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Assessment of the Effect of Dumpsite Leachate on Soil Physico-chemical Parameters at Oghara, Delta State, Nigeria

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Abstract
The effect of waste dumpsite leachates on soil physico-chemical parameters and corrosivity in Oghara municipality is here evaluated. Six Soil samples were randomly collected near the waste dumpsites using a stainless steel hand-auger at 2m apart to varying depths of 0-20cm, 20-40cm and 40-100cm. 12 vertical electrical soundings (VES) were also investigated using the Mini-Res Resistivity meter with maximum current electrode AB/2 of 100m and potential electrode MN/2 of 10m. The Schlumberger electrode configuration was adopted. The soil physico-chemical parameters such as conductivity, nitrate, Lead, iron, and sulphates and chlorides (at depth of 40cm and beyond) were higher than the permissible standards. Resistivity results delineated 5 layers of lateritic topsoil, sandy-clay, fine-coarse sand, medium coarse-sand, and coarse-sand with varied apparent resistivity, thickness and depth. Soil corrosivity was evaluated using the resistivity values of the first layer on each VES station and it showed that 25% of soil was moderately corrosive, 42% was slightly corrosive, and 33% was practically non-corrosive within a depth range of 0.13m to 1.76m due to low resistivity signatures, low pH values and high nitrates, lead, iron, chlorides and sulphates ions arising from dumpsite leachate infiltration to the subsurface at greater depth. Using the resistivity values of the second and third layers on each VES stations revealed that the soil exhibited slight to moderate corosivity within a depth range of 5.07m to 31.07m arising from the dumpsite waste leachate. Cathodic protection should be adopted to avoid corrosion of buried transmission pipelines.

Keywords: *Cathodic Protection, Dumpsite Leachate, Transmission Pipelines, Soil Corrosivity, Soil Physico-chemical Parameters, Vertical Electrical Sounding (VES)*

Introduction

Wastes are materials that result from human activities or processes which does not have immediate economic value and demand, therefore must be discarded (Ehirim *et. al.*, 2009). These wastes are generated daily in most of the urban centres in Nigeria and are disposed indiscriminately into the lakes, streams, rivers and landfills without consideration to the underground environment (Ekeocha *et. al.*, 2012). The rural urban migration as a result of economic activities had caused these urban cities to keep increasing in population with attendant increase in generation of wastes thus further expansion had forced some of these dumpsites to be abandoned and in most cases, they are not properly closed and contained using geo-membranes (Omolayo and Tope, 2014). Solid waste landfills are abandoned or disused exhumed pits used for road construction, and are therefore, not engineered for the containment of landfill emissions into the environment (Ekeocha *et. al.*, 2012). Most of the dumping sites in Oghara are located within residential areas, markets, farms and roadsides. These wastes are generated by industrial activities as well as human/household activities (such as sewage, human and animal remains). Releasing such substances into the environment causes serious health problems. It also enhances the soil corrosivity, threatens underground water, soil strength, road facilities and the aesthetics of the area. At the peak of the rainy season, dumpsites in Oghara are usually covered by flood water and this contributes to leachate formation. Leachate plumes normally have low resistivity values because of high ion concentration (Rosqvist *et. al.*, 2003) thus giving the landfill or dumpsite high conductivity signatures. This property makes the electrical resistivity method very suitable to map leachate plumes and it has been employed in many parts of the world by several researchers such as MacFarlane *et. al* (1983), Becker (2002), Ehirim *et. al*. (2009), Jegede *et. al.*(2011) and Carpenter and Reddy (2011).

Dumpsite wastes contain toxic substances which decompose or biodegrade in the soil making it corrosive and in the presence of infiltrating water produce organic liquids or leachates which contaminate groundwater with time as they migrate thereby resulting in environmental pollution and outbreak of diseases. Formation of waste dumpsite leachates (which comprises ions of nitrates, chlorides and sulphates) in the soil, lowers the soil pH, weakens the soil's strength and further enhances soil corrosivity. These variables are aggressive and tend to attack buried crude oil and gas pipelines and other buried metallic materials. According to Ekine and Emujakporue (2010) and Obadina (1999), out of all the oil spilled incidences from Shell Petroleum Development Company facilities in 1997, greater percentage was due to corrosion of ageing pipes. In August 1983, a major pipeline (Ogoda-Brass 24) failed at Oshika Village in Ahoada Local Government Area of Rivers State and an estimated 5,000 barrels of oil was spilled. The cost of the incident was conservatively put at $1.5 million Powel *et. al*. (1998). NAOC (2005) reported 8 cases of oil pipe failure arising from corrosion along the pipeline route between 1994 and 2004. The Nation Newspaper (2008) also chronicled cases of ruptured oil/gas pipeline explosion in Jesse and Warri area of Delta State between 1998 and 2000 arising from corrosion along pipeline route which resulted in over 850 deaths. This study therefore aimed at assessing the effect of waste dumpsites on soil physico-chemical parameters and corrosivity at Oghara.

Location and Geological Setting of Study Area

Regional Geology and Topography

Oghara, in Ethiope West Local Government Area of Delta State, Nigeria, is located approximately on Latitude 05^0 59' North of the Equator and Longitude 05^0 42' East of the Greenwich Meridian (Figure 1). The area is part of the *Benin Formation* often referred to as *the Coastal Plain Sands* of the lower Quaternary period and Pliocene-Pleistocene epoch. The inclusive Aluvium belongs to the upper Quaternary (Recent Sediments) and consists of silty clayey sands, sand and gravels. Topographically, the area is flat lying with both marine and fluvial sediments. The flat-floored river Ethiope traversed the area and drains into the Atlantic Ocean. The floodplains are prone to flooding in the wet season mainly due to heavy rainfall, high ground water table and the flat-floored valleys.

Dumpsite Locations in the Study Area

Solid and liquid wastes are indiscriminately deposited in Ogharefe municipality in open dumpsites without regard to proximity of inhabited homes/houses, the nature of soil, and the hydrogeology of the area. The

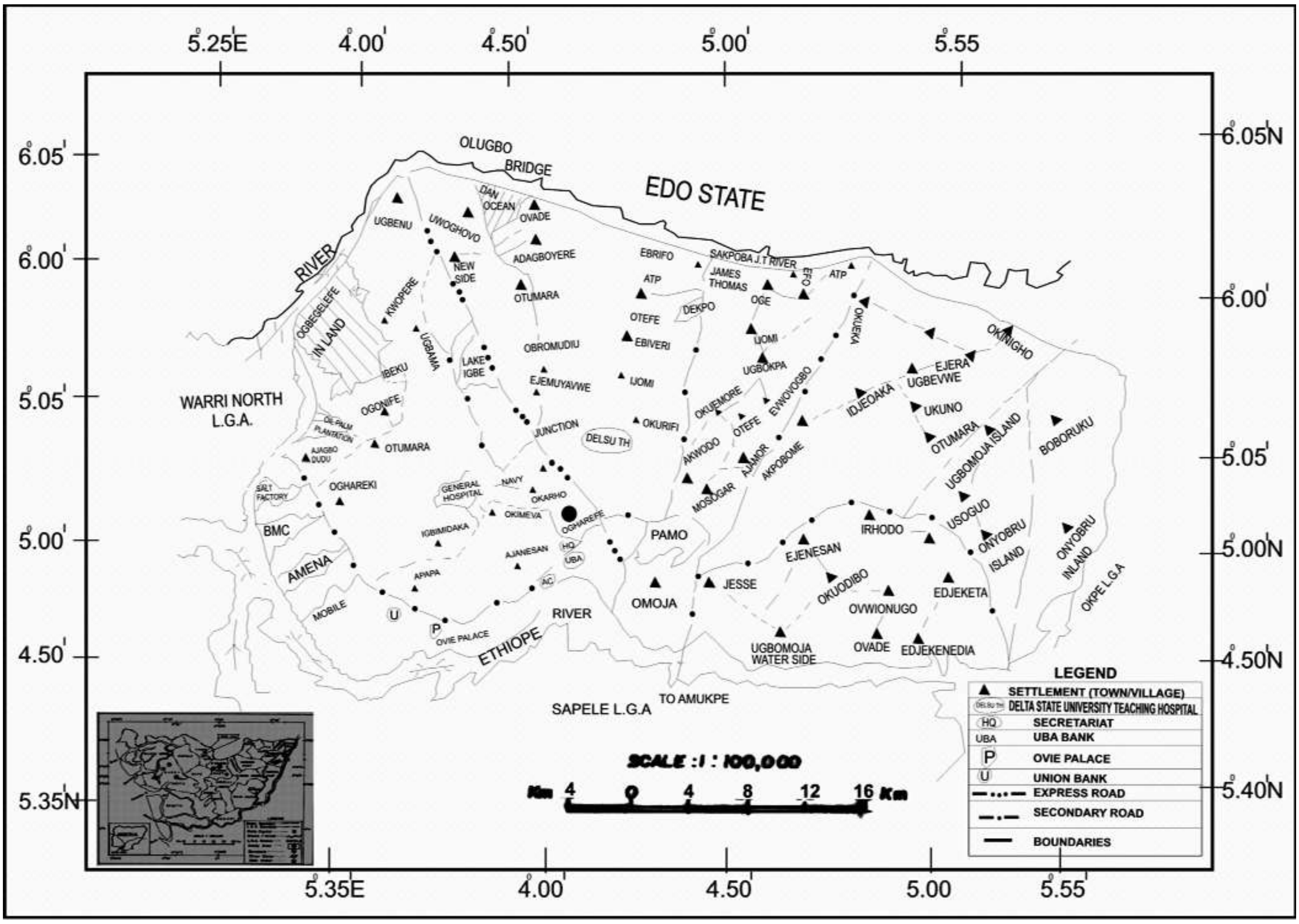

Fig. 1: Map of Ethiope West Local Government showing Location of the study Area

study investigated 2 dumpsites at Ogharefe community in Oghara town. One of the dumpsites is a burrow pit that lies within 5° 56' 50.10"N and 5° 39' 34.12"E located opposite Keldor hotel along Ibori road, Ogharefe. The dimension of the burrow pit is 20m by 40m and the age is conservatively between 20 and 30 years. The burrow pit is where the residents in the area dump their domestic and liquid wastes. The attendants of Keldor hotel also empty the liquid wastes from swimming pool, dirty dishes and laundry into the burrow pit which they channel through underground waste pipe (Figures 2a and 2b). The second dumpsite is located within the residential area enclosed by Scot road, Sakponba road and Shrimp road in Ogharefe which lies on co-ordinates 5° 56' 52.58"N and 5° 39' 34.45"E. The dumpsite covers a total length of about 632m from Otorho road by Scot Road junction to Sakponba Road. It is the belief of the local inhabitants that this dumpsite has been in existence for over 50 years (Figures 3a and 3b).

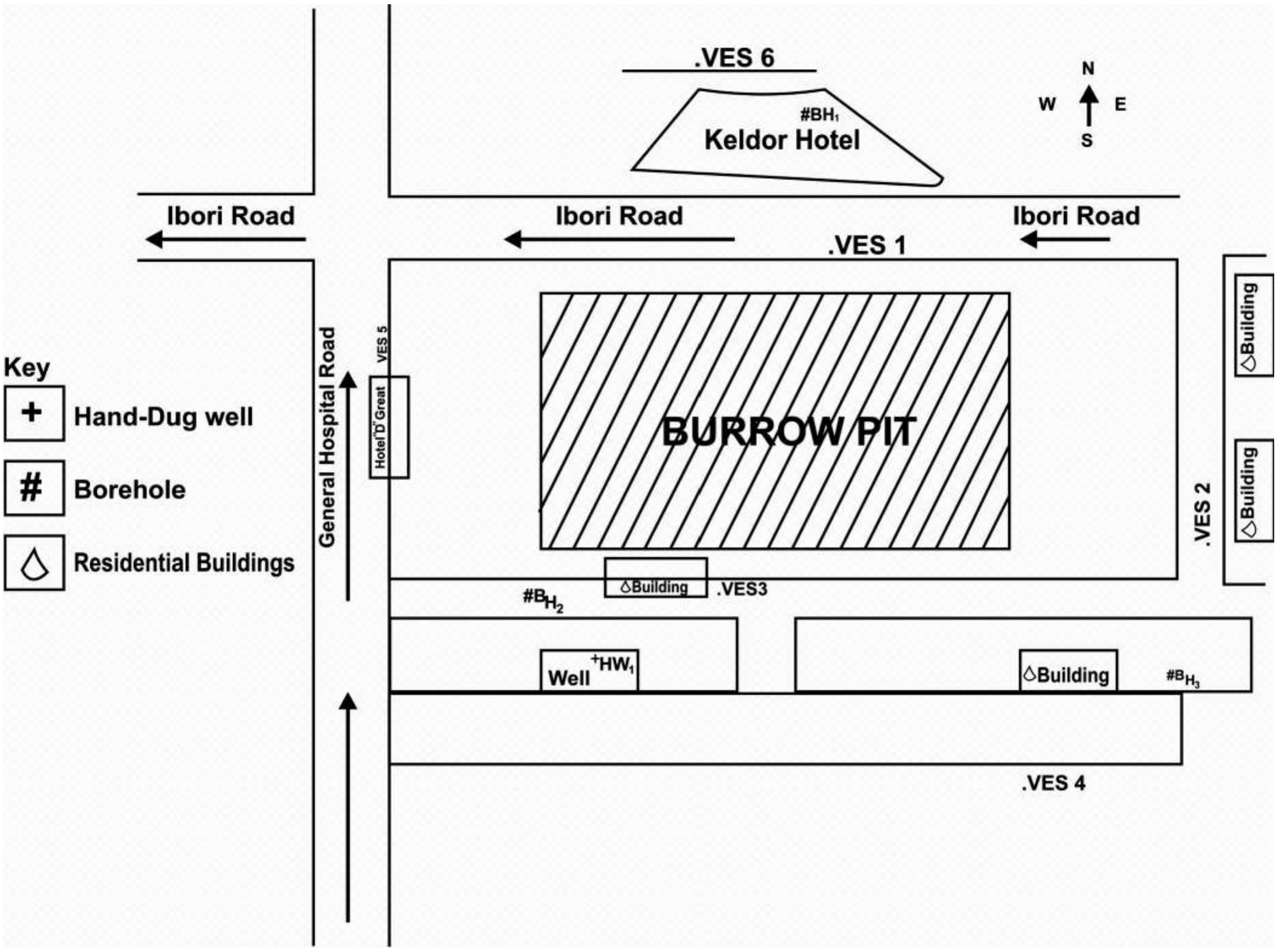

Fig. 2a: Map Showing VES Locations at the burrow pit dumpsite

Materials and Methods

Data Acquisition

Soil Samples Collection

0.5kg of 3 soil samples was randomly collected near each of the 2 dumpsites at 2m apart to a varying depth of 0-20cm, 20-40cm and 40-100cm using a stainless steel soil hand-auger and a spatula. Thus, a total of 6 soil samples were collected at the 2 dumpsites for the physico-chemical parameter analysis. The 6 soil samples were each stored in sample polyethyelene bags where they were dried at $105^{\circ}C$ for 48 hours and thereafter sieved with <2mm stainless sieves in order to remove large debris, plant roots and gravel size materials. The sieved samples were further homogenized by grinding with pestle and mortar and then kept in desiccators before chemically digested. Strong acid digestion method was used to dissolve the

Fig. 2b: Burrow Pit dumpsite opposite Keldor Hotel along Ibori Road

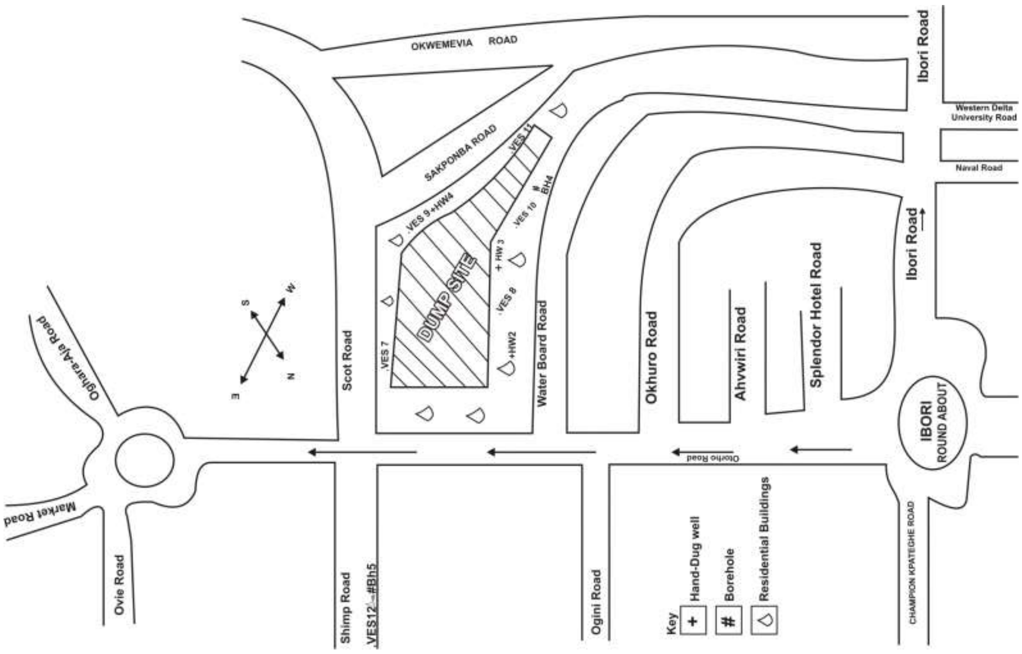

Fig. 3a: Map Showing VES Locations at the dumpsite enclosed within Scot Road, Sakponba Road and Shrimp Road

Fig. 3b: Dumpsite Enclosed within Scot Road, Sakponba Road and Shrimp Road

samples and their inorganic contents in solution. Samples were taken to the laboratory for analysis. However, pH and electrical conductivity (EC) was respectively determined in-situ using pH meter model HANNA HI8314 and conductivity meter model HANNA HI98303. The procedure involved weighing 50g of soil in a beaker and adding 100ml of water then stirred gently and allowed to stand for 30 minutes before introducing the EC probe and pH meter into the soil-water suspension for 60 seconds thereafter readings were taken.

Geophysical Data Acquisition

The geophysical survey data was acquired using ***mini-res resistivity meter***. This is a signal averaging system where consecutive readings are taken automatically and the results are averaged continuously. The continuously updated running average is displayed as resistance automatically. It uses a micro-processor to monitor and control all the measurement so as to ensure optimal accuracy and sensitivity. It also uses a switching frequency of 5.00 Hertz which provides nearly perfect attenuation of 50 and 60 Hertz power line noise.

A total of 12 Vertical Electrical Soundings (VES) were carried out for the study and were run at the 2 dumpsites. The VES stations were taken 10m away from each of the 2 dumpsites on the northern, southern and eastern side. Electrode spacing of 1m, 2m, 3m, 4m, 6m, 8m, 10m, 12m, 14m, 16m, 18m, 20m, 25m, 30m, 35m, 40m, 45m, 50m, 60m, 70m, 80m and 90m was used with a total distance of 100m. These electrode spacing were chosen closely together so that minor or suppressed layer can easily be detected and this helps in identifying the leachate plume and its migration path. Again, since environmental geophysical surveys are concerned with near surface of depths less than 30m according to Uchegbulam and Ayolabi (2014), small electrode spacing was adopted in order to provide considerable details of any plumes related to leachates from the dumpsites. A maximum current electrode expansion

(AB/2) of 100m and potential electrode expansion (MN/2) of 10m were utilized in the survey, using Schlumberger array because it is faster, more economical to use and less sensitive to lateral variation. For each resistivity station where measurement was made, a reading of resistance R of the volume of the earth material within the electrical space of the electrode configuration was obtained. The measured resistance values (R) were converted into apparent resistivity (ρ_a) by multiplying with a geometric factor (k), such that:

$$\rho a = \pi R \frac{[(AB/2)^2-(MN/2)^2]}{MN} \quad \text{.................................(1)}$$

where:

$\left\{\frac{[(AB/2)^2-(MN/2)^2]}{MN}\right\}$ is the geometric factor = K

ρa = apparent resistivity (Ohm-m), R = resistance (Ohm), AB = distance between current electrodes (m), MN = distance between potential electrodes (m), π = Constant = 3.142.

Results

Soil Physico-Chemical Parameters

The result of the physico-chemical parameters of the soil samples at the 2 dumpsites were compared to the international permissible limits (Table 1).

VES Data Results

The data acquired from the VES were processed and interpreted qualitatively and quantitatively where apparent resistivity was plotted against half current electrode spacing for each VES sounding points (stations) and the sounding curves types generated are HKH, KH, KHK, KHA and QH with 5 soil layers delineated consisting of lateritic topsoil, sandy clay, fine coarse sand, medium coarse sand, and coarse sand (Figures 4 and 5).

Table 1: Physico-chemical Parameters of Soil Samples Compared to International Permissible Standards

Location	Depth (cm)	Measured Physico-chemical Parameters						
		Conductivity (µs/cm)	pH	No_3^- (mg/kg)	Cl^- (mg/kg)	So_4^{2-} (mg/kg)	Pb^{2+} (mg/kg)	Fe^{2+} (mg/kg)
Burrow-pit Dumpsite along Ibori Road	0-20	3.18	7.7	18.67	60.20	120.30	0.48	44.30
	20-40	3.15	7.3	15.20	82.10	124.20	0.39	45.72
	40-100	3.06	5.8	13.62	135.60	262.50	0.32	38.91
Mean		**3.13**	**6.9**	**15.83**	**92.63**	**169.00**	**0.39**	**42.98**
Dumpsite within Scot Road and Sakponba Road	0-20	3.16	6.5	19.70	73.70	131.40	0.78	65.83
	20-40	3.09	6.2	17.82	92.80	138.60	0.62	62.53
	40-100	3.03	5.6	13.47	143.60	269.20	0.51	63.05
Mean		**3.09**	**6.1**	**16.99**	**103.37**	**179.73**	**0.64**	**63.80**
FAO/WHO (2011); AASHTO Standard		**1.0**	**6.5-8.5**	**5-10**	**100**	**200**	**0.35**	**5.0**

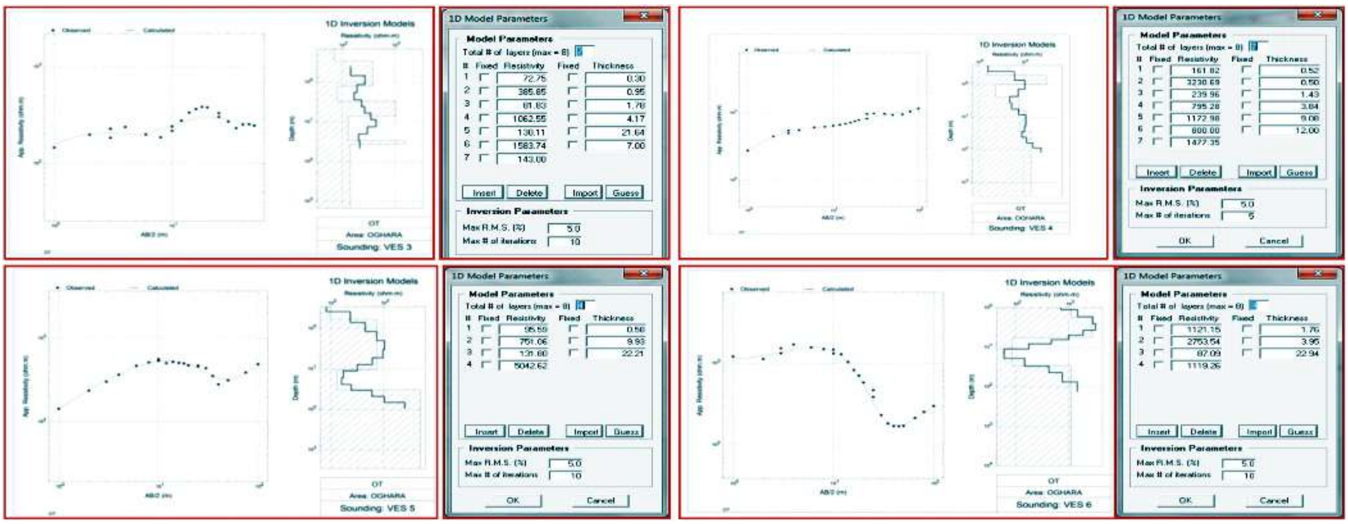

Fig. 4: VES Stations at the Burrow Pit Dumpsite opposite Keldor Hotel

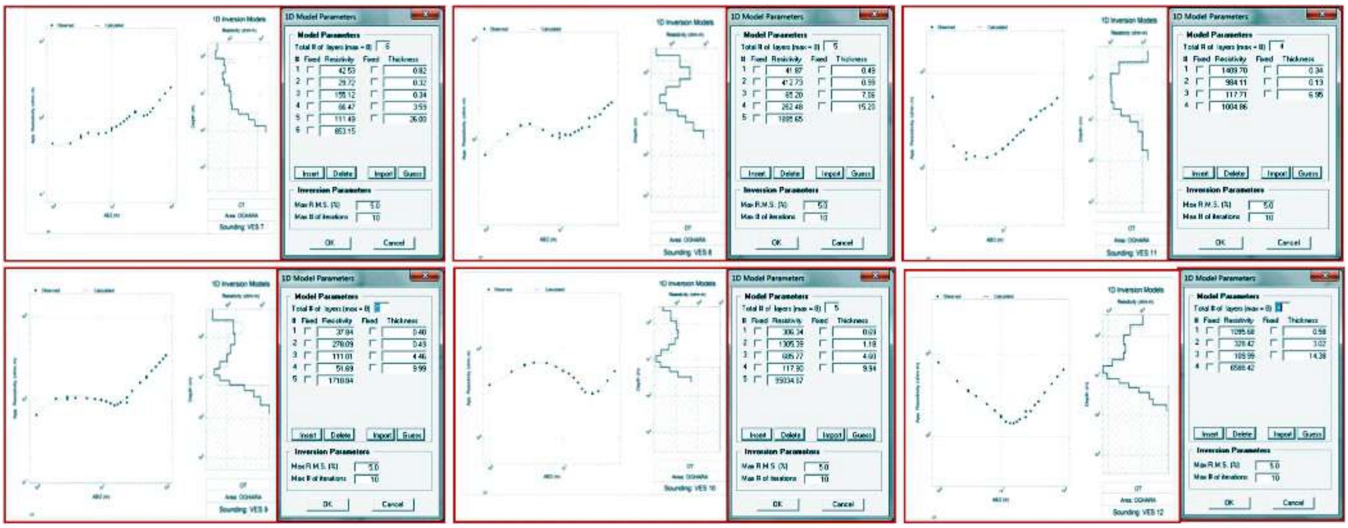

Fig. 5: VES Stations at the Dumpsites enclosed by Scot Road, Sakponba Road and Shrimp Road

Discussion

Soil Physico-Chemical Parameters

The results of the physico-chemical parameters of the soil samples revealed that the electrical conductivity (EC), Nitrates (NO_3^-), Lead (Pb^{2+}) and Iron (Fe^{2+}) contents of the soil at varying depths (0-20cm), (20-40cm) and (40-100cm) are above their respective international permissible standards of 1.0µs/cm, 5-10mg/kg, 0.35mg/kg and 5.0mg/kg. Sulphate and chloride values at a depth of 40cm and beyond are higher than the permissible limits. However, the following are the findings of the soil physico-chemical parameters at the 2 waste dumpsites:

Electrical Conductivity (EC) Content of Soil at Waste Dumpsites: The EC of the soil at the 2 waste dumpsites ranged from 3.03µs/cm to 3.18µs/cm with mean values of 3.13µs/cm and 3.09µs/cm and it agrees well with the works of Uba *et. al.* (2008) of some dumpsites at Zaria and that of Obasi *et. al.* (2012) on the assessment of physico-chemical properties and heavy metals bioavailability in dumpsites along Enugu-PortHarcourt Express Ways, South-East Nigeria. These EC values are higher than the permissible standard of 1.0µs/cm. It should be noted that EC is a function of dissolved ions from the organic and inorganic waste, therefore high conductivity value of the waste dumpsite soil may be attributable to the metal scrap constituents of the waste which indicates that the soil contains more soluble salts, making it corrosive.

pH Content of Soil at Waste Dumpsites: The pH of the soil at the 2 waste dumpsites ranged from 5.6 to 7.7 with mean values of 6.9 and 6.1 respectively. The above table revealed that pH values increased with depth at the 2 dumpsites implying that soil in the study area becomes more acidic with depth probably due to downward gravitational flow of the leachate from the decomposed organic and inorganic wastes. Acidic soils are not good for plant growth, laying of underground pipelines for crude oil transportation and it has a very high risk of contaminating groundwater aquifer by making it acidic. The acidic soils and its resultant effect on groundwater aquifer would no doubt pose serious health challenge to the inhabitants of the area when used for domestic purposes.

Nitrate (NO_3^-) Content of Soil at Waste Dumpsites: The mean values of the nitrates in the waste dumpsite soil are respectively 15.83mg/kg and 16.99mg/kg at the 2 dumpsites. The NO_3^- ranged from 13.47mg/kg to 19.70mg/kg and these values are above the acceptable permissible limits of 5-10mg/kg in soil by FAO/WHO (2011). The high nitrate ion concentration may have resulted from the leachate generated during the decomposition or biodegradation of wastes containing organic matter, dangerous pathogens and dissolved solids. This lowers the electrical resistivity of soil. Again, the high nitrate ion concentration revealed that the leachate generated from these dumpsites by decomposition may pose health challenge to the inhabitants of the area arising from the fact that they will migrate with the presence of infiltrating water to pollute groundwater with time.

Lead (Pb^{2+}) Content of Soil at Waste Dumpsites: The Pb values of soil ranged from 0.32mg/kg to 0.78mg/kg at the 2 dumpsites with mean values of 0.39mg/kg and 0.64mg/kg respectively. The Pb values are all above the permissible limit of 0.35mg/kg recommended by FAO/WHO (2011) except at the burrow-pit dumpsite at a depth range of 40-100cm. The high value of Pb above the acceptable limit shows that the soil has been contaminated with lead and this may percolate from the soil to contaminate groundwater aquifer thereby exposing the inhabitants of the area to high risk of Pb poisoning when such water is consumed. The sources of Pb at the dumpsite are discarded fluorescent tubes, lead batteries, metal scraps, engine oil, e.t.c..

Iron (Fe^{2+}) Content of Soil at Waste Dumpsites: The iron (Fe) content of the waste soil ranged from 38.91mg/kg to 65.83mg/kg at the 2 dumpsites with mean values of 42.98mg/kg and 63.80mg/kg. These values of Fe in the soils at the 2 dumpsites are far above the acceptable standard of 5.0mg/kg by FAO/WHO (2011). The local geology may have favoured the high iron content in the waste dumpsites soil, but the higher concentration of this parameter can be attributed to the iron scraps that were dumped in the waste dumpsites. This high Fe concentration in the waste dumpsites soil also implied that this metal may be potentially toxic if not regulated arising from their high mobility with increasing depth hence migrating through percolation to contaminate groundwater aquifer. The use of such water may stain plumbing system and eventually corrode/rust metallic pipes and utensils.

Chlorides (Cl^-) and Sulphates (SO_4^{2-}) Content of Soil at Waste Dumpsites: The chloride values of the soil at the 2 dumpsites ranged from 60.20mg/kg to 143.60mg/kg with mean values of 92.63mg/kg and 103.37mg/kg. The chloride values at the 2 dumpsites are within permissible limits of 100mg/kg by AASHTO (2004) to a depth of 0-40cm, but beyond the 40cm depth, the values (135.60mg/kg and 143.60mg/kg) are above the permissible limit at the 2 dumpsites. The sulphate values of the soil at the 2 waste dumpsites ranged from 120.30mg/kg to 269.20mg/kg with mean values of 169.00mg/kg and 179.73mg/kg. The sulphate values at the 2 waste dumpsites are within permissible limits of 200mg/kg by AASHTO (2004) to a depth of 0-40cm. However, at depth beyond 40cm the values (262.50mg/kg and 269.20mg/kg) are above the permissible limit at the 2 dumpsites. These high chloride and sulphate values at depth beyond 40cm would have adverse effect on pipelines, buildings and other engineering structures due to the corrosive propensity of the soil thus leading to shorter life span of such structures. It should be noted that chlorides and sulphates are the chief agents in promoting corrosion as it attacks metal culverts, or the reinforcement in concrete pipe as in the process of returning metals to their native state of oxides or salts Oyedele *et. al.* (2012). Chloride and sulphate content above recommended limits propagates corrosion very significantly toward buried-materials and according to Bradford (1993) the most corrosive anion for metals is the presence of chloride ions (Cl^-) which is naturally present as a result of external sources. Bradford (1993) and Oyedele *et. al* (2012) further stated that Cl^- not only promote corrosion because they are conductive by nature, but they also inhibit passivity of the metal, i.e they inhibit the formation of an oxide layer on the metal surface which protects the metal from corrosion. Its attack is localized and more dangerous than the uniform corrosion, because it also participates in pit initiation on the surface of stainless steels resulting to pitting corrosion (i.e perforation of the metal surface). Again, the presence of chloride in soils tends to decrease soil resistivity (Uhlig and Revie, 1991).

Sulphate content in soil is generally harmful for buried-structural materials due to the fact that it directly participates in the electrochemical reactions that take place during corrosion process. Sulphate ion also propagates pit initiation of stainless steels by increasing the soil conductivity Bhattarai (2013). Sulphate ion is similar to chloride ion content in soil since the highest sulphate content gives the highest corrosion rates (Noor *et. al.*, 2012) and the ions (i.e SO_4^{2-} and Cl^-) are more aggressive/corrosive in acidic soil medium. Chlorides, sulphates and other dissolved salts at waste dumpsites decreases resistivity thereby enhancing the flow of corrosion currents, but impeding the formation of protective layers (Oyedele *et. al.*, 2012).

Vertical Electrical Sounding

The VES data delineated 5 soil layers consisting of lateritic topsoil, sandy clay, fine coarse sand, medium coarse sand, and coarse sand. The number of layers delineated, their thicknesses and resistivities were processed with the aid of the **WINGLINK** modeled subsurface resistivity interpretation software. The apparent resistivity values obtained for the 5 delineated layers of the 1-D inversion model varies between 37Ωm and 1409.70Ωm for the first layer, 29.72Ωm and 3230.69Ωm for the second layer, 36.06Ωm and 1431.55Ωm for the third layer, 51.69Ωm and 5042.62Ωm for the fourth layer, and 111.49Ωm and 1172.98Ωm for the fifth layer. The thickness of the layers ranges from 0.30m to 1.76m for the first layer, 0.13m to 9.93m for the second layer, 0.34m to 22.94m for the third layer, 3.84m to 15.20m for the fourth layer, and 9.08m to 26.00m for the fifth layer. The lithologic delineation and curve types are shown in table 2.

Table 2: Lithologic Delineation and Curve types from the VES 1D Inversion Model

VES Points	Location	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve Type
VES1	IBORI ROAD (OPPOSITE KELDOR HOTEL), OGHAREFE	1	102.97	0.52	0.52	Lateritic Top Soil	$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5$ HKH
		2	31.05	0.58	1.10	Sandy Clay	
		3	36.06	0.35	1.45	Fine Coarse Sand	
		4	984.43	6.07	7.52	Medium Coarse Sand	
		5	192.68	21.24	28.76	Coarse Sand	
		6	913.80	-	-	Sand	
VES 2		1	88.65	0.57	0.57	Lateritic Top Sand	$\rho_1<\rho_2>\rho_3<\rho_4$ KH
		2	208.10	1.35	1.92	Sandy Clay	
		3	1431.55	3.64	5.56	Fine Coarse Sand	
		4	107.09	8.81	14.37	Medium Coarse Sand	
		5	95398.52	-	-	Coarse Sand	
VES 3		1	72.75	0.30	0.30	Lateritic Top Sand	$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5$ KHK
		2	385.85	0.95	1.25	Sandy Clay	
		3	81.83	1.78	3.03	Fine Coarse Sand	
		4	1062.55	4.17	7.20	Medium Coarse Sand	
		5	130.11	21.64	28.84	Coarse Sand	
		6	1583.74	7.00	35.84	Sand	
		7	143.00	-	-	Fine Sand	
VES 4		1	161.82	0.52	0.52	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4<\rho_5$ KHA
		2	3230.69	0.50	1.02	Sandy Clay	
		3	239.96	1.43	2.45	Fine Coarse Sand	
		4	795.28	3.84	6.29	Medium Coarse Sand	
		5	1172.98	9.08	15.37	Coarse Sand	
		6	800.00	12.00	27.37	Sand	
		7	1477.35	-	-	Fine Sand	
VES 5		1	95.59	0.58	0.58	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$ KH
		2	751.06	9.93	10.51	Sandy Clay	
		3	131.80	22.21	32.72	Fine Coarse Sand	
		4	5042.62	-	-	Medium Coarse Sand	
VES 6		1	1121.15	1.76	1.76	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$ KH
		2	2753.54	3.95	5.71	Sandy Clay	
		3	87.09	22.94	28.65	Fine Coarse Sand	
		4	1119.26	-	-	Medium Coarse Sand	
VES 7	WITHIN SCOT ROAD, SAKPONNBA ROAD AND SHRIMP ROAD, OGHAREFE	1	42.53	0.82	0.82	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$ KH
		2	29.72	0.32	1.14	Sandy Clay	
		3	155.12	0.34	1.48	Fine Coarse Sand	
		4	66.47	3.59	5.07	Medium Coarse Sand	
		5	111.49	26.00	31.07	Coarse Sand	
		6	853.15	-	-	Sand	
VES 8		1	41.87	0.49	0.49	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$ KH
		2	412.73	0.99	1.48	Sandy Clay	
		3	65.20	7.06	8.54	Fine Coarse Sand	
		4	262.48	15.20	23.74	Medium Coarse Sand	
		5	1895.65	-	-	Coarse Sand	
VES 9		1	37.84	0.40	0.40	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$ KH
		2	278.09	0.43	0.83	Sandy Clay	
		3	111.01	4.46	5.29	Fine Coarse Sand	
		4	51.69	9.99	15.28	Medium Coarse Sand	
		5	1718.84	-	-	Coarse Sand	
VES 10		1	306.34	0.69	0.69	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$ KH
		2	1305.39	1.18	1.87	Sandy Clay	
		3	685.77	4.60	6.47	Fine Coarse Sand	
		4	117.90	9.94	16.41	Medium Coarse Sand	
		5	95034.67	-	-	Coarse Sand	
VES 11		1	1409.70	0.34	0.34	Lateritic Top Soil	$\rho_1<\rho_2>\rho_3<\rho_4$ KH
		2	984.11	0.13	0.47	Sandy Clay	
		3	117.71	6.95	7.42	Fine Coarse Sand	
		4	1004.86	-	-	Medium Coarse Sand	
VES 12		1	1095.68	0.58	0.58	Lateritic Top Soil	$\rho_1>\rho_2>\rho_3<\rho_4$ QH
		2	328.42	3.02	3.60	Sandy Clay	
		3	109.99	14.38	17.98	Fine Coarse Sand	
		4	6588.42	-	-	Medium Coarse Sand	

Geo-Electric Section

The layering parameters in terms of layer resistivities and thicknesses from the interpretation of the apparent resistivity curves of the VES points were further processed into geo-electric section from the 1-D model parameters. This further reduced the number of lithologic layers from 5 to 3 (Table 3). The produced 3 layer geo-electric sections along profile line consists of lateritic topsoil, sandy clay, and medium coarse-coarse sand (Figures 6-8) and it is in agreement with the works of Okolie *et. al.* (2007). The geo-electric section

Table 3: Lithologic Delineation of the Study Area from the VES Geo-electric Section

VES Points	Location	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
VES1	IBORI ROAD (OPPOSITE KELDOR HOTEL), OGHAREFE	1	103	0.52	0.52	Lateritic Top Soil
		2	984	7.00	7.52	Sandy Clay
		3	192	21.24	28.76	Medium Coarse- Coarse Sand
		4	913	-	-	
VES 2		1	89	0.57	0.57	Lateritic Top Sand
		2	1432	4.99	5.56	Sandy Clay
		3	107	8.81	14.37	Medium Coarse- Coarse Sand
		4	95399	-	-	
VES 3		1	73	0.30	0.30	Lateritic Top Sand
		2	1062	6.00	7.20	Sandy Clay
		3	1584	28.64	35.84	Medium Coarse- Coarse Sand
		4	143	-	-	
VES 4		1	162	0.52	0.52	Lateritic Top Soil
		2	795	5.77	6.29	Sandy Clay
		3	800	21.08	27.37	Medium Coarse- Coarse Sand
		4	1477	-	-	
VES 5		1	96	0.58	0.58	Lateritic Top Soil
		2	751	9.93	10.51	Sandy Clay
		3	132	22.21	32.72	Medium Coarse–Coarse Sand
		4	5043	-	-	
VES 6		1	1121	1.76	1.76	Lateritic Top Soil
		2	2753	3.95	5.71	Sandy Clay
		3	87	22.94	28.65	Medium Coarse- Coarse Sand
		4	1119	-	-	
VES 7	WITHIN SCOT ROAD, SAKPONNBA ROAD AND SHRIMP ROAD, OGHAREFE	1	43	0.82	0.82	Lateritic Top Soil
		2	66	4.25	5.07	Sandy Clay
		3	111	26.00	31.07	Medium Coarse- Coarse Sand
		4	853	-	-	
VES 8		1	42	0.49	0.49	Lateritic Top Soil
		2	65	8.05	8.54	Sandy Clay
		3	262	15.20	23.74	Medium Coarse- Coarse Sand
		4	1895	-	-	
VES 9		1	38	0.40	0.40	Lateritic Top Soil
		2	111	4.89	5.29	Sandy Clay
		3	52	9.99	15.28	Medium Coarse- Coarse Sand
		4	1719	-	-	
VES 10		1	306	0.69	0.69	Lateritic Top Soil
		2	686	5.78	6.47	Sandy Clay
		3	118	9.94	16.41	Medium Coarse- Coarse Sand
		4	95035	-	-	
VES 11		1	1409	0.13	0.13	Lateritic Top Soil
		2	984	0.34	0.47	Sandy Clay
		3	118	6.95	7.42	Medium Coarse- Coarse Sand
		4	1005	-	-	
VES 12		1	1095	0.58	0.58	Lateritic Top Soil
		2	328	3.02	3.60	Sandy Clay
		3	109	14.38	17.98	Medium Coarse-Coarse Sand
		4	6588	-	-	

attempts to correlate different layers at each VES point and the geo-electric profiles were generated using the WINGLINK software. These geo-electric profiles are the geo-electric section of each VES location combined into one profile with a definite directional orientation. The ordinate (x-axis) represent resistivity and the abscissa (y-axis) represents the depth in metres below ground level. The first geo-electric section connects VES 4, VES 3, VES 1 and VES 6. The second geo-electric section connects VES 2, VES 1, and VES 5, while the third geoelectric section connects VES 12, VES 7, VES 8, VES 9, VES 10 and VES 11.

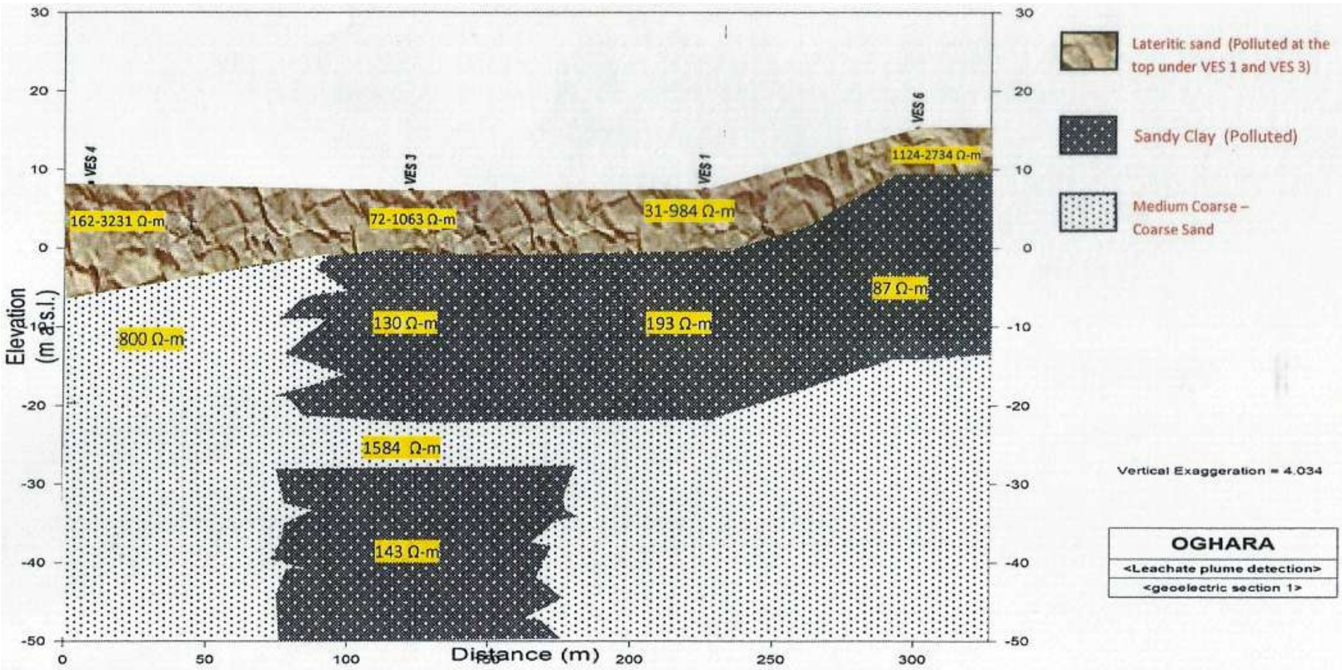

Fig. 6: The Geoelectric Section Connecting VES 1, VES 3, VES 4 and VES 6

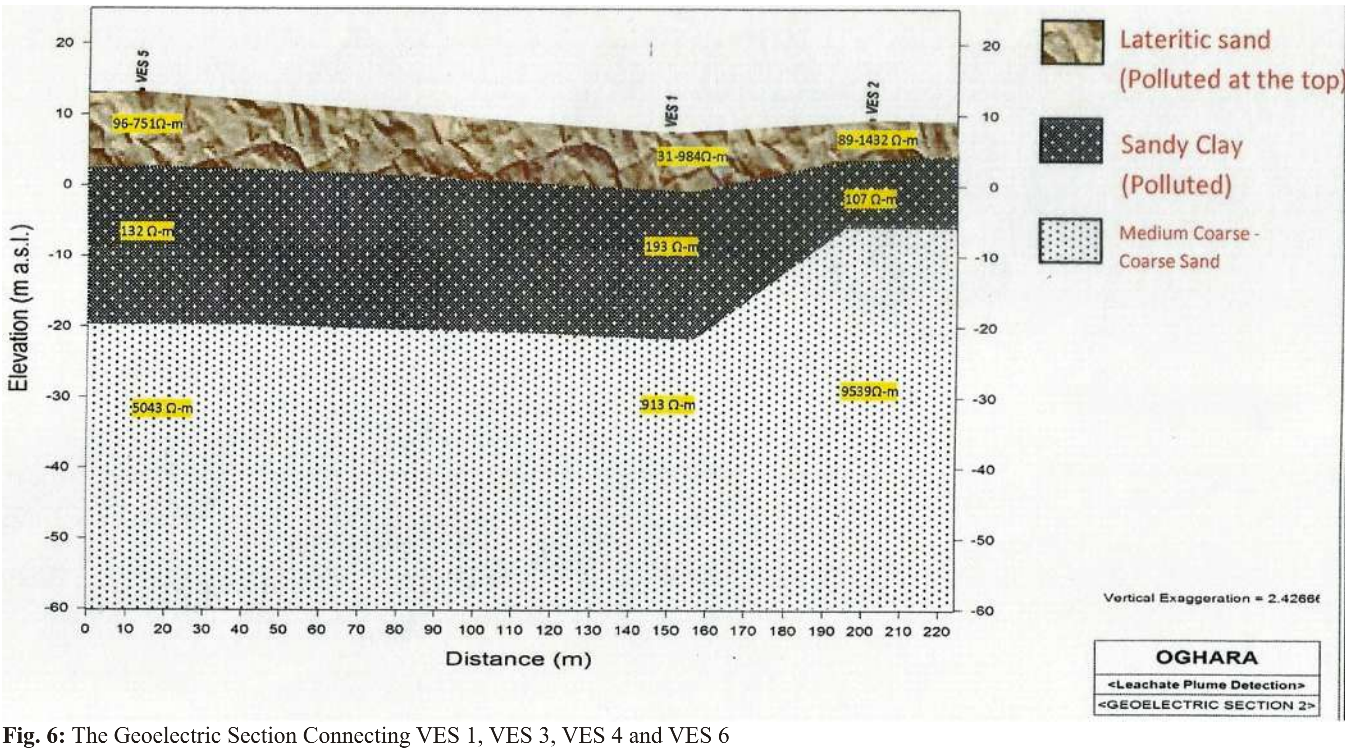

Fig. 6: The Geoelectric Section Connecting VES 1, VES 3, VES 4 and VES 6

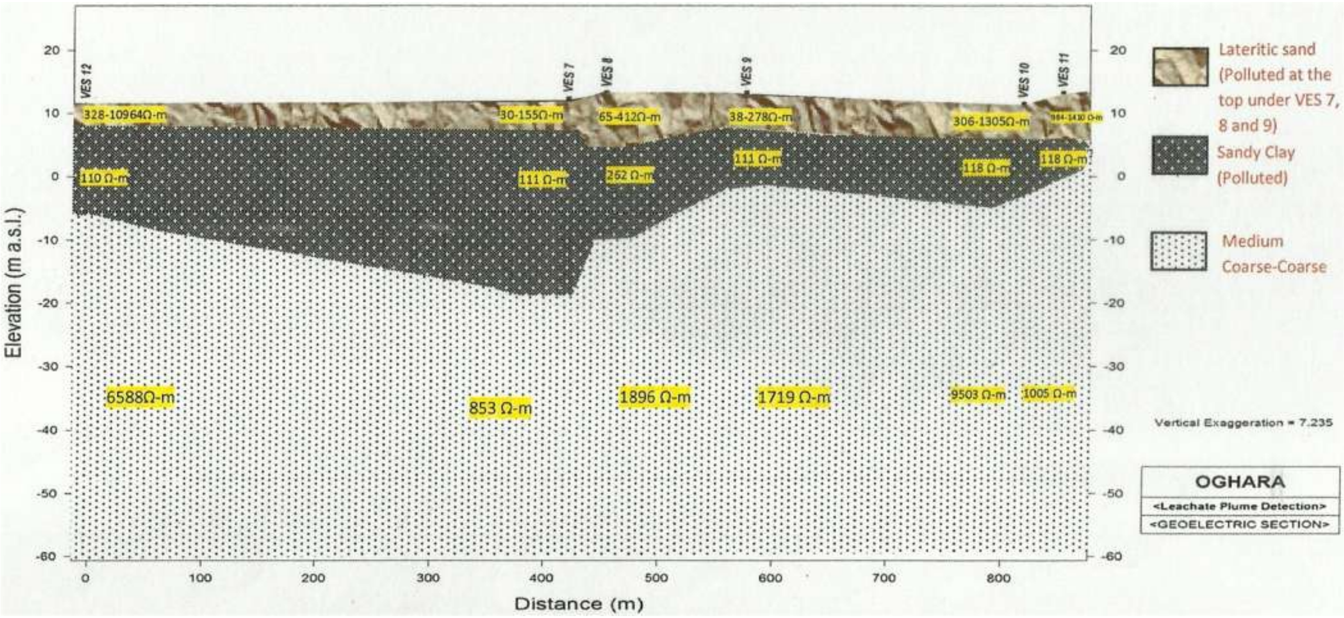

Fig. 8: The Geo-electric Section Connecting VES 12, VES 7, VES 8, VES 9, VES 10 and VES 11

Soil Corrosivity around the Dumpsite

Keswick *et. al*. (1982) and Obiora *et. al*. (2015) acknowledged that when the underlying geologic material is unconsolidated and uncompacted, such as coarse sand, the polluting influents are capable of escaping into the subsurface to contaminate groundwater, rendering the soil corrosive and forming a polluting plume that extends hundreds of metres. There is therefore a chance that pipelines buried in such environment could leak or rupture and a pipeline failure can constitute serious hazards to the environment, assets, and even humans due to explosion and leakage Yahaya *et. al*. (2009). In this study, soil corrosivity was evaluated using the resistivity values of the first, second and third layer on each VES station by comparing with the corrosivity ratings (Table 4) adopted by Baeckmann and Schwenk (1975), Agunloye (1984) and Oladapo *et. al.* (2004). The resistivity values of the first layer on each VES stations are approximately to a depth range of 0.13m to 1.80m from the surface and it was used for this evaluation because this is the layer that is above the sandy clay zone of the lithologic unit.

Table 4: Classification of Soil Resistivity in terms of Corrosivity (Baeckmann and Schwenk (1975), Agunloye (1984) and Oladapo et. al. (2004))

Soil Resistivity (Ω-m)	Soil Corrosivity
<10	Very Strongly Corrosive (VSC)
10-60	Moderately Corrosive (MC)
60-180	Slightly Corrosive (SC)
≥180	Practically Non-corrosive (PNC)

Moreover, attention was also given to the resistivity values of the second and third layers on each VES station in order to determine the depth of soil corrosivity free zone at which reservoir storage tanks and oil and gas transmission pipelines would be buried to avoid corrosion. The soil corrosivity ratings of the study area as a function of the apparent resistivity values of the layers are presented in table 5 and it showed that the soil corrosivity of the first layer at VES 6, 10, 11 and 12 are practically non-corrosive within a depth range of 0.13m to 1.76m. These areas of practically non-corrosive soil are absolutely good for burying underground iron tanks and pipelines without deterioration since the effect of waste dumpsite leachate is negligible. The corrosivity of the soil of the first layer at VES stations 7, 8 and 9 are moderately corrosive within a depth range of 0.40m to 0.82m while that of the soil at VES stations 1, 2, 3, 4 and 5 indicated slightly corrosive soil within a depth range

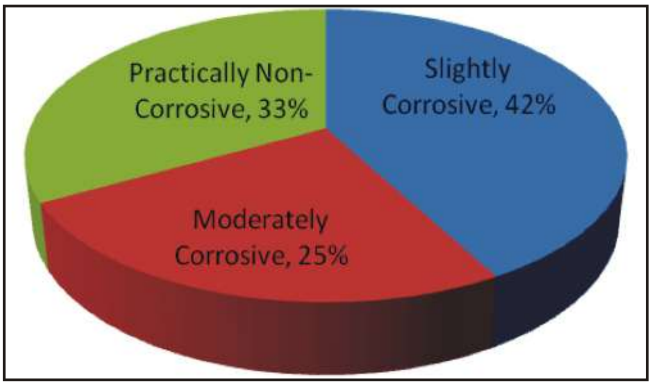

Fig. 9: Percentage Rating of Soil Corrosivity in the Study Area

of 0.30m to 0.58m. These areas of moderately corrosive soil exhibit low resistivity values and high moisture content of soil. The low resistivity values were due to the high content of nitrate ions (NO_3^-), chloride ions (Cl^-) and sulphate ions (SO_4^{2-}) emanating from the dumpsite leachate thereby giving the soil a high conductivity signature, making it corrosive. The leachate also migrates to the underground water aquifer leading to contamination. Underground iron storage tanks, iron pipes and oil/gas transmission pipelines are not to be buried within these depths as they could get deteriorated and rupture resulting in leakages occasioned by the reactions of corrosive materials with buried pipes and eventually causes environmental hazards to humans,

Table 5: Corrosivity of Soil derived from the Resistivity values at the dumpsites in the Study Area

VES Points	Location	Layer	Resistivity (Ωm)	Depth (m)	Soil Corrosivity	Lithology
VES1	IBORI ROAD (OPPOSITE KELDOR HOTEL), OGHAREFE	1	103	0.52	SC	Lateritic Top Soil
		2	984	7.52	PNC	Sandy Clay
		3	192	28.76	PNC	Medium Coarse- Coarse Sand
		4	913	-		
VES 2		1	89	0.57	SC	Lateritic Top Sand
		2	1432	5.56	PNC	Sandy Clay
		3	107	14.37	SC	Medium Coarse- Coarse Sand
		4	95399	-		
VES 3		1	73	0.30	SC	Lateritic Top Sand
		2	1062	7.20	PNC	Sandy Clay
		3	1584	35.84	PNC	Medium Coarse- Coarse Sand
		4	143	-		
VES 4		1	162	0.52	SC	Lateritic Top Soil
		2	795	6.29	PNC	Sandy Clay
		3	800	27.37	PNC	Medium Coarse- Coarse Sand
		4	1477	-		
VES 5		1	96	0.58	SC	Lateritic Top Soil
		2	751	10.51	PNC	Sandy Clay
		3	132	32.72	PNC	Medium Coarse–Coarse Sand
		4	5043	-		
VES 6		1	1121	1.76	PNC	Lateritic Top Soil
		2	2753	5.71	PNC	Sandy Clay
		3	87	28.65	SC	Medium Coarse- Coarse Sand
		4	1119	-		
VES 7	WITHIN SCOT ROAD, SAKPONNBA ROAD AND SHRIMP ROAD, OGHAREFE	1	43	0.82	MC	Lateritic Top Soil
		2	66	5.07	SC	Sandy Clay
		3	111	31.07	SC	Medium Coarse- Coarse Sand
		4	853	-		
VES 8		1	42	0.49	MC	Lateritic Top Soil
		2	65	8.54	SC	Sandy Clay
		3	262	23.74	PNC	Medium Coarse- Coarse Sand
		4	1895	-		
VES 9		1	38	0.40	MC	Lateritic Top Soil
		2	111	5.29	SC	Sandy Clay
		3	52	15.28	MC	Medium Coarse- Coarse Sand
		4	1719	-		
VES 10		1	306	0.69	PNC	Lateritic Top Soil
		2	686	6.47	PNC	Sandy Clay
		3	118	16.41	SC	Medium Coarse- Coarse Sand
		4	95035	-		
VES 11		1	1409	0.13	PNC	Lateritic Top Soil
		2	984	0.47	PNC	Sandy Clay
		3	118	7.42	SC	Medium Coarse- Coarse Sand
		4	1005	-		
VES 12		1	1095	0.58	PNC	Lateritic Top Soil
		2	328	3.60	PNC	Sandy Clay
		3	109	17.98	SC	Medium Coarse- Coarse Sand
		4	6588	-		

flora and fauna in the area. Plastic pipes should be a preferable option to use in these areas. Soils that exhibit slightly corrosivity also have low resistivity values, although not as low as those characterized as moderately corrosive soil. Slightly corrosive soils (like moderately corrosive soils) are acidic due to leachate contaminants from dumpsites.

The corrosivity ratings of the soils of the first layer on each VES station at the dumpsites in the study area showed that 25% is moderately corrosive, 42% is slightly corrosive, and 33% is practically non-corrosive (Figure 9). Further application of the corrosivity ratings to evaluate the second and third layers formation (Table 5) revealed that soils at VES stations 2, 6, 7, 8, 9, 10, 11 and 12 exhibited slightly to moderate corrosivity within a depth range of 5.07m to 31.07m. Thus, for soils in this area, construction of concrete underground reservoir for water storage as well as the use of steel pipes for piling oil and gas should be adopted. Considering the resistivity values of the first, second and third layers on each VES station at the dumpsites with their corresponding corrosivity ratings with depth; it is highly recommended that cathodic protection method be applied to buried oil and gas transmission pipes in order to avert pipeline corrosion.

Conclusion

The soil physico-chemical parameter results showed that some parameters such as electrical conductivity, nitrates, pH, pb, Fe, and chlorides and sulphates (beyond 40cm depth) were higher than the recommended permissible standards. Hence they are capable of escaping further into the subsurface by infiltration to a greater depth rendering the soil corrosive and contaminating groundwater. The 12 VES field data was used to corroborate with the physico-chemical parameters as well as to produce a 1-D resistivity inversion model which helped to reveal that the area comprises 5 formations viz: lateritic topsoil, sandy clay, fine coarse sand, medium coarse sand, and coarse sand. The data was further processed to produce geoelectric sections of 3 layers consisting of lateritic topsoil, sandy clay, and medium coarse-coarse sand. Moreover, the soil of the first layer formation at VES stations 1, 2, 3, 4, 5, 7, 8 and 9 recorded low resistivity (high conductivity) signatures within a depth range of 0.30m to 0.82m occasioned by the high content of nitrate ions, chloride ions and sulphate ions emanating from the leachates at the dumpsites. Soil corrosivity was evaluated using the resistivity values of the first layer on each VES station in the study area by comparing with the corrosivity ratings adopted by Baeckmann and Schwenk (1975), Agunloye (1984) and Oladapo *et. al.* (2004). Results showed that 25% is moderately corrosive, 42% is slightly corrosive, and 33% is practically non-corrosive within a depth range of 0.13m to 1.76m.

The study further used the corrosivity ratings to evaluate the second and third layers formation and it revealed that soils at VES stations 2, 6, 7, 8, 9, 10, 11 and 12 exhibited slight to moderate corrosivity within a depth range of 5.07m to 31.07m. Thus, Oil and gas transmission pipelines buried around and within the dumpsite locations could get deteriorated and rupture due to the reactions of corrosive materials causing environmental hazards in the area. It is recommended that cathodic protection method be applied to buried oil and gas transmission pipelines to avoid corrosion. To avoid rupture and leakage of pipelines due to corrosion, it is also recommended that plastic pipes be used for groundwater supply in areas of moderate corrosive soils which are located at VES stations 7, 8 and 9 considered as moderately corrosive zone.

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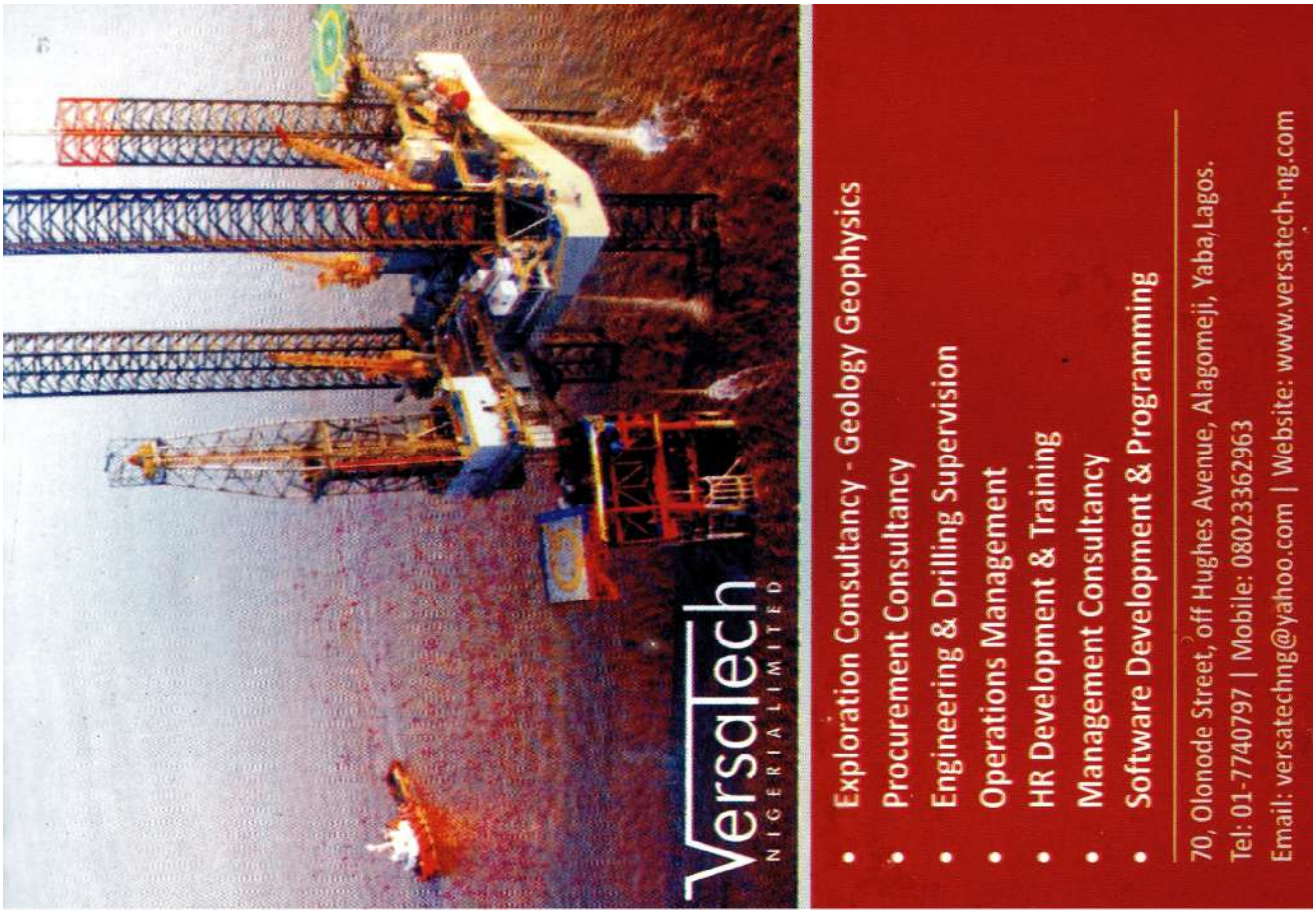

Pictorial view of the new NMGS House under construction at Abuja.