Delineation of Subsurface Migration Pathways of Petroleum Contaminants in Ikarama, Okordia Clan of Bayelsa State.

ABSTRACT

Oil spillage is a known source of groundwater contamination in developing oil-producing countries. Oil spillage usually occurs as a result of many factors which include poor handling and maintenance of oil facilities, breakdown of oil infrastructures and vandalization of pipelines by oil thieves. This study provides an evaluation of the subsurface oil contaminant flow in an oil production field at Ikarama community in Okordia clan of Yenagoa Local Government Area in Bayelsa state. The electrical resistivity tomography technique has been applied along three (3) VES surrounding the spill location of oil spill site, schlumberger array method was used. Resistivity value was obtained by taking reading using the ABEM TERRAMETER SAS1000 resistivity meter, three (3) vertical electrical sounding (VES) was carried out in the study area.Theoretical soil resistivity response versus fluid resistivity for different caption exchange capacity values has been studied. The inverted results revealed resistivity values ranging from 0.17Ωm to 146.8Ωm. The low resistivity values 0.17 to 12.12Ωm reflect the general salinity of the area, while the high resistivity values (21.54 to 146.8Ωm) are as a result of the hydrocarbon pollution (Oil Plumes). This study, has confirmed that the 2D resistivity method is an efficient tool for investigating hydrocarbon pollution in a coastal environment.

Keywords: Ikarama, schlumberger, resistivity, oil spill

1. INTRODUCTION

Oil spillage is a known source of groundwater contamination in developing oil-producing countries. About 9343 cases of oil spillage were reported in Nigeria between 2005 and 2015

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(NOSDRA, 2015). This gives an average of 1000 cases per year. In Nigeria, oil spillage usually occurs as a result of many factors which include poor handling and maintenance of oil facilities, breakdown of oil infrastructures and vandalization of pipelines by oil thieves. Hydrocarbon oil (here simply refers to as oil) is a non-aqueous phase liquid (NAPL) that exists in a separate, immiscible phase when in contact with water-saturated sands. When oil infiltrates coastal sands, it does not stay in one place, it moves vertically and horizontally, thereby contaminating surface water, groundwater, soil and porous rocks; leading to loss of soil fertility and biodiversity and causing damages to human health and socio-economic well-being of the people. Hydrocarbons are potentially toxic to human health [1]; [2] when present in water, food, or fruits. Geophysical study of oil contaminated sites is important for the assessment of the extent of the damages caused by the oil spill, designing methods of remediation and evaluating the effectiveness of a remediation process [3]. Compared to the traditional method of soil sampling and chemical analysis, geophysical methods of investigating oil-contaminated site are cheaper, time inexpensive and non-destructive.

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Oil spillage is the release of petroleum substance or product into the streams, lakes, rivers, seas, beaches, oceans and lands, which becomes poisonous and thus makes the water and land fouled and threatened the rich coastal habitat. Oil spillage is an environmental problem in Nigeria. It is common in oil producing areas. During a spillage, oil floats on land and water surfaces and forms an oil slick that is about 0.1mm thick continuing to spread; the slick becomes 0.1mm thick.

Oil is a very complex mixture of predominantly hydrocarbons, the light (less dense) portions of oil are more toxic but also more likely to evaporate. Evaporation can reduce the volume of crude oil slick. Heavier oil can wash to the shore causing serious short-term harm to shellfish and plants life. Oil spillage on soil makes it unsatisfactory for plant growth; this is due to insufficient aeration of the soil because of air from the space between the soil particles by oil spillage. During the early stages, coming in contact with the soil may kill seabirds and mammals because of the toxic chemicals. Oil on feathers hinders water repellency and poisons the birds from oral consumption of the toxic materials fur bearing animals, seabirds and seals lose their buoyancy and insulation when oil fouls their fur they either drown or suffer hypothermal and die the effects on fish and unclean.

In areas where wildlife is very healthy or full recovery has been seen within two or four years but if the spill occurs during migration or breeding season, it could be devastating and prompt action is crucial. The communities have remained grossly socio economically under developed amidst, the immense oil wealth owing the systematic disequilibrium production, exchange the relationship between the state transnational companies and the people. Huge amount of money had been derived from oil export but the area has been subjected to severe land degradation, socio-economic disorganization, increasing poverty, misery militancy occupation and blood violence. Oil extraction has impacted most disastrously on the socio-physical environmental of the community. The socio and environmental cost of oil production have been extensive. They include destruction of wildlife and biodiversity, loss of fertile soil, pollution of air and drinking water, degradation of farmland and damage to aquatic ecosystem, all of which causes serious health problems for the inhabitants of the area/community.

Most of the people who lived in that community/area depended upon fishing for their livelihood. The oil spillage changed their occupations and they lost their jobs. As at Monday 27th September, 2021, the minister of environment, Mohammed Abubakar has disclosed that Nigeria have recorded 4,919 oil spills between 2015 to March 2021 and lost about 4.5 trillion barrels of oil to

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theft in four years. When oil infiltrates coastal sands, it does not stay in one place, it moves vertically and horizontally, thereby contaminating surface water, ground water, soil and porous rocks, leading to loss of soil fertility and biodiversity.

Hydrocarbons are potentially toxic to human health [1] ; [2]when present in water, food or fruits. Geophysical study of oil contaminated sites is important for the assessment of the extent of the damages caused by the oil spill, designing method of remediation and evaluating the effectiveness of a remediation process [3]. Compared to the traditional method of soil sampling and chemical analysis, geophysical method of investigating oil contaminated sites/areas are cheaper, time inexpensive and non-destructive. Oil spill, a common outcome of oil exploration and exploitationin the Niger delta region has an estimated spillage incident of over 7000 over a 50-year period [4].

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Oil spillage occurs usually from activities of humans in their environment and witnessed especially in the marine ecosystem but oil spillages can also happen on land. Whatever the terrain is, whether land, water or swamp, its effect is not encouraging, its health threatening, it is harmful and should be avoided.

In Nigeria, there are serious environmental issues ranging from drought to flood, to oil spillages, to illegal refining and so on but it is interesting to note that the major environmental issues hinging around the Niger Delta are from the petroleum industry. Oil theft, operations, illegal refining, mystery spills and sabotage are amongst major causes of oil spills in our environment. Whatever the cause may be, be it sabotage or mystery spills or whatever, there must be a joint investigation followed by the clean-up and remediation processes which are done by the shell petroleum development company of Nigeria limited joint venture (SPDC JV).

Oil spill have posed a major threat to the environment of the oil producing areas, which if not effectively checked can lead to the total destruction of ecosystems. The Niger delta is among the ten most important wetlands and marine ecosystems in the world. The oil industry located within this region has contributed immensely to the growth and development of the country which is a fact that cannot be disputed but unsustainable oil exploration activities has rendered the Niger delta region one of the five most severely petroleum damaged ecosystem in the world. Studies have shown the quantity of oil spilled over 50 years was a least 9-13 million barrels, which is equivalent to 50Exxon Valdez spills [5].

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Electrical resistivity, very low frequency electromagnetic (VLF-EM), induced polarization, spontaneous potential and electromagnetic induction methods have been used to evaluate environmental problems arising from oil spills, dumpsite leachates, sea water intrusion, hazardous wastes and groundwater potentials [6]; [7]; [8]; [9];[10]; [11]; [12]; [13]; [14]; [15]. Among the geophysical methods, the success of multi-electrodes resistivity surveyfor investigating environmental contamination is outstanding [16]; [17]; [18]. Multi-electrodes resistivity data is usually processed by electrical resistivity tomography (ERT).

ERT is a multi-dimensional resistivity imaging technique that is used to image two-dimensional and three-dimensional resistivity distribution in geological structures. The method is particularly suitable for studying oil spillage because oil contamination is a three-dimensional environmental problem that results from a combination of dispersion and advection processes. In recent time, 4D (time-lapse) survey has been used in different applications.

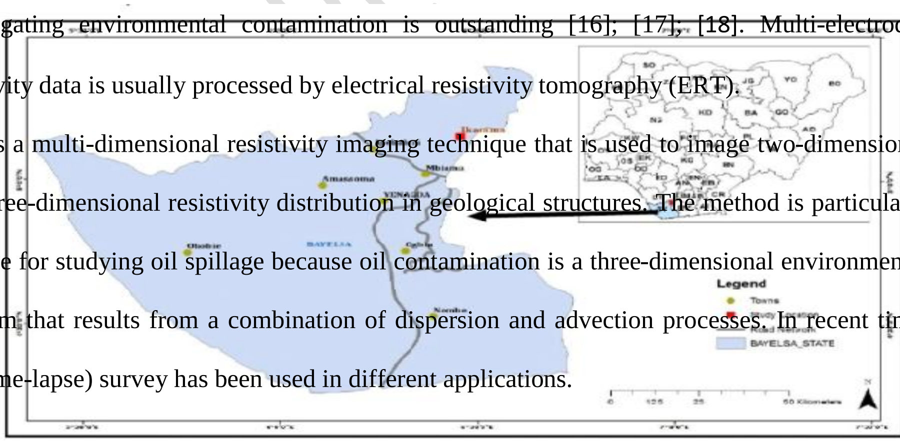

Figure [illegible] study sites are located. Inset: Map of Nigeria showing different states

1.1 THE STUDY AREA AND GEOLOGICAL SETTING.

The intended study area is Ikarama community in Okordia clan Latitude 05°09°16° N and Longitude 06°27°11°E, a small community situated within Yenagoa Local Government Area of

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Bayelsa State, Nigeria. Bayelsa State is strategically located at the Centre of the Niger Delta region of Nigeria, which is one of the richest wetlands in the world with a tropical climate condition of rainy season ,April - November and dry season, December - March and an annual rainfall ranging between 1500 and 4000mm [19]. Ikarama is a host community to Nigeria AGIP Oil Company and Shell Petroleum Development Company (SPDC). The SPDC pipelines links Delta, Bayelsa and River states in Nigeria pass through Ikarama community and oil spill from equipment failure have been reported to be the major environmental contamination of this community. The study site was chosen because of the frequent occurrences of oil spills in the sites.Below is the map of Bayelsa showing Ikarama community where the study site is located inset.

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1.2 History of Oil Exploration and Exploitation in the Niger Delta Region

The British discovered oil in the Niger Delta in the late 1950s and crudeoil was discovered in commercial quantity, which is now called Royal Dutch Shell at Oloibiri.A village in the Niger Delta and in 1958 commercial production began with a production of about 6,000 barrels a day [20] ; [21]. The region has huge oil and gas reserves, and ranks the sixth world's largest exporter of crude oil and ranked as the third world's largest explorer followed by Indonesia [22]. Oil from the Niger Delta region accounts for more than 90% of Nigeria's exports and about 80% of the government's revenue, from as far back as December 1981. In these present times the overall contribution of the oil sector to the national economy grew from 84% in 2000 and 95% in 2002 to about 96.7% in 2003 [23]. The Niger Delta region has emerged as one of the most ecologically sensitive regions in Nigeria. Oil and gas from the region are the main source of revenue for the Nigerian state, accounting for about 97% of the country's total export. Since the discovery of oil in the region, oil has dominated the country's economy. The Niger Delta is highly susceptible to adverse environmental changes, occasioned by climate changes because it is located in the coastal region. Conclusive reports have stated that due to oil exploration and exploitation activities, the area has become an ecological wasteland. Today, the Niger delta is best known as a region that sustains much oil exploration and exploitations by western economic powers. The Niger delta basin is considered the mainstay of the Nigerian economy for its significantly high level of oil reserves. The region is also naturally endowed with viable deposits of hydrocarbon and gas reserves.

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1.3 Oil Production in Nigeria

Nigeria has been a member of Organization of Petroleum Exporting Countries (OPEC) since 1971. It has the largest natural gas reserve in Africa, has the second largest oil reserve in Africa and is the African continents primary oil producer. As of the1980s oil revenue provided 90% of Nigeria foreign exchange earnings and 85% of the government revenue [24], with estimated reserves extending beyond 20-30years (NNPC, 1984). Shell D'Arcy the pioneer oil company in Nigeria, which started commercial production in 1958 with a production rate of 5100 barrels per day and a peak production of 2.44 million [25]. According to NNPC (1984) through OPEC, production rates dropped to 1.5million international companies working 122 fields, containing over 970 oil wells.

Previously the majority shares of the refineries were held by Shell and British Petroleum, with the Federal and Defunct Eastern Region Government having majority shares [26]. The four refineries came under the ownership and management of the NNPC in 1986. Numerous Niger Delta region oil wells also have taps to large quantities of natural gas, with reserves estimated at 1422 billion cubic meters [24]. Extensive gas flaring has been continuous in the Niger Delta region since 1970. In 2001, Nigeria proven oil reserve was approximately 30 million barrels [26]. As of January 2009, the Oil and Gas Journal (OGJ) estimated that Nigeria has 36.2 billion barrels of oil reserve with present oil exploration and production in and outside continental shelf [26]. Activities mainly in the onshore dry or swamplands of the Niger Delta basin and deep offshore locations of the Dahomey Basin [26]. Small fields characterize Nigeria crude oil production which produces 500-5,000 barrels per day, 65% of the oil produced being light sweet crude which is a very high-quality crude with an API –gravity of 35°C and above. Shell produces over 50% of Nigeria crude from over 100 fields and Shell has an oil reserve of over 11 billion

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1.4 THEORITICAL BACKGROUND OF SCHLUMBERGER ARRAY METHOD

Schlumberger array is commonly used for Vertical Electrical Sounding (VES) for groundwater and mineral aggregating. This array has four electrodes that are placed around a common midpoint. It comprises of two potential electrodes which are placed close to each other and another two current electrodes placed far apart.

For each measurement, the two outer electrodes A and B are moved to greater distances although the survey. The inner electrodes are fixed at a point through the survey unless the observed voltages are too small and insignificant to record. Hence, the inner electrodes are moved outwards to a new spacing of about one-fifth of the distance between the two outer electrodes A and B.

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The resistivity is calculated thus

Resistivity

$\rho = G_s \mathrm{R}$ (1)

Where G_s is the Geometric factor

$G_s = \pi \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}$ (2)

AB = Current electrode spacing

MN = Potential electrode spacing

From Ohms law after several evaluations

$R = \frac{\Delta V}{I}$ (3)

$$\rho = \pi \frac{(AB)^2 - (MN)^2}{MN} \frac{\Delta V}{I} \quad (4)$$

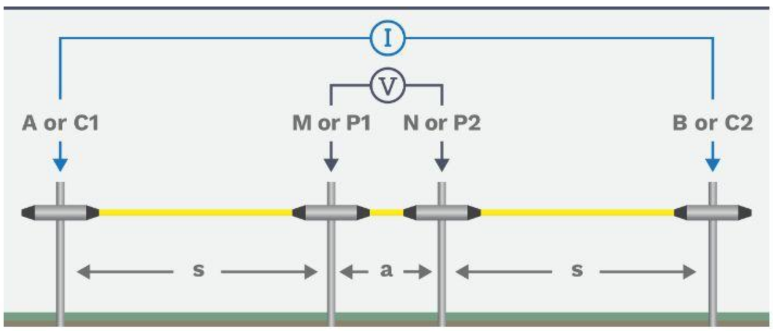

Fig 2. Diagram of Schlumberger array configuration

2. MATERIALS AND METHOD

Resistivity Meter called ABEMTerrameter SAS 1000,Global positioning system (GPS),Measuring Tape, Electrode; was used to send electrical signals into the ground in order to record the resistance of the earth, there are four types of electrodes that were used during the field survey, they are; 2 current and 2 potential voltage. Reference electrode; this is also known as geo-reference Electrode, it was used to indicate the reference point (the center point of the electrodes),Conducting wire; was used to transfer electrical signals from the resistivity meter to the electrodes, Direct Current (Battery); this is a source of electrical power for the resistivity meter, Geophysical Hammer; was used to drive the electrodes into the ground for contact, IP2WIN software was used to interpret the Schlumberger vertical electrical sounding (VES), Notepad was used to edit and lunched the software.

The Method that was used in this study was vertical electrical sounding (VES) using Schlumberger configuration (C_1 P_1 -P_2C_2). Resistivity value was obtained by taking reading using the ABEM TERRAMETER SAS1000 resistivity meter, three (3) vertical electrical sounding (VES) was carried out in the study area.

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The Schlumberger configuration was adopted due to its reliability in depth sounding and strength of geology material determination. The Schlumberger vertical electrical sounding was carried out along the profile using SAS 1000 ABEM TERRAMETER. The maximum Electrode (AB/2) spread ranged from 1m to 50m in the study area. The electrode movement on the current electrode C_1, C_2 are moved outward symmetrically, keeping P_1 and P_2 fixed at the center with this procedure often called electric drilling, the property of the subsurface was explored to determine the load carrying strength capacity of the soil, in situ soil nature and the water table across the study area.The Schlumberger array is an array where four electrodes are placed in line around a common midpoint. The two outer electrodes, A and B, are current electrodes, and the two inner electrodes, M and N, are potential electrodes placed close together. With the Schlumberger array, for each measurement the current electrodes A and B are moved outward to a greater separation throughout the survey, while the potential electrodes M and N stay in the same position until the observed voltage becomes too small to measure (source). At this point, the potential electrodes M and N are moved outward to a new spacing. As a rule of the thumb, the reasonable distance between M and N should be equal or less than one-fifth of the distance between A and B at the beginning. This ratio goes about up to one-tenth or one-fifteenth depending on the signal strength.

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Fig 3. Field work carried out at Ikarama community oil spill site

Fig 4. Spill oil site in Ikarama community (view one)

Fig 5. Spill oil site in Ikarama community (opposite view one)

3. RESULTS AND DISCUSSION

The data is acquired from Ikarama community and are presented below in table 1 to 3

Table 1 Showing the VES reading for the oil spill site at Ikarama community VES 1

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Half current electrode spacing (m) AB/2	Half potential electrode spacing (m) Mn/2	Resistance (Ώ)	Apparent Resistance (Ώm)
1	1	0.028307	0.0445
1.5	1	0.023547	0.0832
2	1	0.0039347	0.0247
3	1	0.042395	0.5993
5	1	0.020909	0.8211
7	3	0.008428	0.2162
10	3	0.022237	1.1643
15	6	0.026665	1.5707
20	6	0.016832	1.7626
25	6	0.0022988	0.3761
30	6	0.0044939	1.0589
35	6	0.011660	3.7394
40	6	0.002251	0.9429
45	6	0.017115	9.0734
50	6	0.0061332	4.0142

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Table 2 Showing the VES reading for the oil spill sit at Ikarama community VES 2

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Half current electrodes spacing(m) AB/2	Half potential electrode spacing(m) Mn/2	Resistance (Ώ)	Apparent Resistance (Ώm)
1	1	0.012853	0.0202

1.5	1	0.0064450	0.0235
2	1	0.0016613	0.0101
3	1	0.018208	0.2574
5	1	0.0006563	0.0258
7	3	0.0008291	0.2127
10	3	0.12231	6.4041
15	6	0.0018026	0.1062
20	6	0.0099456	1.0415
25	6	0.36332	59.4481
30	6	0.081333	19.1636
35	6	0.064385	20.6485
40	6	0.14509	60.7752
45	6	0.045228	23.9773
50	6	0.16074	105.2041

Table 3 showing VES reading for Ikarama community oil spill site VES 3

Half current electrode spacing(m) AB/2	Half potential electrode spacing(m) Mn/2	Resistance (Ω)	Apparent Resistance (Ωm)
1	1	0.022495	0.0353
1.5	1	0.0096410	0.0341
2	1	0.066306	0.4166
3	1	0.027447	0.3880

Comment [IS53]: Avoid breaking the table, place it on a separate page

5	1	0.050736	1.9924
7	3	0.022947	0.5887
10	3	0.035245	1.8454
15	6	0.048095	2.8330
20	6	0.10585	11.0846
25	6	0.065423	10.7048
30	6	0.24321	57.3050
35	6	0.43554	139.6795
40	6	0.70042	239.3912
45	6	0.84761	449.3552
50	6	0.16323	106.8338

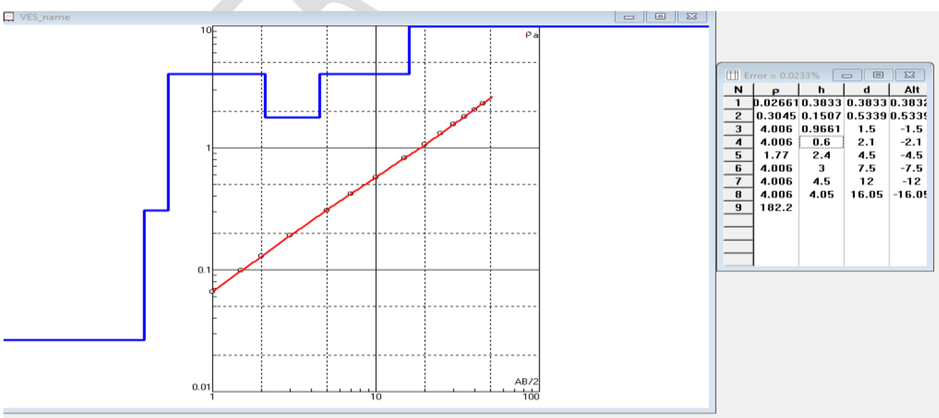

Fig 6 Inverted Model Layer for VES 1: Ikarama Oil Spill Site

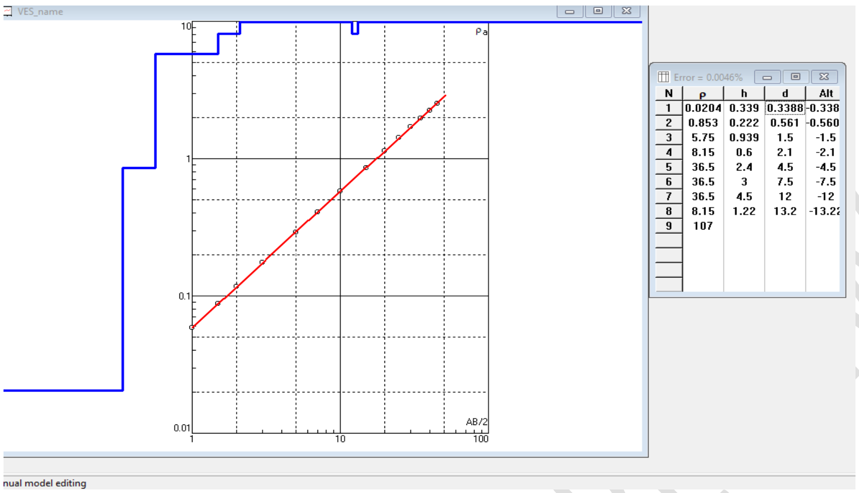

Fig 7. Inverted Model Layer for VES 2: Ikarama Oil Spill Site

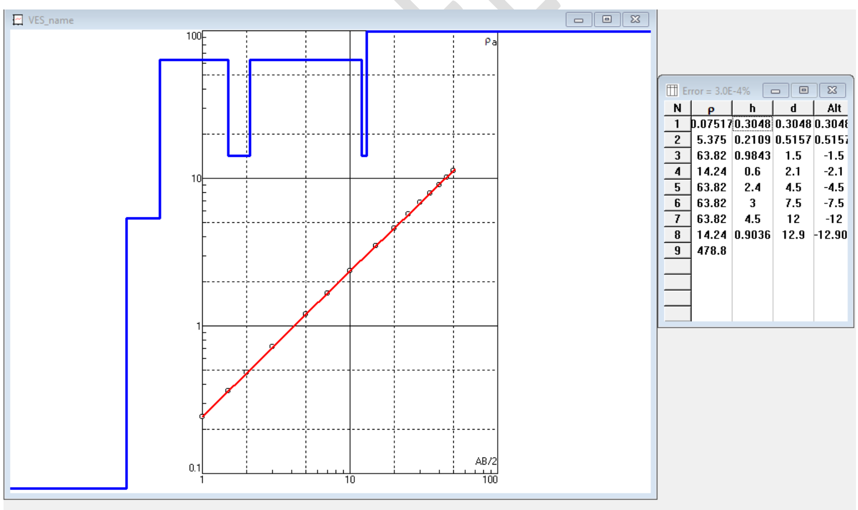

Fig 8 Inverted Model Layer for VES 3: Ikarama Oil Spill Site

The result of Vertical Electrical Sounding (VES) acquired in the study area showed that the resistivity of hydrocarbon in Ikarama oil spill site ranges from 1.77 to 63.82Ωm. The resistivity model of VES (profile) shows variation of resistivity values ranging from about 0.1 to 146.8 Ωm and has a depth of 1.5 to 4.5m. The top soil has resistivity values ranging from about 0.1 to 6.8 Ωm and thickness of about 0.68 to 1.5 m. The low resistivity values (0.1–15.8 Ωm). While the high resistivity values (21.54 – 146.8 Ωm). However, the result of VES 3 for the study area has a resistivity model showing variation of resistivity values ranging from about 0.15 to 284.8 Ωm and has a depth of about 1.5 to 4.5m. The top soil has resistivity values ranging from about 0,15 of about 2.1 m. The low resistivity values is (0.1 to 6.5 Ωm). While its high resistivity values is (35.11 to 284.8 Ωm)

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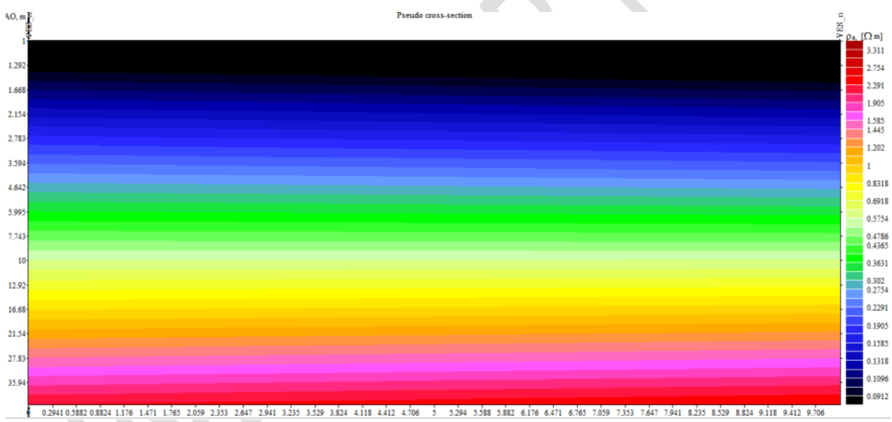

Fig 9. Pseudo cross section VES 1

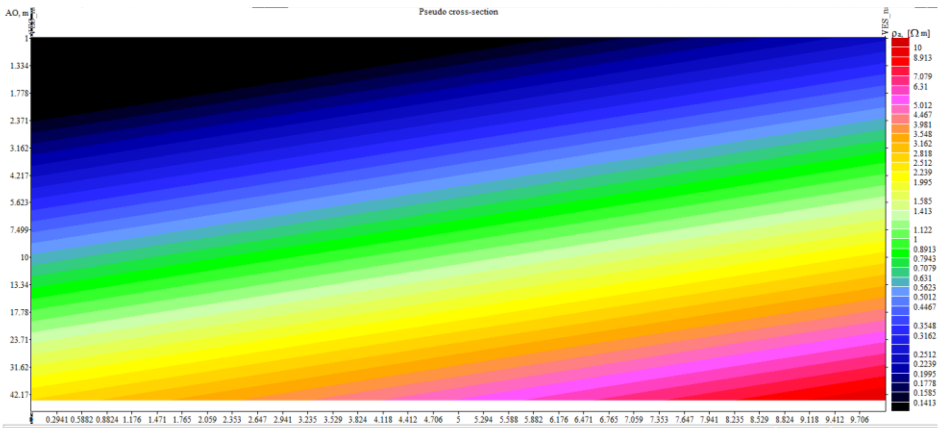

Fig 10. Pseudo cross section VES 2

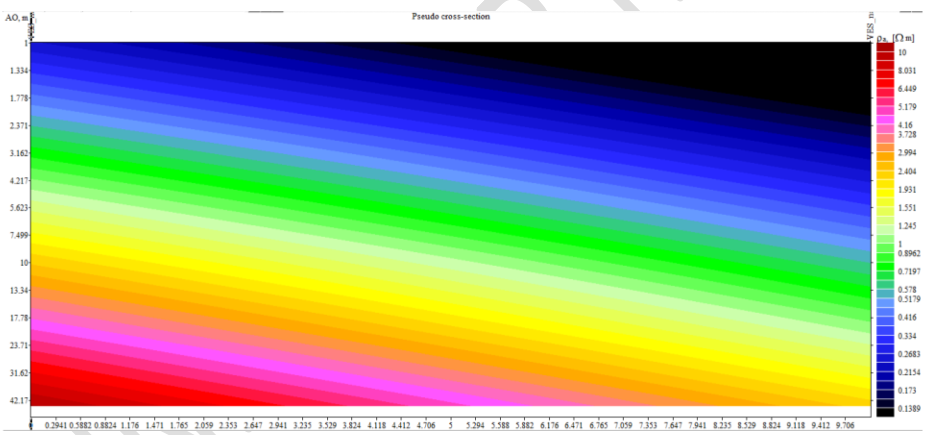

Fig 11. Pseudo cross section VES 3

The results of the 2D resistivity inversion in Ikarama Community Oil Spill Site are shown in Figures 9 to 11 as 2D inverted resistivity structures. The electrode separation between adjacent electrodes was 3m. The profile length is 50m and 3m from the adjacent profiles. The inverse 2D resistivity model of VES (profile) 1 within the hydrocarbon spill site is shown in Figure 9.The

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inverted resistivity model shows variation of resistivity values ranging from about 0.1 to 146.8 Ωm and has a depth of 1.5 to 4.5m. The top soil has resistivity values ranging from about 0.1 to 6.8 Ωm and thickness of about 0.68 to 1.5 m. The low resistivity values (0.1–15.8 Ωm) are as a reflection of the general salinity of the area. While the high resistivity values (21.54 – 146.8 Ωm) are as a result of the hydrocarbon pollution (Oil Plumes).

to 10 Ωm and thickness The inverse 2D resistivity model of VES(profile) 2 also within the polluted area is shown in Figure 10. The inverted resistivity model shows variation of resistivity values ranging from about 0.3 to 464.2Ωm and has a depth of 2.1 to 7.5m. The top soil has resistivity values ranging from about 0.3 to 3.8 Ωm and thickness of about 1.5 m. The low resistivity values (0.3 to 5.6 Ωm) is as a result of the salinity of the area. The resistivity values of the polluted area range from 38.31 to 464.2Ωm. This low resistivity value may be as a result of the mature spill while the high resistivity values are the oil plumes.

VES (profile) 3 is also within the spilled area and the 2D resistivity model is shown in Figure 11. The inverted resistivity model shows variation of resistivity values ranging from about 0.15 to 284.8 Ωm and hass a depth of about 1.5 to 4.5m. The top soil has resistivity values ranging from about 0,15 of about 2.1 m. The low resistivity values (0.1 to 6.5 Ωm) is as a result of the salinity of the area. While the high resistivity values (35.11 to 284.8 Ωm) is as a result of the hydrocarbon pollution (Oil Plumes).

4. CONCLUSION

Electrical resistivity survey was conducted in a crude oil spill site at Ikarama community in Okordia clan in Bayelsa state with the aim of investigating the migration pathway/spread of the hydrocarbon. The inverted results revealed resistivity values ranging from 0.17Ωm to about 146.8Ωm. The low resistivity values (0.17 to 12.12Ωm) reflect the general salinity of the area,

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Ill have impact on the top soil? State the depths at which you encountered low resistivity and high resistivity values. Also use the legend to explain the low and high resistivities.

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while the high resistivity values (21.54 to 146.8Ωm) are as a result of the hydrocarbon pollution (Oil Plumes). The lateral distributions of the hydrocarbon spill were generated from the inverted 2D models. This study, has confirmed that the 2D resistivity method is an efficient tool for investigating hydrocarbon pollution in a coastal environment.

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Comment [IS65]: State the date and country

Comment [IS66]: Put 'and' to connect the two names. However, depending on what is obtainable in the author's guidelines. Be consistent in your referencing. Some of the initials of the authors do not have full stops separating them while some others have full stops separating them. Please check the author's guidelines.

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