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Delineation of Oil – Polluted Sites in Emohua LGA of Rivers State Using Resistivity and Induced Polarization Techniques

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ABSTRACT

A geophysical investigation was conducted in Obele Community in Emohua Local Government Area of Rivers State, Nigeria using the dipole-dipole electrode configuration to assess the impact of oil spillage on the environment. Oil spillage occurs due to a number of causes which include corrosion of pipelines, sabotage and oil production operations. Sabotage and oil siphoning has become a major issue in the Niger Delta States as well contributing to further environmental degradation. The study used vertical electrical sounding (VES) and resistivity/IP tomography to examine the extent of oil contamination in the soil and groundwater. The results showed that the study area is heavily impacted by oil spillage, with high resistivity values (up to 10,000Ω-m) indicating the presence of hydrocarbons. The contamination was found to be widespread, affecting both the soil and groundwater and originating from a possible point source along a pipeline section. The study also revealed that the aquifer in the area is unconfined, with high hydraulic conductivity values, making it vulnerable to contamination. The groundwater flow direction was found to be from NW to SE, indicating the potential direction of contaminant migration. The study recommends cleanup and remediation efforts to mitigate the environmental impact of the oil spillage. Going forward, security operatives should adopt a more robust way of handling apprehended vehicles and vessels containing stolen crude oil (oil Bunkry).

Keywords:
Electrical resistivity,
Induced polarization,
Conductivity,
Oil spill investigation,
Tomography.

INTRODUCTION

Crude oil spill is the unintentional release of liquid petroleum hydrocarbon into the environment as a result of human activity and equipment failure. The term often refers to marine oil spills where oil is released into the ocean or coastal waters. Most manmade oil pollution comes from land-based activity. Oil spillage occurs due to a number of causes which include corrosion of pipelines, sabotage and oil production operations. Sabotage and oil siphoning has become a major issue in the Niger Delta States as well contributing to further environmental degradation (Anderson, 2005). Damaged lives may go unnoticed for days and repair of the damaged pipes take even longer. Oil siphoning has become a big business with the stolen oil quickly making its way into the black market (Human Rights Watch, 1999).

Niger Delta is a region in Nigeria with ecologically and economically significant globally is one of the largest wetlands of the world and hosts Nigeria's oil & gas industry. Rivers State, one of the 9 States of the Niger Delta region with a significant amount of crude oil and condensate in Nigeria with some of the pipe lines of international oil companies (IOCs) passing through Emohua LGA.

In a decisive effort to curb illegal oil activities and to enforce law and order, whenever the security operatives apprehend any truck or vessel with illegal oil product, it will be burnt down in the LGA along the East West Road close to the Orashi River and on the sea. In the course of burning these vehicles large quantities of the oil are spilled to the environment including oil spills from pipelines bursts (vandalizations) and road tanker accidents as well as used oil dumped in the environment are huge and enormous An agency, the National Oil Spill Detection and Response Agency (NOSDRA) which was established in 2006 identified over 2,000 crude oil polluted sites needing remediation in the Niger Delta, with majority of these sites being SPDC sites.

Different methods can be used in delineating oil polluted sites. This research project on the delineation of oil polluted sites in Emohua LGA using Resistivity and IP techniques which is the first step in addressing the environmental pollution and its consequent damages due to oil & gas exploration and production (E&P) activities around the area. The induced polarization method (IP) is one of the electrical methods in geophysics which measures the responses generated from mineralized bodies that contain electric charges. Soils and rock materials contain polarized minerals within them such as clay minerals which differ from other minerals. The presence of clay minerals in the subsurface can cause these bodies to act as charge carriers whenever a direct current is passed through them. This is because the clay minerals exhibit membrane polarization which is due to the presence of residual charges on their surfaces. These minerals act as charge carriers therefore; they can store charges and release it along with the resistivity data during field acquisition. The capacity of the induced potentials can be high especially if certain fluids are present within the membranes of the clay mineralization (Weller, 1996). The IP measurements are largely dependent upon the grain size, clay, mineral type, cation exchange and water content respectively. Clay surfaces are covered with charges and this gives them the capacity to store and conduct electric current within their membranes. The ability of these clay earth materials to be polarized is because they contain some minerals which can be polarized and store electric charges (Elis et al, 2016).

IP surveys have been very useful in providing key information about the subsurface in oil spill contaminated sites. It is an electrical method similar to the 1-D and 2-D geo-resistivity techniques such as the Wenner and Schlumberger electrical resistivity techniques but it differs because it usually measures the response of the earth resistance to residual charges from polarized materials (Flyhammer, 2007). It can also be used to signify the earths' response to the moisture content, soil type, fluid type, rock properties such as porosity and permeability. The presence of earth materials can generally affect the resistivity. However, the IP anomalies occur with resistivity anomalies of interest and are generated in response of the earth due to some potentials induced by the presence of some earth minerals within the subsurface. This IP anomaly is usually caused by presence of minerals and there is need to isolate them to be able to delineate the actual resistivity anomalies. Examples, some clay minerals can generate and increase IP. The induced mineralization measures the chargeability in time domain (Nabigian 1976).

Location and Geomorphology of the Study Area

The study area (figure 1) is located between Longitudes 6° 41′ and 6° 41′ East and Latitudes 5° 0′ 11 and 5° 0′15 North. The study area is underlined by quaternary deposits of the Sombreiro Deltaic Plain directly overlying the prolifically aquiferous Benin Formation (Coastal Plain sands) which outcrops on the surface to the east and beyond, usually covered by laterite. The typical lithology of this area is sand, silt and gravel of varying thickness, occasionally including clay lenses. A thin veneer of alluvium is found on the course of the Sombreiro River draining north-southward to the west of the study area.

The geomorphology of the land is dominated by an almost flat terrain that is only few meters above mean sea level. Depressions and a few minor undulations that are perennially flooded also occur in the area. The hydrogeology of the area is characterized by relatively low water table. Borehole cuttings are often comprised mostly of well-sorted fine to coarse-grained sand formation. Some part of the aquifer is unconfined at while some portions are confined with significant clay layers outcropping to the surface in some segments of the surface runoff pathways into the Sombreiro River and the aquiferous materials are mainly sands. The aquifer recharge depends on rainfall and on hydraulic exchanges with the Sombreiro River.

The area considered in this study has close proximity to oil and gas exploration and production facilities including pipelines passes through the area. It is located in the north-west of Port Harcourt, Rivers state. The area has a large expanse of dense rainforest vegetation. The Orashi and Sombreiro river systems drain the area through several smaller streams and channels that crisscross the entire community (Awosika, 1995). The major occupations in the area are farming, fishing, trading and hunting.

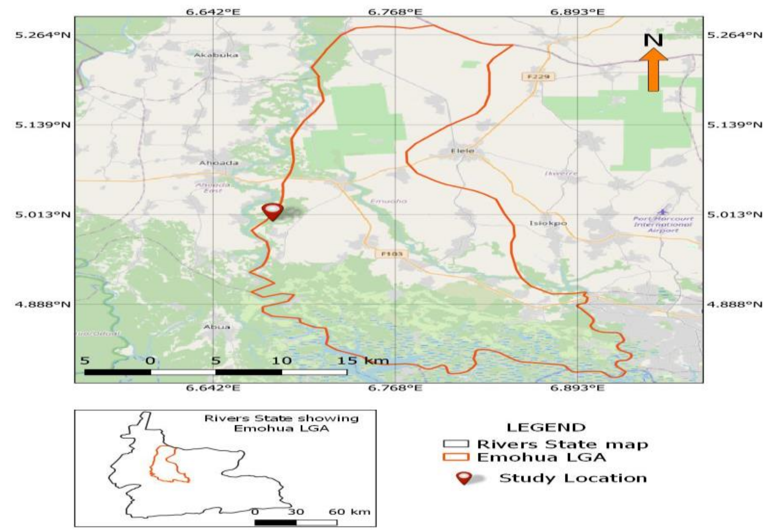

Figure 1: Map of Rivers State Showing Study Area in Emohua LGA

MATERIALS AND METHODS

The material and equipment that were used are complete set of SuperSting resistivity/IP/SP meter, cables, electrodes, hammer, water, meter tape, battery, cutlas, Weather protection shade, Contact resistance improvement sets, Personal Protective Equipment (PPEs), Cutlass and Shovels.

Similar to Hafiz et. al (2022), the geophysical field data were acquired utilizing Electrical Resistivity method (Vertical Electrical Sounding VES) and induced polarization IP using the dipole-dipole array electrode configuration. The study area was 160m X 60m and 160m X 30m with electrode spacing of 3m and profile interval of 20m (total of 4 profiles or line were done). With this configuration, current 'I' is passed into the ground using two electrodes A and B placed a distance 'L' apart. At the center of the two electrodes, the voltage is measured between two potential electrodes M and N, placed a distance 'b' apart. A pair of electrodes is energized by the meter and direct current is applied. This electrode pair creates a circuit through the earth and the current moves. As a result, a voltage potential is produced normal to current path. Adjacent electrodes then measure the voltage potential and the process is repeated with another electrode pair. Electrical resistivity imaging can differentiate between different lithologic materials (such as clay, sands, consolidated and unconsolidated deposits etc.) and the degree of water saturation (aquifer mapping) by measuring differences in the materials ability to conduct direct current electricity. Depth of penetration is a function of the length of the line. The IP technique is performed with the same equipment as resistivity but measures the time the earth material takes to discharge the induced charge thereby measuring the chargeability. Upon termination of the current, the ions will redistribute or relax back to the pre-energized conditions. This relaxation is the source of the IP effect. The IP response can only be used qualitatively and invasive techniques such as boring/sampling were used to confirm that the IP response is caused by non-aqueous phase liquid (NAPL). The infiltration of the water-saturated stratum by oil forms immiscible plumes producing irregular shapes of different sizes, thereby impacting the stratum's resistivity (Raji et al. 2018). The location of the oil plumes can be predicted from the size and distribution of the anomaly of the resistivity image (tomogram) (Loke and Barker 1996; Win et al. 2011). Therefore, the interpretation of the resistivity tomograms was based on this principle. Trimble GNSS Global satellite Positioning System was used to determine the geodetic system of actual coordinates and approximate altitude above sea level.

RESULTS AND DISCUSSION

It was observed that any resistive plume far below the water table is not being significantly naturally attenuated (the breakdown of the contamination is not decreasing significantly) as the conductivity values are very low in comparison to values at the groundwater table-NAPL interphase. The potential migration of resistive hydrocarbon materials to lower depths in this region has been reported by Abidoye and Wairagu 2013. The area is the distal part of the drainage into the south-eastern segment of the ox-bow swamp of the Sombrero River as well as a discharge point for the ground water flowing from north. The results obtained is similar to that of Hafiz et. al (2022). Table 1 shows the summary results of resistivity, induced polarization and conductivity of the study area.

Table 1: Summary Results of Resistivity, Induced Polarization and Conductivity of the Study Area

S/N	Line NO.	Resistivity (Ohm-m)					Induced Polarization (ms)				Conductivity (mS/m)			
		Inter Length (m)	Min	Max	Mean	STDEY	Min	Max	Mean	STDEY	Min	Max	Mean	STDEY
1	Line 1	0	49.5	10000	966.35	1162.7	-9.42	1154.11	226.07	265.51	1	20.87	3.19	2.82
2	Line 2	20	38.39	2655.55	597.71	531.07	-312.9	1098.57	192.14	217.16	1	28.27	3.49	2.99
3	Line 3	40	50.13	1619.04	408.78	315.42	-255.48	908.77	245.27	243.85	1	51.21	3.99	4.28
4	Line 4	60	30.99	2143.41	583.31	536.73	-201.76	865.19	187.85	178.78	1	45.92	4.14	4.41

Resistivity and IP Section Line 1

The inverted resistivity values along the survey line ranged from 49.5 to 10,000Ωm, with the highest readings concentrated within the Right of Way (ROW), particularly at the likely location of the pipeline crossing (Figures 1 & 2). Lower resistivity values were noted around the water table, although high resistivity also appeared near the surface in some areas. Depth-specific resistivity at 2.0m and 3.5m is illustrated in Figures 3 and 4, while Figures 5 to 7 display readings at specific points along the line 144.75m, 146.25m, and 147.75m. Resistivity lows (depressions) are evident in Figures 5 and 6 while a rebound is shown in Figure 7. Induced polarization (IP) values ranged from -9.4 to 1154ms (Figure 1 & 8), with a notable IP anomaly plume observed within the pipeline ROW, suggesting a potential groundwater discharge zone due to the upward spread of anomalies. This discharge zone may act as a source of re-contamination during the rainy season through the resurgence of free-phase oil. Conductivity readings along the line varied from 0.17 to 20.9 mS/m, with higher values closely following the water table zone, and lower values found both above and below the dissolved hydrocarbon plumes and non-aqueous phase liquid (NAPL) layers. The highest conductivity concentrations were recorded in the ROW area, indicating elevated IP anomalies within the water table fringe (Figure 14). A particularly significant conductivity spike was observed at approximately 144.75m along the line (Figure 12), which is likely the primary incident point.

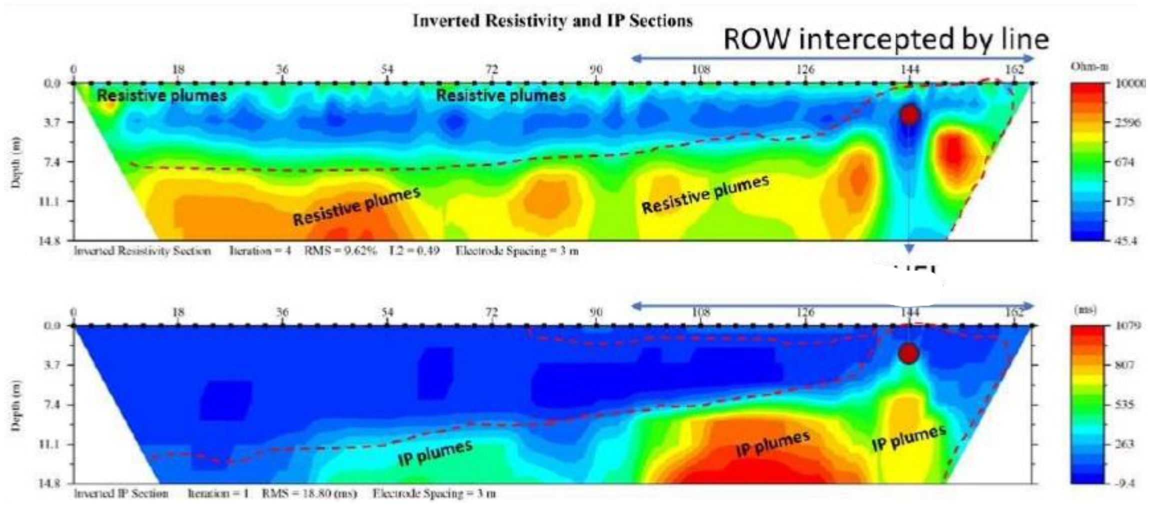

Figure 2: Line 1 Resistivity and IP Tomograph

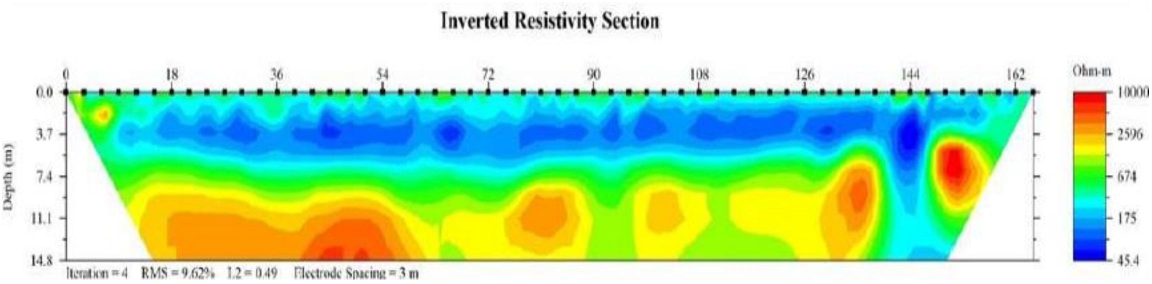

Figure 3: Line 1 Resistivity Tomograph

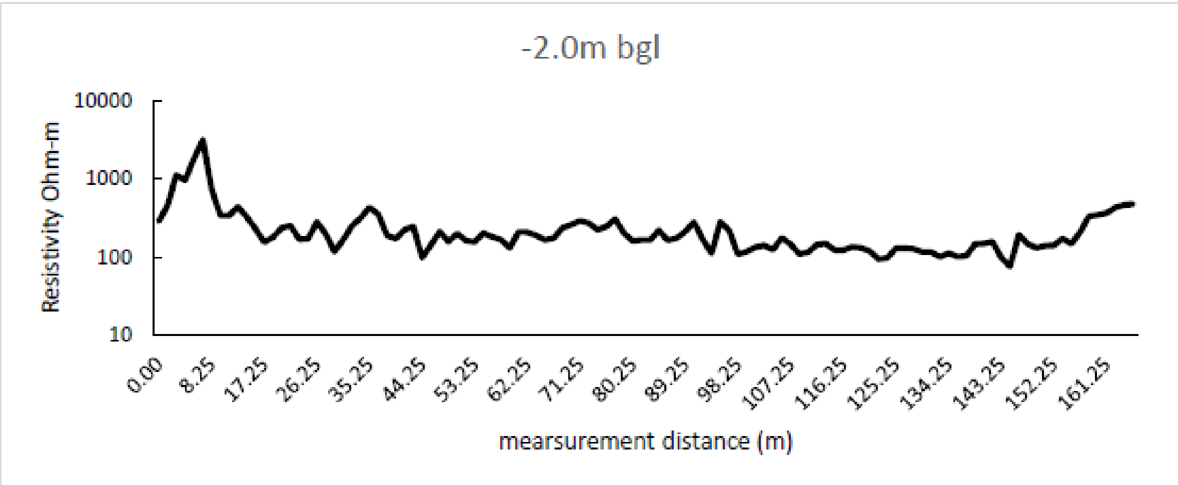

Figure 4: RES Value Graph of Line 1 at -2.0m bgl (Below Ground Level)

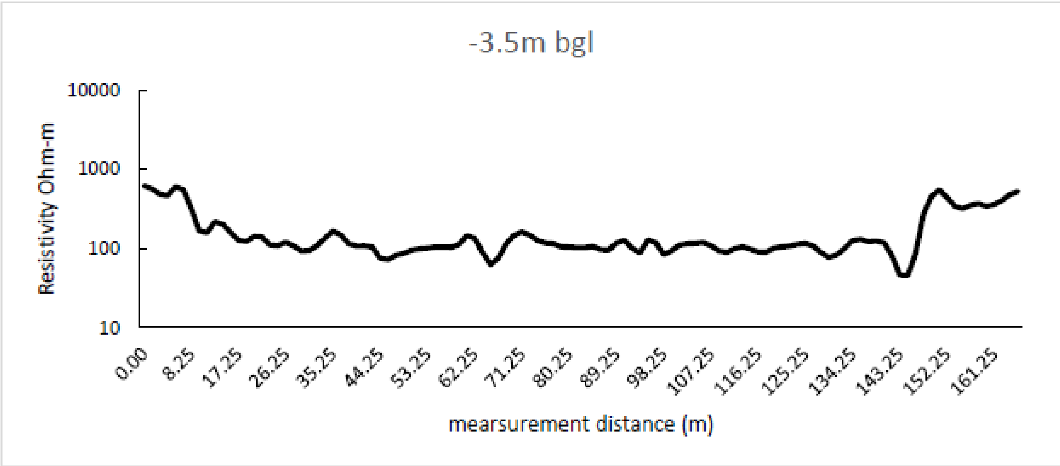

Figure 5: RES Value Graph of Line 1 at -3.5m bgl (Below Ground Level)

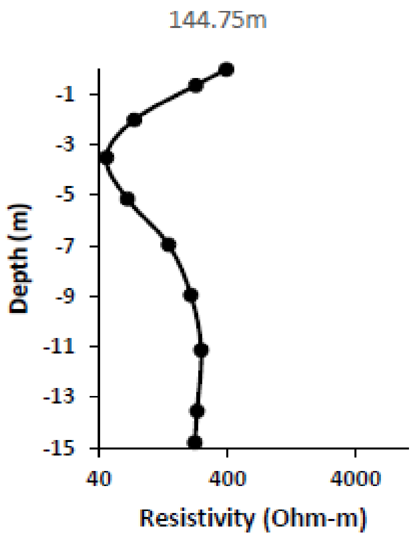

Figure 6: RES Value Graph of Line 1 at 144.75m

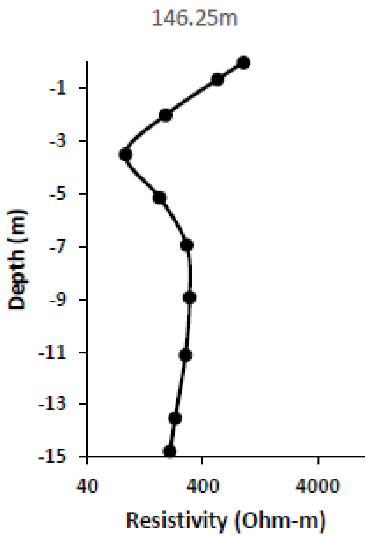

Figure 7: RES value graph of Line 1 at 146.25m

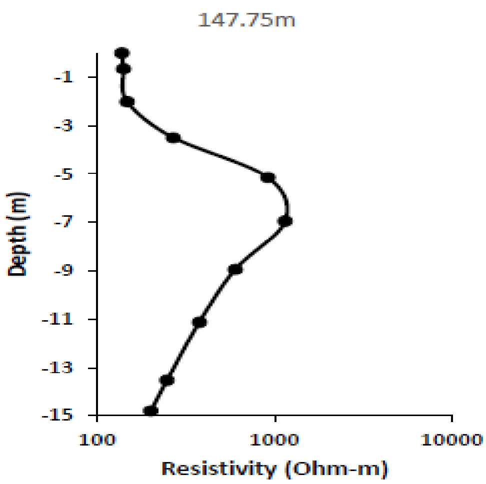

Figure 8: RES Value Graph of Line 1 at 147.75m

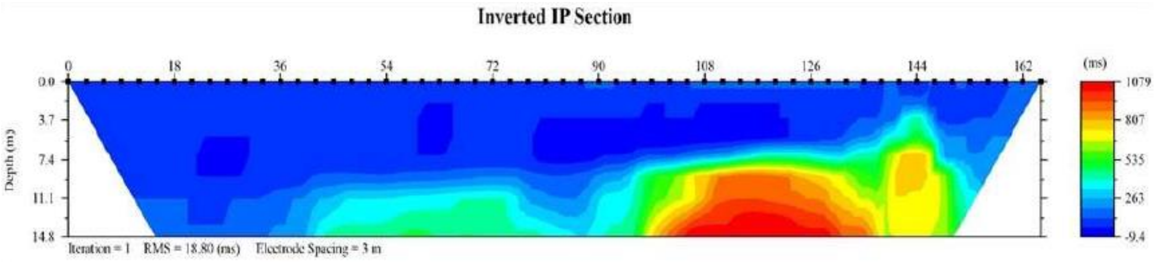

Figure 9: Line 1 Induced Polarization Tomograph

Figures 10 and 11 show the IP trends at two depth profiles -2.0m and -3.5m bgl, figures 11 – 13 show the IP values at three different points along the line 144.75m, 146.25m and 147.75m respectively.

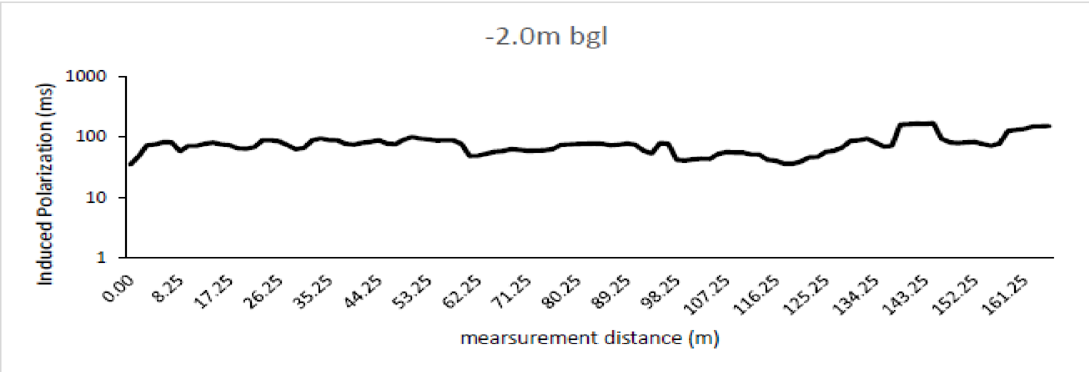

Figure 10: IP Value Graph of Line 1 at -2.0m bgl (Below Ground Level)

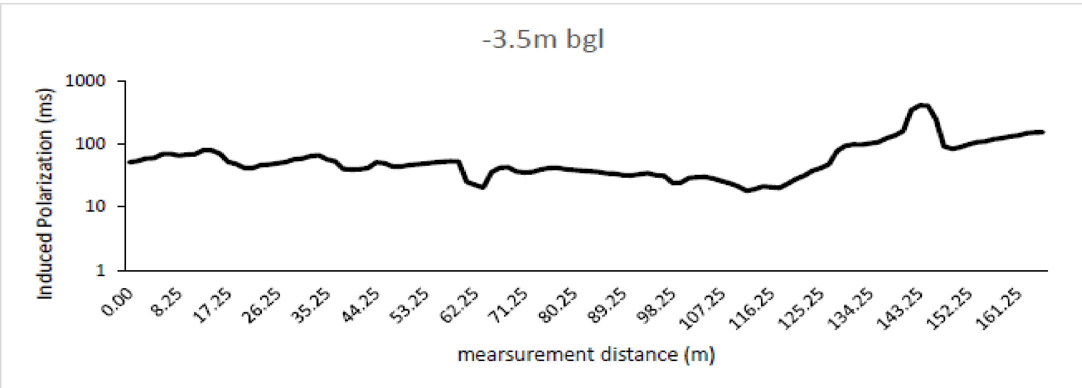

Figure 11: IP Value Graph of Line 1 at -3.5m bgl (Below Ground Level)

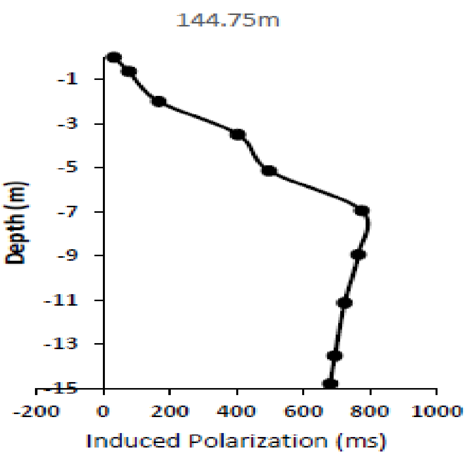

Figure 12: IP Value Graph of Line 1 at 144.75m

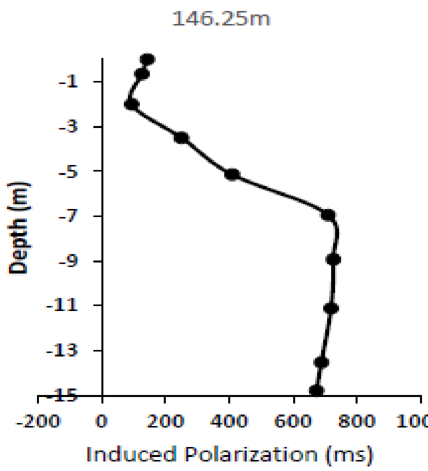

Figure 13: IP Value Graph of Line 1 at 146.25m

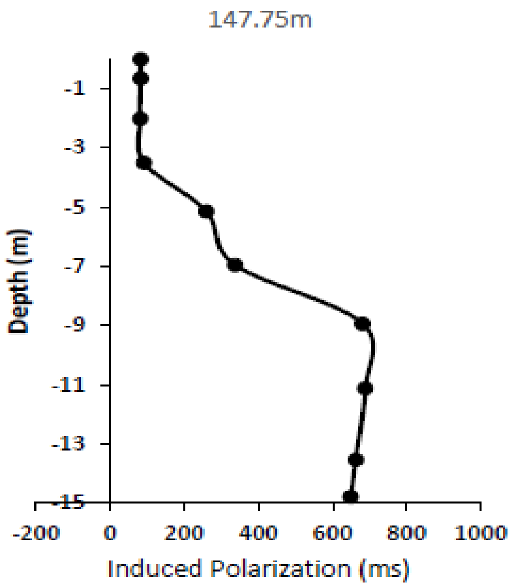

Figure 14: IP Value Graph of Line 1 at 147.75m

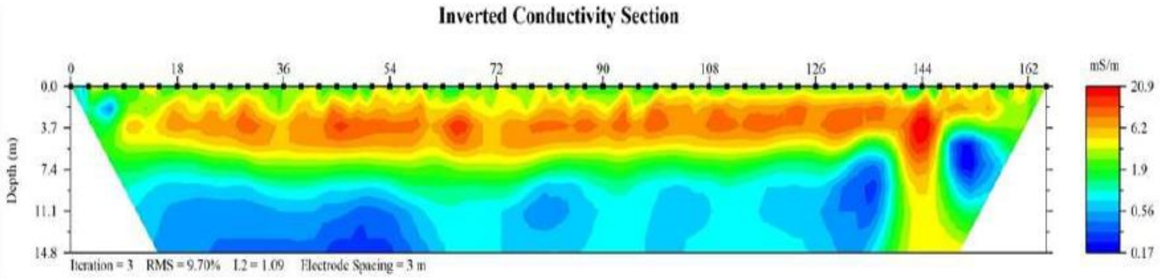

Figure 15: Line 1 Conductivity Tomograph

Figures 16 and 17 show the conductivity signature raw data graph at two depth profiles 2.0m and -3.5m bgl, while figures 18 – 20 show the conductivity values at three different points along the line 144.75m, 146.75m and 147.75m respectively. The characteristic shark fin shaped graph was observed at points with hydrocarbonoclastic activities with normalization at areas with reduced or non activities especially at the discharge points.

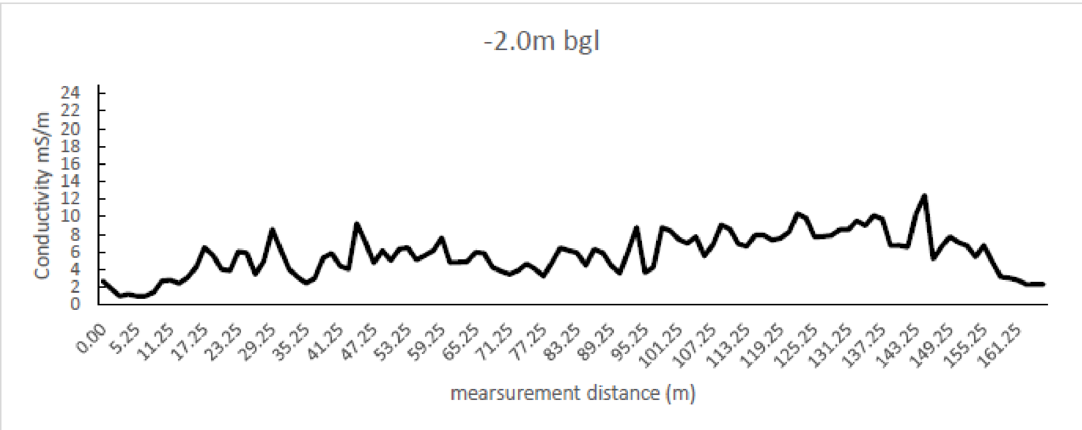

Figure 16: Conductivity Value Graph of Line 1 at -2.0m bgl (Below Ground Level)

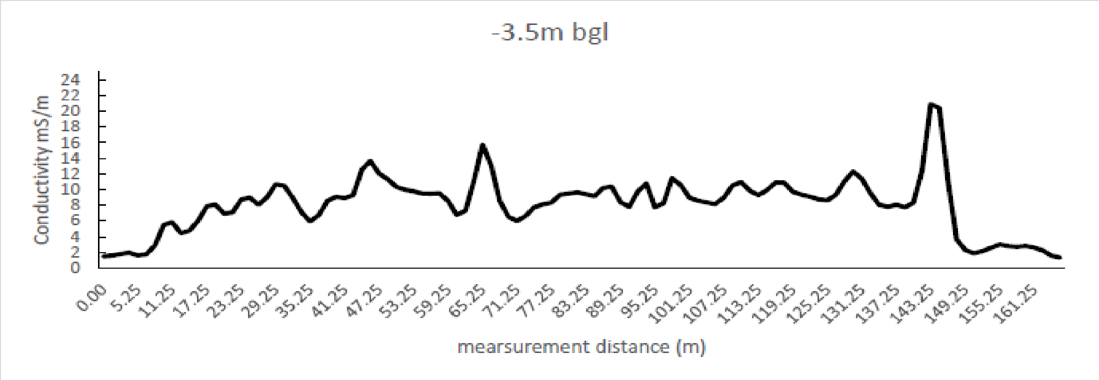

Figure 17: Conductivity Value Graph of Line 1 at -3.5m bgl (Below Ground Level)

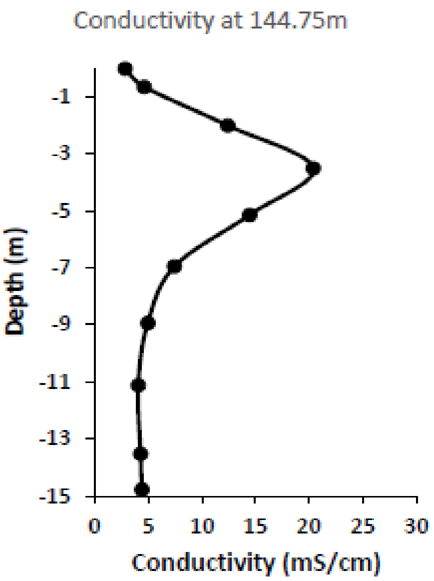

Figure 18: Conductivity Value Graph of Line 1 at 144.75m

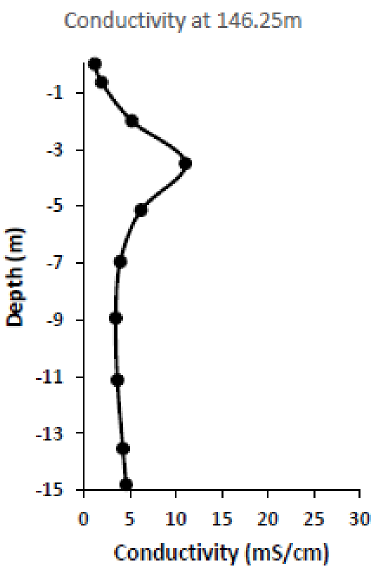

Figure 19: Conductivity Value Graph of Line 6 at 146.25m

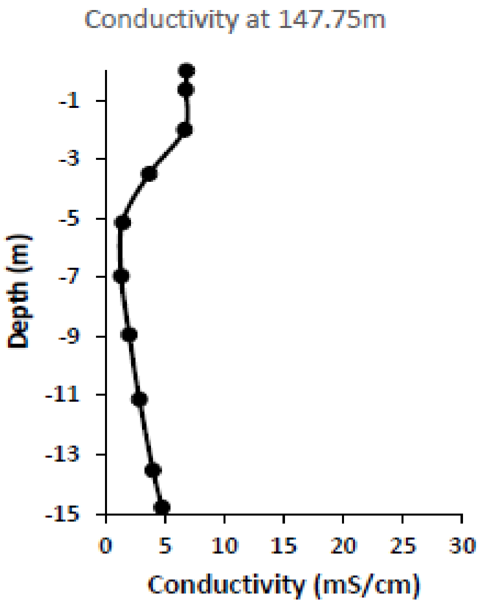

Figure 20: Conductivity Value Graph of Line 1 at 147.75m

Inverted Resistivity Section Line 2

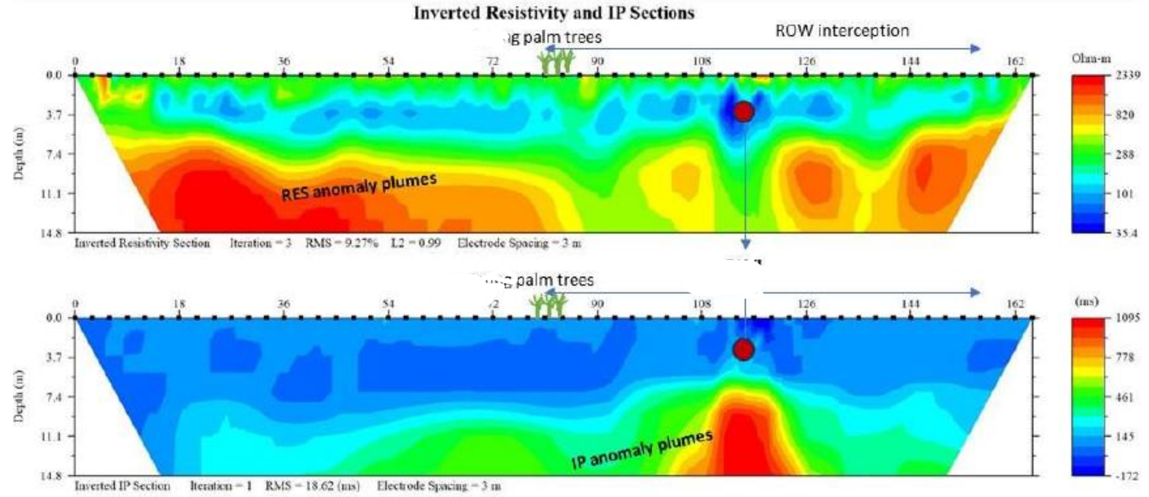

Figure 21: Line 2 RES/IP Tomographs

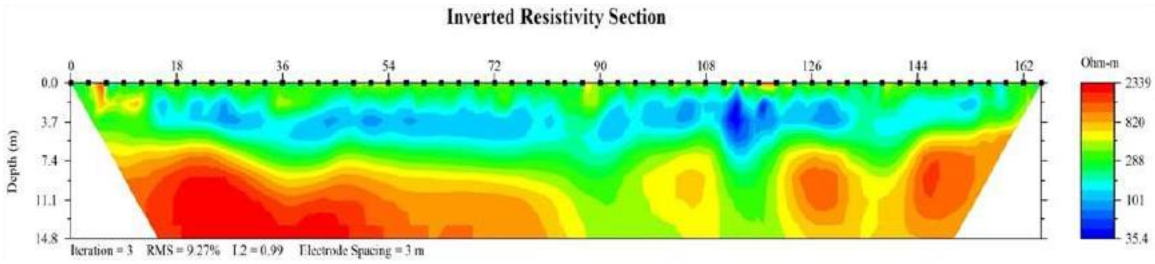

Figure 22: Line 2 Resistivity Tomograph

The resistivity values recorded along Line 2 ranged from 38.39 to 2655.55Ωm (Figures 21 & 22), with the most resistive zone appearing near the Right of Way (ROW) at the far end of the line where it intersects the pipeline, though this anomaly is located at greater depths. This resistive pattern is similar to what was observed on Line 1. The water table zone exhibited lower resistivity values compared to both the deeper layers and the near-surface zones before saturation. Notably, resistivity dropped significantly above the suspected incident point on the line. In contrast, the conductivity increased in this area. Induced polarization (IP) readings were most prominent beneath the pipeline and extended across a highly chargeable zone. From a depth of 7.4m below ground level (bgl) up to the surface, IP values were generally lower than those found at greater depths, particularly beneath the likely point of hydrocarbon release. IP values in this section ranged between -172 and 1095ms (mV/m), suggesting that the IP plume beneath the pipeline could be contributing to the residual charge distribution through groundwater movement. Conductivity values along the water table in Line 2 were generally higher than those in Line 1, ranging from 0.43 to 28.3 mS/m, with the highest readings concentrated around the ROW where the pipeline runs. The conductivity in the water table zone was significantly elevated in this section compared to distal areas closer to the swamp and known discharge zones. This suggests that a major spill of highly chargeable hydrocarbons may have occurred at this location, resulting in the deep migration of contaminants and a noticeable conductivity signature well below 7.4m bgl.

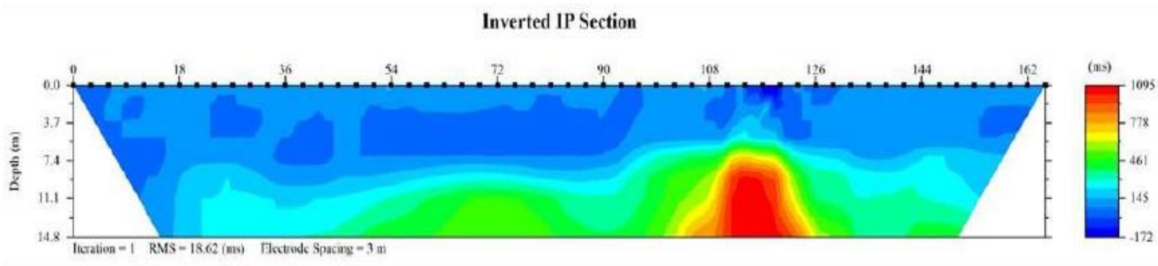

Figure 23: Line 2 Induced Polarization Tomograph

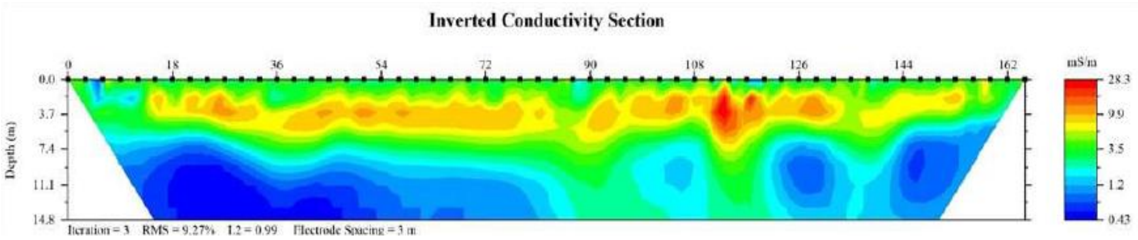

Figure 24: Line 2 Conductivity Tomograph

Inverted Resistivity Section Line 3

Line 3 which intersected the pipeline between 72m and 138m recorded resistivity values ranging from 20.8 to 4800Ωm. The highest resistivity zones were observed away from the ROW boundary at the pipeline location, possibly indicating the presence of residual, highly resistive materials from past spill incidents that may have migrated from the ROW. The spread of the resistivity signal suggests that the ROW could be a significant source of resistive contaminants migrating eastward toward the seasonal swamp. Surface observations along the line revealed visible hydrocarbon staining, and an auger hole drilled at 81m confirmed the presence of free-phase oil at the water table. The IP (Induced Polarization) readings along the line revealed a plume that increases in intensity upward, clearly originating from the pipeline at the ROW. This plume spread laterally across the line, with values ranging from -107 to 894ms (mV/m), gradually decreasing as it extended outward. Near-surface IP values (0–2m) were relatively low, around 100 mV/m, but the auger hole findings confirmed hydrocarbon presence below the surface and at the water table. Conductivity values ranged between 0.21 and 57.5 mS/m, with a notable increase around the likely incident point at 89.25m indicating a strong correlation between high conductivity and hydrocarbon contamination in that area. Raji et al. (2018) applied 2D electrical resistivity tomography (ERT) and vertical electrical sounding (VES) to map out areas contaminated by oil spills in the coastal areas of the Ijegun Community of Lagos, Nigeria. The results revealed that there was the presence of contaminants of different extents and shapes around the area. It was discovered that the top aquifer around Ijegun has been infiltrated by oil plumes and the contaminant plumes emanating from oil spills are yet to undergo complete degradation as at the period of the research.

Inverted Resistivity Section Line 4

Resistivity values along Line 4 ranged from 30.9 to 2143Ωm displaying a pattern and orientation similar to those observed in Line 3. The distribution of resistivity indicates a likely source of contamination originating from the pipeline Right of Way (ROW) with notable resistive inputs at the water table level, as shown by the broad spread of the resistivity signature across the line. A horizontal resistive layer was identified on the northwest side of the ROW which was found to be a layer of Low-Density Polyethylene (LDPE), a remnant of an in-situ biocell remediation system previously installed at the site. The Induced Polarization (IP) values mirrored the resistivity distribution, with the strongest IP responses found beneath the pipeline ROW, spreading northeast and southwest. IP readings ranged from -39 to 855ms (mV/m). Lower IP values were observed from 8.6m depth to the surface, with the lowest occurring within the water table zone — a pattern likely linked to intense microbial hydrocarbon degradation at that depth. The most significant IP plume centred around the suspected spill point on the ROW. The conductivity pattern resembled a mushroom shape radiating from the pipeline incident area, similar to Line 3, but with higher values at deeper depths, suggesting more extensive hydrocarbon breakdown. Conductivity was notably elevated across the line down to 7.4m below ground level, with values ranging from 0.43 to 63 mS/m.

In Algeria, Brahmi et al. (2021) used electrical resistivity tomography (ERT) and induced polarization (IP) techniques to investigate groundwater and soil pollution in Tebessa municipal landfill in North East Algeria. The study revealed large zones of decomposing waste bodies saturated with highly conducting leachate. The high mineralization concentration in the unsaturated zone can be attributed to leachate leakage through the limestone of the area. Water quality analysis showed that Cd, Pb, Cu, Zn, Fe, and Mg element concentrations in sediments of the area have caused water quality deterioration. Similarly, Hudson et al. (2018) used the electrical resistivity tomography subsurface imaging method to assess the surface and subsurface hydrological contamination at Esgair Mwyn, an abandoned mine in Ceredigion Wales. The electrical resistivity tomography subsurface imaging revealed a seepage plane within the tailing's lagoon wall, while the main tailings heap showed increased saturation with depth. Shao et al. (2019) mapped contaminant plumes of an abandoned hydrocarbon disposal site in Jiangsu, China, using geophysical and geochemical methods. The study indicated that the source zone of the contaminants had undergone long-term natural attenuation and continual organic matter output to support contaminant plume expansion had ceased. The delineation of contaminant plume distribution revealed that its distribution in the vertical direction was related to the hydrocarbon release history (release rate and volume) and was influenced by fluctuations in the groundwater level. While these methods have been applied in many parts of the globe and in some parts of Nigeria for environmental pollution, they have not been widely applied by individuals or researchers for such purposes due to associated costs but mostly by companies. However, few studies available such as Addressing Environmental Health Problems in Ogoni land through the implementation of United Nations Environment Program Recommendations (Yakubu 2017) and “Hydrocarbon pollution in the Niger Delta: Geographies of impacts and appraisal of lapses in the extant legal framework” (Anejionu et al. 2015) showed that there is extensive environmental pollution in the Niger Delta area. This present study supports the findings from the previous studies. In addition, this study revealed the types of hydrocarbons that are present in the study area which can be of importance in correlating the associated diseases in the area with the location of facilities such as water wells and the types of hydrocarbon contaminants.

CONCLUSION

Results obtained from the geophysical investigation indicate that several soil matrices within the study area including the ground water are potentially impacted with a high resistive material as a result of several wilful sabotage within the area. The site is generally impacted with a higher than natural level resistivity elevating material in the soil and ground water to a measured depths of 7.0 - 22 m below the ground surface. The results also show the sources of this material in the area to have originated from a possible point along the pipeline section within the measured grid. There are several secondary (residual) sources of re-contamination enhanced by the groundwater movement (seasonality) in the area. Ground truthing evidences via auger holes and trial pits confirm the high-level suitability of the Resistivity/IP data for the identification of hydrocarbon contaminated sites. From the findings, it is recommended that immediate cleanup and remediation of the study area aimed at removing the deep siting hydrocarbon residues. Post cleanup and remediation geophysical imaging to ascertain the absence of hydrocarbon risks plume in the subsurface soil and groundwater systems. The security operatives should find a more robust way of managing stolen crude oil (oil bunkry) activities. They should stop burning vehicles and vessels containing or conveying illegal products to the environment. Maybe take the product (oil) to our refinery for better distillation and the money will be remitted to the federation account.

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