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Comparative Analysis of Crude Oil Contaminated Soil Remediation Using Water Hyacinth, Compost, and Oclansorb

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ABSTRACT

Crude oil contamination of soils remains a persistent environmental challenge in oil-producing regions, particularly in the Niger Delta of Nigeria, where artisanal refining and pipeline failures are prevalent. This study evaluated and compared the effectiveness of phytoremediation and amendment-based strategies using water hyacinth–compost combinations and Oclansorb in restoring crude oil–contaminated soils from Obi-Ayagha Community, Ughelli South Local Government Area, Delta State. A repeated-measures experimental design was employed over a nine-week remediation period, involving six treatment regimes (three combination treatments and three Oclansorb-only treatments) alongside an uncontaminated control. Key parameters assessed included total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), pH, total organic carbon (TOC), nutrient levels, and microbial populations, particularly hydrocarbon-degrading bacteria (HDB).Results revealed substantial reductions in TPH across all amended treatments, with the 100% compost–water hyacinth combination achieving the highest reduction (94.01%) by Week 9. PAHs were completely eliminated (100% reduction) in all treated samples within three weeks, demonstrating rapid remediation of persistent aromatic compounds. Soil pH shifted toward neutral to mildly alkaline conditions, enhancing microbial activity and soil health. TOC levels declined significantly, indicating effective mineralization of hydrocarbon carbon. Increases in hydrocarbon-degrading bacterial populations further confirmed biologically driven degradation processes. Overall, combination treatments consistently outperformed Oclansorb-only applications, suggesting synergistic benefits of organic amendments and phytoremediation. The findings underscore the potential of integrated, low-cost, and environmentally sustainable remediation strategies for restoring oil-impacted soils in resource-limited settings of the Niger Delta.

Keywords: *Crude oil contamination, Water hyacinth, Compost, Oclansorb, Niger Delta, bioremediation.*

1. Introduction

Crude oil is a complex mixture of hydrocarbons that has supported global industrial development for over a century. Its derivatives fuel transportation, agriculture, manufacturing, and petrochemical industries, making petroleum a cornerstone of modern economies. [16] Despite increasing interest in renewable energy, petroleum remains dominant due to its high energy density and entrenched infrastructure. However, oil exploration, transportation, and informal refining pose significant environmental risks, particularly in developing regions. [8,13].

In Nigeria, the Niger Delta hosts extensive petroleum infrastructure and has experienced decades of environmental degradation linked to oil spills, pipeline breaches, and artisanal refining activities. Soil contamination by petroleum hydrocarbons disrupts physicochemical properties, inhibits plant growth, alters microbial communities, and introduces toxic compounds such as polycyclic aromatic hydrocarbons (PAHs), which are persistent and carcinogenic[5] Conventional remediation methods are often costly and disruptive, making them unsuitable for rural and resource-limited communities. Consequently, attention has shifted toward sustainable remediation approaches such as phytoremediation, organic amendment-enhanced bioremediation, and sorbent-based treatments. Water hyacinth and compost provide nutrients and microbial substrates, while sorbents such as Oclansorb immobilize hydrocarbons and reduce bioavailability. [3].This study aims to comparatively evaluate these approaches in remediating crude oil–contaminated soil from Obi-Ayagha, Delta State.

2. Materials and Methods

2.1 Study Area

The study was conducted at an abandoned artisanal refinery site in Obi-Ayagha Community, Ughelli South Local Government Area, Delta State, Nigeria (5°30′N, 5°50′E). The area lies within the humid tropical Niger Delta climate, characterized by high rainfall and seasonally inundated floodplains. Soils are predominantly sandy-clay with variable organic content and poor drainage. A control site with similar geomorphology was established approximately 500 m upstream.

2.2 Sample Collection

Surface soils (0–15 cm) were collected as composite samples from multiple points within each treatment unit to minimize spatial heterogeneity. Additional subsamples from deeper horizons (15–60 cm) were archived when visible contamination was observed.

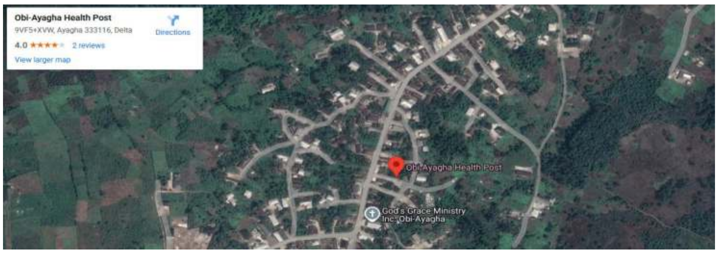

Figure 1: Satellite view of Obi-Ayagha Community, Ughelli South LGA, Delta State, Nigeria. Source: Google Maps

2.3 Experimental Design and Treatments

Six treatment regimes were evaluated: three compost, water hyacinth combination treatments (25%, 50%, and 100% w/w) and three Oclansorb only treatments at corresponding concentrations. Each treatment contained 2000g of contaminated soil mixed with varying proportions of amendments. An uncontaminated soil served as a control.

Table 1: Experimental layout showing treatment combinations and amendment ratios for contaminated soil remediation

Treatment Code	Treatment Description	Biostimulant Concentration (w/w)	Contaminated Soil (g)	Uncontaminated Soil (g)	Biostimulant (g)
COMB25	compost + hyacinth	25%	2000	1500	500
COMB50	compost + hyacinth	50%	2000	1000	1000
COMB100	compost + hyacinth	100%	2000	0	2000
OCB25	Oclansorb	25%	2000	1500	500
OCB50	Oclansorb	50%	2000	1000	1000
OCB100	Oclansorb	100%	2000	0	2000

Key: COMB (Compost and Water Hyacinth), OCB (Oclasorb

2.4 Analytical Procedures

Total petroleum hydrocarbons were analyzed using GC-FID following modified USEPA Method 8240, while PAHs were quantified using GC-MS after silica gel fractionation. Soil nutrients (nitrate, phosphate, and sulphate), pH, total organic carbon, and microbial populations were determined using standard laboratory protocols.

3. Results

3.1 Baseline Soil Characteristics

Initial analysis revealed elevated TPH concentrations, slightly acidic pH, and high TOC, confirming heavy petroleum contamination at the site. Table 3.1

Table 3.1: Physicochemical Characteristics of Water Hyacinth Sample

Parameters	Units	Value
Ph	-	5.50
Phosphate	mg/kg	15.12
Nitrate	mg/kg	119.20
Sulphate	mg/kg	0.86
Total organic Content (TOC)	%	3.17

Table 3.2: Physicochemical Characteristics of Compost

Parameters	Units	Results
pH		8.00
Conductivity	µs/m	13830
Temperature		27.90
Nitrate	Mg/kg	309.93
Total Organic Carbon	%	118.08
Moisture Content		1.70

3.2 Total Petroleum Hydrocarbon Reduction

Figure 3.0 shows the TPH concentrations for all treatments across the four sampling periods. A progressive decrease in TPH values was observed in the treated samples compared with the control, indicating active degradation of hydrocarbons over time. (95.31 mg/kg).

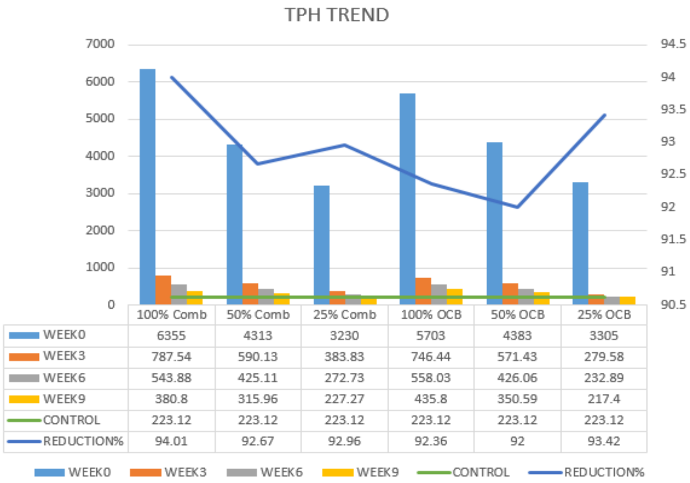

Figure 3.1: Trend of Total Petroleum Hydrocarbon (TPH) reduction across treatments over the 9-week remediation period

All amended treatments exhibited significant TPH reductions over nine weeks. The 100% compost water hyacinth treatment achieved the highest reduction (94.01%), followed closely by 25% Oclansorb (93.42%). Control soils showed negligible change.

3.3 Polycyclic Aromatic Hydrocarbon (PAH)

PAH concentrations (7.82–9.29 mg/kg) declined to non-detectable levels in all treated soils by Week 3, representing 100% removal, while control soils remained unchanged.

Figure 3.2: Polycyclic Aromatic Hydrocarbon (PAH) concentrations (mg/kg) during remediation

3.4 Soil pH and Organic Carbon

Soil pH shifted from slightly acidic to near-neutral or mildly alkaline ranges (7.1–8.1). TOC declined significantly, particularly in the 100% combination and Oclansorb treatments, indicating active hydrocarbon mineralization.

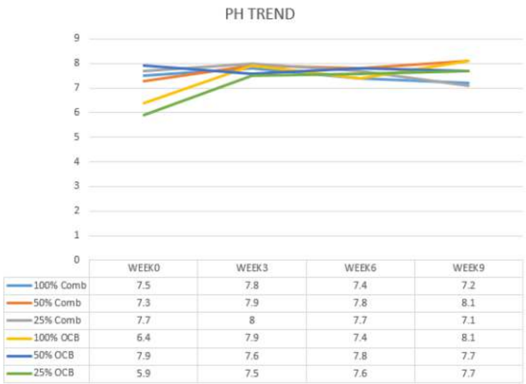

Figure 3.3: Variation in soil pH across treatments during remediation

3.5 Total Organic Carbon (TOC)

Over the nine-week remediation period, TOC levels declined across all treatments, with the 100% combination and 100% Oclansorb treatments showing the greatest reductions of 60.98% and 59.95%, respectively. The 50% combination (Compost and Water hyacinth) and 50% Oclansorb treatments also exhibited noticeable TOC declines (43.45% and 20.25%), while the 25% treatments showed comparatively lower reductions. The 25% Oclansorb treatment even recorded a slight increase in TOC (−2.37%),

Figure 3.4: Total Organic Carbon (TOC) (%) changes during remediation

3.6 Microbial Dynamics

Hydrocarbon-degrading bacterial populations increased in combination treatments, with the highest rise observed in the 100% compost–hyacinth mixture. Oclansorb treatments showed transient increases followed by stabilization.

Figure 3.5 Changes in the hydrocarbon-degrading bacterial (HDB) population during the remediation period

Table 3.3: Summary of nutrient dynamics, moisture content, and microbial populations
(Contains EC, nitrate, phosphate, sulphate, water content, HB, HF, and HDB)

Parameter	Treatment	Week 0	Week 3	Week 6	Week 9
EC (µS/cm)	,	,	,	,	,
	100% Comb	27.143	5150	2500	2842
	50% Comb	3381	2200	3500	3530
	25% Comb	2921	2410	2100	3280
	100% OCB	2798	2086	5100	2058
	50% OCB	2164	2400	3400	4960
	25% OCB	3626	2856	4200	5060
Nitrate (mg/kg)	,	,	,	,	,
	100% Comb	56.16	31.04	142.47	12.56
	50% Comb	59.25	22.34	78.41	6.41
	25% Comb	163.2	16.75	20.19	21.73
	100% OCB	10.95	26.3	128.55	2.93
	50% OCB	12.87	18.66	96.93	5.01
	25% OCB	9.47	21.48	69.08	14.76
Phosphate (mg/kg)	,	,	,	,	,
	100% Comb	8.47	31.2	23.7	4.92
	50% Comb	9.5	36.32	17.46	4.42
	25% Comb	10.75	20.33	8.85	7.36
	100% OCB	0.24	24.62	136.7	2.12
	50% OCB	0.15	33.4	3.51	2.371
	25% OCB	0.42	28.91	21.92	5.117
Sulphate (mg/kg)	,	,	,	,	,
	100% Comb	18.42	24.82	23.38	26.91
	50% Comb	21.04	18.92	18.62	18.44
	25% Comb	11.33	20.33	23.16	14.62
	100% OCB	13.47	34.16	27.31	21.34
	50% OCB	10.21	27.87	41.02	26.38
	25% OCB	9.88	30.62	38.3	31.22
Water Content (%)	,	,	,	,	,
	100% Comb	4.68	2.38	2.28	8.61
	50% Comb	3.06	3.1	3.11	5.33
	25% Comb	1.33	2.63	2.41	9.62
	100% OCB	4.4	3.06	3.33	7.42
	50% OCB	3.81	1.62	1.47	13.04
	25% OCB	1.62	3.42	2.61	10.2
Heterotrophic Bacteria (HB) ($x10^4$ cfu/g)	,	,	,	,	,
	100% Comb	2.0	2.1	2.2	1.85
	50% Comb	2.45	2.05	2.2	1.6
	25% Comb	1.95	2.45	2.15	2.12
	100% OCB	2.0	2.0	1.95	2.2
	50% OCB	2.25	2.15	2.0	1.7
	25% OCB	2.15	2.5	1.8	2.0
Heterotrophic Fungi (HF) ($x10^4$ cfu/g)	,	,	,	,	,
	100% Comb	1.8	1.75	1.9	1.5
	50% Comb	1.95	1.8	1.75	1.5
	25% Comb	1.7	1.9	1.95	1.85
	100% OCB	1.75	1.7	1.6	1.6
	50% OCB	1.8	1.65	1.85	1.5
	25% OCB	2.0	1.85	1.5	1.9
Hydrocarbon Degrading Bacteria (HDB) ($x10^3$ cfu/g)	,	,	,	,	,
	100% Comb	1.05	1.07	1.15	1.2
	50% Comb	1.09	1.17	1.09	1.05
	25% Comb	1.07	1.1	1.17	1.15
	100% OCB	1.1	1.7	1.1	1.09
	50% OCB	1.08	1.15	1.07	1.07
	25% OCB	1.05	1.11	1.05	1.1

Key: Comb. (Compost and Water Hyacinth)
OCB. (Oclasorb)
HB: Heterotrophic Bacteria
HF: Heterotrophic Fungi
HDB:Hydrocarbon Degrading Bacteria

4. Discussion

The soil exhibited high total petroleum hydrocarbon (TPH) concentration, slightly acidic pH, and elevated organic carbon content. [10] The solubility of soil macronutrients in compost is strongly influenced by pH [2]. In this study, the compost analyzed had a pH of about 8.0, indicating an alkaline and relatively stable amendment. Its conductivity was measured at 13,830, temperature around 27 °C, nitrate concentration at 309.93, total organic carbon (TOC) at 118.08, and moisture content at 1.70. Another nitrate reading of 17.61 further highlights that moisture is a limiting factor during biodegradation [11]. Biodegradation of petroleum hydrocarbons is shaped by several limiting factors. The most critical is the chemical composition and inherent biodegradability of the pollutant, which determines whether a remediation strategy will be effective. Physical conditions also play a major role, with temperature being especially important. Temperature not only alters the chemistry of hydrocarbons but also influences microbial physiology and diversity [18] At lower temperatures, oil viscosity increases while the volatility of lighter, toxic hydrocarbons decreases, slowing the onset of biodegradation. Temperature also affects hydrocarbon solubility, and although biodegradation can occur across a wide range of temperatures, the rate generally declines as temperatures drop. Recent studies confirm this: microbial activity and degradation efficiency are strongly linked to ambient temperature, which shapes both the properties of spilled oil and microbial adaptation [18, 22]. Moreover, [21] demonstrated that different microorganisms isolated from petroleum hydrocarbon pollutants exhibit distinct degradation pathways, with environmental factors such as temperature directly influencing their performance. Notably, significant biodegradation has even been observed in cold, psychrophilic environments, underscoring the resilience of microbial communities in diverse conditions.

The combination treatments (Compost and Water hyacinth) consistently performed better than the Oclansorb-only treatments, suggesting synergistic effects of the organic amendments (compost, water hyacinth, and uncontaminated soil) in stimulating microbial activity and enhancing degradation. The control sample maintained a relatively constant TPH concentration (223.12 mg/kg) since it was not subjected to any amendment, serving as a baseline reference. [21]. However, the trend demonstrates that both the combination and Oclansorb treatments were highly effective for hydrocarbon reduction, with the 100 % combination treatment emerging as the most efficient for crude oil-impacted soil remediation in Obi-Ayagha. [19,3].The rapid disappearance of PAHs within the first three weeks suggests enhanced microbial and physicochemical degradation, likely supported by improved aeration, organic matter availability, and sorptive action of the amendments. The compost and water hyacinth components in the combination treatments may have provided additional nutrients and microbial support for PAH breakdown, while Oclansorb likely facilitated adsorption and immobilization of residual hydrocarbons [12].

Overall, the complete reduction of PAHs across all treatments within a short remediation period demonstrates the strong efficacy of both remediation approaches, with the combination treatments offering a sustainable, eco-friendly solution for eliminating carcinogenic hydrocarbon fractions from contaminated soils. [5].

Across all treatment levels, there was a noticeable upward adjustment in pH towards neutrality or mild alkalinity as remediation progressed. By Week 9, pH values ranged between 7.1 and 8.1 in most treatments. The highest pH shift was observed in the 25% and 100% Oclansorb treatments, which increased from 5.9 and 6.4 to 7.7 and 8.1, respectively, suggesting that Oclansorb improved soil buffering capacity and reduced acidity through hydrocarbon adsorption and stabilization effects [10].Across all treatment levels, there was a noticeable upward adjustment in pH towards neutrality or mild alkalinity as remediation progressed. By Week 9, pH values ranged between 7.1 and 8.1 in most treatments. The highest pH shift was observed in the 25% and 100% Oclansorb treatments, which increased from 5.9 and 6.4 to 7.7 and 8.1, respectively, suggesting that Oclansorb improved soil buffering capacity and reduced acidity through hydrocarbon adsorption and stabilization effects.

Over the nine-week remediation period, TOC levels declined across all treatments, with the 100% combination and 100% Oclansorb treatments showing the greatest reductions of 60.98% and 59.95%, respectively. These substantial decreases suggest active mineralization of hydrocarbon carbon into simpler compounds such as carbon dioxide, facilitated by microbial degradation and plant–microbe interactions The 25% Oclansorb treatment even recorded a slight increase in TOC (−2.37%), which could be attributed to partial adsorption of hydrocarbons without significant microbial breakdown during the early remediation stage. [4].The 100% Oclansorb treatment exhibited a temporary rise in bacterial count at Week 3 (1.7×10^3 CFU/g), which later normalized, likely due to the limited nutrient availability within the sorbent medium compared to the organic combination treatments.

The superior performance of compost water hyacinth combinations highlights the importance of nutrient availability, microbial stimulation, and plant-microbe interactions in hydrocarbon degradation. Rapid PAH removal suggests enhanced bioavailability and effective microbial metabolism. While Oclansorb effectively immobilized hydrocarbons, its limited nutrient contribution constrained sustained microbial activity. The observed pH stabilization further supported optimal microbial processes. [7]

Conclusion

This study demonstrates that integrated phytoremediation and organic amendment strategies offer an effective, low-cost, and environmentally sustainable solution for crude oil-contaminated soils in the Niger Delta. Compost and water hyacinth combinations consistently outperformed sorbent-only treatments, achieving substantial reductions in petroleum hydrocarbons and restoring soil health within a short timeframe. These findings support their adoption for large scale remediation in crude oil-impacted, resource-limited communities.

Competing Interests

Authors have declared that no competing interest exist

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