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INTEGRATED GEOPHYSICAL AND GEOCHEMICAL CHARACTERIZATION OF HYDROCARBON CONTAMINATED SITE IN ERHOIKE-KOKORI, SOUTHERN NIGERIA

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ABSTRACT

The effectiveness of geophysical and geochemical methods in delineating hydrocarbon contamination in a spill site is carried out around theErhoike flow station in Kokori, Ethiope East LGA, Delta State. Wenner array was used for the transverse in acquiring the data which spanned a transverse of 200m and 3D model resistivity images were obtained from the inversion and presented in horizontal depth slices. Well water samples were also taken for Total Petroleum Hydrocarbon (TPH) content while soil samples from the location were also taken for Porosity and coefficient of permeability. The result of the 3D horizontal depth slices in the location reveals that Erhoike is impacted with hydrocarbon plume to a depth of 31.7m. The concentration of TPHCs from the water analysis shows that the wells around the suspected zones are affected by hydrocarbon. The laboratory tests for porosity (Φ) and coefficient of permeability (k) for the soil samples are indicative of sand/silty sand which thus allows the flow of PHCs plume to the soil and groundwater in the study area. The results of the study have shown that the soil is permeable and porous which would allow the passage of the leaked and spilled PHCs through the soil to groundwater where the PHCs could mix, float and sink into groundwater. The 3D analysis revealed the presence of PHCs up to a depth of 33.7m but prominent at a depth of 10m which indicates the presence of PHCs in the wells. The hydrochemical analysis also proved the same results as that of the 3D which authenticated the reliability of the method used in the study.

Keywords: Total Petroleum Hydrocarbon, Plume, Geophysical, Geochemical

INTRODUCTION

Oil pollution is also widespread and arises at all stages of the petroleum industry: extraction, transportation, refining and distribution (Shevnin*et al*., 2003). A serious environmental concern is the movement of pollutants to the water table and subsequent contamination of drinking water resources (Okezie and Elijah, 2014). When oil leakages and spills happen, both surface and underground water are affected negatively resulting in the need to ascertain the extent to which subsurface water has been affected by hydrocarbon leakage (Nwankwo and Emujakporue, 2012).

Each year, several post-impact assessment studies are carried out to assess the impact of hazards caused by oil activities and spills on the physical and social environments. Several of these studies have reported the negative socioeconomic impacts of oil spills, such as a decrease in agricultural productivity due to farmland degradation, pollution of traditional fishing grounds and destruction of aquatic life, as well as negative effects on soils, forests and water bodies (Gbadegesin, 1997; Omofonmwan and Odia, 2009; Egbe and Thompson, 2010).

Soil contamination by hydrocarbons has been a serious problem for the environment for many years to human life, marine life, wildlife and micro-organisms in the soil. To conductadequate remediation, the characterization of the contaminated zone should be performed by different techniques, usually direct methods, such as physical analysis (i.e., odour, colour, and texture) and chemical analysis (i.e., pollutant concentration) (Arrubarrena-Moreno and Arango-Galván, 2013).

Geophysical surveys of sites contaminated by oil are important for estimating the extent of damage caused by oil spills, designing repair methods, and evaluating the effectiveness of the repair process (Yihdego and AlWeshah 2016). Compared with traditional soil sampling and chemical analysis methods, the geophysical methods used to investigate oil-contaminated areas are cheaper, more time-saving, and nondestructive. Resistivity, very low frequency electromagnetic (VLFEM), induced polarization, self-generated potential, and electromagnetic induction methods have been used to assess environmental problems caused by oil spills, landfill leachate, seawater intrusion, hazardous waste, and groundwater potential (Shevnin*et al*., 2005; Atakpo 2013; Abubakar*et al*., 2014; Raji and Adeoye 2017, Elmamy*et al*., 2021). Among the geophysical methods, the success of the resistivity method using the Wenner and dipole-dipole array for investigating environmental pollution is outstanding (Hinnell *et al*., 2010, Win *et al*., 2011). These methods are particularly suitable for investigating oil spills, because oil pollution is a three-dimensional environmental problem caused by a combination of decentralized and advection processes.

In this study, the research work was done to characterize the subsurface soil and delineate the hydrocarbon contamination plume in the study area using electrical resistivity and hydrogeochemical methods.

MATERIALS AND METHODS

The Study Area

Erhoike is an oil-producing community under Kokori town in Ethiope East Local Government Area of Delta State. The area is located within longitudes and latitudes E 006 03’32.56 to 006 04’01.62 and N 05 38’38.28 to 05 38’47.36. The area is blessed with so many oil wells and oil platforms. Also, the community is underlain with many oil pipelines crisscrossing the community. Farming is the main occupation of the people of the area and cassava and palm fruit production is their major agricultural produce.

Method

For the geophysical part of this study, ten (10) traverses were done in a grid format as shown in Fig 1. The Wenner array was embraced and the Res2Dinvx software was used for the inversion of the resistivity data to generate the2D resistivity image and the 3D depth slices were also generated to map the continuity of the contaminant in the subsurface. The images were then interpreted qualitatively and semi-quantitatively to map out the possible impacted zones within the area. For the geochemical analysis, soil samples were taken from two (2) locations within the study area using the soil auger. The soil samples were taken at depths of 0 to 10 cm, 10 to 25 cm and 25 to 30 cm respectively. The topsoil was removed up to the depth of 15 cm and then the soil beneath was taken; this was repeated for subsequent sampling points.Also, the location coordinates of the four(4) water sample points were collected from the study area. Three (3) from the affected area and one (1) far from the affected

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area which serves as a control sample. The samples were collected using one liter of cleaned plastic bottle for each and then sealed. Well (W1-W4) at Erhoike Community was taken with a Global Positioning System (GPS). Water samples were collected from a borehole at 45 m deep located at the northern, northwestern and southwestern parts of the area Figure 1. The physical parameter observed in the field was the color of the water. The collected samples were not preserved because the samples were sent directly to the laboratory for analysis. The water samples were filtered to remove suspended particulates from the samples before analysis.

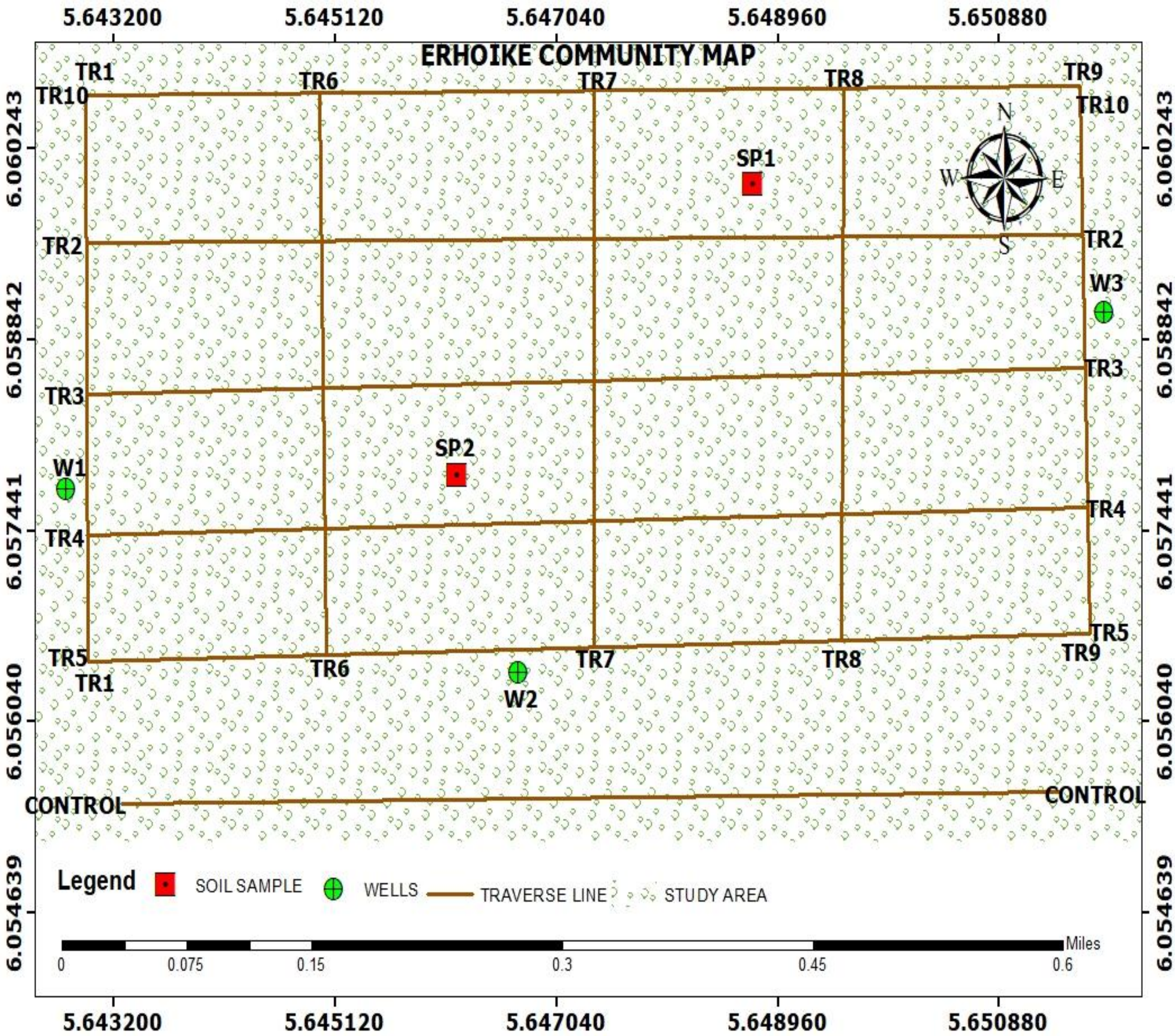

Fig.1: Basemap of Erhoike showing traverse lines, wells and soil sample points

RESULTS

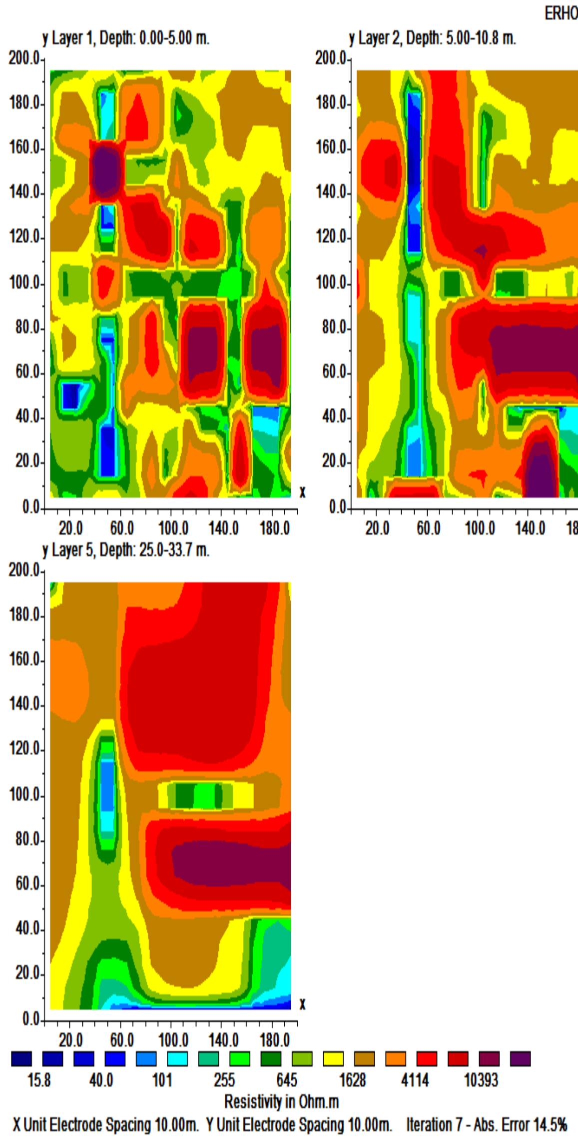

Figure 2: Horizontal Depth Slices obtained from the 3D Inversion of Square 2D Profiles in Erhoike Community.

Table 1: Water samples analysis results of Erhoike

S/N	Sample Code	Water Table Depth (m)	Coordinate	Elevation (m)	Concentration Of Total Petroleum Hydrocarbon (Mg/L)	Fmenv (1991) Permissible Limit (Mg/L)
1	Well 1	11.5	N05°38′55.2″ E06°01′ 29.2″	10	11.8	10
2	Well 2	10.8	N05°38′49.6″ E06°01′ 35.4″	11	11.2	10
3	Well 3	13.8	N05°38′47.6″ E06°01′ 27.1″	11	12.7	10
4	Control	4.9	N05°44′31.1″ E05°54′ 09.8″	11	Nil	

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Table 2: Soil analysis results of Erhoike

Soil Sample no:	Location	Coefficient of permeability K (cm/s)	Porosity (∅)
1	N05º38′39.86″ E06°03′ 55.42″	5.76942×10^{-3}	0.586
2	N05º38′44.62″ E06°03′ 53.48″	7.68711×10^{-3}	0.563

Table 3: the standard coefficient of permeability values of soil (Evirgen*et al*., 2015).

Soil Type	Coefficient of permeability K (cm/s)
Clean Gravel	1.0-100.0
Coarse Sand	1.0-0.01
Fine Sand	0.01-0.001
Silty	0.001-0.00001
Clay	Less than 0.000001

Table 4: The standard Porosity values of soil (de*Castro et al., 2014)*.

Unconsolidated deposits	Coefficient of permeability K (cm/s)
Gravel	0.25–0.40
Sand	0.25–0.50
Silty	0.35–0.50
Clay	0.40–0.70

DISCUSSION

Figure 2 displays the 3D depth slices of the Erhoike community. The structure revealed clayey sand/sandy clay, sand and sand impregnated with hydrocarbon having resistivity values ranging from 73.4 – 24872 Ωm. At depth range of between 0 – 5 m, the resistivity values range from about 2049 – 24872Ωm which is indicative of sand impregnated with hydrocarbon. At a depth range of between 5 – 10.8 m, the resistivity values range from 891 – 24872Ωm which is representative of sand and sand impregnated with hydrocarbon. At a depth of 10.8 – 17.4 m, the resistivity ranges from 388 - 4708Ωm representing sand and sand impregnated with hydrocarbon. At a depth of 17.4 – 33.7 m, the resistivity ranges from 73.4 - 4708Ωm indicating clayey sand/sandy clay, sand and sand impregnated with hydrocarbon. The sand impregnated with hydrocarbon is decreasing with depth. Generally, the 3D depth slices show that the resistivity values progressively increased downward with the highest resistivity values occurring at a depth of 25 – 33.7 m. This result correlates positively with other similar research such as Eze *et. al.* (2013), Airen and Emenim (2021), Eze*et. al.* (2021). This indicates that the hydrocarbon pollutant has moved downward to a depth of more than 33.7 m.

Discussion of water sample analysis

Table 4.1 shows the results of the water samples analysis with depth to water table of 10.8 – 13.8 m. The results indicated that all the water samples contained petroleum hydrocarbons (Well 1 – Well 3) except the control. Total petroleum hydrocarbons (TPHCs) levels of the samples ranged from 11.2 to 12.70 mg/L in Erhoike. Water samples from well 3 had a concentration of approximately 13.00 mg/L which was the highest level of TPHCs recorded in the studied water samples. This level was higher than 10.0 mg/L which was the permissible limit of the Federal Ministry of Environment in Nigeria (FMEnv 1991). The value of Total Petroleum Hydrocarbons in the water sample from well 3 was 12.7 mg/L. The value of TPHCs is higher here because of the suspected source of TPHCs leaking point. The higher level of the TPHCs in wells 3 and 4 could be attributed to the fact that it was located at the bottom of the slope and that TPHCs flow follows the topography pattern of the environment. The presence of TPHCs is not noticeable in the control sample because the well is a distance away from the suspected site.

Discussions of the porosity and coefficient of permeability test

The results of the laboratory test for coefficient of permeability (K) and porosity **(∅)** of the soil samples are presented in Table 4.3. The value of K for the study location ranges from 5.76942 $\times 10^{-3}$ to 7.68711$\times 10^{-3}$ $_{cm/s}$; the characteristics of sand thus allow the flow of PHCs plume to the soil and groundwater in the study area.This is in line with similar work by Eze *et. al.* (2021). The values of the coefficient of permeability obtained may be influenced by (1) textural properties (i.e., pore size/ grain size, grain size distribution, the shape of grains and packing of grains), (2) gas slippage, (3) amount distribution and type of clays, (4) type and amount of secondary porosity, (5) overburden pressure, (6) reactive fluids, and (7) high-velocity flow effects (Fakunle*et al.*, 2021). The coefficient of permeability determined in this work was compared with the standard coefficient of permeability values of soil (Evirgen*et al*., 2015) in Table 3. This showed that the host of the PHCs is composed of sand/silty sand. The value of the porosity that was determined in the laboratory in this work ranges from 0.563 to 0.586 which was compared with the standard porosity values of soil de (Castro *et al*., 2014) in Table 4. It showed that the porosity of the contaminant layer is high being silty sand/sand.

CONCLUSION

3D electrical resistivity techniques supported by the geochemical method have been effectively used to assess the extent of hydrocarbon contamination in an oil-contaminated site located in the Erhoike community, south-south, Nigeria. The results of the study have shown that the soil is permeable and porous which could allow the passage of the leaked and spilled PHCs through the soil to groundwater where the PHCs could mix, float, and sink into the groundwater. This is evident in the results of 3D resistivity. The 3D analysis revealed the presence of PHCs up to a depth of 33.7 m but very prominent at a depth of 10.0 m which, indicated the presence of PHCs in the wells. However, at a far distance, the effect of the PHCs reduced drastically. Hydrochemical results also proved the same results as that of the 3D which authenticated the reliability of the method used in the study.

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