



Research Article

Remediation of Hydrocarbon Impacted Soil Using Clogen

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Abstract

Hydrocarbon pollution of soil remains one of the most critical environmental challenges in oil-producing regions such as the Niger Delta, where crude oil exploration, transportation, and refining activities frequently result in environmental contamination. This study investigated the remediation of hydrocarbon-impacted soil using CLOGEN, a locally developed electro-ionic biopolymer formulated by Andelsta Ltd. and approved by the Federal Government of Nigeria under Patent No. R.16273. Laboratory and field investigations were conducted to evaluate the efficiency of CLOGEN in reducing Total Petroleum Hydrocarbons (TPH) in contaminated soils. Site characterization revealed that the soil lithology consisted of sand, sandy clay, silty clay, coarse sand, and fine sand, with the site predominantly classified as a clay-based soil. The fine-grained clay structure exhibited low effective porosity and a high affinity for petroleum hydrocarbons due to strong adsorption characteristics. The nitrate concentration in the soil ranged from 10.06 mg/kg to 27.42 mg/kg, while ammonium concentration reached a maximum value of 11.018 mg/kg, indicating low nitrogen availability and the need for nutrient supplementation during remediation to maintain an optimum carbon: nitrogen: phosphorus (C:N:P) ratio for microbial activity. Initial TPH concentrations ranged from 454 mg/kg to 8,528 mg/kg, exceeding the permissible limit of 1,000 mg/kg established by the Hydrocarbon Pollution Remediation Project (HYPREP) and the National Oil Spill Detection and Response Agency (NOSDRA). Soil samples were analyzed before and after treatment to determine changes in physicochemical properties and microbiological activity. The results revealed a substantial reduction in TPH concentrations, with remediation efficiency reaching up to 96%, thereby reducing contamination levels to within regulatory standards. Furthermore, the remediation process enhanced microbial population density and improved soil nutrient balance, indicating the capability of CLOGEN to restore ecological functionality in hydrocarbon-impacted soils. Overall, the findings demonstrate that CLOGEN is an effective and environmentally sustainable remediation agent for petroleum-polluted environments in the Niger Delta.

Keywords

CLOGEN, TPH, HYPREP, NOSDRA, Niger Delta, Remediation

1. Introduction

Remediation refers to the process of removing, neutralizing, or containing pollutants from soil and water to re-

store the environment to a safe and usable condition. However, biological approaches such as bioremediation, phy-

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toremediation, and enhanced natural attenuation are increasingly preferred due to their cost-effectiveness, environmental friendliness, and ability to restore natural soil functions [1, 2]. Recent advancements focus on integrated remediation strategies combining nutrient amendments, microbial inoculation, organic additives, and plant-microbe synergy to accelerate hydrocarbon degradation [3]. Emerging materials such as organomineral sorbent and biostimulants have also been explored to enhance soil structure and improve degradation efficiency [4, 5] demonstrated that poultry manure and urea amendments enhanced the biodegradation of petroleum hydrocarbons in Niger Delta soils. Similarly, [6] reported that NPK fertilizers significantly increased microbial counts and hydrocarbon degradation rates in oil-polluted environments. [7] highlighted the combined effectiveness of bioaugmentation and biostimulation, noting that the introduction of hydrocarbon-degrading consortia alongside nutrient amendments accelerated degradation processes compared to nutrient-only treatments. In another study, [8] found that cow dung and poultry manure amendments increased microbial activity and reduced total petroleum hydrocarbons (TPH) in polluted soils. [9] demonstrated that the combination of biopile technology and NPK fertilization significantly reduced TPH levels in contaminated soils within a shorter timeframe. Similar successes have been documented by SPDC and NAOC in NOSDRA-supervised projects, where bioaugmentation and nutrient-assisted biostimulation reduced TPH to acceptable regulatory thresholds [10, 11] found that bioaugmentation with hydrocarbon-degrading bacteria significantly enhances total petroleum hydrocarbon (TPH) reduction, particularly in cold and nutrient-deficient soils. [12] reported that plant-microbe interactions (phytoremediation) can improve rhizodegradation of petroleum pollutants, highlighting the synergy between plant roots and microbial communities. [13] The study investigated the remediation of petroleum-hydrocarbon-contaminated soil using bone char and NPK fertilizer as treatment amendments. The researchers evaluated the reduction of petroleum hydrocarbons and developed kinetic models to describe the degradation process. The findings showed that nutrient supplementation enhanced microbial activity and accelerated hydrocarbon degradation. The study is relevant to CLOGEN because it demonstrates how amendments can improve the biological degradation of hydrocarbons in contaminated soils.

The researchers evaluated cassava peel as a locally available organic biostimulant for the remediation of crude-oil-polluted soil. [14] Different quantities of cassava peel were incorporated into contaminated soil and monitored over time. The treatment enhanced microbial activity and resulted in substantial reductions in total hydrocarbons and TPH. The study demonstrated the potential of agricultural waste materials to provide nutrients and stimulate indigenous microorganisms responsible for petroleum hydrocarbon degradation. [15] This

study provided a comprehensive review of petroleum pollution in the Niger Delta, examining the causes and environmental consequences of oil spills and assessing available bioremediation technologies. The authors discussed microbial degradation, nutrient amendment, phytoremediation and other biological approaches for petroleum pollution control. The review highlighted bioremediation as an environmentally sustainable strategy for restoring petroleum-impacted environments in the Niger Delta. [16] The researchers isolated bacteria from crude-oil-contaminated soils in southern Nigeria and investigated their hydrocarbon tolerance, taxonomic characteristics and phylogenetic relationships. The study identified bacterial isolates capable of surviving in petroleum-contaminated environments, demonstrating the presence of indigenous microorganisms with potential for hydrocarbon degradation. The findings support the use of indigenous microbial populations in biological remediation of petroleum-contaminated Nigerian soils.

The study investigated an integrated remediation approach involving indigenous microorganisms and maize phytoremediation. [17] The researchers evaluated the degradation of petroleum hydrocarbons, including aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs). The results demonstrated that microbial degradation combined with plant-assisted remediation could substantially reduce petroleum contaminants while supporting restoration of the contaminated soil ecosystem. [18] The researchers developed an immobilized bacterial remediation system using *Gordonia alkanivorans* W33 for petroleum-contaminated soil. Immobilization was investigated as a means of improving the survival, stability and hydrocarbon-degrading performance of the bacterial agent. The study demonstrated that immobilized microorganisms can provide an effective approach for enhancing petroleum hydrocarbon biodegradation and overcoming some limitations associated with conventional free-cell bioaugmentation. [19] The study examined the combined application of bioaugmentation and biostimulation using kenaf core to enhance petroleum hydrocarbon degradation. The researchers assessed bacterial enzyme activities as indicators of microbial hydrocarbon-degrading processes. The results showed that the combined treatment stimulated microbial biochemical activity and enhanced petroleum hydrocarbon biodegradation. The study is particularly relevant to CLOGEN because it establishes a relationship between remediation amendments, microbial activity and contaminant removal. [20] The researchers compared different biostimulants for the restoration of PAH-contaminated soil and examined their effects on the soil microbial community. The study showed that biostimulant application can modify microbial community structure and enhance the biological degradation of persistent petroleum contaminants. It demonstrates that successful remediation should consider both contaminant removal and recovery of the microbial ecosystem.

The major deficiency across the reviewed studies is that

most relied on nutrient amendments, agricultural wastes, specific microbial strains, microbial consortia, or phytoremediation, while relatively little attention has been given to locally developed electro-ionic biopolymer-based remediation agents such as CLOGEN. Furthermore, several studies emphasized contaminant degradation or microbial activity independently, rather than simultaneously evaluating TPH reduction, soil nutrient availability, microbial population and restoration of soil functionality.

The present study therefore addresses these gaps by investigating CLOGEN as a locally developed remediation agent for hydrocarbon-impacted soil, using both laboratory and field investigations. Its effectiveness was evaluated through TPH reduction, physicochemical characterization, nitrate and ammonium availability, and microbial population changes. The reported remediation efficiency of up to 96% demonstrates the potential of CLOGEN as an alternative and environmentally sustainable remediation technology for petroleum-contaminated soils in the Niger Delta.

2. Materials and Methods

2.1. Materials and Equipment

The materials and equipment used included contaminated soil, CLOGEN, NPK fertilizer, urea, phosphate salts, fibre/bulking materials, spray pump, excavator, payload, hand auger, core sampler, soil-column apparatus, and gas chromatographic equipment. CLOGEN was used as the principal remediation amendment, while N and P sources were applied to maintain an optimum soil C:N:P ratio.

2.2. Soil Sampling and Characterization

Contaminated soil was collected from designated trial pits at depths of approximately 2–10 m below ground level using a hand auger and core sampler. Samples were homogenized, air-dried where appropriate, and stored in Teflon-lined containers at 4 °C prior to laboratory analysis. Baseline characterization included TPH, BTEX, PAHs, moisture content, pH, and nutrient concentrations. The soil consisted predominantly of fine-grained clay, with intercalations of sand, sandy clay, silty clay, coarse sand and fine sand. Initial TPH concentrations ranged from 454 to 8528 mg/kg, with the highest concentration recorded at 5.5 m depth in trial pit TP3.

2.3. Ex-Situ Bioremediation Procedure

Ex-situ remediation was conducted using engineered biocells. A 50 × 40 m biocell was constructed on compacted ground and lined with a 2-mm HDPE liner to prevent contaminant migration; a 300-mm sand layer was placed over the liner for protection and drainage. Contaminated soil was excavated, transported to the treatment area, homogenized and amended with CLOGEN and nutrient supplements.

The treated soil was arranged in approximately 1.0-m-high windrows to facilitate aeration and equipment access. Nutrients were uniformly incorporated into the soil and moisture was adjusted to support microbial activity. The target C:N:P ratio was maintained at 100:5:1 using urea and phosphate-based amendments. Windrows were periodically turned to improve aeration, prevent compaction and promote uniform distribution of amendments. Moisture was maintained at approximately 60% water-holding capacity and pH was adjusted to 7.2 ± 0.3 .

Leachate generated during watering or amendment application was collected through the lined biocell and directed to a contained leachate tank for management and, where required, recirculation. Windrows were covered with waterproof sheets to minimize excessive rainwater infiltration, leachate generation and moisture fluctuations.

2.4. Laboratory Soil-Column Experiment

A laboratory-scale soil-column experiment was performed to simulate hydrocarbon biodegradation under controlled conditions. Plexiglass columns approximately 50 cm in height and 10 cm in diameter were packed with 5 kg of contaminated soil. CLOGEN and nutrient solutions were applied uniformly to the soil, while intermittent air was supplied through a perforated base to promote aerobic conditions. Leachate samples were collected weekly to monitor hydrocarbon removal.

2.5. Hydrocarbon and Soil Analyses

TPH was determined using gas chromatography with flame ionization detection (GC-FID) following USEPA Method 8015B. Soil samples were extracted using hexane at a 1:10 soil-to-solvent ratio, filtered and concentrated before chromatographic analysis. An HP-5 capillary column and FID detector were used, with calibration based on n-alkane standards. Additional hydrocarbon analysis involved dichloromethane extraction and silica-gel cleanup, followed by GC-FID quantification in accordance with ASTM D5765.

Microbial populations were determined by serial dilution and plate-count techniques using nutrient agar. Plates were incubated at 30 °C for 48 h and microbial abundance was expressed as colony-forming units per gram (CFU/g). Measurements were conducted at five-day intervals.

Soil carbon, nitrogen and phosphorus were determined using the Walkley–Black dichromate, Kjeldahl and spectrophotometric methods, respectively.

2.6. Kinetic Modelling

Hydrocarbon degradation was modelled using a first-order kinetic expression:

$$C_t = C_0 e^{-kt} \quad (1)$$

where C_t is the TPH concentration at time t , C_0 is the initial

TPH concentration, k is the first-order biodegradation rate constant, and t is the remediation time. The corresponding half-life was calculated as:

$$t_{1/2} = \frac{\ln 2}{k} \quad (2)$$

Remediation efficiency was calculated as:

$$RE(\%) = \frac{c_0 - c_t}{c_0} \times 100 \quad (3)$$

The model was calibrated against experimental measurements using nonlinear regression in MATLAB. The study also employed a Runge–Kutta numerical solution to predict temporal TPH reduction and compare model predictions with experimental and analytical results.

2.7. Remediation Monitoring and Model Validation

During remediation, TPH concentration, microbial population, moisture and relevant soil properties were monitored periodically. Windrow samples were collected using a hand auger from multiple locations and depths and composited to obtain representative samples. Appropriate quality-assurance and quality-control procedures were followed during sampling, preservation and laboratory analysis.

Model performance was evaluated by comparing predicted concentrations with laboratory and field observations using the coefficient of determination (R^2) and root mean square error (RMSE). The reported model fit gave R^2 values of 0.91 for nutrient-only treatment and 0.94 for CLOGEN treatment, indicating good agreement between predicted and experimental results.

3. Results and Discussion

3.1. Excavation and Field Operations

The remediation process began with site clearing, fencing, and demarcation of the contaminated area.

Excavation was carried out using hydraulic excavators to remove oil-impacted soils to depths varying between 4.5m and 6.0m below ground level, depending on contamination intensity determined from baseline sampling.

Key Details:

Total area remediated: ~3,200 m²

Average excavation depth: 7m

Volume of soil excavated: approximately 3,200 m³

Excavated soils were placed in HDPE-lined temporary storage cells to prevent cross-contamination.

Soil excavation continued until the field hydrocarbon de-

tection limit was less than 1,000 mg/kg using a portable photoionization detector (PID).

Observation:

Strong hydrocarbon odor and oily films were observed in top layers (0–3 m), confirming active contamination.

Subsurface soils (beyond 5.5 m) showed reduced oil saturation, indicating the vertical limit of contamination.

3.1.1. Soil Sorting and Classification

The excavated soils were classified based on hydrocarbon intensity:

Heavily impacted soils → sent for CLOGen microbial treatment.

Moderately impacted soils → subjected to nutrient-only biostimulation.

Lightly impacted soils → used for backfilling and site leveling.

This classification ensured that treatment resources were applied optimally and effectively.

3.1.2. Transportation and Containment

All excavated soils were transported from the field pits to the treatment area using lined dump trucks under strict HYPREP environmental safety protocols.

Each load was accompanied by a chain-of-custody form, which recorded:

- 1) GPS coordinates of the excavation point,
- 2) Depth of sampling,
- 3) Weight and volume of transported soil,
- 4) Time of transport and driver identification.

Temporary containment areas were protected with berms and HDPE liners to prevent infiltration and runoff.

3.2. Baseline Soil Characterization

The baseline assessment revealed:

- 1) Noticeable petroleum odor.
- 2) Poor soil aeration and water infiltration.
- 3) Low microbial count due to toxic hydrocarbon concentration.
- 4) Strong hydrocarbon odor and visibly dark, oily soil patches.
- 5) High moisture retention and poor soil aeration.

These observations confirmed long-term petroleum contamination from leaking NPSC pipeline infrastructure.

3.3. Laboratory Results

Soil samples collected at depths of 3–7 m showed elevated Total Petroleum Hydrocarbon (TPH) concentrations, with all values exceeding HYPREP's remediation benchmark of 1,000 mg/kg.

Table 1. Baseline Soil TPH Concentration.

Sample ID	Dept(mbgl)	TPH(mg/kg)	Hyprep limit(mg/kg)	Exceedence Yes/No
SP-TP1	3.0	472.66	1000	No
SP-TP1	3.50	991.20	1000	No
SP-TP1	4.90	6100.05	1000	Yes
SP-TP1	6.10	2157.96	1000	Yes
SP-TP2	3.30	454	1000	No
SP-TP2	3.90	1667	1000	Yes
SP-TP2	5.90	5233	1000	Yes
SP-TP2	6.70	5071	1000	Yes
SP-TP3	3.70	565	1000	No
SP-TP3	4.30	6560	1000	Yes
SP-TP3	5.50	8528	1000	Yes
SP-TP3	6.40	5323	1000	Yes
SP-TP4	3.00	893	1000	No
SP-TP4	4.00	7537	1000	Yes
SP-TP4	5.90	6916	1000	Yes
SP-TP4	6.70	2742	1000	Yes

Table 1 presents the baseline Total Petroleum Hydrocarbon (TPH) concentrations in soil samples collected from four trial pits (SP-TP1 to SP-TP4) at different depths. The measured TPH concentrations ranged from 454 to 8,528 mg/kg, indicating considerable spatial and vertical variation in hydrocarbon contamination. The highest concentration of 8,528 mg/kg occurred at 5.50 m below ground level (mbgl) in SP-TP3, while the lowest concentration of 454 mg/kg was recorded at 3.30 mbgl in SP-TP2. Using the HYPREP intervention limit of 1,000 mg/kg as the benchmark, several sampling points exceeded the permissible concentration. At SP-TP1, concentrations above the limit occurred at 4.90 and 6.10 mbgl, while SP-TP2 exceeded the limit at 3.90, 5.90 and 6.70 mbgl. Similarly, SP-TP3 recorded exceedances at 4.30, 5.50 and 6.40

mbgl, and SP-TP4 exceeded the limit at 4.00, 5.90 and 6.70 mbgl. Overall, the results indicate that most of the deeper soil horizons were substantially impacted by petroleum hydrocarbons, particularly at SP-TP3 and SP-TP4. These elevated concentrations justified the need for remediation treatment using CLOGEN and nutrient amendments.

3.4. Post-Remediation Results

Following 14–30 days of ex-situ bioremediation in engineered biocells, significant TPH reduction was achieved through nutrient addition and microbial stimulation.

Table 2. Bioremediation Result.

Parameter	Pre-remediation (mg/kg)	Post-Remediation (mg/kg)	Hyprep limit (mg/kg)
TPH	454-8528	350-950	1000
BTEX	<5.0	<5.0	30-1000
PAHs	<0.80	<0.80	70

Table 2 summarizes the concentrations of major petroleum hydrocarbon contaminants before and after remediation and compares the post-remediation values with the HYPREP limits. Before treatment, TPH concentrations ranged from 454–8,528 mg/kg, indicating substantial hydrocarbon contamination. Following remediation, TPH concentrations decreased to 350–950 mg/kg, bringing the treated soil below the HYPREP limit of 1,000 mg/kg. The concentrations of BTEX and PAHs

were already relatively low before remediation, at <5.0 mg/kg and <0.80 mg/kg, respectively, and remained below their corresponding HYPREP limits of 30–1,000 mg/kg for BTEX and 70 mg/kg for PAHs after treatment. Overall, the results demonstrate that the remediation process was effective, particularly in reducing the initially elevated TPH concentrations to levels within the applicable regulatory limit.

3.5. Results of Bioremediation

3.5.1. Reduction in TPH Concentration

Table 3. Reduction in TPH Concentration.

Time(days)	TPH(mg/kg) control	TPH(mg/kg) Nutrients only	TPH(mg/kg) Clogen
0	8000	8000	8000
5	6200	4200	3800
10	4800	2350	1700
15	3800	1200	750
20	4900	800	460
30	2000	580	350

Table 3 shows the variation in TPH concentration with remediation time for the control, nutrient-only treatment, and CLOGEN treatment. All treatments started with an initial TPH concentration of 8,000 mg/kg. After 5 days, TPH decreased to 6,200 mg/kg in the control, 4,200 mg/kg with nutrients only, and 3,800 mg/kg with CLOGEN, indicating a faster initial reduction in the amended treatments. The reduction became more pronounced with increasing treatment time. At 15 days, TPH concentrations were 3,800, 1,200, and 750 mg/kg for the control, nutrient-only, and CLOGEN treatments, respectively. By 30 days, the concentrations declined to 2,000 mg/kg in the control, 580 mg/kg with nutrients only, and 350 mg/kg with CLOGEN. Thus, CLOGEN produced the greatest overall reduction, achieving an approximately 95.6% decrease

in TPH from the initial 8,000 mg/kg, compared with 92.8% for nutrients alone and 75.0% for the control. The results indicate that CLOGEN enhanced hydrocarbon removal more effectively than nutrient addition alone, with the final CLOGEN-treated concentration well below the 1,000 mg/kg HYPREP intervention limit. The progressive decline in TPH also demonstrates that remediation effectiveness increased with treatment duration.

3.5.2. Concentration-Time Relationship

The graph demonstrates exponential decay from 8,000 mg/kg to below 1,000 mg/kg after approximately 14 days, matching analytical model predictions.

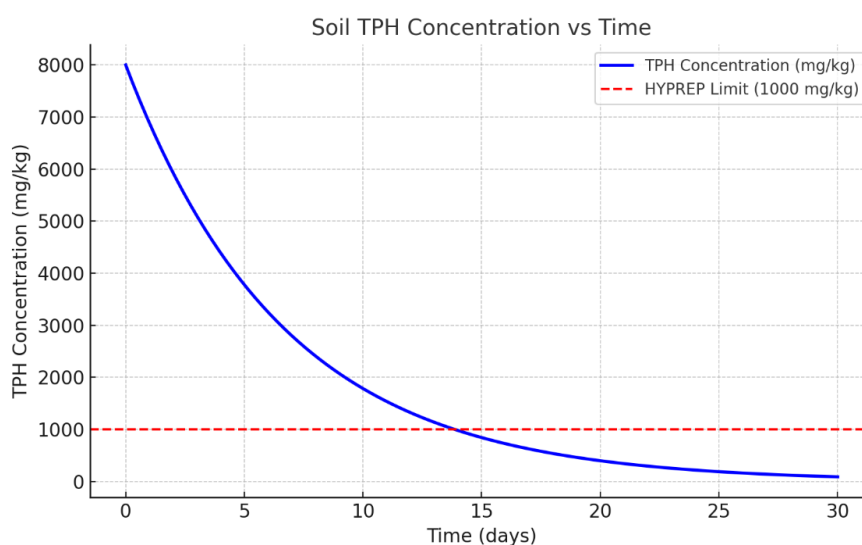


Figure 1. Soil TPH concentration vs time.

Figure 1 illustrates the progressive decline in soil Total Petroleum Hydrocarbon (TPH) concentration with increasing remediation time. The TPH concentration decreased from an initial value of 8,000 mg/kg and approached the HYPREP intervention limit of 1,000 mg/kg with increasing treatment duration. The concentration falls below the HYPREP limit at approximately 14 days, indicating that the modeled remediation process can achieve the regulatory target within the treatment

period. Overall, the figure demonstrates a strong time-dependent reduction in TPH concentration, consistent with the assumed first-order biodegradation behavior.

3.6. Validation of Model Predictions

A strong correlation was observed between the analytical model and experimental results.

Table 4. Model Predictions.

Parameter	Experimental (day ⁻¹)	Model(day ⁻¹)	R ²
Clogen+ Nutrient	0.185	0.182	0.94
Nutrients only	0.143	0.147	0.91
Control	0.093	0.088	0.89

Table 4 compares the experimental and model-derived first-order biodegradation rate constants for the different remediation treatments. The CLOGEN + nutrient treatment recorded the highest experimental rate constant (0.185 day⁻¹), closely matching the model value of 0.182 day⁻¹, with an R^2 of 0.94. This indicates the fastest hydrocarbon degradation among the treatments and a strong agreement between experimental observations and model predictions. The nutrient-only treatment produced an experimental rate constant of 0.143 day⁻¹, compared with 0.147 day⁻¹ from the model, giving an R^2 of 0.91. The control exhibited the lowest degradation rate (0.093 day⁻¹

experimentally and 0.088 day⁻¹ by the model), with an R^2 of 0.89. Overall, the close agreement between experimental and model values and the relatively high R^2 values demonstrate that the first-order kinetic model adequately represented TPH degradation, with the CLOGEN + nutrient treatment providing the most effective degradation rate.

3.7. Microbial Activity Evaluation

Microbial counts (CFU/g) were monitored using the pour plate method.

Table 5. Microbial Activity Evaluation.

Time (day ⁻¹)	Control (CFU/g)	Clogen (CFU/g)
0	2.1×10^4	2.3×10^4
10	4.5×10^5	01.1×10^6
20	5.8×10^5	1.4×10^6
30	4.9×10^5	1.2×10^6

Table 5 presents the changes in microbial population during the 30-day remediation period for the control and CLOGEN-treated soils. The initial microbial populations were 2.1×10^4 CFU/g for the control and 2.3×10^4 CFU/g for the CLOGEN treatment. After 10 days, microbial populations increased substantially to 4.5×10^5 CFU/g in the control and 1.1×10^6 CFU/g in the CLOGEN-treated soil. The microbial population continued to increase to 5.8×10^5 CFU/g in the control and 1.4×10^6 CFU/g under CLOGEN treatment by day 20. At day 30, the population decreased slightly to 4.9×10^5 CFU/g in the control and 1.2×10^6 CFU/g in the CLOGEN treatment. Overall, the consistently higher microbial population in the CLOGEN treatment indicates that CLOGEN promoted microbial proliferation, which is associated with enhanced biological degradation of petroleum hydrocarbons. The results therefore support the higher TPH removal and biodegradation rate observed for the CLOGEN treatment.

4. Conclusion

The remediation of hydrocarbon-impacted soil remains a significant environmental challenge, especially in regions like the Niger Delta where crude oil exploration and production activities are prevalent. This study focused on the assessment and remediation of hydrocarbon-contaminated soil using CLOGEN and NOSDRA-approved nutrient amendments, demonstrating the potential of locally developed bioremediation agents in restoring polluted environments. Results obtained revealed that bioremediation is a sustainable and eco-friendly method for mitigating hydrocarbon pollution. The application of CLOGEN, which contains electro-ionic biopolymers, polysaccharides cellulose, and dispersants, significantly enhanced hydrocarbon degradation by stimulating microbial activity and improving soil physicochemical properties. Similarly, the addition of nutrient amendments approved by the National Oil Spill Detection and Response Agency (NOSDRA) provided essential nutrients (nitrogen, phosphorus, and potassium) necessary for microbial metabolism and accelerated the breakdown of total petroleum hydrocarbons (TPH).

The findings indicate that, after treatment, the TPH levels in the remediated soil were greatly reduced to within acceptable regulatory limits. Soil texture, pH, moisture content, and organic matter were also improved, thereby enhancing soil fertility and

suitability for vegetation growth. This validates that the combined use of CLOGEN and biostimulants can serve as an efficient, cost-effective, and environmentally friendly alternative to conventional soil washing or excavation techniques. Furthermore, this study highlights the importance of adopting indigenous technologies and capacity building in environmental restoration projects such as those managed by HYPREP under the Ogoni clean-up initiative. The integration of local remediation products and scientific monitoring ensures long-term sustainability and community participation in the restoration process.

Abbreviations

TPH	Total Petroleum Hydrocarbons
HYPREP	Hydrocarbon Pollution Remediation Project
NOSDRA	National Oil Spill Detection and Response Agency
SPDC	Shell Petroleum Development Company of Nigeria Limited
NAOC	Nigerian Agip Oil Company Limited
PAH	Polycyclic Aromatic Hydrocarbons
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
HDPE	High-Density Polyethylene

Author Contributions

Abowei Bright Kenyas: Data curation, Resources

Kenneth Kekpugile Dagde: Conceptualization, Supervision

Titus Ndiele Amadi: Writing – review & editing

Jaja Zina: Formal Analysis, Methodology, Software

Conflict of Interest

The authors declare no conflicts of interest.

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