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

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

One well-known cause of groundwater contamination in developing nations that produce oil is oil leaks. Oil leaks are typically caused by a variety of circumstances, such as inadequate management and upkeep of oil facilities, equipment failure, and pipeline vandalism by oil criminals. This research evaluates the movement of underground oil contaminants in an oil production field at the Okordia clan's Ikarama hamlet in the Yenagoa Local Government Area in the state of Bayelsa. Schlumberger array was utilized in order to apply the electrical resistivity tomography technique along three (3) VES surrounding the oil spill spot. Values for resistivity were found. In the locations under study, three (3) vertical electrical soundings (VES) were conducted. Comparison of theoretical soil resistivity to measured fluid resistivity for various caption exchange Values of capacity have been researched. The resistivity values, when reversed, ranged from 0.17 m to 146.8 m. The hydrocarbon contamination (oil plumes) is the cause of the high resistivity values (21.54 –

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146.8 Ωm) and the low resistivity values (0.1–15.8 Ωm). The 2D resistivity approach is an effective tool for examining pollution caused by hydrocarbon in a coastal environment, as this study has proven.

Keywords: Ikarama; schlumberger; resistivity; oil spill.

1. INTRODUCTION

Oil leakage is a known source of underground water pollution in developing oil-producing countries. About 9343 cases of oil leakage were reported in Nigeria between 2005 and 2015 (NOSDRA, 2015). This gives an average of 1000 cases per year. In Nigeria, oil leakage usually occurs as a result of many factors which include poor managing and servicing of oil amenities, breakdown of oil structures by oil thieves. Hydrocarbon oil (here simply refers to as oil) is a non-aqueous phase liquid (NAPL) that exists in a separate, insoluble phase when in contact with water-saturated sands. Oil that seeps into coastal sands travels both vertically and horizontally, contaminating soil, groundwater, surface water, and porous rocks. This results in a loss of soil fertility and biodiversity as well as harm to the socioeconomic and health well-being of the populace. When hydrocarbons are found in food, water, or fruits, they may be harmful to human health [1,2]. For the purpose of determining the full extent of the damages resulting from an oil spill, developing remediation strategies, and assessing the efficacy of such strategies, geophysical analysis of oil-contaminated locations is crucial [3]. Geophysical approaches are less expensive, time-consuming, and non-destructive when examining oil-contaminated sites than conventional procedures that involve soil sampling and chemical analysis.
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 grease stain. More oil has the potential to wash up on the coast, seriously harming vegetation and shellfish in the near term. Unrefined When oil spills into soil, the air from the spaces between the soil particles causes insufficient aeration of the soil, which is why the soil is not suitable for plant growth. Because of the toxic substances present in the soil during the early stages, seabirds and mammals may die when they come into touch with it. In regions where wildlife is in excellent health or where full recovery has been observed in two or four years, swift intervention is essential. However, if the spill happens during migratory or breeding season, it might be disastrous. Despite the enormous oil wealth, the communities' socioeconomic development has remained glaringly underdeveloped due to the systematic manufacturing of disequilibrium, exchange the relationship between the state transnational companies and the people. Although the region has seen significant land deterioration, socioeconomic disarray, increasing impoverishment, hardship militancy occupation, and chaos, an enormous amount of money has been made from oil exports. The local environment has suffered greatly as a result of crude oil exploitation. There are significant environmental and socioeconomic consequences associated with oil production. These include the deterioration of farming and wildlife, loss of biodiversity and biodiversity, depletion of fertile soil, contamination of drinking water and the air, and harm to aquatic ecosystems, all of which have a major negative impact on the health of the local population. The majority of the residents in that community or area made their living from fishing. Their jobs were lost and their occupations were altered by the oil disaster. Nigeria has recorded 4,919 oil leakages between 2015 to March 2021 and lost about 4.5 trillion barrels of oil to theft in four years. Oil that seeps into coastal sands travels both vertically and horizontally, polluting soil, water from the ground, and porous rocks. This results in a decline in fertility of the soil and biological diversity.

Although oil leaks can sometimes occur on land, they are typically caused by human activity in the surrounding environment and are most noticeable in the marine environment.

Regardless of the terrain—land, lake, or swamp—it is detrimental, unhealthy, and ought to be avoided. Its effects are not encouraging.

Serious environmental problems plague Nigeria, including floods, droughts, oil spills, illicit refining, and more. However, it's fascinating to notice that the majority of these problems are related to the Niger Delta from the petroleum industry. Some of the main reasons why oil leaks happen in our environment are destruction, bad operations, illicit refining, theft of oil, and mystery leaks. Any cause, including sabotage or mysterious spills, needs to be thoroughly investigated before the shell petroleum development company of Nigeria limited joint venture (SPDC JV) may begin the cleanup and remediation procedures.

The environment in oil-producing regions has been seriously threatened by oil spills, which, if left unchecked, might completely destroy ecosystems. One of the top ten most significant wetlands and marine ecosystems in the world is the Niger Delta. Undoubtedly, the oil industry in this region has played a significant role in the country's growth and development. However, unsustainable oil exploration activities have left the Niger delta region among the five most severely damaged ecosystems worldwide due to petroleum contamination. Research has indicated that over a 50-year period, at least 13 million barrels of oil had been spilled [4,5]. Methods such as electrical resistivity, induced polarization, spontaneous potential, very low frequency electromagnetic (VLF-EM), and electromagnetic induction have been employed to assess environmental issues brought on by oil spills, landfill leachates, seawater intrusion, hazardous wastes, and groundwater potentials. The following: [6-15]. Multi-electrode resistivity survey has proven to be an incredibly successful geophysical tool for examining environmental contamination [16-18]. Electrical resistivity tomography (ERT) is typically used to process resistivity data from several electrodes.

The two- and three-dimensional resistivity distribution in geological structures can be seen using the multi-dimensional resistivity imaging technique known as ERT. Because oil pollution is a three-dimensional environmental issue that arises from a combination of dispersion and advection processes, the approach is especially well-suited for researching oil spills. Time-lapse (4D) surveys have found several uses in recent years.

1.1 The Study Area

Ikarama town in Okordia tribe, is a tiny town located within Yenagoa Local Government Area of Bayelsa State, Nigeria. The study area has its position of latitude 05°09'16° N and its longitude is 06°27'11°E. Ideally situated in the heart of Nigeria's Niger Delta, one of the world's richest wetlands. Bayelsa State enjoys a tropical climate with two distinct seasons: the rainy season, which runs from April to November, and the dry season, which runs from December to March. The state receives between 1500 and 4000 mm of rainfall annually [19]. The Nigeria AGIP Oil Corporation and the Shell Petroleum Development Corporation (SPDC) are housed in the town of Ikarama. The biggest environmental impact of the SPDC pipelines, which connect Nigeria's Delta, Bayelsa, and River states and run through the Ikarama town, has been claimed to be an oil spill caused by mechanical failure. The study site was chosen because of the frequent occurrences of oil leaks in the sites causing contamination in the community.

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

Shell Dutch at Oloibiri a Niger Delta hamlet, and commercial production started there in 1958 with a daily output of roughly 6,000 barrels [20,21]. Massive quantities of gas and oil exist in the region, which is also the sixth-largest crude oil exporter globally and the third-largest explorer globally, behind Indonesia [22]. Since December 1981, almost 90% of Nigeria's exports and about 80% of the country's income have come from oil extracted in the Niger Delta. The oil industry's overall economic contribution to the country increased from 84% in 2000 and 95% in 2002 to almost 96.7% in 2003 [23]. One of Nigeria's most environmentally vulnerable areas is now the Niger Delta. Nearly 97% of Nigeria's total exports come from oil and gas, making this region the country's primary source of income. The economy of the nation has been dominated by oil since the discovery of oil in the area. Due to its maritime location, the Niger Delta is particularly vulnerable to unfavorable environmental changes brought on by climate change. According to conclusive assessments, the area has turned into an ecological wasteland as a result of oil exploration and exploitation activities. The Niger Delta is most well-known today for being a hub for oil discovery and exploitation by western economies. Because of its huge oil reserves, the Niger Delta basin is regarded as the backbone of

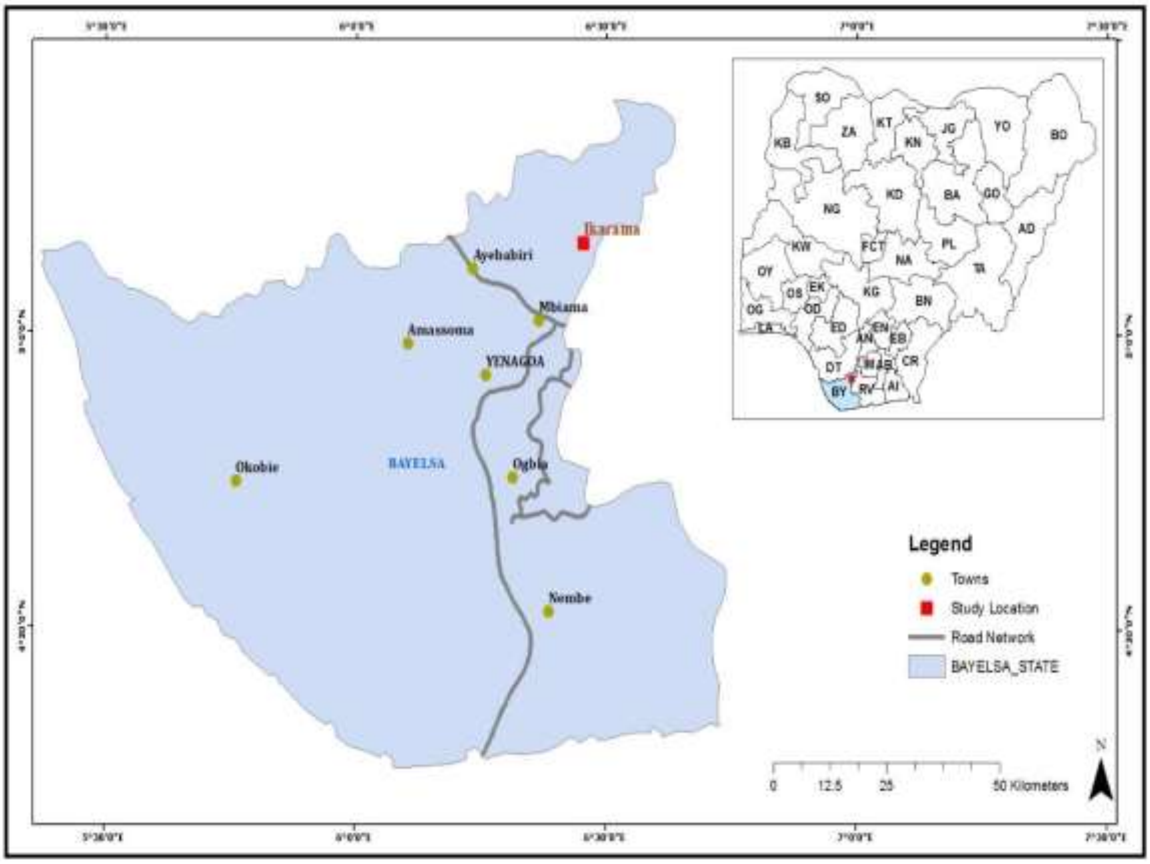

Fig. 1. Above is the map of Bayelsa State showing Ikarama community where the study site is located

the Nigerian economy. Additionally, the area has abundant natural gas and hydrocarbon deposits.

1.3 Oil Production in Nigeria

Since 1971, Nigeria has belonged to the Organization of Petroleum Exporting Countries (OPEC). Nigeria is the continent's main oil producer, accounting for 90% of its foreign exchange revenues and 85% of government revenue. It also boasts the greatest natural gas deposit and second-largest oil reserve in Africa [24]. Shell D'Arcy, the first oil business in Nigeria, began commercial production in 1958 at a rate of 5100 barrels per day, reaching a peak production of 2.44 million [25]. Its estimated reserves extend beyond years (NNPC, 1984).Production rates fell to 1.5 million foreign enterprises operating in 122 fields with over 970 oil wells, according to NNPC (1984) through OPEC. Prior to Shell and British Petroleum acquiring the majority of the refineries' shares, the Federal and the now-defunct Eastern Region Government controlled the majority of the shares [26]. In 1986, the NNPC assumed ownership and administration of the four refineries. Large amounts of natural gas are also accessible through a number of oil wells in the Niger Delta region; reserves are estimated to be 1422 billion cubic meters [24]. Since 1970, the Niger Delta region has been continuously engaged in extensive gas flaring. Nigeria has proven oil reserves of about 30 million barrels in 2001 [26]. With current oil development and production both inside and outside the continental shelf, Nigeria is projected to have 36.2 billion barrels of oil reserves as of January 2009 by the Oil and Gas Journal (OGJ) [26]. primarily in the deep offshore regions of the Dahomey Basin and the arid or swampy onshore areas of the Niger Delta basin [26]. Nigeria produces 500–5,000 barrels of crude oil per day from small fields, with light sweet crude accounting for 65% of the production. Light sweet crude is a very high-quality petroleum with an API gravity of 35°C and higher. Shell has an oil resource of more than 11 billion barrels per day, which is more than Mobil and Chevron put together. Shell produces more than 50% of

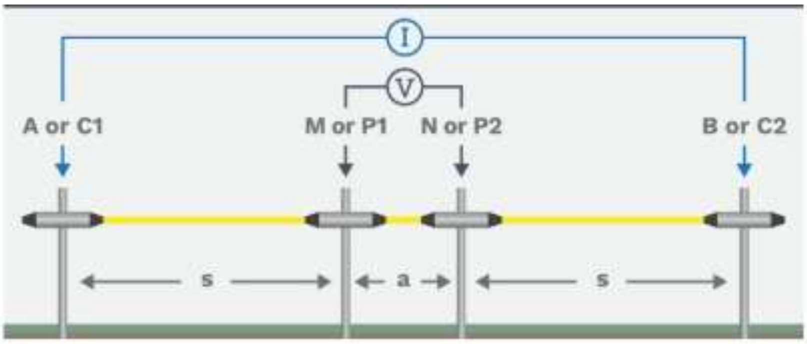

Fig. 2. Diagram of Schlumberger array configuration

Nigeria's petroleum from more than 100 fields. Mobil has two offshore operating bases: Escravos, in Delta State, and Eket, in Akwa-Ibom State.

1.4 Theoretical Background about the Schlumberger Array Method

Vertical Electrical Sounding (VES) for groundwater and mineral aggregation is a popular application for Schlumberger arrays. Four electrodes are positioned around a common midway in this array. It consists of two current electrodes spaced far apart and two potential electrodes positioned near to one another.

Throughout the survey, the two outer electrodes, A and B, are pushed farther apart for every measurement. Unless the detected voltages are too little and negligible to record, the inner electrodes are fixed at a certain point during the survey. As a result, the two outer electrodes, A and B, are separated by approximately one-fifth of their original distance, with the inner electrodes shifted outward.The resistivity is calculated thus

Resistivity

$$\rho = G_s R \quad (1)$$

Where G_s is the Geometric factor

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

AB = Current electrodes

MN = Potential electrodes

From Ohms law after several evaluations

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

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

2. MATERIALS AND METHODS

A resistivity meter called the ABEM Terrameter SAS 1000, Global Positioning System (GPS), measuring tape, and electrode were 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: two currents and two potential voltages. Reference electrode; this is also known as geo-reference. The electrodes were 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 for interpretation.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. 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 from1 m to 50 m in the study area. The electrode movements on the current electrodes C1 and C_2 are moved outward symmetrically, keeping P1 and P2 fixed at the center. With this procedure, often called electric drilling, the properties of the subsurface were explored to determine the load-carrying capacity of the soil, the in situ soil nature, and the water table across the study area.An array with four electrodes arranged in a line around a central midway is known as a Schlumberger array. The two inner electrodes, M and N, are potential electrodes positioned near to each other, and the two outer electrodes, A and B, are current electrodes. With the Schlumberger array, the potential electrodes M and N remain in the same location until the detected voltage becomes too low to measure, while the current electrodes A and B are pushed outward to a greater separation for each measurement (source). The potential electrodes M and N are now shifted to a new spacing outward. The appropriate distance between M and N should, as a general rule, be equal to 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.

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

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

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

3. RESULTS AND DISCUSSION

The data was acquired from the Ikarama community and is presented below in Tables 1 to 3.

Table 1. Showing the VES readings for the oil spill site at Ikarama Community VES 1

Half-current electrode spacing (m) AB/2	Half- potential electrode spacing (m) MN/2	Resistance (Ω)	Apparent Resistance (Ωm)
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

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

Half-current electrode spacing (m) AB/2	Half- potential electrode spacing (m) MN/2	Resistance (Ω)	Apparent Resistance (Ωm)
1	1	0.012853	0.012853
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. Shows the VES reading for the Ikarama community oil spill site

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
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

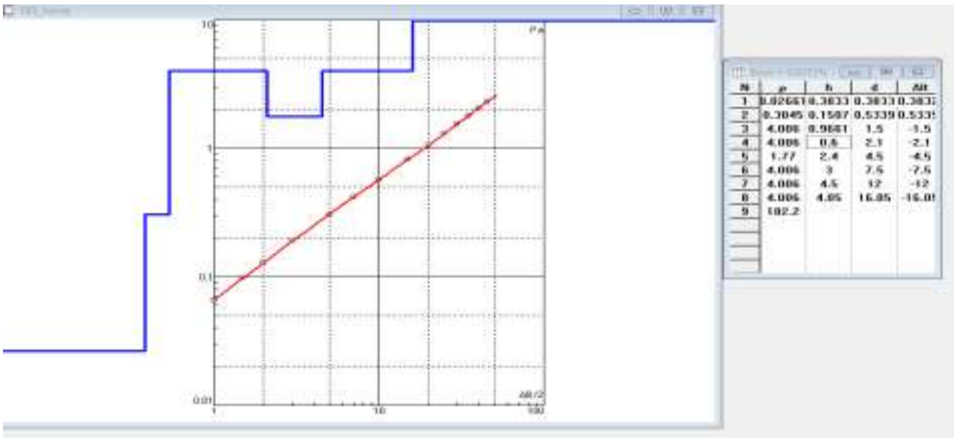

Fig. 6. Inverted Model Layer for VES 1: Ikarama Oil Spill Site

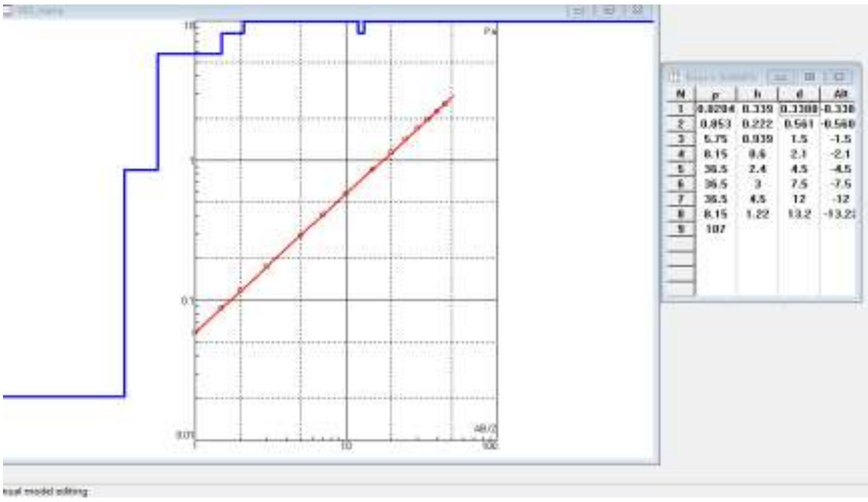

Fig. 7. Inverted Model Layer for VES 2: Ikarama Oil Spill Site

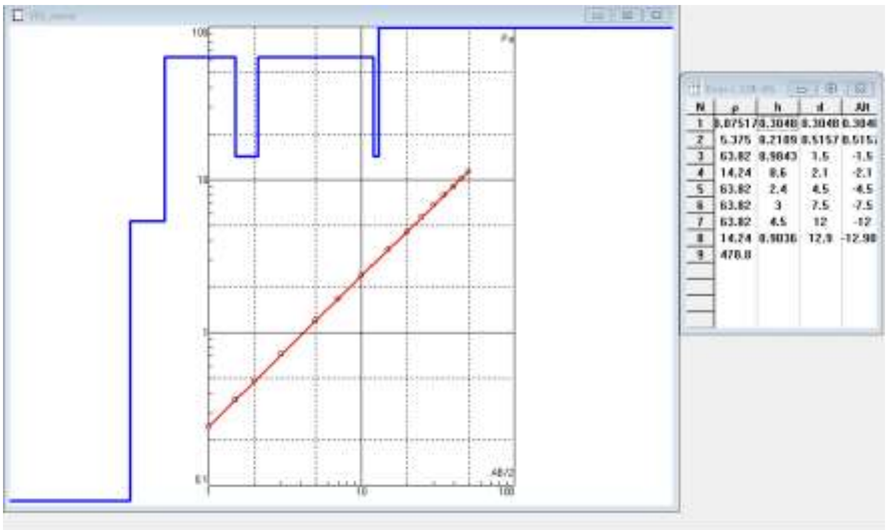

Fig. 8. Inverted Model Layer for VES 3: Ikarama Oil Spill Site

The research area's Vertical Electrical Sounding (VES) results indicated that the hydrocarbon resistivity at the Ikarama oil leak site varies from 1.77 to 63.82 Ωm. The resistivity model of the VES has a depth of 1.5 to 4.5 m and varies in resistivity values from 0.1 to 146.8 Ωm. The resistivity values of the top soil vary from 0.1 to 6.8 Ωm, and its thickness ranges from 0.68 to 1.5 m. Low resistivity values range from 0.1 to 15.8 Ωm, whereas high resistivity values range from 21.54 to 146.8 Ωm. Nonetheless, the resistivity model in the VES 3 result for the study region varies, with resistivity values falling between 0.15 and 284.8 Ωm and a depth between 1.5 and 4.5 m. The top soil has resistivity values ranging from about 0.15 to about 2.1 m. The low resistivity values are 0.1 to 6.5 Ωm. While its high resistivity values range from 35.11 to 284.8 Ωm. It now showed that because of the high resistivity in some areas of the study, it means that those places are highly infiltrated with crude oil and the contamination is high. That means the soil is no longer fertile for plant growth and aquatic life are endangered also.

The 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.

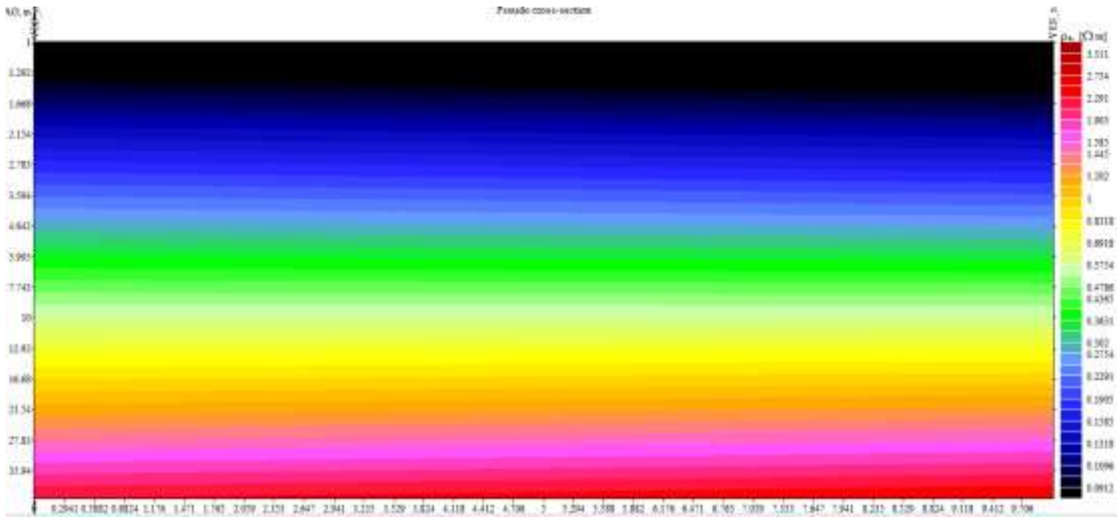

Fig. 9. Pseudo cross section VES 1

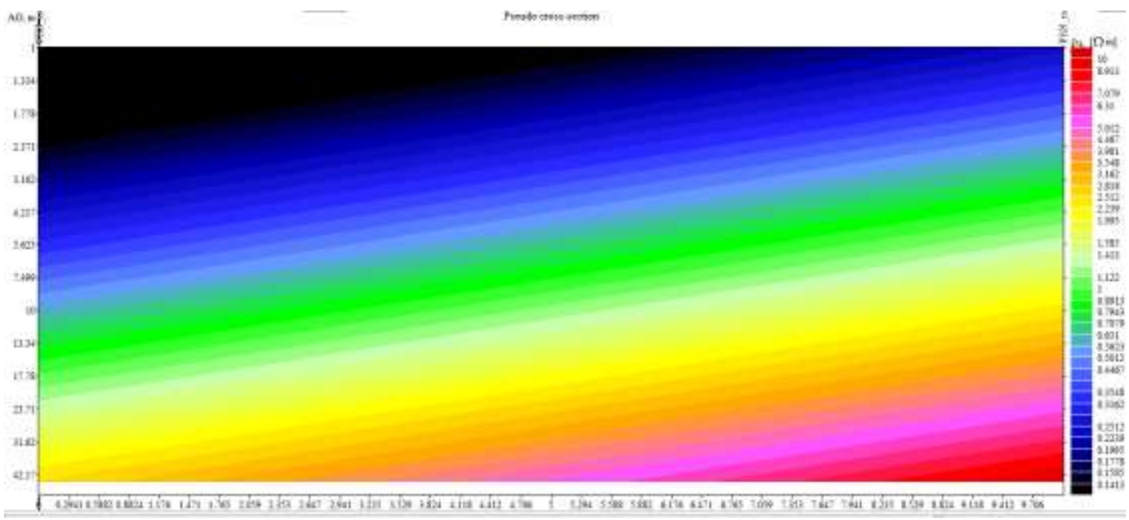

Fig. 10. Pseudo cross section VES 2

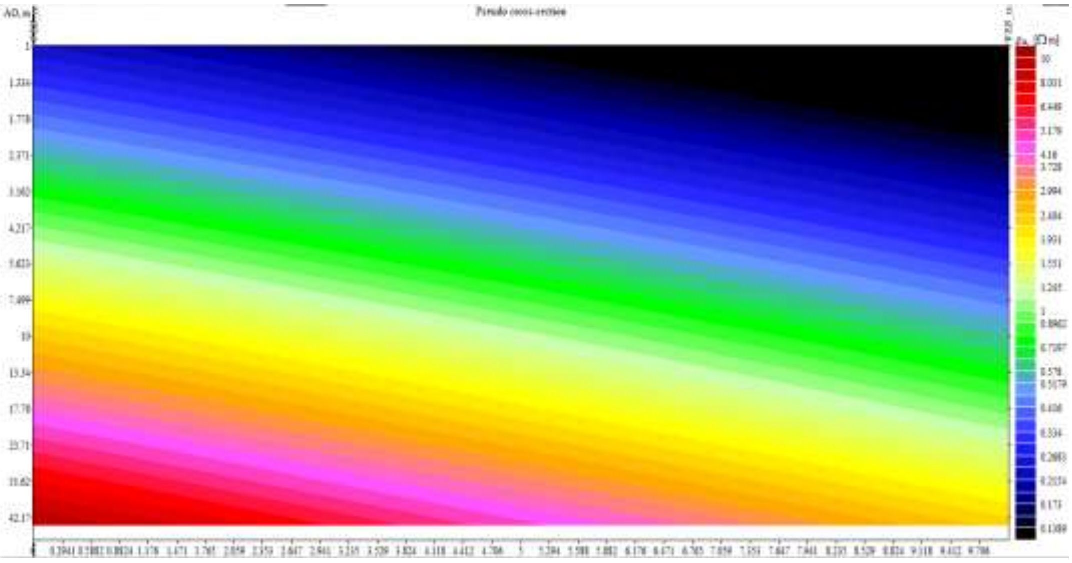

Fig. 11. Pseudo cross section VES 3

Figs. 9 through 11 display the 2D inverted resistivity images that are the outcome of the resistivity inversion process conducted at the Ikarama Community Oil leak site. Three meters separated the neighboring electrodes. The profile is 50 m long and 3 m apart from the profiles that are neighboring. Fig. 9 displays the inverse 2D resistivity model of VES (profile) 1 within the hydrocarbon spill site. The area's overall salinity is reflected in the low resistivity values (0.1–15.8 Ωm). While the hydrocarbon contamination (Oil Plumes) is the cause of the high resistivity values (21.54 – 146.8 Ωm). The top soil is impacted by the crude oil leak. It kills anything that is placed on the soil and lowers fertility. At depths of 1 to 12 meters, little resistivity is found, and high resistivity is found between 15 and 30 meters. Fig. 10 displays the inverse 2D resistivity model of VES (profile) 2, which is located within the polluted area. The inverted resistivity model has a depth of 2.1 to 7.5 meters and a resistivity value variation ranging from roughly 0.3 to 464.2 m. The resistivity values of the top soil range from around 0.3 to 3.8 Ωm, and its thickness is approximately 1.5 m.The area's salinity is the cause of the low resistivity readings (0.1–15.8 Ωm). The polluted area's resistivity values range from 38.31 to 464.2 m. The immature spill is the cause of this low resistivity value, whereas the oil plumes are responsible for the high resistivity values.

The spilled region also includes VES (profile) 3, and Fig. 11 displays the 2D resistivity model. The resistivity values in the inverted resistivity model vary, with a range of around 0.15 to 284.8 Ωm and a depth of approximately 1.5 to 4.5 m. The resistivity values of the top soil range from roughly 0.15 to roughly 2.1 m. The area's salinity is the cause of the low resistivity values (0.1 to 6.5 Ωm). While the hydrocarbon contamination (Oil Plumes) is the cause of the high resistivity values (35.11 to 284.8 Ωm).

4. CONCLUSION

In order to look into the hydrocarbon's migratory route and spread, an electrical resistivity survey was carried out at the site of a crude oil spill in the Ikarama community of the Okordia tribe in the state of Bayelsa. The resistivity values, when reversed, ranged from 0.17 m to around 146.8 m. The area's general salinity is reflected in the low resistivity values (0.17 to 12.12 m), but hydrocarbon pollution (Oil Plumes) is the cause of the high resistivity values (21.54 to 146.8 m). The inverted 2D models produced the lateral distributions of the hydrocarbon spill. The effectiveness of the 2D resistivity approach for examining hydrocarbon pollution in a coastal environment has been validated by this study. It now showed that because of the high resistivity in some areas of the study, it means that those places are highly infiltrated with crude oil and the contamination is high. That means the soil is no longer fertile for plant growth and aquatic life are endangered also.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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