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Integrated 2D Electrical Resistivity Tomography and Hydrochemical Assessment of Hydrocarbon Contamination around Oil Tank Farms in Apapa, Southwestern Nigeria

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Abstract
Oil spills from tank farms in Apapa, southwestern Nigeria, pose significant risks to groundwater, surface water, and soil due to the area's geologically vulnerable coastal materials. This study assessed the environmental impact of oil spillage at two facilities, Wesb Oil and Rein Oil, focusing on subsurface conditions and water quality. Two - dimensional Electrical Resistivity Tomography (ERT) using a Wenner array was conducted along four traverses to delineate subsurface structures. In addition, physicochemical, geochemical, and microbiological analyses were performed on water samples from both sites and a control location. ERT results identified two to three geoelectric layers, with high-resistivity anomalies (>110 Ωm) at Wesb Oil, indicating the presence of the hydrocarbon plume. The Water quality analysis showed marked deviations from World Health Organization standards. All samples were acidic, while Wesb Oil recorded elevated salinity, electrical conductivity, total dissolved solids, biochemical oxygen demand, and heavy metal concentrations, indicating severe contamination. Microbiological results revealed high microbial loads, including fecal contamination at Wesb Oil and the control site, as well as hydrocarbon-utilizing microorganisms, confirming petroleum pollution and associated health risks. In contrast, Rein Oil showed no detectable contaminant plume, likely due to effective containment measures that limited hydrocarbon infiltration. Overall, Wesb Oil is significantly polluted and poses a serious threat to groundwater and the surrounding ecosystem, whereas Rein Oil demonstrates better environmental management. It is recommended that bioremediation and improved containment systems such as concrete floor around the gantry be implemented at Wesb Oil, alongside continuous environmental monitoring to protect public health and ensure sustainability.

***Keywords**: Oil Spill, Groundwater, Contamination, Electrical Resistivity, Geochemical*

Introduction

Crude oil contamination is a significant source of subsurface pollution in coastal industrial zones such as Apapa, Lagos, where dense tank farm activities and shallow sandy aquifers increase vulnerability to hydrocarbon leakage. The area's high permeability and shallow groundwater table promote rapid migration of contaminants, posing risks to soil quality, groundwater resources, and public health (Adeoti *et al.*, 2013; Oladapo *et al.*, 2018). Hydrocarbon compounds, classified as non-aqueous phase liquids (NAPLs), persist in the subsurface and migrate both vertically and laterally, leading to widespread environmental degradation and potential human exposure through contaminated water and agricultural pathways (WHO, 2011; Adeniran *et al.*, 2023).

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Assessment of such contamination requires an integrated approach. Geophysical methods, particularly electrical resistivity techniques, provide a rapid, non-invasive means of delineating subsurface hydrocarbon plumes due to the resistivity contrasts between contaminated and uncontaminated zones (Khanate *et al.*, 2000; Shevnin *et al.*, 2005). The application of multi-electrode Electrical Resistivity Tomography (ERT) enables high-resolution 2D imaging of plume geometry, making it suitable for complex coastal environments (Loke *et al.*, 2013). However, geophysical data alone may not fully characterize the chemical impact of contamination.

Water quality analysis is, therefore, essential for validating geophysical interpretations and assessing the extent of groundwater pollution. Parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and hydrocarbon-related indicators provide direct evidence of contamination and its potential health implications (Ukaogo *et al.*, 2020). Elevated TDS and conductivity, for instance, may reflect the dissolution of contaminants or by-products of hydrocarbon degradation, while deviations in pH can indicate geochemical alterations within the aquifer system.

Despite existing studies on hydrocarbon contamination, there remains limited integration of high-resolution geophysical imaging with water quality assessment in coastal tank-farm settings such as Apapa.

This study integrates 2D ERT using the Wenner array and geochemical (laboratory) analyses of groundwater quality to investigate shallow subsurface conditions in Apapa, Lagos, to map hydrocarbon contaminant plume distribution, delineate geoelectric layering, and provide independent validation of geophysical interpretations using laboratory-derived water quality data and evaluate its impact on the shallow aquifer system.

Location of Study

Geology of the Study Area

The Apapa area is located within the Dahomey Basin, a coastal sedimentary basin composed predominantly of sands, shales, and occasional limestone units.

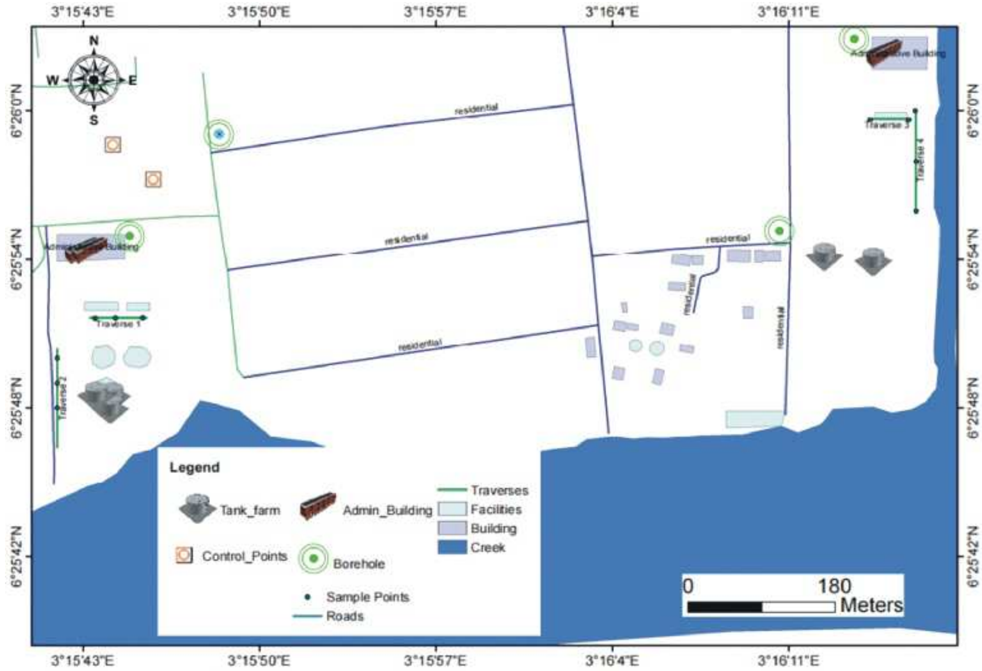

Fig. 1: Map of the study area

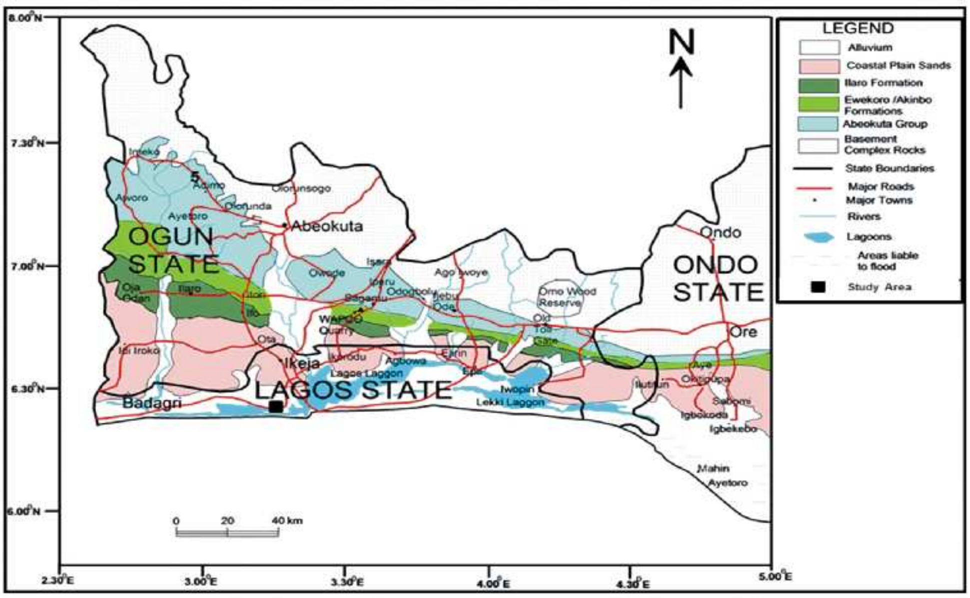

Fig. 2: Geological map of Dahomey Basin (Modified from Jones and Hockey 1964).

The study area (Figure 1), situated along the southwestern coast of Nigeria between latitudes 6°25′48″N and 6°25′54″N and longitudes 3°15′40″E and 3°15′50″E, falls within a well-documented stratigraphic succession described by Omatsola and Adegoke (1981) and Elueze and Nton (2004). This succession comprises, from oldest to youngest, the Abeokuta Group (Ise, Afowo, and Araromi Formations), overlain by the Ewekoro, Akinbo, Oshosun, and Ilaro Formations (Figure 2).

The Ise Formation, being the earliest, is characterized by basal conglomerates overlain by coarse- to medium-grained sands interbedded with kaolinite clay. Above this, the Afowo Formation consists mainly of medium-grained sandstones interspersed with shale layers. The Araromi Formation, which is the youngest unit within the Abeokuta Group, features fine- to medium-grained sandstones that are subsequently overlain by shale and siltstone. The sediments within the Dahomey Basin exhibit permeability values ranging between 7.6 and 28.3 millidarcies, as documented by Omatsola and Adegoke (1981).Above the Abeokuta Group lies the Ewekoro Formation, which dates to the Palaeocene epoch and iscomposed of limestone. This is followed by the Akinbo Formation, spanning the Late Palaeocene to Early Eocene, whose primary lithologies are shale and clay. The Oshosun Formation, attributed to the Eocene epoch, consists mainly of mudstone and claystone, while the Ilaro Formation, also from the Eocene, comprises a combination of sandstone, clay, and shale. The Abeokuta Group lies unconformably over the crystalline rocks of the Basement Complex, as illustrated in Figure 2.

While these formations define the regional geology, the near-surface stratigraphy beneath Apapa is typically dominated by unconsolidated to poorly consolidated coastal plain sands of the Ilaro Formation and recent alluvial deposits. These materials are predominantly medium- to coarse-grained, highly porous, and permeable, often interbedded with thin clay or shale lenses. Such lithological characteristics are critical for contaminant transport: the sandy units facilitate rapid vertical and lateral migration of hydrocarbons, whereas the discontinuous clay layers may locally retard flow, leading to plume accumulation or stratified contamination.

This shallow, heterogeneous sandy sequence, combined with a high-water table typical of coastal environments, enhances the vulnerability of the aquifer system to hydrocarbon infiltration and spread. Consequently, understanding the distribution and properties of these near-surface units is essential for accurately delineating contaminant plumes and interpreting geophysical responses in the Apapa tank farm area.

Materials and Methods

Geophysical Data Collection

Two-dimensional (2D) electrical resistivity data were acquired using the Wenner electrode configuration (Figure 3) along two profiles at each study location, giving a total of four profiles across both locations. At Rein Oil, Traverse 1 and Traverse 2 extended 65 m and 120 m, respectively, while at Wesb Oil, Traverse 3 and Traverse 4 had profile lengths of 46 m and 125 m, respectively.

The same acquisition design was applied at both locations using the Wenner array and the Allied Omega resistivity meter, ensuring consistency in data quality and interpretation. Resistivity measurements were obtained by injecting current into the ground through two current electrodes and measuring the resulting potential difference across two potential electrodes. The electrode spacing ('a') was varied to achieve depth sounding and lateral coverage: at Rein Oil, 'a' ranged from 5–30 m (AB/3) across traverses 1 and 2, while at Wesb Oil, 'a' ranged from 2–12 m(AB/3) along Traverse 3 and 5–30 m along Traverse 4.

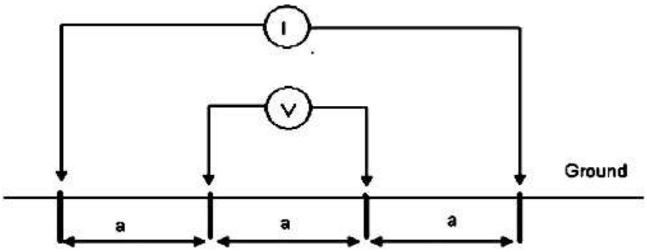

Fig. 3: The Wenner electrodes configuration (Modified from Loke *et al.*, 2013)

The rationale for acquiring 2D resistivity datasets was to generate resistivity-depth maps for the interpretation of subsurface geoelectric layering and to enable depth-slice comparisons of resistivity responses between the contaminated and uncontaminated zones. The resistivity data obtained from the survey were processed through an inversion routine based on geophysical tomography principles. In this process, the measured apparent resistivity values were iteratively compared with synthetic data generated from a forward model. The inversion algorithm minimized the misfit between the observed and modelled data through successive iterations until the model with the lowest root mean square (RMS) error was obtained. This final model was then adopted as the most representative subsurface resistivity section. For the Rein Oil site, the RMS errors and number of iterations were 6.5% (7 iterations) for Traverse 1 and 9.8% (7 iterations) for Traverse 2. At the Wesb Oil site, the corresponding values were 8.6% (6 iterations) for Traverse 1 and 3.7% (7 iterations) for Traverse 2. The inversion was performed using the finite-difference smoothness-constrained least-squares algorithm developed by Loke and Barker (1996) and later refined by Loke (2000).

Physical and Geochemical Data Acquisition

A total of six composite samples were collected: four from the study locations (two per location, each representing five sub-samples composited into one) and two from control locations. Samples were obtained from boreholes and near-surface aquifers at depths of approximately 1.5–5 m, corresponding to the hydrogeologic unit investigated in the resistivity survey. Sampling points were selected along or adjacent to the ERT profiles to enable spatial correlation between geophysical and geochemical data. Control samples were collected from a background location within the same hydrogeologic unit but outside the influence of tank-farm activities.

Water samples for heavy metal analysis were collected in pre-cleaned high-density polyethylene (HDPE) bottles, while separate clean containers were used for total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), benzene-toluene-ethylbenzene-xylene (BTEX), and microbiological analyses. Samples designated for metal analysis were acidified in the field to pH < 2 using ultrapure HNO_3, whereas microbiological samples were stored without preservatives. All samples were preserved in an ice chest at approximately 4°C and transported to the laboratory within 6–12 hours. Following sample preparation, concentrations of PAH, BTEX, and TPH were determined using gas chromatography–mass spectrometry (GC–MS).

Physicochemical parameters, including pH, electrical conductivity, total dissolved solids, and temperature, were measured in situ using calibrated portable multiparameter meters (e.g., Hanna or WTW), in accordance with APHA Standard Methods. Heavy metal concentrations were analyzed using atomic absorption spectrophotometry (AAS), with detection limits of approximately 0.001 mg/L. Microbiological analysis was conducted using the standard plate count method, and results were reported as colony-forming units per millilitre (CFU/mL).

Quality assurance and quality control (QA/QC) procedures followed established protocols. All analyses were performed in duplicate, and control and blank samples were included to ensure analytical accuracy and precision.

Results and Discussion

Results

2D Electrical Resistivity Profiling

The resulting 2D resistivity tomography sections are presented in Figures 4 -7 . Traverse 1 and 2 shows the inverted resistivity models for Rein Oil (Figures 4 and 5 respectively). The inverse model resistivity sections achieved good depth resolution up to 7.5 m for the first traverse and up to 17.5 m for the second traverse. Resistivity values ranged from 1.13 to greater than 224 9 m for the first traverse, delineating a layered subsurface with a prominent high-resistivity zone between approximately 40 m and 50 m along the profile, while the second traverse showed resistivity values ranging from 0.40 to greater than 110 9 m, revealing a low-resistivity zone at depth and a localized high-resistivity feature near 80 - 90 m along the traverse.

For WesbOil, the 2D resistivity inversion model for traverses 3 and 4 are shown in figures 6 and 7 respectively. The result shows a depth of probe up to 7.5 and 17.5 for traverse 3 and 4 respectively with a variation in resistivity that ranges from 0.4 to greater than 110 9 m.

Water Quality Analyses

The results of the geochemical and microbiological analyses of the water samples, expressed as mean values, are presented in Tables 1 and 2, respectively.

Discussion of Results

Electrical Resistivity Tomography

The resistivity values measured at Rein Oil range from 0.4 to 230 9 m (Figures 4 and 5). Along the first traverse, two geoelectric layers were delineated. The first layer represents the topsoil, composed predominantly of clay

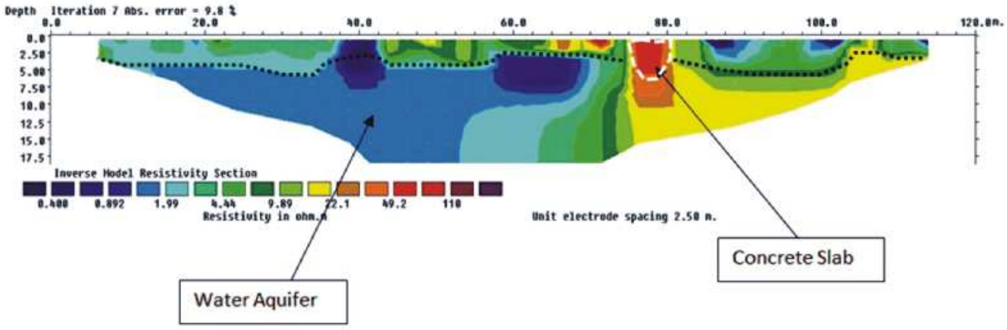

Fig. 4: 2-D Resistivity Tomography Profile (Wenner Array) at Traverse 1

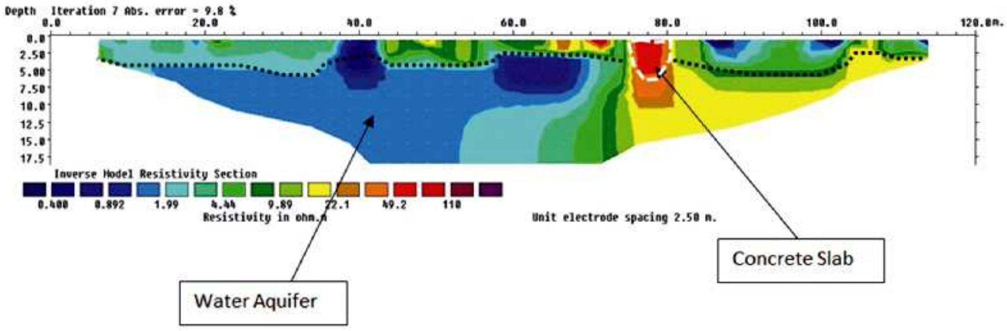

Fig. 5: 2-D Resistivity Tomography Profile (Wenner Array) at Traverse 2

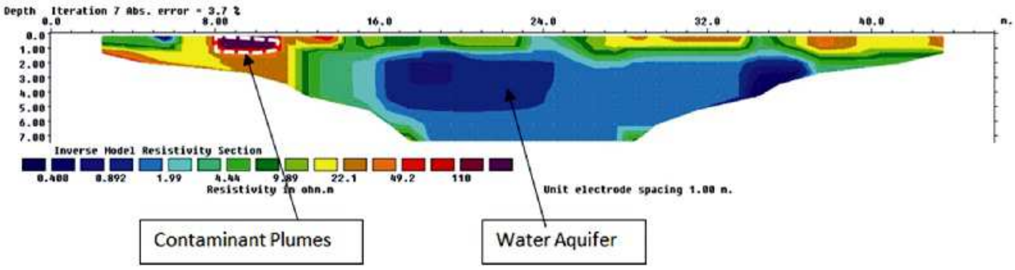

Fig. 6: 2-D Resistivity Tomography Profile (Wenner Array) at Traverse 3

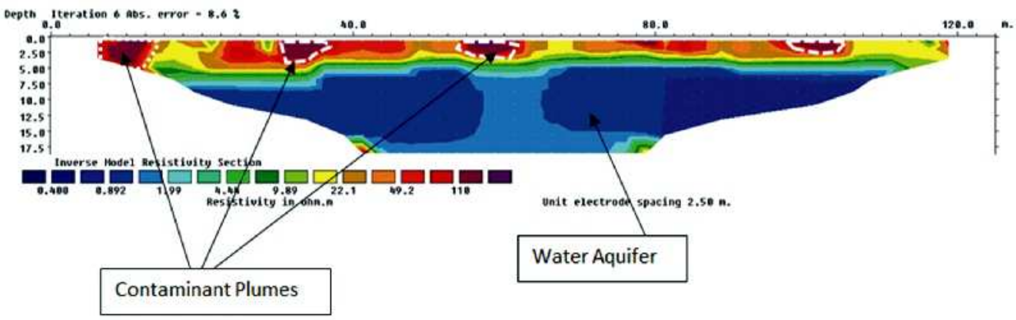

Fig. 7: 2-D Resistivity Tomography Profile (Wenner Array) at Traverse 4

to sandy clay, with resistivity values ranging from 2 to 30 ^{9} m and thicknesses between 2.5 and 5.0 m. The second layer is interpreted as a clayey sand to sand unit, with resistivity values of 40 to 100 ^{9} m and an average thickness of approximately 3 m. An isolated zone of exceptionally high resistivity (>224 ^{9} m) observed between 3^{7}.5 and 42.5 m along the traverse is interpreted as a buried gas pipeline rather than hydrocarbon contamination.

The second traverse, located along the untarred road beside the Rein Oil facility and oriented perpendicular to the gantry, also revealed two geoelectric layers. The upper layer has resistivity values of 10 to 50 ^{9} m and a

Table 1: Summary of the Results of the Geochemical Analysis (mean values)

Parameter	Unit	Rein Oil (Mean, n=2)	Wesb Oil (Mean, n=2)	Control (Mean, n=2)	WHO Guideline Limit	NSDWQ Limit (Nigeria)
Temperature	°C	30.01	30.11	29.74	—	Ambient
pH	—	4.59	5.53	5.52	6.5–8.5	6.5–8.5
ORP	mV	156	156	53		
Electrical Conductivity	mS/cm	0.155	9.2	3.93	—	1
Turbidity	NTU	1.6	12.9	0.9	≤5	≤5
Dissolved Oxygen (DO)	mg/L	5.81	5.5	5.58	—	—
Total Dissolved Solids (TDS)	mg/L	159	5800	2502	<1000	<500
Salinity	Ppt	0.02	5.13	2.07	—	—
Acidity	mg/L as $CaCO_3$	139	115	100		
Alkalinity	mg/L as $CaCO_3$	50	100	75	—	—
Chloride	mg/L	15.9	2945	1217	≤250	≤250
Total Hardness	mg/L as $CaCO_3$	325	1800	950	—	≤150
Total Solids (TS)	mg/L	460	10240	3640	—	—
Total Suspended Solids (TSS)	mg/L	301	4440	1120	—	—
Biochemical Oxygen Demand (BOD_5)	mg/L	47.65	187.92	120.81	—	—
Total Hydrocarbon Content (THC)	mg/L	BDL	0.005	0.002		
Polycyclic Aromatic Hydrocarbons (PAH)	mg/L	BDL	0.003	BDL	Compound-specific	—
BTEX	mg/L	BDL	BDL	BDL	Compound-specific	—
			Metals			
Cadmium (Cd)	mg/L	BDL	0.131	0.096	0.003	0.003
Chromium (Cr)	mg/L	0.001	0.136	0.042	0.05	0.05
Copper (Cu)	mg/L	0.006	0.008	0.021	2	1
Iron (Fe)	mg/L	1.081	1.622	1.431	0.3*	0.3
Nickel (Ni)	mg/L	0.004	0.012	0.017	0.07	0.02
Lead (Pb)	mg/L	0.026	0.018	0.013	0.01	0.01
Zinc (Zn)	mg/L	0.034	1.347	0.021	3	3

Table 2: Summary of the Results of the Microbial Analysis

Sample Code	Total Heterotrophic Bacteria (Cfu/mL)	Total Heterotrophic Fungi (Cfu/mL)	Total Coliforms (Cfu/mL)	Total Hydrocarbon Utilizing Bacteria (Cfu/mL)	Total Hydrocarbon Utilizing Fungi (Cfu/mL)	Some Predominant Species Of Micro Organisms Isolated
Rein Oil	10.0×10^1	2.0×10^1	0.00	0.00	1.0×10^1	*Lactobacillus spp* *Rhizopus stolonifer* *Mucor spp.*
Wesb Oil	2.24×10^7	9.0×10^4	1.14×10^3	74.0×10^3	6.2×10^2	*Bacillus spp.* *Pseudomonas aeruginosa* *Escherichia coli* *Apergillus niger* *Trichoderma spp.* *Norcadia spp.*
Control	1.26×10^9	8.0×10^3	1.48×10^2	58.0×10^3	6.4×10^2	*Bacillus spp.* *Staphylococcus aureus* *Penicillium spp.* *Pseudomonas aeruginosa* *Escherichia coli* *Apergillus niger* *Trichoderma spp.* *Norcadia spp.*

thickness range of 1 to 5 m, consisting of interbedded clay, sandy clay, and clayey sand. The underlying layer, with resistivity values of 0.4 to 22 ^{9} m, is interpreted as a saline/brackish water-bearing sandy aquifer. A localized high-resistivity anomaly (>100 ^{9} m) between ^{7} 5 and 80 m is attributed to the concrete slab at the entrance gate of the facility. Overall, the results indicate that the aquifer beneath Rein Oil had not been impacted by hydrocarbon infiltration (DPK) at the time of investigation. The observed high-resistivity anomalies are associated with buried infrastructure and concrete surfaces rather than contaminant plumes. Therefore, Rein Oil does not show significant evidence of hydrocarbon contamination within the investigated subsurface.

At Wesb Oil, measured resistivity values range from 0.4 to approximately 120 ^{9} m (Figures 6 and ^{7}). Variations in resistivity distribution were interpreted using the colour scale of the 2D resistivity tomograms. The first traverse, located parallel to the gantry, revealed an excavated topsoil section to a depth of about 1.5 m. Two geoelectric layers were identified. The upper layer has resistivity values of 10 to 110 ^{9} m and thicknesses from 0 to 1.8 m, consisting of intercalated clay, sandy clay, and clayey sand. The second layer, with resistivity values of 0.4 to 10 ^{9} m, is interpreted as a saline/brackish water sand aquifer. A pronounced high-resistivity anomaly (>100 ^{9} m) between 8 and 9 m along the traverse, close to the PMS dispensing pump, is interpreted as a hydrocarbon contaminant plume. This suggests that portions of the shallow subsurface were contaminated at the time of the survey, with plume penetration extending to an approximate depth of 2.5 m.

The second traverse at Wesb Oil was resolved into three geoelectric layers. The first layer, representing the topsoil, has resistivity values of 22 to 120 ^{9} m and thicknesses between 2.5 and 5 m. The second layer is interpreted as a clay unit with resistivity values of 5 to 22 ^{9} m and an average thickness of about 4 m. The third layer exhibits very low resistivity values of 0.4 to 4 ^{9} m, characteristic of saline or brackish groundwater intrusion, with the top of the first aquifer occurring at approximately 10 m depth. High-resistivity anomalies (>110 ^{9} m) within the first layer are interpreted as hydrocarbon plumes that infiltrated the shallow sandy horizon following spill incidents around the gantry area. The contaminant effect decreases progressively away from the gantry toward the plant section, indicating that pollution is more concentrated near the spill source. The plume occurs as irregular, immiscible bodies that significantly modify the resistivity of the affected shallow sands (Figure ^{7}).

Physical, Geochemical Analysis Results

Comparing the results of the physical and geochemical analyses with both the World Health Organization (WHO, 201^{7}) and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) limits reveals notable water quality concerns across the study sites. The pH values at all locations - Rein Oil (4.59), Wesb Oil (5.53), and the control (5.52) - fall below the acceptable range of 6.5 - 8.5 specified by both standards, indicating acidic conditions. This acidity may be associated with hydrocarbon degradation, dissolved gases, or related contamination processes, with Rein Oil being the most acidic.

The Total Dissolved Solids (TDS), Rein Oil (159 mg/L) is within the WHO and NSDWQ desirable limit of $\leq$500 mg/L and below the maximum allowable 1000 mg/L, indicating acceptable salinity levels. However, Wesb Oil (5800 mg/L) and the control (2502 mg/L) exceed both standards, suggesting severe mineralization or contaminant loading, particularly at Wesb Oil. Chloride concentrations at Rein Oil (15.9 mg/L) are well below the permissible limit of 250 mg/L. Even though the control (121^{7} mg/L) and Wesb Oil (2945 mg/L) greatly exceed this value, indicating possible saline intrusion, industrial contamination, or leachate influence.

With respect to Total Hardness (as $CaCO_3$), Rein Oil (325 mg/L) falls below the maximum permissible level of 500 mg/L, although it indicates moderately hard water. In contrast, Wesb Oil (1800 mg/L) and the control (950 mg/L) exceed acceptable limits, indicating very hard water that may result in scaling, taste impairment, and operational problems. The heavy metal assessment also reveals varying levels of contamination. Cadmium (Cd) was below the detection limit at Rein Oil, but Wesb Oil (0.131 mg/L) and the control (0.096 mg/L) exceeded the WHO and NSDWQ limit of 0.003 mg/L, indicating serious contamination. Chromium (Cr) at Rein Oil (0.001 mg/L) is within permissible levels (0.05 mg/L), whereas Wesb Oil (0.136 mg/L) exceeds the standard, while the control (0.042 mg/L) remains within limits.

Copper (Cu) concentrations (0.006 - 0.021 mg/L) are below the WHO and NSDWQ limit of 2.0 mg/L. Iron (Fe) concentrations (1.081 - 1.622 mg/L) exceed the recommended limit of 0.3 mg/L, suggesting possible taste deterioration, staining, and corrosion issues. Zinc (Zn) values (0.034 - 1.34^{7} mg/L) remain within the allowable limit of 3.0 mg/L, while Nickel (Ni) concentrations (0.004 - 0.01^{7} mg/L) are below the

WHO guideline value of 0.0^{7} mg/L. However, Lead (Pb) concentrations at Rein Oil (0.026 mg/L), Wesb Oil (0.018 mg/L), and the control (0.013 mg/L) all exceed the WHO and NSDWQ limit of 0.01 mg/L, representing a significant public health concern, with Rein Oil recording the highest concentration.

The non-detection of BTEX (benzene, toluene, ethylbenzene, and xylene) suggests no significant recent petroleum infiltration into the aquifer with respect to these volatile compounds. However, the presence of low concentrations of PAHs at Wesb Oil remains important because these compounds are persistent, slowly degradable, and capable of long-term accumulation if contamination persists. Furthermore, the higher Total Hydrocarbon Content (THC) recorded at Wesb Oil supports the PAH findings and reinforces evidence that Wesb Oil poses a greater threat to groundwater quality within the study area than Rein Oil. Overall, the combined results identify Wesb Oil as the most contaminated site, while Rein Oil revealed localized heavy metal apprehensions despite lower hydrocarbon impact.

Microbial Analysis Results

The microbiological analysis of water samples collected from Rein Oil, Wesb Oil, and the control site shows clear spatial differences in microbial abundance and activity, indicating varying degrees of contamination and biodegradation processes.

Rein Oil recorded the lowest microbial counts, with total heterotrophic bacteria (THB) of 1.0×10^{2} CFU/mL, heterotrophic fungi (THF) of 2.0×10^{1} CFU/mL, and hydrocarbon-utilizing fungi (HUF) of 1.0×10^{1} CFU/mL. Coliform bacteria and hydrocarbon-utilizing bacteria (HUB) were not detected. The dominant isolates included *Lactobacillus* spp., *Rhizopus stolonifer*, and *Mucor* spp. These low counts suggest limited organic and hydrocarbon contamination, likely reflecting the effectiveness of the concrete flooring and containment structures in restricting contaminant migration.

Wesb Oil exhibited markedly higher microbial loads, with THB of 2.24×10^{7} CFU/mL, THF of 9.0×10^{4} CFU/mL, coliforms of 1.14×10^{3} CFU/mL, HUB of ^{7} .4 $\times 10^{4}$ CFU/mL, and HUF of 6.2×10^{2} CFU/mL. Identified organisms included *Bacillus* spp., *Pseudomonas aeruginosa*, *Escherichia coli*, *Aspergillus niger*, and *Trichoderma* spp. The elevated microbial population, particularly hydrocarbon degraders, indicates significant contamination and active natural attenuation through biodegradation. The control site showed the highest THB (1.26×10^{9} CFU/mL) and measurable counts of coliforms (1.48×10^{2} CFU/mL), HUB (5.8×10^{4}CFU/mL), and fungi (6.4×10^{2} CFU/mL). Isolates included *Bacillus* spp., *Staphylococcus aureus*, and *Penicillium* spp., suggesting a naturally active microbial ecosystem with possible background environmental or anthropogenic influences.

Overall, Wesb Oil demonstrates the strongest microbial response to hydrocarbon pollution, consistent with active biodegradation and higher contamination levels. Rein Oil shows comparatively low microbial activity, supporting the effectiveness of existing containment measures, while the control site reflects natural microbial activity with some evidence of external inputs.

These microbiological findings are consistent with the 2D Electrical Resistivity Tomography (ERT) and geochemical results. Rein Oil, characterized by lower contaminant indicators (e.g., below detection limit for some metals and lower TDS), corresponds with a two-layer geoelectric structure and the absence of significant contaminant plumes. In contrast, Wesb Oil shows evidence of contaminant migration and ongoing natural attenuation, confirming a stronger pollution impact than Rein Oil.

Conclusion

The study focused on evaluating the impact of oil spills from two specific tank farms in the region: Wesb Oil and Rein Oil. To achieve this, the study employed 2D Electrical Resistivity Profiling (2D ERT) with a Wenner array configuration, conducted across four traverses. Additionally, geochemical and microbial analyses were performed to characterize the subsurface conditions and assess contamination levels. The processed 2D ERT data revealed two to three distinct geoelectric layers at both sites. Notably, high-resistivity anomalies (>110 Ωm) observed at Wesb Oil indicated the presence of oil plumes in varying sizes near the spill zones. Geochemical analyses further revealed that Wesb Oil showed higher levels of contamination compared to Rein Oil and a control site. The microbial analysis depicts the presence of hydrocarbon contamination at the Wesb Oil and control site. The spill containment measures at Rein Oil, particularly the presence of a concrete floor around the spill area, were effective in preventing the spread of contaminants, including dual-purpose kerosene (DPK), with no detectable contaminant plumes in the local aquifer. However, future monitoring studies is still required. In contrast, Wesb Oil displayed ongoing subsurface contamination, which could pose a serious threat to the region's groundwater-dependent ecosystem. Given the coastal geology of Apapa and its susceptibility to pollution, the study strongly recommends urgent remediation efforts at Wesb Oil to mitigate the presence of residual hydrocarbons. For future research consideration, ERT monitoring, soil sampling, and engineered remediation design should be conducted.

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