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Geoelectrical Characterisation of A Hydrocarbon Contaminated Site at Alesa-Eleme, Rivers State, Nigeria

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Abstract**:** *The effect of crude oil and gas on soil resistivity was evaluated in order to characterize and determine the level of hydrocarbon contamination in the soil and the depth of groundwater contamination. Twelve vertical electrical soundings (VES) was carried out in the area using ABEM SAS 1000 TERRAMETER with electrode spacing (AB/2) ratio of 60m at intervals thus probing to a depth of about 20m. The data was interpreted with WINGLINK computer software. The result showed that there are four layers in the area with thickness varying between 0.11m and 5.12m. The apparent resistivity values of the contaminated soil at Alesa ranged from 93.37Ωm to 5336.63Ωm while that of the uncontaminated soil at Okirika ranged from 0.57Ωm to 113.60Ωm. The soil at Alesa thus depicts a random distribution of contaminant at the subsurface ranging from low impact zone to a very high impact zone to a depth of about 20m. It is therefore recommended that a deep and well grouted borehole be sunk to a depth beyond 35m to abstract clean, portable and uncontaminated water from the aquifer in the Alesa area.*

Key Word: *Aquifer, inhomogeneity, Hydrocarbon, Soil Resistivity, Vertical Electrical Sounding (VES).*

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I. Introduction

Surface and subsurface contamination by hydrocarbon is one of the most challenging environmental issues among the industrialized and third world country today arising from oil spillages. Oil spillage in the Nigerian oil and gas industry is caused by factors ranging from oil facility sabotage, corrosion of oil delivery pipeline, operation of oil and gas producing companies and many more which has been a major threat to the inhabitants. The Niger Delta is a petroleum-rich region which has been the centre of controversies and litigations over pollution between the oil companies and the entire region (Patrick, 2011). Often times, the magnitude of this pollution are investigated by researchers with different interest, one of which prompted this research.

Electrical resistivity has long been utilized by the petroleum industries to determine directly the nature of the geologic materials and pollutants beneath the surface and in solving environmental issues. Many authors such as Zaw Win *et. al.* (2011), Uchegbulam and Ayolabi (2014), Arrena-Moreno and Arango-Galvan (2013), Godio and Naldi (2003) & Tse and Nwankwo (2013), have carried out researches on hydrocarbon polluted site using different geophysical methods and they have often times base the interpretation of their survey from a simple intuitive model. Atekwana *et. al.* (2000) conducted a research on geoelectrical signature at a hydrocarbon contaminated site in central Michigan using 2-D surface resistivity, ground penetrating radar (GPR) and electromagnetic method (EM). They observed a tremendous change in geoelectric signature from high resistivity to high conductivity where significant changes of hydrocarbon transformation occured and suspected the existence of this conductive layer to be as a result of biodegradation of the contaminants mass. A 2D electrical resistivity imaging of unsaturated and saturated zone for crude oil spillage was carried out at Awirhie and Omovovwe communities in Agbarha, Ughelli area of Delta State by Ohwoghere *et. al.* (2014) and Arrubarrena-Moreno and Arango-Galvan (2013). They observed that the two sites are already undergoing natural attenuation prior to the investigation, which is an indication of the low resistivity signature that characterizes the shallow subsurface. Amadi *et. al.* (2012) however noted that so many factors other than hydrocarbon pollution, such as the lithology, nearness of the survey site to coastland and chemical interactions can also increase the subsurface resistivity and cause ambiguity in the interpretation. Consequently, the geological characteristics of the survey site were adequately considered prior to the investigation to eliminate any doubt. This study therefore aimed at assessing the effect of crude oil and gas on soil resistivity in order to characterize and determine the level of hydrocarbon contamination in the soil and the depth of groundwater contamination at Alesa- Eleme community of Rivers State.

II. Location and Geology of the Study Area

Alesa, situated in Eleme Local Government Area of Rivers State is located approximately on Latitude $4^0\ 46^{'}\ 01.6^{''}$ North of the Equator and Longitude $7^0\ 06^{'}\ 32.4^{''}$ East of the Greenwich meridian (Fig. 1).

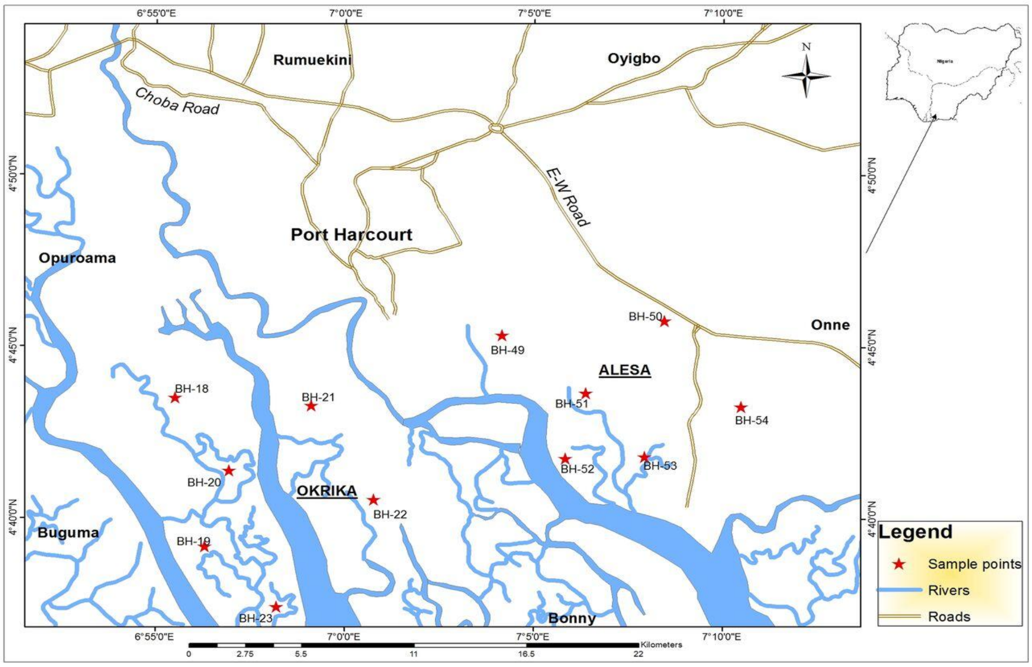


Fig 1: Map of the study area showing sample point.

This area is part of *Benin formation*, an extremely prolific hydrocarbon province and has been discussed extensively by Short and Stauble, (1967) and Reyment (1965). The area consists of fluvial sediments recently transported by river distributaries such as Niger, Andoni, Bonny and new Calabar River. These material which are deposited as regolith of overburden thickness of about 30m consists of clays, peat, silt, sand and gravel (OnlineNigeria.com, 2003). According to Short & Stauble, (1967), The *Benin formation* is also composed of loosely consolidated sand and gravel with minor intercalation of shale. It is a freshwater bearing formation.

III. Material and Methods

The geophysical data was acquired with ABEM SAS 1000 TERRAMETER which is a signal averaging system that uses a micro- processor to monitor and control all the measurements so as to ensure very good accuracy and sensitivity. The apparent resistivity (ρa) of the subsurface was calculated with the formula:

$$\rho_a = \pi R \; \frac{[(AB/2)^2-(MN/2)^2]}{MN}$$

Where:

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

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

A total of 12 vertical electrical sounding (VES) was conducted to determine the characteristics and depth of the hydrocarbon contamination at the sites. Six survey profiles were laid in the study area so as to map the contaminated zone while another six profiles were laid outside the contaminated area which was taken as the control. Consequently, the six VES stations runned at the contaminated site at Alesa-Eleme were depicted as VES 49, VES 50, VES 51, VES 52, VES 53 and VES 54 while the other six VES station at the uncontaminated (control) site at Okrika is depicted as VES 18, VES 19, VES 20, VES 21, VES 22 and VES 23. The Wenner array was employed for all the VES with an array configuration of AB = 60m which utilizes a spread ratio of 1/3 of AB thus probing to a depth of about 20m to produce a 1-D apparent resistivity curve (Fig. 2 a&b). This array was employed for use due to its sensitivity to near surface inhomogenuity. The 1-D resistivity data was further converted to 2-D resistivity imaging of geoelectric section with the use of the WINGLINK resistivity computer software to show areas of very high, high and low impact zones in the area (Fig.3).

The field procedure involves injecting current into the subsurface via the current electrodes and recording the potential difference by the corresponding potential electrode. The result of this process is displayed as apparent resistivity on the resistivity meter.
Other than the VES survey, a visual inspection of the area was carried out to ascertain the vegetation condition.

IV. Result and Discussion

The data acquired from the VES were processed qualitatively and quantitatively (tables 1, 2 and 3) with KQ and HKH prevalent: KQ(2), HKH(2), AK and KQH types with 3 to 4 layers at the contaminated sites in Alesa-Eleme (Table.3). The sounding curves at the uncontaminated site in Okirika showed a prevalent AA and single KH curve types with 3 soil layers (Table.3). The result at Alesa-Eleme showed that the topmost soils except for VES station 52 has anomalous high resistivity value ranging from ≥245Ωm to ≤2167.0Ωm, which is an indication of a near surface hydrocarbon contamination (Zaw Win et. al., 2011). This contamination is attributed to the activities of the oil companies in the area. Beneath the top soil is a layer which follows similar trend as the first with a random distribution of resistivity, ranging from ≥171Ωm to ≤4302.42Ωm. The third, fourth and fifth layers are not left out as they also reveal abnormal high resistivity values ranging from ≥131Ωm to ≤5336.63Ωm, ≥93Ωm to ≤1900Ωm, ≥900Ωm to ≤1489.62Ωm. However this trend is slightly different in VES 52 as it shows a moderate range of resistivity values.

The VES interpretation at Okirika showed a subsurface characterized of soil material with resistivity ranging from ≥1.21Ωm to ≤823.36Ωm in all the layers. This minimal variation and moderate range of resistivity correlates with subsurface devoid of contamination according to the lithology of the area. Generally, the water table in this area is dynamic and ranges between 3-8m depending on the season. The resistivity signature as obtained from the two sites (Fig 3 a&b), shows a random distribution of pollution around the Alesa area ranging from very high impact zone, high impact zone to low impact zone from shallow depth to a depth above 20m (fig. 3a) while at Okrika area, a no impact zone was delineated at a shallow surface (about 0-3m) in all the points and a further low impact zone was delineated from about 4-12m, which is attributed to the fluid content of the area (fig. 3b).

Table 1: Vertical Electrical Soundings Field Data for Alesa-Eleme Soil

VES Station	AB(M)	Electrode Spacing a (m)	MN/2	K Constant.	Resistance (ohm)	Resistivity (Ohm.m)	Depth of Probe (m)
VES 49	1.5	0.5	0.25	3.14	184.8	580.272	0.5
	2.25	0.75	0.375	4.71	179.6	845.916	0.75
	4.5	1.5	0.75	9.42	176.9	1666.398	1.5
	6	2	1	12.56	143.6	1803.616	2
	7.5	2.5	1.25	15.7	126.3	1982.91	2.5
	10.5	3.5	1.75	21.98	84.38	1854.6724	3.5
	15	5	2.5	31.4	57.68	1811.152	5
	22.5	7.5	3.75	47.1	29.69	1398.399	7.5
	30	10	5	62.8	22.64	1421.792	10
	45	15	7.5	94.2	15.23	1434.666	15
	60	20	10	125.6	10.2	1281.12	20
VES 50	1.5	0.5	0.25	3.14	39.816	125.02224	0.5
	2.25	0.75	0.375	4.71	21.464	101.09544	0.75
	4.5	1.5	0.75	9.42	10.782	101.56644	1.5
	6	2	1	12.56	61.809	776.32104	2
	7.5	2.5	1.25	15.7	65.807	1033.1699	2.5
	10.5	3.5	1.75	21.98	61.248	1346.231	3.5
	15	5	2.5	31.4	69.021	2167.2594	5
	22.5	7.5	3.75	47.1	66.858	3149.0118	7.5
	30	10	5	62.8	73.904	4641.1712	10
	45	15	7.5	94.2	107.36	10113.312	15
	60	20	10	125.6	160.5	20158.8	20
VES 51	1.5	0.5	0.25	3.14	467.2	1467.008	0.5
	2.25	0.75	0.375	4.71	354.7	1670.637	0.75
	4.5	1.5	0.75	9.42	224.6	2115.732	1.5
	6	2	1	12.56	161.7	2030.952	2
	7.5	2.5	1.25	15.7	145.3	2281.21	2.5
	10.5	3.5	1.75	21.98	86.77	1907.2046	3.5
	15	5	2.5	31.4	37.35	1172.79	5
	22.5	7.5	3.75	47.1	17.1	805.41	7.5
	30	10	5	62.8	11.13	698.964	10
	45	15	7.5	94.2	7.142	672.7764	15
	60	20	10	125.6	6.228	782.2368	20

VES 52	1.5	0.5	0.25	3.14	82.214	258.15196	0.5
	2.25	0.75	0.375	4.71	56.65	266.8215	0.75
	4.5	1.5	0.75	9.42	26.682	251.34444	1.5
	6	2	1	12.56	21.09	264.8904	2
	7.5	2.5	1.25	15.7	17.287	271.4059	2.5
	10.5	3.5	1.75	21.98	13.494	296.59812	3.5
	15	5	2.5	31.4	9.6531	303.10734	5
	22.5	7.5	3.75	47.1	6.7843	319.54053	7.5
	30	10	5	62.8	5.2547	329.99516	10
	45	15	7.5	94.2	4.3376	408.60192	15
	60	20	10	125.6	4.0312	506.31872	20
VES 53	1.5	0.5	0.25	3.14	376.2	1181.268	0.5
	2.25	0.75	0.375	4.71	233.4	1099.314	0.75
	4.5	1.5	0.75	9.42	116.3	1095.546	1.5
	6	2	1	12.56	93.99	1180.5144	2
	7.5	2.5	1.25	15.7	73.98	1161.486	2.5
	10.5	3.5	1.75	21.98	46.25	1016.575	3.5
	15	5	2.5	31.4	24.18	759.252	5
	22.5	7.5	3.75	47.1	11.79	555.309	7.5
	30	10	5	62.8	7.237	454.4836	10
	45	15	7.5	94.2	4.772	449.5224	15
	60	20	10	125.6	4.235	531.916	20
VES 54	1.5	0.5	0.25	3.14	532.93	1673.4002	0.5
	2.25	0.75	0.375	4.71	305.88	1440.6948	0.75
	4.5	1.5	0.75	9.42	96.561	909.60462	1.5
	6	2	1	12.56	42.948	539.42688	2
	7.5	2.5	1.25	15.7	17.138	269.0666	2.5
	10.5	3.5	1.75	21.98	9.714	213.51372	3.5
	15	5	2.5	31.4	5.1099	160.45086	5
	22.5	7.5	3.75	47.1	3.8606	181.83426	7.5
	30	10	5	62.8	3.6191	227.27948	10
	45	15	7.5	94.2	3.3896	319.30032	15
	60	20	10	125.6	3.4695	435.7692	20

Table 2: Vertical Electrical Soundings Field Data for Okirika Soil

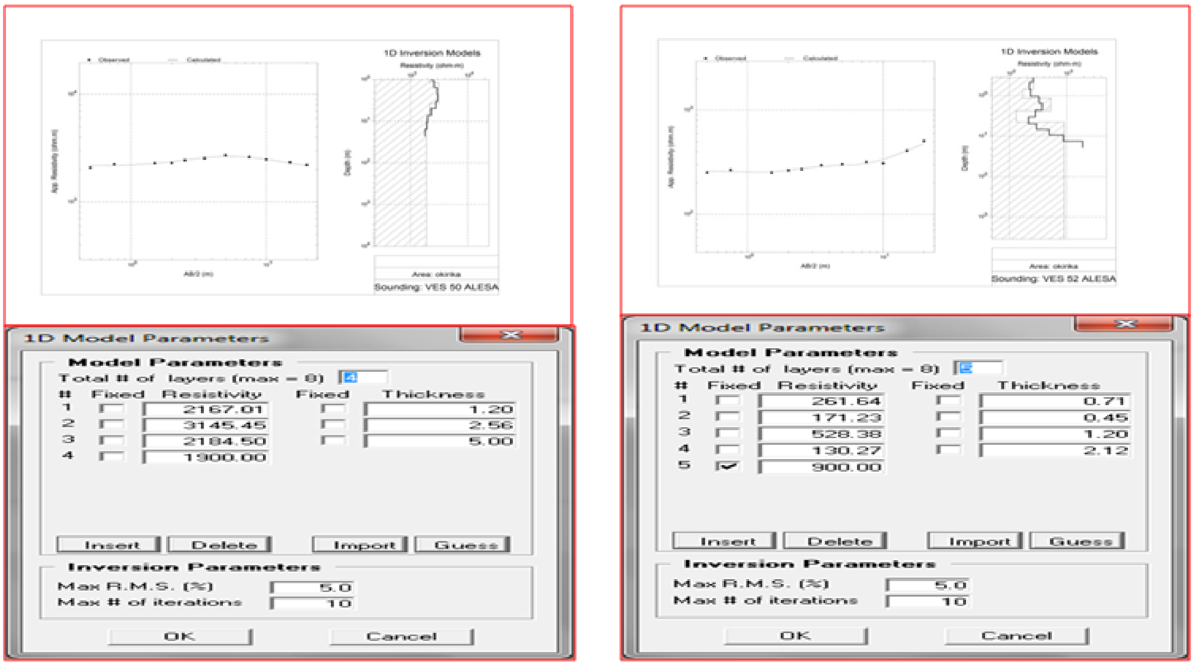
VES Station	AB(M)	Electrode Spacing a (m)	MN/2	K Constant.	Resistance (ohm)	Resistivity (Ohm.m)	Depth of Probe (m)
VES 18	1.5	0.5	0.25	3.14	0.952	2.98928	0.5
	2.25	0.75	0.375	4.71	0.903	4.25313	0.75
	4.5	1.5	0.75	9.42	0.883	8.31786	1.5
	6	2	1	12.56	0.883	11.09048	2
	7.5	2.5	1.25	15.7	0.883	13.8631	2.5
	10.5	3.5	1.75	21.98	0.875	19.2325	3.5
	15	5	2.5	31.4	0.772	24.2408	5
	22.5	7.5	3.75	47.1	0.857	40.3647	7.5
	30	10	5	62.8	0.816	51.2448	10
	45	15	7.5	94.2			15
	60	20	10	125.6			20
VES 19	1.5	0.5	0.25	3.14	0.6	1.884	0.5
	2.25	0.75	0.375	4.71	0.593	2.79303	0.75
	4.5	1.5	0.75	9.42	0.579	5.45418	1.5
	6	2	1	12.56	0.591	7.42296	2
	7.5	2.5	1.25	15.7	0.541	8.4937	2.5
	10.5	3.5	1.75	21.98	0.538	11.82524	3.5
	15	5	2.5	31.4	0.529	16.6106	5
	22.5	7.5	3.75	47.1	0.522	24.5862	7.5
	30	10	5	62.8	0.518	32.5304	10
	45	15	7.5	94.2			15
	60	20	10	125.6			20
VES 20	1.5	0.5	0.25	3.14	1.541	4.83874	0.5
	2.25	0.75	0.375	4.71	1.529	7.20159	0.75
	4.5	1.5	0.75	9.42	1.521	14.32782	1.5
	6	2	1	12.56	1.513	19.00328	2
	7.5	2.5	1.25	15.7	1.513	23.7541	2.5
	10.5	3.5	1.75	21.98	1.506	33.10188	3.5

	15	**5**	**2.5**	**31.4**	**1.394**	**43.7716**	**5**
	22.5	**7.5**	**3.75**	**47.1**	**1.476**	**69.5196**	**7.5**
	30	**10**	**5**	**62.8**	**1.476**	**92.6928**	**10**
	45	**15**	**7.5**	**94.2**			**15**
	60	**20**	**10**	**125.6**			**20**
VES 21	**1.5**	**0.5**	**0.25**	**3.14**	**0.994**	**3.12116**	**0.5**
	2.25	**0.75**	**0.375**	**4.71**	**0.864**	**4.06944**	**0.75**
	4.5	**1.5**	**0.75**	**9.42**	**0.749**	**7.05558**	**1.5**
	6	**2**	**1**	**12.56**	**0.727**	**9.13112**	**2**
	7.5	**2.5**	**1.25**	**15.7**	**0.714**	**11.2098**	**2.5**
	10.5	**3.5**	**1.75**	**21.98**	**0.68**	**14.9464**	**3.5**
	15	**5**	**2.5**	**31.4**	**0.703**	**22.0742**	**5**
	22.5	**7.5**	**3.75**	**47.1**	**0.703**	**33.1113**	**7.5**
	30	**10**	**5**	**62.8**	**0.692**	**43.4576**	**10**
	45	**15**	**7.5**	**94.2**			**15**
	60	**20**	**10**	**125.6**			**20**
VES 22	**1.5**	**0.5**	**0.25**	**3.14**	**0.317**	**0.99538**	**0.5**
	2.25	**0.75**	**0.375**	**4.71**	**0.308**	**1.45068**	**0.75**
	4.5	**1.5**	**0.75**	**9.42**	**0.298**	**2.80716**	**1.5**
	6	**2**	**1**	**12.56**	**0.299**	**3.75544**	**2**
	7.5	**2.5**	**1.25**	**15.7**	**0.306**	**4.8042**	**2.5**
	10.5	**3.5**	**1.75**	**21.98**	**0.295**	**6.4841**	**3.5**
	15	**5**	**2.5**	**31.4**	**0.29**	**9.106**	**5**
	22.5	**7.5**	**3.75**	**47.1**	**0.291**	**13.7061**	**7.5**
	30	**10**	**5**	**62.8**	**0.282**	**17.7096**	**10**
	45	**15**	**7.5**	**94.2**			**15**
	60	**20**	**10**	**125.6**			**20**
VES 23	**1.5**	**0.5**	**0.25**	**3.14**	**0.96**	**3.0144**	**0.5**
	2.25	**0.75**	**0.375**	**4.71**	**0.959**	**4.51689**	**0.75**
	4.5	**1.5**	**0.75**	**9.42**	**0.947**	**8.92074**	**1.5**
	6	**2**	**1**	**12.56**	**0.961**	**12.07016**	**2**
	7.5	**2.5**	**1.25**	**15.7**	**0.956**	**15.0092**	**2.5**
	10.5	**3.5**	**1.75**	**21.98**	**0.952**	**20.92496**	**3.5**
	15	**5**	**2.5**	**31.4**	**0.949**	**29.7986**	**5**
	22.5	**7.5**	**3.75**	**47.1**	**0.943**	**44.4153**	**7.5**
	30	**10**	**5**	**62.8**	**0.937**	**58.8436**	**10**
	45	**15**	**7.5**	**94.2**			**15**
	60	**20**	**10**	**125.6**			**20**

Table 3: Result of the interpreted VES curve

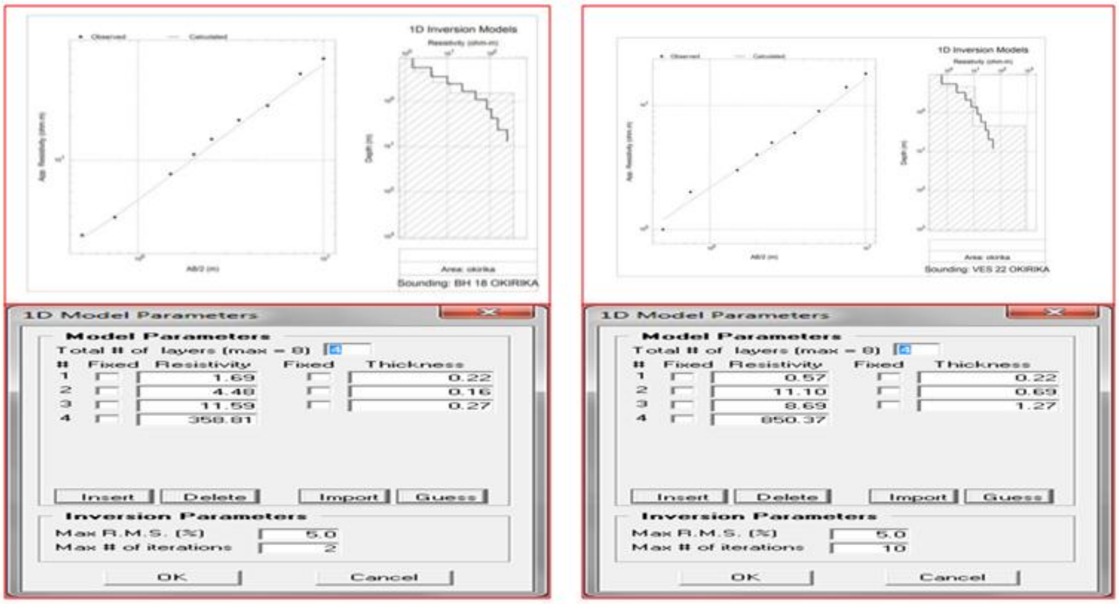
S/N	**VES STATION**	**LAYER RESISTIVITY(ΩM)**	**THICKNESS(M)**	**REMARK**	**NUMBER OF LAYERS**	**CURVE TYPE**
1	VES 49 ALESA	245.47 579.93 5336.63 1013.19	0.11 0.12 1.02 --	Cannot be inferred with resistivity value due to pollution.	3	AK
2	VES 50 ALESA	2167.01 3145.45 2184.50 1900	1.20 2.56 5.00 --	√	3	KQ
3	VES 51 ALESA	1228.25 4302.42 626.54 566	0.40 0.82 3 --	√	3	KQ
4	VES 52 ALESA	261.64 171.23 528.38 130.27 900	0.71 0.45 1.20 2.12 --	√	4	HKH
5	VES 53 ALESA	1356.26 858.85 1740.42 245.52 981.56	0.25 0.49 1.35 5.12 --	√	4	HKH
6	VES 54	1632.82	0.31		4	KQH

	ALESA	2083.22 131.96 93.37 1489.62	0.34 2.39 1.85	√		
7	VES 18 OKRIKA	1.69 4.48 11.59 358.81	0.22 0.16 0.27 --	Top soil Sandstone Clayed layer Weathered basement	3	AA
8	VES 19 OKRIKA	1.21 3.81 18.82 104.86	0.21 0.12 0.5 --	Top soil Sandstone Clayed layer Sandy clay	3	AA
9	VES 20 OKRIKA	1.69 4.39 14.84 394.51	0.19 0.17 1.20 --	Top soil Sandstone Clayed layer Weathered basement	3	AA
10	VES 21 OKRIKA	2.92 8.18 113.60 466.21	0.24 0.15 0.55 --	Top soil Sandstone Sandy clay Weathered basement	3	AA
11	VES 22 OKRIKA	0.57 11.10 8.69 850.37	0.22 0.69 1.27 --	Brackish top soil Clayed layer Sandstone Weathered basement	3	KH
12	VES 23 OKRIKA	1.48 2.49 34.00 823.36	0.14 0.20 0.11 --	Top soil Sandy layer Sandy clay Weathered basement	3	AA



(a) KQ curve (b) HKH Curve

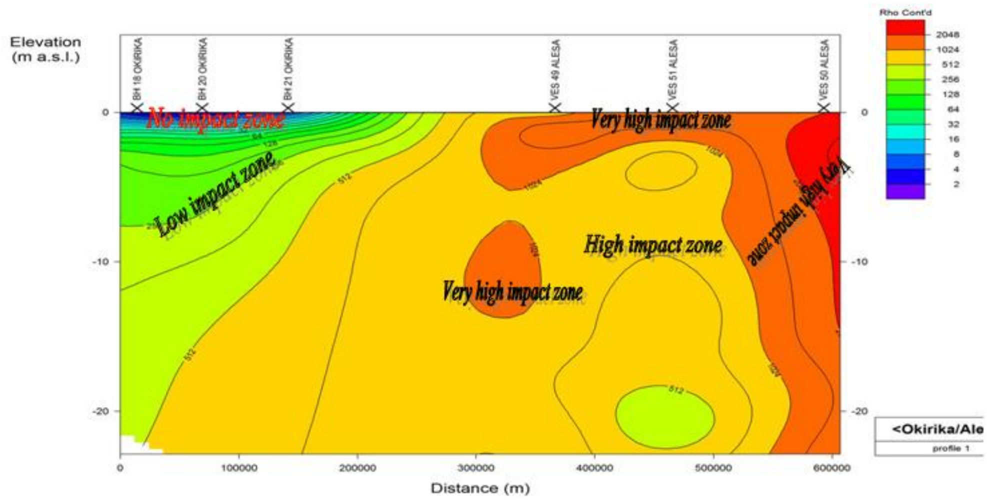
Fig 2 a: Typical VES curve obtained at the contaminated site (Alesa-Eleme).



(c) AA curve (d) KH curve

Fig 2b: Typical VES curve obtained at the contaminated site (Okirika).

(a)



(b)

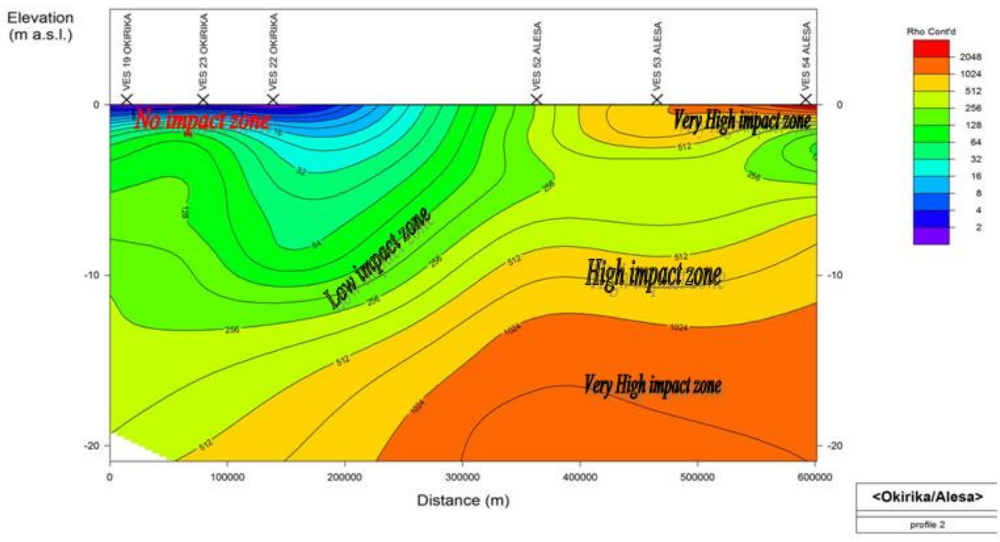


Fig. 3 (a and b): Geoelectric section of the study areas showing the level of contamination

V. Conclusion

Three to four soil layers were delineated in the area of study. In all soil resistivity ranged from 0.57Ωm to 5336.63Ωm across the area. The apparent resistivity values of the hydrocarbon contaminated soil at Alesa-Eleme ranged from 93.37Ωm to 5336.63Ωm while that of the uncontaminated soil at Okirika ranged from 0.57Ωm to 113.60Ωm. Random distribution of the hydrocarbon contaminant in the subsurface will no doubt affect the soil conductivity with characteristic effect of low crop yield arising from chlorophyl degradation on the vegetation due to insufficient oxygen in the subsurface and shallow underground water pollution in the area. The random distribution of pollution at Alesa-Eleme to a depth of 20-25m exposed the groundwater in the area at risk of contamination by the hydrocarbon. Therefore for a clean and potable water abstraction from the aquifer in the area, it is highly recommended that a deep and well grouted borehole be sunk to depth of about 35m and above.

Aknowledgement

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