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BIOREMEDIATION OF OIL-POLLUTED SOILS USING INDIGENOUS MICROBIAL CONSORTIA ISOLATED FROM CONTAMINATED SITES IN NORTHWESTERN NIGERIA

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Article Info

Abstract

Oil pollution remains one of the most pressing environmental challenges in Nigeria, particularly in agricultural and semi-urban regions where crude oil leakage and spillage degrade soil fertility, threaten food security, and endanger public health. Conventional remediation strategies, though effective in some contexts, are costly, energy-intensive, and may lead to secondary environmental impacts. Bioremediation using indigenous microorganisms offers a eco-friendlier and more sustainable alternative. This study investigated the bioremediation potential of microbial consortia isolated from crude oil-polluted soils in Northwestern Nigeria. Microbes were identified through enrichment culture, morphological, biochemical, and molecular techniques, with key isolates including aeruginosa, Bacillus subtilis, and Aspergillus niger. Microcosm experiments were set up to compare natural attenuation, single-strain treatment, and consortium inoculation. Results demonstrated that microbial consortia achieved the highest total petroleum hydrocarbon (TPH) reduction of 78% within 30 days, compared to 68% by single strains and 20% under natural attenuation. The synergistic interactions between bacteria and fungi enhanced degradation efficiency, particularly due to bio surfactant production and complementary enzymatic pathways. These findings suggest that indigenous microbial consortia hold significant promise as scalable, cost-effective, and environmentally friendly agents for oil spill remediation in Nigeria and beyond. Future research should focus on field-scale applications, optimization of environmental conditions, and integration into national environmental policies.

Keywords:
Bioremediation, Oil Pollution, Indigenous Microbes, Hydrocarbon, Degradation, Nigeria.

1. Introduction

1.1 Background

Oil pollution is a global environmental concern driven by extraction, transportation, and industrial use of petroleum products. Spills and leakages introduce hydrocarbons into ecosystems, many of which are toxic, persistent, and carcinogenic. In developing regions, the impacts are magnified by limited remediation infrastructure and weak regulatory enforcement (Alvarez & Illman, 2022; UNEP, 2022).

Nigeria, Africa's leading oil producer, faces severe challenges from oil pollution. While the Niger Delta has historically been the most studied, other regions such as Northwestern Nigeria are Increasingly affected due to transportation, illegal refining, and storage-related spills. This has significant consequences for agricultural productivity, soil health, biodiversity, and food security (Olajire, 2020; Adedeji et al., 2021).

1.2 Problem Statement

Northwestern Nigeria is not traditionally known as a petroleum-producing hub, but oil transportation through pipelines and storage facilities in this region has resulted in recurrent leakages and spillage events. Unlike the Niger Delta where research and remediation have been concentrated, Northwestern Nigeria suffers from limited attention despite increasing pollution incidents. The sandy-loam soils and semi-arid climate further exacerbate the persistence of hydrocarbons, limiting natural attenuation and causing long-term degradation of soil fertility. There is an urgent need to explore low-cost and eco-friendly remediation approaches tailored to local environmental conditions.

1.3 Rationale of the Study

Bioremediation using indigenous microorganisms offers an innovative solution, as locally adapted microbial strains have evolved mechanisms to degrade hydrocarbons under site-specific environmental conditions. This avoids the challenges of introducing foreign microbes, which may fail to establish or cause ecological imbalances. Harnessing microbial consortia—combinations of bacteria and fungi with complementary metabolic pathways—has shown superior efficiency compared to single isolates (Mukherjee et al., 2020). Therefore, this study fills a crucial research gap by investigating microbial consortia isolated from Northwestern Nigeria for their potential in bioremediation of oil-polluted soils.

1.4 Objectives

This study aimed to:

1. Isolate and characterize indigenous hydrocarbon-degrading microorganisms from oil-contaminated soils in Northwestern Nigeria.
2. Evaluate the bioremediation potential of microbial consortia compared to single-strain inoculation and natural attenuation.
3. Assess the efficiency of microbial treatments in degrading total petroleum hydrocarbons (TPH).
4. Provide recommendations for field-scale application and policy integration.

2. Literature Review

2.1 Global Context of Oil Pollution

Globally, oil spills have been linked to severe ecological damage. In marine ecosystems, spills disrupt fisheries, coral reefs, and mangroves, while in terrestrial environments, hydrocarbons alter soil chemistry, reduce fertility, and impair microbial communities (Das & Chandran, 2011). Major oil spill disasters such as the Exxon Valdez (1989) and Deepwater Horizon (2010) have shaped global perspectives on oil remediation strategies. In Africa, the Niger Delta remains one of the world's most contaminated regions, with an estimated 13 million barrels of crude oil spilled over five decades (UNEP, 2022).

2.2 Conventional Remediation Techniques

Traditional methods for oil pollution remediation include physical recovery (skimming, booms), chemical dispersants, incineration, and soil excavation. While these methods can provide immediate relief, they are expensive and often unsustainable. For example, dispersants break oil into smaller droplets but may introduce additional toxicity (Haritash & Kaushik, 2009). Soil excavation displaces the pollution problem rather than resolving it, while thermal desorption consumes large amounts of energy. These limitations highlight the need for bioremediation as a cost-effective and eco-friendly strategy.

2.3 Principles of Bioremediation

Bioremediation is the use of living organisms, primarily microorganisms, to degrade pollutants into less toxic forms. Microbial degradation of hydrocarbons typically involves oxidation by enzymes such as oxygenases and peroxidases, transforming complex compounds into simpler molecules like carbon dioxide and water (Varjani, 2017). Two main strategies exist:

Bio Stimulation: Enhancing the activity of native microbes through nutrient addition.

Bioaugmentation: Introducing specialized microbes or consortia to contaminated sites

2.3 Role of Microbial Consortia

Microbial consortia, involving both bacteria and fungi, often outperform single strains due to complementary pathways. For instance, Pseudomonas aeruginosa produces bio surfactants that emulsify hydrocarbons, Bacillus subtilis enhances enzymatic degradation, while fungi like Aspergillus niger degrade complex polycyclic aromatic hydrocarbons (PAHs) (Marchant & Banat, 2012; Onyena & Sam, 2020). Recent studies emphasize synergistic interactions where fungi break down recalcitrant hydrocarbons into simpler substrates for bacterial consumption (Udeh et al., 2021).

2.5 Nigerian Case Studies

Several Nigerian studies confirm the potential of microbial consortia. Rahman et al. (2002) reported that a mixed bacterial consortium degraded 85% of crude oil in controlled experiments. Udeh et al. (2021) demonstrated that indigenous consortia in Delta State achieved higher degradation compared to single strains. However, research on Northwestern Nigeria remains limited, justifying the focus of this study.

3. Materials and Methods

3.1 Study Area and Sampling

Soil samples were collected from oil-contaminated sites in Gwadabawa and Sokoto, Northwestern Nigeria. Control soils were obtained from nearby uncontaminated agricultural fields. The region's semi-arid climate, with mean annual rainfall of 500–700 mm and sandy-loam soil texture, strongly influences microbial dynamics and hydrocarbon fate.

3.2 Microbial Isolation and Identification

Microorganisms were enriched using Bushnell-Haas medium with crude oil as the sole carbon source. Colonies with distinct morphologies were purified and characterized by:

Morphological identification: Colony color, shape, elevation, and margin.

Biochemical tests: Catalase, oxidase, citrate utilization, and sugar fermentation (Cappuccino & Sherman, 2014).

Molecular identification: 16S rRNA sequencing for bacteria and ITS sequencing for fungi. Key isolates included Pseudomonas aeruginosa, Bacillus subtilis, and Aspergillus niger.

3.3 Microcosm Experiments

Microcosms (500 g contaminated soil) were prepared in sterile containers and treated as follows:

T1: Control (no inoculation).

T2: Single strain (Pseudomonas aeruginosa).

T3: Consortium (Pseudomonas aeruginosa, Bacillus subtilis, Aspergillus niger).

Crude oil was added at 5% w/w, and microcosms were incubated at 30°C for 30 days with 60% moisture maintained. TPH degradation was quantified gravimetrically at 5-day intervals.

3.3 Data Analysis

Degradation efficiency was calculated as percentage TPH reduction. Statistical differences among treatments were determined using one-way ANOVA ($p < 0.05$).

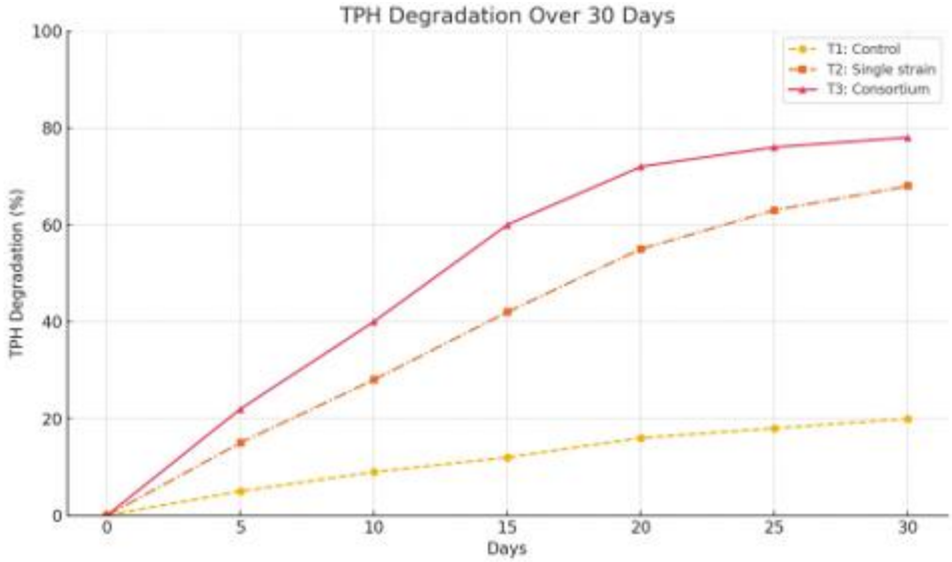
4. Results

The microbial consortium demonstrated the highest degradation efficiency with 78% TPH reduction after 30 days, compared to 68% by single-strain treatment and 20% under natural attenuation. The results are summarized in Table 1.

Table 1: TPH Reduction under Different Treatments

Treatment	Days 10	Days 20	Days 30	Final Reduction (%)
Control (T1)	5%	12%	20%	20
Single strain (T2)	25%	47%	68%	68
Consortium (T3)	35%	62%	78%	78

Figure 1: TPH Degradation Trends across Treatments (A line graph showing TPH reduction percentages across 30 days for T1, T2, and T3).



5. Discussion

5.1 Comparative Performance

The microbial consortium significantly outperformed single-strain treatments and natural attenuation. This is consistent with literature highlighting the role of metabolic diversity and synergistic interactions in microbial consortia (Mukherjee et al., 2020). Pseudomonas aeruginosa and Bacillus subtilis produce bio surfactants that emulsify hydrocarbons, while Aspergillus niger oxidizes complex hydrocarbons, making them accessible to bacteria.

5.2 Limitations of Natural Attenuation

The control treatment showed only 20% degradation after 30 days, indicating the limitations of natural attenuation in semi-arid Northwestern soils. The low moisture and nutrient availability in sandy-loam soils hinder microbial activity, underscoring the need for bio augmentation or bio stimulation.

5.3 Policy and Socio-Economic Implications

Adopting microbial consortia for field-scale remediation could restore agricultural productivity, safeguard food security, and reduce dependence on costly chemical methods. Community-based remediation initiatives, coupled with government policy support, can make bioremediation a sustainable strategy. Integration into Nigeria's national oil spill contingency framework would institutionalize microbial-based solutions.

5.4 Global Relevance

The findings resonate beyond Nigeria, particularly in other African and semi-arid regions facing similar challenges. Indigenous consortia can be harnessed in situ, avoiding the ecological risks of imported strains.

Figure 2: Conceptual Framework of Microbial Bioremediation in Oil-Polluted Soils (A schematic showing microbial synergy: biosurfactant production, PAH oxidation, and TPH degradation pathways).

6. Conclusion

This research confirms the potential of indigenous microbial consortia in bioremediation of oil-polluted soils in Northwestern Nigeria. The microbial consortium of Pseudomonas aeruginosa, Bacillus subtilis, and Aspergillus niger achieved 78% hydrocarbon degradation, outperforming single strains and natural attenuation. Harnessing indigenous microbial communities represents a cost-effective, sustainable, and scalable strategy for restoring polluted soils.

7. Recommendations

1. Conduct pilot-scale and field-scale trials to validate laboratory findings.
2. Integrate microbial bioremediation into Nigeria's national oil spill management policy.
3. Explore nutrient amendments (nitrogen, phosphorus) to enhance microbial activity.
4. Investigate genetic and metabolic adaptations of indigenous microbes for advanced biotechnological applications
5. Promote community participation and training in bioremediation practices.

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