of the leading causes of loss of human lives, destruction of valuable properties and environmental degradation. Statistics has shown that most of the reported accidents due to leakage of pipelines were as a result of corrosions which might be external or internal as well as the activities of the vandals which have continued to be challenging to most nations.

Therefore, it follows that primary protection of the earth buried pipelines against failure due to external corrosion by surface coatings and backfill are essential together with cathodic protection systems serving as secondary protection, especially where there are coating holidays (Raajani et al., 2003).

Cathodic protection is a process in which an electric current is allowed/constrained to flow from and auxiliary anode into the structure to be protected against corrosion, thus making the entire structure a cathode (Liu and Shi, 2011). It has become a widely used method for controlling the corrosion deterioration of metallic structures such as water storage tanks, gas pipelines, oil platform supports that are in contact with most forms of electrolytically conducting environments, i.e. environments containing enough ions to conduct electricity such as soils, seawater and basically all natural waters. During pipeline construction campaign, parts of the exercise should involve or begin with the identification of potentially corrosive conditions in the area where pipeline construction is planned. It is equally beneficial to have a thorough understanding of corrosion and its causes in order to properly evaluate available methods of protection. . In geotechnical studies, Standard Penetration Test (SPT) furnishes data about the resistance of soils to penetration, which can be used to evaluate the soil strength in terms of number of blows (N_{SPT} - values) (Kumari et al., 2009).

The need therefore arises for studies to be carried out in order to seek ways of minimizing the occurrence of these problems and providing guide to the most appropriate positions suitable for burying the pipelines. Against this backdrop, the assessment of the corrosion and cathodic protection potential of the subsurface layers for the installation of gas pipeline was carried out using electrical resistivity method with standard penetration test.

METHODOLOGY

Acquisition of data

A geo-electric survey using the 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 540m. The study area was geo- referenced by using Garmin Etrex model Global Positioning System (GPS). A total of fifteen (15) VES points were acquired along three traverses (Figure 1).The PASI Terrameter (Earth Resistivity Meter) was used for the data acquisition. Four boreholes were also drilled in order to show the secession of strata based on recorded samples using Shell and Auger cable percussion boring technique by means of a Dando rig to a maximum depth of 35m below existing ground level. During boring, samples were recovered at regular interval of 0.25m where standard penetration test (SPT) were carried out at 1.5m interval in cohesionless strata. The SPT resistance (i.e. the NSPT -value) which is the number of blows required to drive the sampler through a distance of 300mm after an initial penetration of 150mm was recorded.

Data processing

The geo-electrical data acquired from the field was processed to remove noise arising from instrumentation and environmental influences. The first task involved using manual curve matching with the master and auxiliary curves. The apparent resistivity data were reproduced in the form of curves which were obtained by plotting the apparent resistivities (ρ_a) against the half current electrode separation(AB/2) using a transparent tracing paper superimposed on a log – log graph. The curves obtained were curve matched using a set of two layered modeling curves. In this technique, the field curves were superimposed on the theoretical master curves while keeping the respective axes parallel, the field curve was moved over and around the theoretical curve until a good match was obtained for as many points on the field curve. The aim of the curve matching was to obtain layer parameter of resistivity thickness and depth. To obtain layers true resistivities of the successive strata underneath each VES point, one-dimensional resistivity inversion was carried out using WinGlink software program. The WinGlink software uses the results of the curve matching as the initial model parameters and draws theoretical and field curves on a display screen together with the resistivity model curves. The procedure follows an iterative way and stopped when the root mean square (RMS) value which is the difference in apparent resistivity between the true and the predicted models is less than an acceptable value or convergence after certain iterations. The model parameters obtained (i.e. layer resistivity and thickness) were used to produce three geo-electric sections using AUTOCAD software. The interpretation and classification of the subsurface strata on the basis of resistivity-corrosiveness was done using guidelines proposed by Gopal, 2010 as shown in Table 1.

In geotechnical method, Standard Penetration Tests (SPT**)** was done to supplement the electrical resistivity method. The N_{SPT}-values recorded were compared with the guideline proposed by Peck et al., 1953 as presented in Table 2. These correlations were used in subsoil classifications.

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

Table 2: Classification of soil (Peck et al., 1953)

Relative Density Sand and Gravels	Blows/Ft (N_{SPT})
Very loose	0-4
Loose	4-10
Medium	10-30
Dense	30-50
Very dense	Over 50

SITE DESCRIPTION AND GEOLOGY OF STUDY AREA

The area of investigation (figure 1) is located at Chibo Ofodile close within Lekki Penninsula Scheme 1 along Lekki – Ajah Express way in Eti – Osa Local Government Area, Lagos. It is accessible through Admirality road via Ladipo Crescent. It is bounded to the North, East and West by the sea but to the South by residential buildings.The study area is located within Lagos state in Nigeria. It belongs to parts of the Dahomey basin. Lagos State lies in Southwestern part of Nigeria and the formations found there occur within the sedimentary sequence. According to Jones and Hockey, 1964 the geology of Southwestern Nigeria reveals a sedimentary basin which is classified under five major formations. The state overlies the Dahomey basin which extends almost from Accra in Ghana, through the Republic of Togo and Benin to Nigeria where it is separated from the Niger Delta basin by the Okitipupa rigde at the Benin hinge flank. According to their geological formation age, the five formations include: the Littoral and the Lagoon deposits, Coastal Plain sands, the Ilaro formation, the Ewekoro formation and the Abeokuta formation overlying the crystalline basement complex with their ages ranging from Recent to Cretaceous (Short and Stauble,1967). Four of these formations excluding Ilaro, constitute aquifers in the Dahomey Basin, from which the geological section of Lagos was drawn. The Ilaro formation is composed predominantly of shaley clay (argillaceous sediments). Limestone forms the aquifer material in the Ewekoro formation while sands and gravels constitute the materials in aquifers of the recent sediments, Coastal plain sands and Abeokuta formations contain brackish water. In the Republic of Benin part of the basin, the geology is fairly well known (Billman, 1976). On the onshore, Cretaceous strata are about 200 m thick (Okosun , 1990). A non-fossiliferous basal sequence rests on the Precambrian basement. This is succeeded by coal cycles, clays and marls which contains fossiliferous horizons. Also, Billman 1976 reported that on the offshore of the basin a thick sequence consisting of sandstones followed by black fossiliferous shales is present and is dated from Pre-Albian to Maastrichtian. The Cretaceous is divisible into two geographic zones, north and south. The sequence in the northern zone consists of basal sand that progressively grades into clay beds with intercalations of lignite and shales.

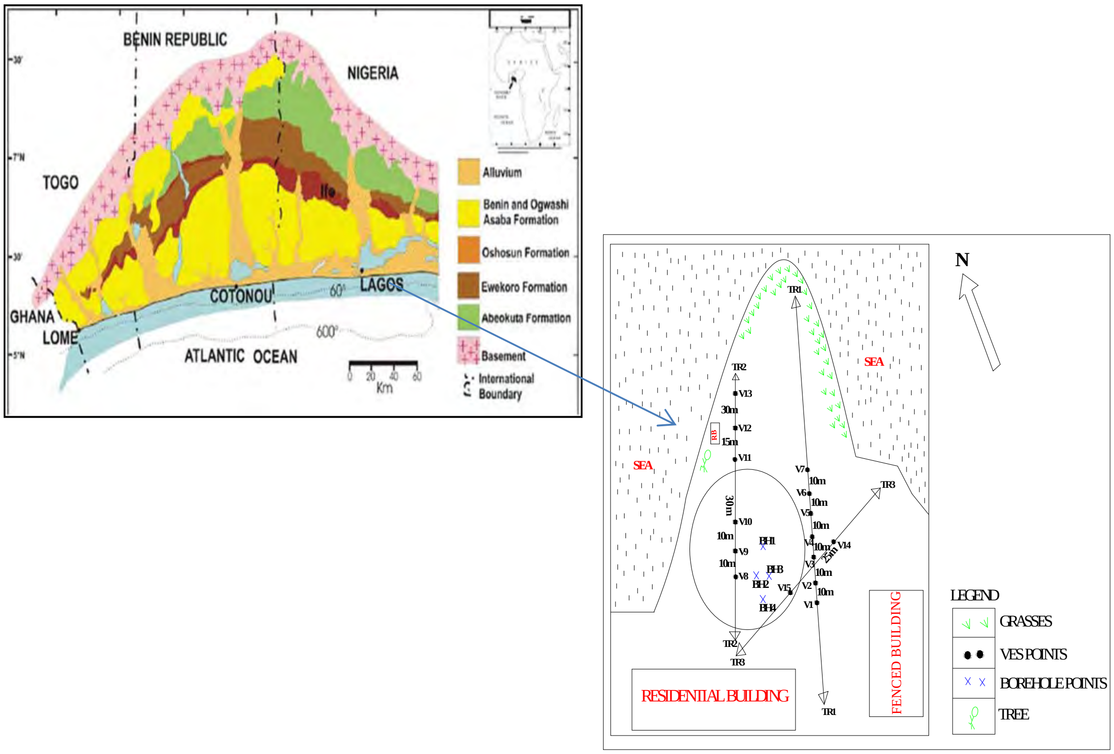

Figure 1: Location map showing the geological map of Dahomey Basin (Bankole et al. 2006) and base map of the study area reflecting VES and borehole points.

RESULTS AND DISCUSSION

The samples of resistivity curves are shown in figure 2(a) to 2(b). The qualitative interpretation revealed five distinct curve types for the study area. These are QH, QQH, QHK, HK and QHA curves. Also, a summary of the interpreted VES data, corrosion status and cathodic potentionl status is presented in table 3. The generated geo-electric sections beneath the VES points are presented as shown in figures 3(a) to 3(c). Also, summaries of the four borehole lithologies with their corresponding N_{SPT}-values are presented in Tables (4) to (7).

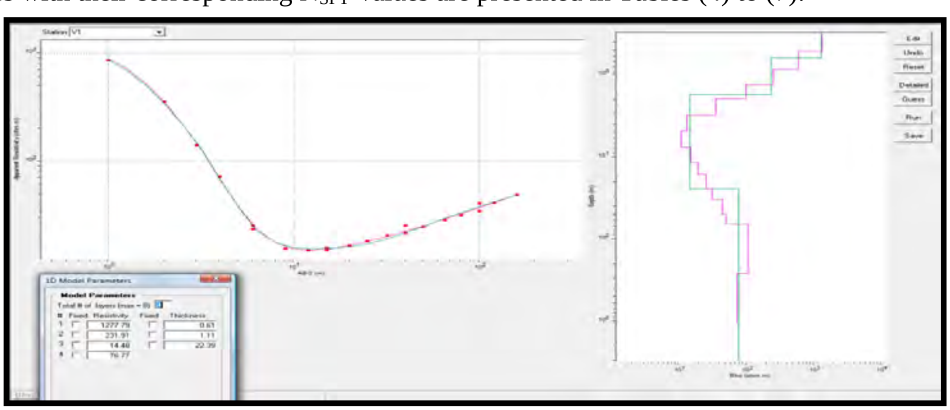

Figure 2a: Resistivity curve for VES 1

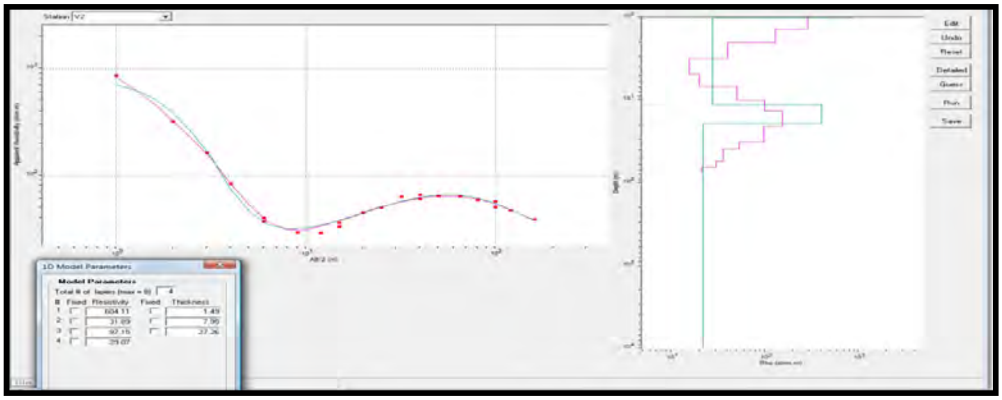

Figure 2b: Resistivity curve for VES 2

Table 3: Summary of VES model parameters, corrosion status and cathodic protection status

VES Station	Number of layers	Resistivity (Ω m)	Thickness (m)	Depth (m)	Lithology	Corrosive status	Cathodic protection status
	1	1277.79	0.61	0.61	Top soil	Negligible	Very Good
1	2	231.9	1.11	1.72	Sand	Negligible	Very Good
	3	14.5	22.4	24.11	Saline sand	Very high	Very Poor
	4	76.77			Sand	High	Relatively Poor
	1	604.11	1.49	1.49	Topsoil	Negligible	Very good
	2	31.89	7.95	9.44	Saline Sand	Very high	Very poor
2	3	97.15	27.26	36.70	Sand	High	Relatively poor
	4	29.07			Saline sand	Very high	Very poor
	1	619.15	0.54	0.54	Topsoil	Negligible	Very Good
	2	148.16	1.47	2.01	Sand	Low	Relatively Good
3	3	30.09	3.95	5.96	Saline Sand	Very high	Very Poor
	4	63.20	55.55	61.51	Sand	High	Relatively poor
	5	127.46			Sand	Low	Relatively Good
	1	654.87	0.56	0.56	Topsoil	Negligible	Very Good
	2	34.15	3.48	4.04	Saline sand	Very high	Very Poor
4	3	89.19	16.58	20.62	Sand	High	Relatively Poor
	4	37.10	39.02	59.64	Saline sand	Very high	Relatively Poor
	5	89.9			Sand	High	Relatively Poor
	1	280.43	0.57	0.57	Topsoil	Negligible	Very good
5	2	34.97	11.33	11.90	Saline Sand	Very high	Very Poor
	3	434.29			Sand	Negligible	Very Good
	1	82.6	0.56	0.56	Topsoil	High	Relatively poor
	2	21.47	1.63	2.19	Saline sand	Very high	Very Poor
6	3	7.71	4.15	6.34	Saline sand	Very high	Very Poor
	4	88.81	…	…	Sand	high	Relatively poor
	1	66.02	0.58	0.58	Topsoil	high	Relatively Poor

7	2	6.85	6.85	7.43	Saline sand	Very high	Very Poor
	3	336.22	….	…	Sand	Negligible	Very Good
	1	219.17	1.28	1.28	Topsoil	Negligible	Very Good
8	2	50.68	1.57	2.85	Sand	High	Relatively Poor
	3	6.52	10.32	13.17	Saline Sand	Very High	Very Poor
	4	17.1	…	…	Saline Sand	Very High	Very Poor
	1	149.42	1.04	1.04	Topsoil	Low	Relatively Good
	2	31.10	1.53	2.58	Saline sand	Very high	Very Poor
9	3	5.53	10.3	12.8	Saline sand	Very High	Very Poor
	4	65.45	….	….	Sand	High	Relatively Poor
	1	145.81	1.53	1.53	Topsoil	Low	Relatively Good
10	2	9.12	10.41	11.94	Saline Sand	Very High	Very Poor
	3	24.90	5.51	17.45	Saline Sand	Very High	Very Poor
	4	168.5	…	…	Sand	Low	Relatively Good

Table 3: Summary of VES model parameters, corrosion status and cathodic protection status

VES Status	Number of Layers	Resistivity (Ω m)	Thickness (m)	Depth (m)	Lithology	Corrosive status	Cathodic protection status
	1	177.40	0.56	0.56	Topsoil	Low	Relatively Good
	2	21.09	1.72	2.28	Saline Sand	Very High	Very Poor
11	3	4.59	18.11	20.39	Saline Sand	Very High	Very poor
	4	127.50	…	…	Sand	Low	Relatively good
	1	850.53	0.56	0.56	Topsoil	Negligible	Very Good
	2	73.59	2.97	3.53	Sand	High	Relatively Poor
12	3	17.62	12.25	15.78	Saline Sand	Very High	Very Poor
	4	61.00	17.68	33.46	Sand	High	Relatively Poor
	5	18.2	….	….	Saline sand	Very High	Very Poor
	1	1515.7	0.37	0.37	Topsoil	Negligible	Very Good
13	2	349.97	1.05	1.42	Sand	Negligible	Very Good
	3	22.37	23.70	25.12	Saline Sand	Very High	Very Poor
	4	206.9	…	…	Sand	Negligible	Very Good
	1	226.51	0.56	0.56	Topsoil	Negligible	Very Good
	2	11.18	4.03	4.59	Saline Sand	Very High	Very Poor
14	3	41.79	3.60	8.19	Saline Sand	Very High	Very Poor
	4	2.17	16.37	24.56	Saline Sand	Very High	Very Poor
	5	12.57	…	…	Saline sand	Very High	Very Poor
	1	617.09	0.62	0.62	Topsoil	Negligible	Very Good
15	2	149.20	1.82	2.44	Sand	Low	Relatively Good
	3	10.19	3.04	5.48	Saline Sand	Very High	Very Poor
	4	168.6	3.1	8.5	Sand	Low	Relatively Good
	5	12.1	….	….	Saline Sand	Very High	Very Poor

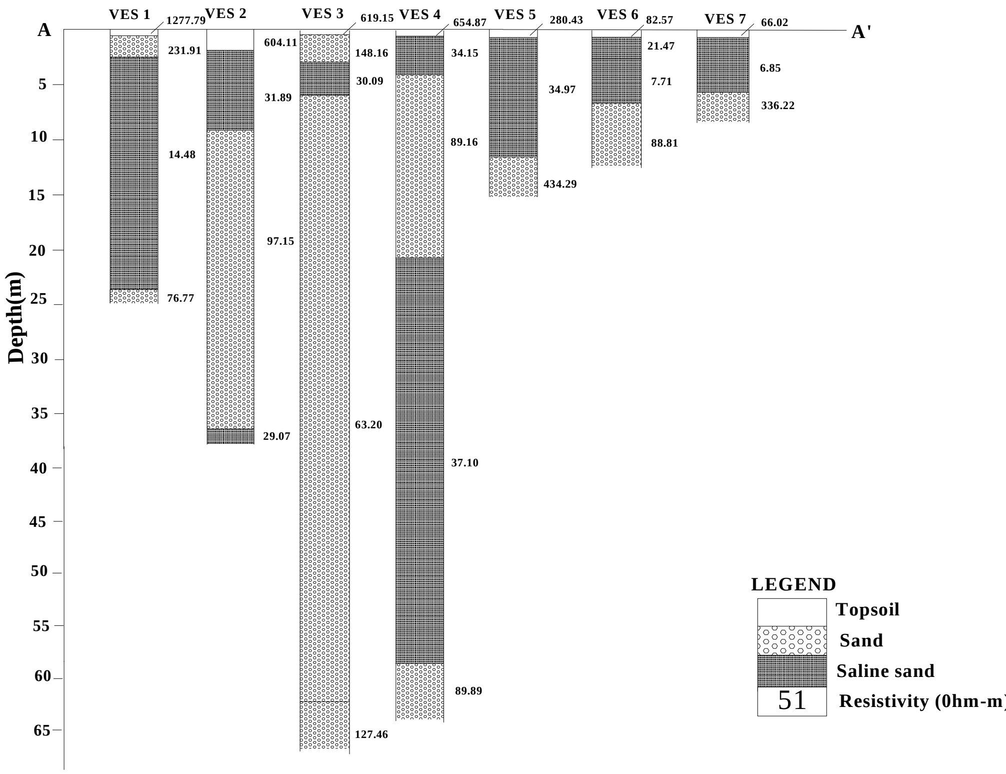

Figure 3a: Geo-electric section along AA'

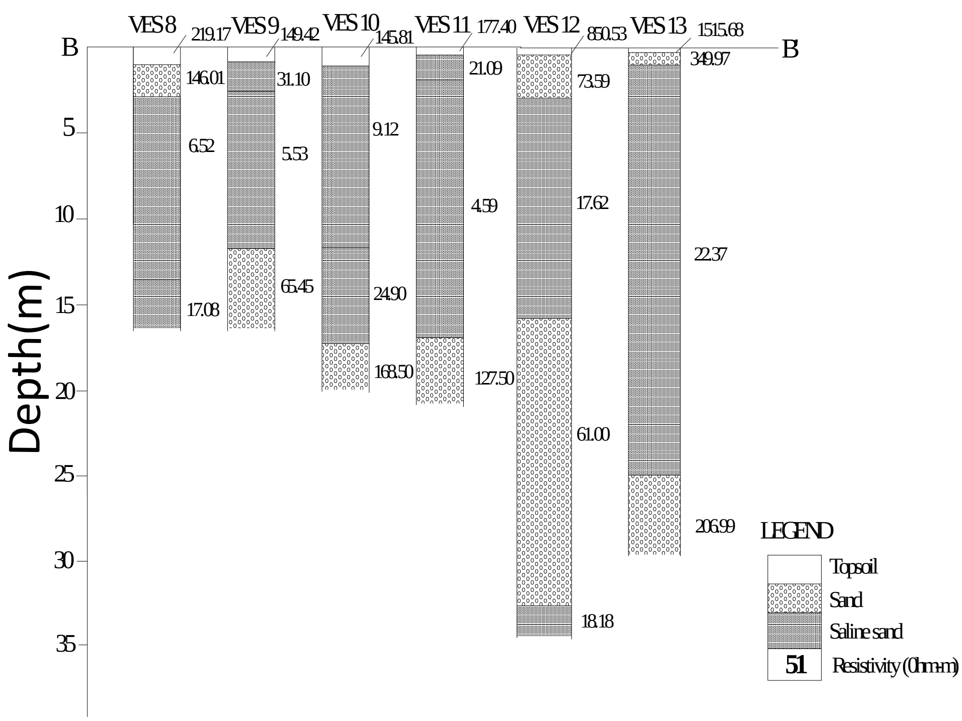

Figure 3b: Geo-electric section along BB'

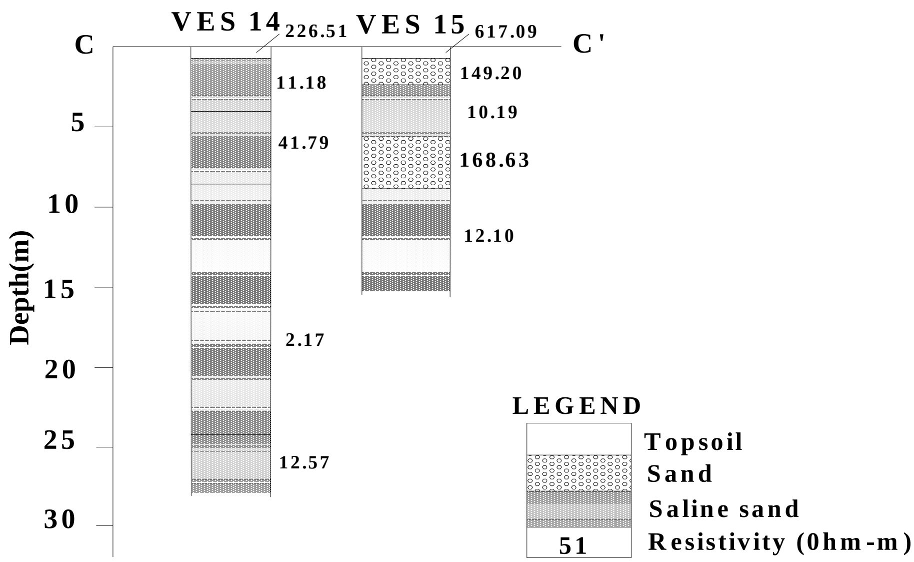

Figure 3c: Geoelectrical section along CC'

Table 4: Lithologic units relationship with N_{SPT} -values at different depth for borehole 1

No of layer	Thickness(m)	Description of soil types	NSPT -values
		Medium to dense, light and dark	
1	1.5 - 30	grey silty sand with seashells at top layers	15 - 42
		only, becoming coarse sands at depth with	
		semi-rounded fine gravels	
2	30 - 35	Medium to dense, light grey coarse	32 - 39
		sands with semi-rounded fine gravels	

Table 5: Lithologic units relationship with N_{SPT} -values at different depth for borehole 2

No of layer	Thickness (m)	Description of soil types	N_{SPT} -values
		Medium to dense, light and dark	
1	1.5 - 20	grey silty sand with seashells at top layers	26 - 40
		only, becoming coarse sands at depth with	
		semi-rounded fine gravels	
2	20 - 30	Medium to dense, light grey coarse	25 - 35
		sands with semi-rounded fine gravels	
3	30 - 35	Medium to dense, light grey coarse	22 - 32
		sands with semi-rounded fine gravels	

Table 6: Lithologic units relationship with N_{SPT}-values at different depth for borehole 3

No of layer	Thickness(m)	Description of soil types	N_{SPT}-values
		Medium to dense, light and dark	
1	1.5 - 22	grey silty sand with seashells at top layers	28 - 50
		only, becoming coarse sands at depth with	
		semi-rounded fine gravels	
2	22 - 30	Medium to dense, light grey coarse	24 - 32
		sands with semi-rounded fine gravels	
3	30 - 35	Medium to dense, light grey coarse	21 - 30
		sands with semi-rounded fine gravels	

Geo-electric section AA^I

This section comprises seven VES points (1) to (7) trending approximately N-S direction. It has four to five geo-electric layers except for VESs 6 and 7 with three layers. These layers consist of top soil, sand, and saline sand. The first layer corresponds to top soil (comprising loose and coarse sand). Its thickness varies between 0.54 and 1.49 m with layer resistivity values of 66.02 to 1277.79 ohm-m. With this resistivity range and the standard presented above, this layer shows high / negligible corrosive nature and relative poor /very good cathodic protection. The second stratum consists of sand beneath VESs 1 and 3 with resistivity values between 148.16 and 231.91 ohm-m and layer thickness varies between 1.11and 1.47 m which reflect low / negligible corrosive probability and relative good / very good cathodic protection. The same layer under VESs 2,4,5,6, and 7 reveal a low resistivity zone corresponding to saline sand, with resistivity values ranging from 6.85 to 34.99 ohm-m and earth thickness 1.63 to11.33 m. This zone denotes very high corrosive probability and very poor cathodic protection. The observed difference in the composition of this layer might be due to depositional environments. The third identified layer beneath VESs 2,4,5 and 7 is symptomatic of sand with resistivity values between 89.16 and 434.29 ohm-m and layer thickness under VES 2 and 4 falling between 3.48 to 27.26 m. The thickness in VES 5 and 7 could not be determined because current terminated within this zone. This layer denotes high / negligible corrosive probability and relatively poor / very good cathodic protection. The third layer in VESs 1,3, and 6 denotes saline sand with earth thickness between 3.95 to 22.39 m and its resistivity varies from 7.71 to 30.096 ohm-m. This horizon is inferred to have very high corrosive probability and very poor cathodic protection. The fourth substratum layer signifies sand with earth resistivity ranges from 63.20 to 88.81 ohm-m but the thickness in VESs 1 and 6 could not be ascertained because the current terminated within this zone except in VES 3 which has resistivity value of 55.55m. This zone denotes high corrosive probability and relatively poor cathodic protection. The same horizon in VES 2 and 4 represents saline sand with resistivity 29.09 to 37.10 ohm-m. The thickness in VES 4 is 39.02 m but could not be determined in VES 2 because current terminated within this zone. This zone denotes very high corrosive probability and very poor cathodic protection. The fifth horizon in VESs 3 and 4 represents a geo-material indicating sand with earth resistivity 89.89 to 127.46 ohm-m but its thickness could not be ascertained because current terminated within this region. Unlike the layers above it, this layer indicates a combination of high / low corrosive probability and relatively poor / relatively good cathodic protection.

Geo-electric section BB[I]

It is made up of four to five geologic units with six VESs (8) to (13) constituting this profile. It is acquired along NNE-SSW direction of the study area (figure 1). These layers are representative of top soil, sand, and saline sand. The first geo-electric layer signifies topsoil characterized by relatively high resistivity values ranging values from 145.81 to 1515.68 ohm-m with layer thickness between 0.37 and 1.55m.The range of resistivity values for this layer, attest to the fact that the layer has low / negligible corrosive probability and relatively good / very good cathodic protection. The second subsoil stratum below VESs 8, 12, and 13 denotes sand with resistivity values between 50.68 and 349.99 ohm-m. Its layer thickness varies from 1.05 to 2.97 m which shows relatively high / negligible corrosive probability and has relatively poor / very good cathodic protection. The same layer in VESs 9, 10 and 11 is diagnostic of saline sand with earth resistivity between 9.02 to 31.10 ohm-m. The thickness of this layer is between 1.53 to 10.41m. The low resistivity values of the stratum underneath these VES points suggest that its tendency to corrosion is very high and might offer very poor cathodic protection. The third horizon delineated is symptomatic of saline sand with resistivity values ranging from 4.59 to 22.37 ohm-m. Its layer thickness is between 5.51 and 23.70 m. Due to closeness in resistivity values between the second and third layer (equivalent), the layers are superposed as one layer. Like the second layer, it is high susceptible to very high corrosion and any pipe or metallic structure buried in this layer might fail due to the soil corrosivity and little or no cathodic protection.

Also, the fourth subsurface layer in VES 8 is composed of saline sand with earth resistivity value of 17.08 ohm-m. Its thickness could not be determined because the current terminated within this horizon. This zone denotes very high corrosive probability and very poor cathodic protection. The same region in VESs 9 to 13 represents sand with resistivity values 61.0 to 206.9 ohm-m. Its thickness could not be determined because the current terminated within this horizon except in VES 12 which has thickness of 17.68m. This layer infers high / negligible corrosive probability and relatively poor / very good cathodic protection. The fifth stratum in VES 12 corresponds to saline sand with infinite thickness caused by the termination of current within this layer too. This zone denotes very high corrosive probability and very poor cathodic protection.

Geo-electric section along CC[1]

This geo-section comprises of two VESs (14) and (15) trending along NE- SW as shown in figure1. It has five geo-electric layers. These layers correspond to topsoil, saline sand and sand. The first layer of this section, the topsoil, is characterized relatively high resistivity in the range of 226.51 and 617.09 ohm-m with layer thickness 0.56 to 0.62 m providing negligible corrosion and very high cathodic protection. The second geologic unit beneath VES 14 is representative of saline sand with layer thickness 4.03 m and resistivity value of 11.18ohm-m. This zone reflects very high corrosive probability and very poor cathodic protection. The same zone in VES 15 is symptomatic of sand. The layer thickness and resistivity are 1.82 m and 149.20 ohm-m respectively. This substratum layer signifies low corrosive probability and relatively cathodic protection. The third horizon in VESs 14 and 15 signifies saline sand with resistivity values between 10.19 and 41.79 ohm-m. It’s earth thickness ranges from 3.04 to 3.60 m. This zone denotes very high corrosive probability and very poor cathodic protection. The fourth layer in VES 14 delineates saline sand which has earth thickness 16.37m with corresponding resistivity value of 2.17 ohm-m. This horizon infers very high corrosive probability and very poor cathodic protection. The same horizon in VES 15 denotes sand with resistivity value of 168.63 ohm-m and its thickness is 3.12m. This layer shows very low corrosive probability and relatively good cathodic protection. The fifth subsoil under VES points 14 and 15 corresponds to saline sand with earth resistivity 12.10 to 12.57 ohm-m. Its thickness could not be ascertained because the current terminated within this zone. This zone denotes very high corrosive probability and very poor cathodic protection.

Thus, the results presented in table 4 give the subsurface information with resistivity between 219.17 and 1515.68 ohm-m has been inferred to have negligible corrosion probability and very good cathodic protection. The layers with resistivity values ranging from 127.46 to177.40 ohm-m have low corrosion probability and relatively good cathodic protection. The substratum with resistivity ranging from 50.68 ohm-m to 97.15 ohm-m might be region with low corrosion probability and relatively poor cathodic protection while the layer with resistivity variability between 2.17 to 41.79 ohm is probably the region of very high corrosion tendency/ rate and very poor cathodic protection.

Boring with N_{SPT} -values

The results from tables (4) to (7) of the soil samples taken from the boreholes (1) to (4) at depth interval 1.5 to 30m connote medium to dense, light / dark grey silty sand with seashell at top layers only becoming coarse sand at depth with semi-rounded fine gravels based on the lithological analysis and N_{SPT}-values that fall between 15 and 50. Also, the analysis of soil samples taken from the boreholes (1-4) at depth intervals 30-35m reflect medium to dense, light grey coarse sands with semi-rounded fine gravels established from the lithological information and N_{SPT} -values ranging from 21 to 39. The N_{SPT} -values further underline the competence of the soil strength for engineering purposes.

CONCLUSION AND RECOMMENDATION

The vertical electrical soundings (VES) has delineated three to five geo-electrical layers in studied area, the topsoil, sand, and saline sand as the subsurface geological formations. The VES results show that the corrosive capability of the delineated lithologic units is a function of the resistivity values of the subsurface strata. The findings of the study show that the subsurface information is composed of topsoil, sand and saline sand. A sand formation with high resistivity indicates that this layer is not likely to cause corrosion of the buried pipelines as such it provides/gives very good cathodic protection to the pipelines buried within this layer. The saline sand layer is characterized by very low resistivity making this layer to be highly corrosive and relatively poor catholic protection potential. It implies that any pipeline buried within this layer would be highly prone / vulnerable to corrosion. The N_{SPT} -values of the SPT tests, conducted in order to understand the variation in the soil stratification, show good correlation with the depth sounding results and further confirms the competence of the soil strength for engineering purposes. However, the analysis shows the soil type in each layer within geo-electric section is not consistent because it oscillates between sand and saline sand due to their differences in resistivity. Thus, facilities to be installed within the study area due to systems design or other factors should be adequately supported with good cathodic protection systems. This study has shown the effectiveness of carrying out geophysical and geotechnical studies prior to burying of pipelines.

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