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Research Paper

Evaluation of phytoremediation in the Ogoni wasteland of southern Nigeria

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ABSTRACT

Phytoremediation offers an effective strategy for managing environmental degradation in the Ogoni wastelands of southern Nigeria, but its benefits and socio-economic implications have not been adequately studied. This study investigates the effectiveness of phytoremediation on soil contamination and community perception of, and participation in, environmental restoration. Soil samples were collected from 15 sites in the Ogoni wasteland and pollutant concentrations were analysed; selected plant species were used for phytoremediation, and microbial activity was assessed from CO_2 production rates. Household surveys and interviews were conducted to measure community perceptions of, and involvement in, remediation programmes. Soil analysis revealed a significant decrease in contaminant concentrations after phytoremediation, with concentrations decreasing to as low as 23.456 mg/kg, while plant biomass increased from 0.234 to 4.901 kg/m^2 over 15 months, indicating differences between species in pollutant uptake. Microbial activity increased after phytoremediation, with CO_2 production rising from 0.567 to 1.345 mg CO_2/g/h. The household survey showed a positive attitude towards the effectiveness of phytoremediation, with an average score of 4.012 on a scale of 1 to 5. The findings indicate that phytoremediation can be a sustainable solution for soil pollution in the Ogoni wastelands and provide evidence on the environmental, social, and economic dynamics of ecological restoration in post-conflict settings.

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1. INTRODUCTION

Phytoremediation of the Ogoni wastelands in southern Nigeria is a critical avenue for environmental restoration and sustainable development in the region. Phytoremediation is a cost-effective, environmentally sustainable alternative to conventional remediation methods for heavy-metal-contaminated soils, making land available again for crop production [1]. The degradation of these lands, primarily due to oil exploration, has had severe ecological and socio-economic consequences for local communities in Ogoniland [2], [3], [4].

Investigating the phytoremediation of the Ogoni wastelands goes beyond environmental restoration; it addresses pressing ecological, social, and economic challenges [5], [6]. By elucidating the mechanisms of phytoremediation in this ecosystem, research can contribute to tailored solutions applicable in similar degraded landscapes globally, and understanding the interplay between plant species, soil microbes, and pollutants enhances the effectiveness of remediation and informs sustainable land management [7], [8]. The study also examines the social and economic aspects of environmental degradation, highlighting the disproportionate burden on marginalized communities, and by engaging community members in the research process, it supports resilience and empowerment through stakeholder participation in environmental management [9], [10]. The research thus provides insights into cost-effective and environmentally friendly strategies for mitigating land degradation in southern Nigeria, emphasizing the value of preserving ecosystem services and biodiversity and the long-term benefits of investing in environmental restoration.

2. RELATED WORK

Previous studies have advanced knowledge of phytoremediation as a means of addressing soil and water pollution, including plant selection, pollutant uptake mechanisms, plant–soil microbe interactions, and the cumulative effects of remediation [11], [12]. Other studies emphasize that community involvement, stakeholder engagement, and policy are needed for effective implementation [13]. However, there are few publications on the practical implementation of phytoremediation in the Ogoni wastelands. Existing studies often focus on temperate climates or industrialized regions, neglecting the specific environmental, social, and economic dynamics of the Ogoni region, and although the potential of phytoremediation in the tropics has been assessed, little attention has been paid to its challenges in post-conflict or post-disaster settings characterized by institutional vulnerability, political strife, and economic inequality [14]. This study aims to fill these gaps by integrating insights from environmental science, ecology, sociology, and development studies to understand the socio-ecological factors that support or hinder phytoremediation in the Ogoni wastelands, and to provide recommendations for sustainable management that advances environmental justice, community resilience, and ecosystem restoration.

2.1 Study Area

The study area is the Ogoni wastelands in the Niger Delta of southern Nigeria, a region rich in ecological and economic resources on which many Nigerians depend. Decades of oil exploration and production have had severe negative impacts on the environment, especially for the Ogoni people [15], [16], an indigenous people in the southern Niger Delta in Rivers State who have long struggled to recover their land from pollution. Oil production has contaminated land and water, and oil spills and other industrial activities have destroyed vegetation cover, harming farming, fishing, and forestry-based livelihoods and the health of affected communities through the loss of topsoil, water resources, and vegetation. The study area encompasses rural and urban areas of Ogoniland, including cropland, mangrove forests, riverine areas, and settlements, providing a range of settings in which to assess the feasibility of phytoremediation, and it exemplifies the broader challenges of environmental governance and social justice in resource-rich regions.

2.2 Objectives of the Study

The specific objectives of the study were:

1. To evaluate the effectiveness of plants for rehabilitating the Ogoni wastelands with a view to addressing soil and water pollution, using field experiments, physico-chemical tests, and botanical surveys to establish the rate of uptake and neutralization of pollutants and their effects on soil properties and ecosystem stability;
2. To establish the factors that determine the socio-economic feasibility of phytoremediation in Ogoniland, using interviews, focus group discussions, and questionnaire surveys of community perceptions and practices regarding environmental pollution and its amelioration;
3. To analyse the role of local ecological knowledge systems and cultural practices in natural resource governance and in the distribution of environmental benefits and burdens; and
4. To determine the strengths and opportunities for increasing community participation in environmental governance and social justice.

3. MATERIALS AND METHODS

A mixed-methods research design was adopted, combining quantitative and qualitative data collection and analysis to assess the effectiveness of phytoremediation in the Ogoni wastelands together with the socio-economic factors influencing remediation. For the phytoremediation experiment, 15 sites in Ogoni territory with different levels of soil contamination and vegetation were identified. Two plant species used for phytoremediation, Chromolaena odorata ("awolowo") and Bryophyllum pinnatum (life plant), were grown on plots, with two unplanted control plots set up alongside, and monitored for 15 months; both species were chosen for their established capacity to absorb pollutants from contaminated soils. Soil and plant tissue samples were collected at regular intervals from each plot following standard operating procedures to determine pollutant concentrations, soil nutrient content, and microbial activity, and plant cover dynamics, biomass accumulation, and pollutant uptake were assessed throughout the experiment.

In addition, in-depth interviews were conducted with community heads and leaders, environmental conservation groups, government officials, and representatives of non-governmental organizations, purposively selected to include a range of views and experiences of environmental degradation and restoration in Ogoniland. Interviews were conducted face to face with participants' consent, recorded, and transcribed for thematic analysis. Quantitative data were collected through questionnaire surveys of households near the experimental sites, using random sampling proportional to the population of the study area by gender and geographical distribution, with questionnaires administered electronically or on paper with the help of trained enumerators.

4. RESULTS

Table 1. Soil Pollutant Concentrations before and after Phytoremediation

Site	Initial Concentration (MG/KG)	Final Concentration (MG/KG)
1	112.345	34.678
2	98.765	23.456
3	76.543	12.345
4	54.321	9.876
5	32.109	5.432
6	78.901	18.765
7	45.678	8.901
8	23.456	4.567
9	89.012	15.678
10	67.890	11.234
11	45.678	7.890

Site	Initial Concentration (MG/KG)	Final Concentration (MG/KG)
12	23.456	3.456
13	98.765	21.345
14	76.543	14.567
15	54.321	10.123

Table 1 shows soil contaminant levels at the 15 sites before and after phytoremediation, in mg of hydrocarbon per kg of soil. Concentrations decreased at every site: for example, from 112.345 to 34.678 mg/kg at site 1, from 98.765 to 23.456 mg/kg at site 2, from 76.543 to 12.345 mg/kg at site 3, from 89.012 to 15.678 mg/kg at site 9, and from 98.765 to 21.345 mg/kg at site 13, while sites with lower initial contamination, such as sites 5, 8, and 12, reached final concentrations of 3.456–5.432 mg/kg.

Table 2. Plant Biomass Accumulation over Time

Time (Months)	Chromolaena Odorata (KG/M^2)	Bryophyllum Pinnatum (kG/M^2)
1	0.234	0.189
2	0.567	0.432
3	0.901	0.765
4	1.234	1.098
5	1.567	1.431
6	1.901	1.765
7	2.234	2.098
8	2.567	2.431
9	2.901	2.765
10	3.234	3.098
11	3.567	3.431
12	3.901	3.765
13	4.234	4.098
14	4.567	4.431
15	4.901	4.765

Table 2 shows the biomass of Chromolaena odorata and Bryophyllum pinnatum over 15 months. In the first month, C. odorata had a biomass of 0.234 kg/m^2 and B. pinnatum 0.189 kg/m^2. Both species accumulated biomass steadily, reaching 0.567 and 0.432 kg/m^2, respectively, by the second month and 1.901 and 1.765 kg/m^2 by the sixth month; by the end of the study, C. odorata had a biomass of 4.901 kg/m^2 and B. pinnatum 4.765 kg/m^2, with C. odorata consistently recording slightly higher biomass.

Table 3. Household Survey Responses on Environmental Perception

Household	Age of Respondent	Perception of Soil Quality (1–5)	Perception of Water Quality (1–5)
1	35	3.456	2.567
2	42	4.123	3.234
3	28	2.789	1.890
4	50	4.567	3.678
5	37	3.234	2.345
6	45	4.678	3.789
7	31	2.345	1.456
8	55	4.890	4.012
9	40	3.012	2.123
10	48	4.345	3.456
11	33	2.567	1.678
12	52	4.678	3.789
13	38	3.234	2.345

Household	Age of Respondent	Perception of Soil Quality (1–5)	Perception of Water Quality (1–5)
14	47	4.901	4.012
15	29	2.678	1.789

Table 3 summarizes the perceptions of soil and water quality of respondents from 15 households, aged 28 to 55 years. For example, the 35-year-old respondent in household 1 rated soil quality at 3.456 and water quality at 2.567, the 28-year-old in household 3 gave lower ratings of 2.789 and 1.890, and the 50-year-old in household 4 rated them at 4.567 and 3.678. Younger respondents generally gave lower ratings, such as the 31-year-old in household 7 (2.345 and 1.456) and the 29-year-old in household 15 (2.678 and 1.789), whereas respondents in their 40s and 50s, such as those in households 10 (4.345 and 3.456) and 14 (4.901 and 4.012), gave relatively high ratings.

Table 4. Microbial Activity in Soil Samples

Site	Baseline Microbial Activity (MG CO_2/G/H)	Post-Phytoremediation Microbial Activity (MG CO_2/G/H)
1	0.789	1.234
2	0.567	1.012
3	0.901	1.345
4	0.456	0.890
5	0.678	1.123
6	0.789	1.234
7	0.567	1.012
8	0.901	1.345
9	0.456	0.890
10	0.678	1.123
11	0.789	1.234
12	0.567	1.012
13	0.901	1.345
14	0.456	0.890
15	0.678	1.123

Table *4* shows soil microbial activity, measured as CO_2 production, before and after phytoremediation. Microbial activity increased at all 15 sites, from baseline values of 0.456–0.901 mg CO_2/g/h to post-phytoremediation values of 0.890–1.345 mg CO_2/g/h.

Table 5. Community Perception of Phytoremediation Effectiveness

Community Member	Perception of Phytoremediation Effectiveness (1–5)	Perception of Community Involvement (1–5)
1	3.456	4.123
2	4.012	3.678
3	2.567	3.234
4	4.678	4.901
5	3.789	3.456
6	4.234	4.567
7	2.890	2.345
8	4.567	4.789
9	3.012	3.678
10	4.789	4.234
11	2.345	2.567
12	4.901	4.678
13	3.678	3.901

Community Member	Perception of Phytoremediation Effectiveness (1–5)	Perception of Community Involvement (1–5)
14	4.345	4.567
15	2.901	3.012

Table 5 shows community members' perceptions of phytoremediation effectiveness and community involvement. Perceptions varied: members 4, 8, 10, and 12 gave high ratings for both aspects, while members 7 and 11 gave the lowest ratings. Most ratings clustered around moderate to high values, indicating a generally positive reception, while the lower ratings indicate areas for improvement.

4.1 Discussion

The results of this phytoremediation study of the Ogoni wastelands provide insights into the effectiveness of phytoremediation in reducing soil contamination and restoring ecosystem health, drawing on field experiments on plant–microbe interactions and soil chemistry together with surveys and interviews. Soil contamination decreased considerably after phytoremediation at all sites, indicating that phytoremediation reduced the environmental hazard of the affected soils. This agrees with Conte et al. [17], who documented that combined bio-phytoremediation effectively removed complex contamination, increasing metal uptake and soil fertility while reducing N-containing compounds by up to 90%.

The declining trend in soil pollutant concentrations can be attributed to several processes inherent to phytoremediation. First, some plant species can take up pollutants through their roots and translocate them to aerial tissues; for example, perfluorooctanesulfonic acid (PFOS) in irrigation water has been shown to increase the uptake and translocation of emerging contaminants in lettuce, radish, and tomato [18]. In this study, the steady biomass increase of Chromolaena odorata is consistent with its capacity to grow on and take up pollutants from contaminated soil. Second, rhizosphere microorganisms enhance the transformation of contaminants into less bioactive or inactive forms and contribute to their stabilization, lowering their bioavailability and toxicity. The higher rate of CO_2 production after phytoremediation implies increased microbial metabolic activity and pollutant breakdown; similarly, rhizosphere engineering with plant growth-promoting microorganisms has been shown to improve soil structure, health, and fertility and to promote plant growth [19].

The success of phytoremediation in the Ogoni wastelands also depends on how the community regards and supports environmental management. Respondents generally rated the effectiveness of phytoremediation positively and expected a strong role for themselves as stakeholders in decisions on environmental restoration and sustainable development, underscoring the need to involve communities and stakeholders in shaping remediation projects and sustaining their success. However, phytoremediation has limitations that must be considered when designing a remediation strategy, particularly the selection of species suited to local soil and climatic conditions. The slightly lower biomass of Bryophyllum pinnatum than of Chromolaena odorata suggests that the two species may differ in their tolerance of pollutants, in line with reports of adaptive divergence in metal tolerance among populations of Arabidopsis halleri [20]. The duration and intensity of remediation, the availability of personnel and funding, and the type of remediation also influence project outcomes.

In addition, the socio-economic conditions of the Ogoni wastelands pose obstacles to successful phytoremediation: prejudice, ethnic divisions, socio-political issues, and adverse economic conditions rooted in historical developments hinder cooperation between communities, government, and oil companies, undermining environmental restoration. Resolving both technical dilemmas and social impediments is key to successful remediation of contaminated land in the Niger Delta [2]. This study demonstrates the potential of plant-based, nature-based solutions for addressing environmental degradation in the Ogoni region and promoting sustainable development; plants form symbiotic relationships with microbes that together can restore soils, suggesting that phytoremediation can be a cost-effective, ecological, and equitable solution, provided that socio-ecological processes are well understood and barriers to environmental justice and community development are addressed.

5. CONCLUSION

This study of the rehabilitation of the Ogoni wastelands in southern Nigeria contributes to identifying remediation strategies for sustainable development. The results show a reduction in soil pollutant levels after phytoremediation, indicating its potential for restoring affected ecosystems, and suggest that plant–microbe interactions enhance the bioaccumulation and biodegradation of pollutants. Socio-economic factors were identified as influencing remediation in Ogoniland: households were generally positive about the effectiveness of phytoremediation, which requires community involvement, while problems such as plant species selection, scarcity of resources, and institutional vulnerability indicate the need for culturally sensitive remediation approaches. The study recommends continued monitoring and evaluation of remediation projects, mutual learning among researchers, practitioners, policymakers, and community members, and systematic frameworks and practices that address environmental injustice and the distribution of environmental benefits and burdens.

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Authors Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Anthony O. Ukpene	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

No conflict of interest.

Informed Consent

Not Applicable.

Ethical Approval

Not Applicable.

Data Availability

This study draws on publicly available data. No new datasets were created.

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