



## Optimization of Phytocoagulant for Treating Crude Oil-Contaminated Surface Water

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### ABSTRACT

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Crude Oil Pollution, Phytocoagulation, *Moringa oleifera*, Surface Tension, Critical Micelle Concentration.

This study investigates the optimization of phytocoagulants for treating crude oil-contaminated surface water, focusing on the effects of extract concentration and temperature on total petroleum hydrocarbon (TPH) removal and reduction in surface tension. Five locally sourced ethanol extracts, *Moringa oleifera*, *Ficus exasperata*, *Trichostema lanceolatum*, *Senna alata*, and *Cymbopogon citratus* were screened for phytochemical components. Contaminated water samples were collected from the Wakama-Ama River and characterized and treated using standard jar tests to assess the reduction of total petroleum hydrocarbon (TPH) and surface tension at varying extract concentrations (0 – 500 mg/L) and temperatures (24 – 40°C). The results revealed a concentration-dependent reduction in both TPH and surface tension across all extracts. *Moringa oleifera* demonstrated the most efficient performance, reducing TPH from 3586.9 mg/l to 1650.1 mg/l at 450 mg/L, and lowering surface tension from 72.8 mN/m to 51.24 mN/m at just 150 mg/L, indicating a low optimal extract concentration. In contrast, *Cymbopogon citratus* was the least effective, achieving only 2643.7 mg/l TPH at 500 mg/L. Temperature variation also significantly influenced performance, with all extracts showing optimal removal at 34°C. At this temperature, *Moringa oleifera* further reduced TPH to 1450.75 mg/l and surface tension to 45.15 mN/m, outperforming all other extracts. These findings highlight the potential of phytochemical-rich extracts as eco-friendly, biodegradable, and cost-effective alternatives to synthetic coagulants. The study supports the adoption of *Moringa oleifera* and *Ficus exasperata* in scalable water treatment systems for oil-impacted environments.

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## 1. INTRODUCTION

Crude oil pollution in aquatic environments poses a persistent and multifaceted challenge, especially in oil-producing regions such as the Niger Delta of Nigeria. Spills resulting from exploration, transportation, and refining processes introduce harmful hydrocarbons into surface waters, leading to significant degradation of water quality, ecosystem disruption, and adverse human health effects [1]; [2]. Communities depending on contaminated rivers for drinking, fishing, and agriculture are particularly at risk [3]; [4].

Conventional water treatment methods, including mechanical skimming, chemical dispersants, and synthetic coagulants such as alum and ferric chloride, have demonstrated varying degrees of success in remediating petroleum-contaminated water. However, these techniques often suffer from limitations such as high cost, low sustainability, and the introduction of secondary pollutants [5]; [6]. Additionally, their effectiveness diminishes under field conditions where infrastructural and technical constraints prevail.

In response to these limitations, research has increasingly turned to plant-based coagulants that offer a biodegradable, eco-friendly, and cost-effective alternative. These natural agents are rich in phytochemicals, including tannins, saponins, flavonoids, and alkaloids which facilitate the binding and removal of suspended particles, hydrocarbons, and microbes from water [7]; [8]. Plants such as *Moringa oleifera*, *Senna alata*, and *Ficus exasperata* have shown promise in reducing turbidity, microbial load and chemical contaminants in polluted water bodies [9].

However, a gap remains regarding the optimization of these plant extracts for real-world applications, particularly in terms of operational parameters such as extract concentration and temperature. These factors significantly influence the performance of phytocoagulants, determining their effectiveness in removing total petroleum hydrocarbons (TPH) and reducing surface tension in crude oil-contaminated waters. Understanding these influences is crucial for improving the consistency and scalability of plant-based water treatment systems [10].

This study aims to address this gap by evaluating the coagulation efficiency of five selected plant

extracts under various concentrations and temperature conditions. The Wakama-Ama River in Rivers State, Nigeria, a region severely impacted by oil pollution, serves as the case study for this research. The research contributes to the development of an affordable, environmentally friendly, and community-accessible water treatment solution suitable for oil-impacted regions.

## 2. MATERIALS AND METHODS

### 2.1 Collection and Preparation of Plant Extracts

Five plants, namely *Cymbopogon citratus*, *Moringa oleifera*, *Trichostema lanceolatum*, *Senna alata*, and *Ficus exasperata*, were collected from the Choba Campus of the University of Port Harcourt and identified at the herbarium in the Department of Plant Science Biotechnology at the University of Port Harcourt, Nigeria. The plant parts (leaves and stems) were washed, oven-dried at 50°C for 2 days, ground, and sieved using a 0.4 mm mesh. Ethanol-based extraction was carried out by soaking 400 g of each plant powder in 2000 mL of 96% ethanol. After 14 days of maceration, the extracts were filtered and concentrated in a water bath at 40–45 °C, then stored at 4 °C for subsequent use.

### 2.2 Sample Collection and Contamination Profile

Crude oil-contaminated surface water samples were collected from the Wakama-Ama River, Tai Local Government Area, Rivers State, Nigeria. The sampling site exhibited visible signs of pollution, including oil sheens on the water surface and discoloration of sediments (Plate 1). Water samples were collected from eight different points, combined into a 400 L drum, and stored for treatment studies.

Physicochemical parameters were analysed to determine the chemical and physical composition of the contaminated surface water. Surface tension was measured using a Du Noüy ring tensiometer (Krüss K20, Germany) at room temperature, as described by [11]. Total petroleum hydrocarbons (TPH) were extracted from 200 mL of the filtered contaminated water per sample using n-hexane, cleaned according to the method described by [12] and [13], and quantified using an Agilent 5890N gas chromatography (GC).



**Plate 1.** Crude oil-contaminated Wakama-Ama River in Kporgor, Tai Local Government Area of Rivers State, Nigeria (Coordinates: 4°70'39"N, 7°23'29"E).

### 2.3 Jar Test Procedure

The jar test method followed protocols adapted from [14] and [15]. One litre of crude oil-contaminated water was poured into 1 L beakers, mixed rapidly at 200 rpm for 3 minutes, followed by slow mixing at 50 rpm for 30 minutes. The samples were then left to settle undisturbed for 60 minutes before supernatants were collected for analysis.

### 2.4 Effect of Plant Extract Concentration on TPH

Plant extracts were tested at concentrations ranging from 0 to 500 mg/L, by increments of 50 mg/L, to determine the critical micelle concentration (CMC) - the dose beyond which no significant reduction in TPH and surface tension occurred. Measurements of TPH removal were conducted using gas chromatography-mass spectrometry (GC-MS). Surface tension was measured using a Du Noüy ring tensiometer, ensuring each sample was tested in duplicates for accuracy. The critical micelle concentration (CMC) was identified as the point where further increases in extract concentration no longer resulted in significant reduction in surface tension.

### 2.5 Effect of Temperature on the Performance of the Phytocoagulants

To assess temperature effects, jar tests were conducted using the optimal CMC for each plant at temperatures ranging from 24 °C to 40 °C (by 2 °C

intervals). A thermostatically controlled water bath maintained a consistent temperature during treatment. For each temperature point, duplicate samples were prepared and analyzed. TPH removal was quantified using GC-MS, and surface tension measurements were recorded using a Du Noüy ring tensiometer. The Temperature was identified as the point where further increases in treatment temperature no longer resulted in significant reductions in surface tension.

## 3. RESULTS AND DISCUSSION

### 3.1 Physicochemical Profile of the Crude Oil-Contaminated Water

Table 1 shows the physicochemical characteristics of the crude oil-contaminated surface water samples, detailing individual measurements and their average values with standard error.

The surface tension of the water samples measured 72.4 mN/m and 73.2 mN/m. The total petroleum hydrocarbon (TPH) concentration was found to be 3582.3 mg/l and 3591.5 mg/l.

**Table 1.** Physicochemical Profile of the Crude Oil-Contaminated Surface Water

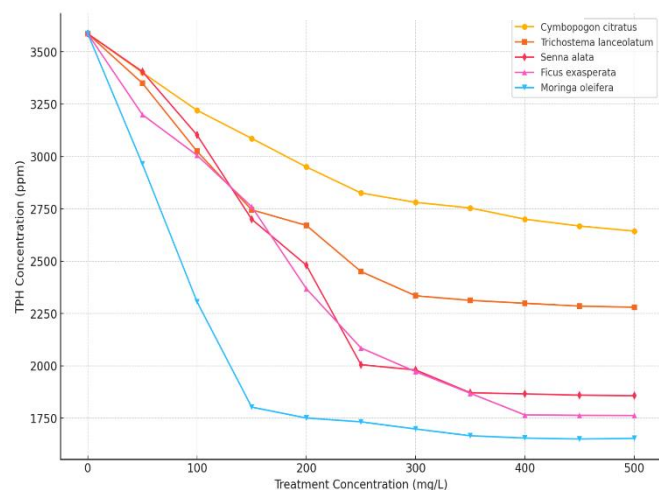
Physicochemical Parameter (Unit)	Amount 1	Amount 2	Average ± SE
Surface Tension (mN/m)	72.4	73.2	72.8 ± 0.4
Total Petroleum Hydrocarbon (mg/l)	3582.3	3591.5	3586.9 ± 4.6

It assessed the deterioration of water quality caused by petroleum pollution and identified specific contaminants that were present. These elevated parameters reflect the severe impact of crude oil contamination on surface water quality. High TPH values indicate an environment heavily burdened with organic pollutants, which impair natural degradation processes and reduce oxygen availability. The significant presence of TPH poses potential ecological and health risks to humans. These findings align with those of [16] and [17], who reported similarly high levels of TPH (up to 3500 mg/l) in oil-polluted Niger Delta waters. These results have several implications. Crude oil is

a major contributor to long-term ecological degradation and the disruption of aquatic ecosystems. These findings emphasize the importance of environmental monitoring, effective pollution control, policy enforcement, and investment in remediation technologies designed explicitly for oil-polluted environments.

### 3.2 Effect of Plant Extract Concentrations on TPH and Surface Tension

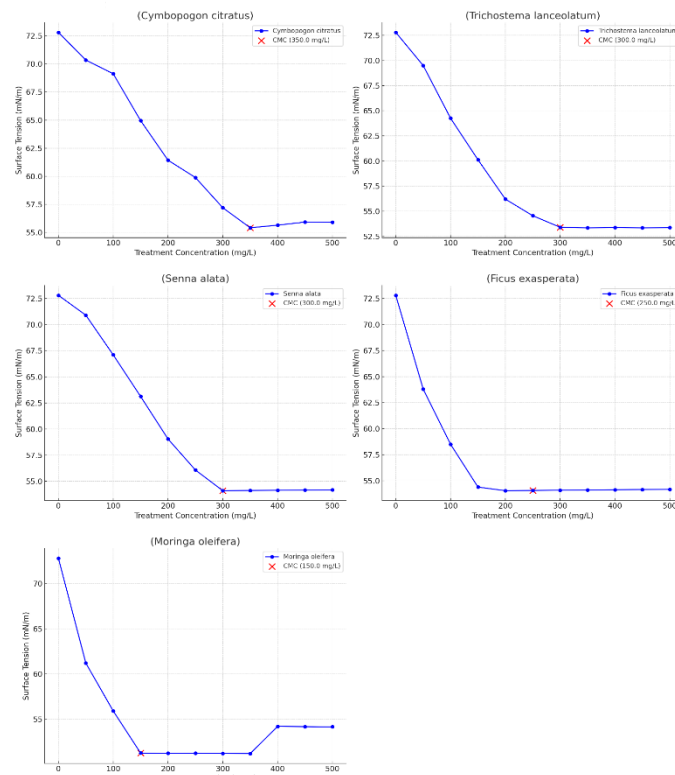
The results demonstrated a concentration-dependent reduction in both TPH content and surface tension across all five plant extracts (Figures 1 and 2). As the concentration of each extract increased, TPH levels decreased progressively, highlighting their effectiveness in hydrocarbon remediation. Among the tested biocoagulants, *Moringa oleifera* exhibited the highest efficiency, reducing TPH from an initial concentration of 3586.90 mg/l to 1650.10 mg/l at a dosage of 450 mg/L. *Ficus exasperata* and *Senna alata* also showed significant reductions, while *Cymbopogon citratus* consistently recorded the least performance, with 2643.70 mg/l TPH at 500 mg/L.



**Figure 1.** TPH Concentration versus Treatment Concentration.

Similarly, surface tension measurements revealed a decreasing trend with increasing extract concentrations. *Moringa oleifera* achieved the lowest surface tension value of 51.24 mN/m at a concentration of just 150 mg/L, establishing it as the best-performing coagulant among the extracts tested. The other extracts, *Ficus exasperata*, *Trichostema lanceolatum*, and *Senna alata*, reached

their critical micelle concentrations (CMC) at 250–300 mg/L, while *Cymbopogon citratus* required 350 mg/L to reach 55.42 mN/m.



**Figure 2.** Surface tension Versus Treatment Concentration.

This study investigated the impact of varying concentrations of different plant extracts on the removal of total petroleum hydrocarbons (TPH) and the reduction of surface tension in crude oil-contaminated surface water. The findings demonstrate a clear dose-dependent trend: as the concentration of plant extracts increased, both TPH levels and surface tension decreased. Among the five extracts, *Moringa oleifera* consistently exhibited the highest efficiency in reducing TPH and lowering surface tension, followed by *Ficus exasperata* and *Senna alata*. *Cymbopogon citratus* was the least effective in both respects. Notably, all extracts showed a relatively plateau effect at higher concentrations, suggesting a saturation point beyond which further increases in concentration produced minimal additional effects.

The results indicate that increasing the plant extract concentration enhances TPH removal and reduces surface tension, confirming the extracts' function as phytocoagulants. The significant

performance of *Moringa oleifera* can be attributed to its high content of cationic proteins and bioactive compounds, which likely improve its ability to destabilise oil-water emulsions and facilitate hydrocarbon aggregation [18]. The observed CMC points for each extract further support their surfactant-like behavior, with *Moringa oleifera* achieving the lowest CMC, reinforcing its superior efficacy at lower doses.

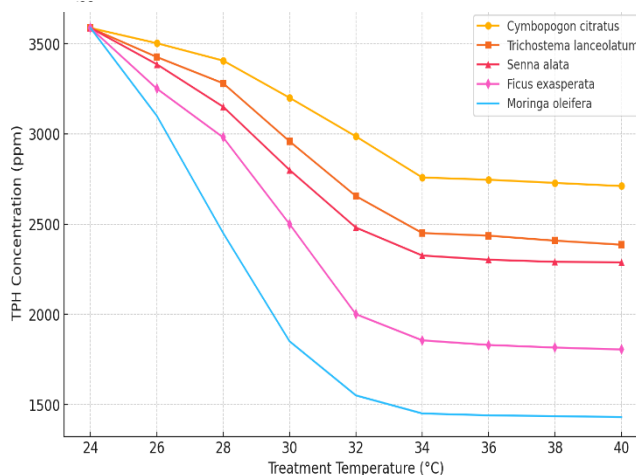
The results on *Moringa* align with those of [19], who reported that *Moringa oleifera* significantly reduces oil pollutants in aqueous media due to its flocculating proteins. However, studies that utilize *Ficus exasperata* as a phytocoagulant to enhance crude oil removal from water samples are either limited or unavailable to the best of my knowledge. The plateau effect observed is also consistent with the work of [20], who reported saturation behavior in natural surfactants beyond their critical micelle concentration (CMC) values. However, the relatively low performance of *Cymbopogon citratus* contrasts with the findings of [21], who observed moderate efficiency in emulsified oil treatment, possibly due to differences in extraction methods or the type and composition of the oil used.

Furthermore, the findings suggest that *Moringa oleifera* and *Ficus exasperata* could be prioritised in eco-friendly water treatment protocols for crude oil contamination. Identifying CMC values helps determine optimal dosages, thereby avoiding unnecessary material usage and associated costs.

### 3.3 Effect of Temperature on Phytocoagulant Performance

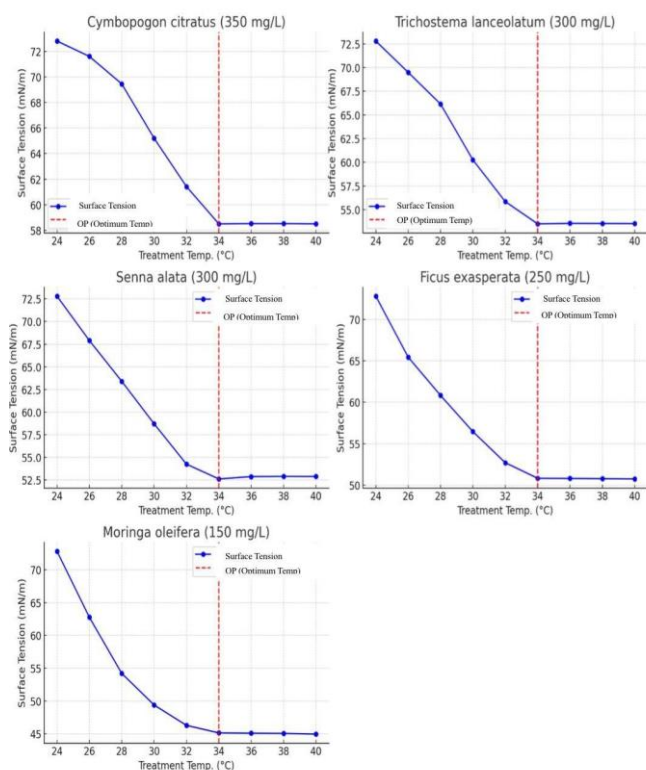
Figure 3 shows that temperature significantly influenced the performance of all five plant-based biocoagulants in removing total petroleum hydrocarbons (TPH) and reducing surface tension from crude oil-contaminated surface water. Across all extracts, a general trend of increasing treatment efficiency was observed with rising temperature, reaching a peak between 30°C and 34°C, after which further temperature increases resulted in minimal additional improvements. *Moringa oleifera* demonstrated the highest temperature-dependent TPH removal, reducing concentrations from 3586.90 mg/l at 24°C to 1450.75 mg/l at 34°C, beyond which removal stabilized. *Ficus exasperata* followed, achieving 1855.85 mg/l at 34°C. *Trichostema lanceolatum* and *Senna alata* showed comparable trends, both reaching optimal performance at 34°C, with TPH values of 2450.40 mg/l and 2325.85 mg/l, respectively. *Cymbopogon citratus* showed the least efficiency,

with TPH reducing to 2710.85 mg/l at 40°C. These results confirm that 34°C was the temperature for optimal hydrocarbon degradation for all extracts.



**Figure 3.** TPH Concentration Versus Treatment Temperature

In figure 4, all extracts reduced surface tension most effectively at 34°C, marking the optimal temperature. *Moringa oleifera*: 45.15 mN/m, *Ficus exasperata*: 50.82 mN/m, *Senna alata*: 52.62 mN/m, *Trichostema lanceolatum*: 53.50 mN/m and *Cymbopogon citratus*: 58.51 mN/m.



**Figure 4.** Surface Tension Versus Treatment Temperature

These results confirm the function of the selected plant extracts as phytocoagulants. *Moringa oleifera* demonstrated the highest efficiency at lower concentrations and moderate temperatures, making it the most promising candidate among the tested extract for practical application in phytoremediation systems. The identification of CMC and temperature values provides critical parameters for optimizing field-based treatment protocols. This study evaluated the influence of temperature on the phytocoagulant performance of selected plant extracts: *Moringa oleifera*, *Ficus exasperata*, *Trichostema lanceolatum*, *Senna alata*, and *Cymbopogon citratus*. The focus is on their capacity to remove total petroleum hydrocarbons (TPH) and reduce the surface tension of crude oil-contaminated surface water. The results showed a consistent temperature-dependent improvement in TPH removal and reduction of surface tension across all five plant extracts, with optimal performance generally occurring between 30°C and 34°C. Beyond this temperature range, the effectiveness of all extracts plateaued. Among the extracts, *Moringa oleifera* consistently achieved the

most significant TPH reduction (down to 1450.75 mg/l) and the lowest surface tension (44.98 mN/m), while *Cymbopogon citratus* was the least effective in both parameters. Each extract had a defined temperature at approximately 34°C, beyond which further temperature increases did not enhance performance.

These findings demonstrate that temperature plays a critical role in modulating the efficiency of plant-based coagulants. The enhanced performance at moderate temperatures (30°C–34°C) is likely due to increased molecular activity, improved solubility of phytochemicals, and faster biochemical interactions between the extract compounds and hydrocarbon pollutants. The flattening of the curves beyond 34°C indicates a thermal threshold, possibly related to saturation effects. *Moringa oleifera*'s superior performance under these conditions, when compared to other plant extracts, highlights its robust biochemical profile.

A comprehensive review of the literature revealed a lack of studies directly examining the temperature-dependent behaviour of the specific plant-based coagulants investigated in this work for crude oil removal. Aside from the study by [22], which reported optimal oil removal efficiency for *Moringa oleifera* at approximately 32°C, no relevant research was identified that offers empirical data under comparable conditions. This absence of directly comparable studies highlights the limited research attention given to temperature effects in such systems and reinforces the novelty of the present findings. As such, the results presented here provide a foundational reference point and underscore the need for further systematic investigations into the thermal influences on phytocoagulant in the treatment of crude oil-contaminated water.

The results confirm the temperature sensitivity of phytocoagulants and indicate that optimal temperature control is crucial for achieving maximum efficiency. In addition, identifying the 30°C–34°C window as the most effective range provides clear guidance for environmental practitioners implementing phytoremediation strategies, particularly in tropical and subtropical climates. Moreover, recognizing the temperature of each extract helps avoid wasteful dosing or heating beyond the point of diminishing returns.

#### 4. CONCLUSION

This study assessed the optimization of plant-based biocoagulants for remediating crude oil-contaminated surface water, with a focus on the effects of extract concentration and temperature on total petroleum hydrocarbon (TPH) removal and reduction in surface tension. The findings provide strong evidence that selected phytocoagulants, particularly *Moringa oleifera*, can significantly enhance water quality through sustainable, low-cost, and environmentally friendly means. Experimental results confirmed that increasing extract concentration consistently reduced TPH and surface tension, indicating dose-dependent phytocoagulation and surfactant activity. Among the five evaluated plant species, *Moringa oleifera* emerged as the most effective, reducing TPH from 3586.9 mg/l to 1650.1 mg/l at 450 mg/L and lowering the surface tension to 51.24 mN/m at just 150 mg/L. In contrast, *Cymbopogon citratus* proved the least efficient, requiring higher doses to achieve modest improvements. Temperature also significantly influenced performance. Across all extracts, increasing the temperature from 24°C to 34°C enhanced TPH removal and reduced surface tension, with optimal performance observed at the temperature of 34°C. Again, *Moringa oleifera* exhibited the most substantial effects, lowering TPH to 1450.75 mg/l and surface tension to 45.15 mN/m. Performance plateaued beyond this temperature, likely due to thermal degradation of active compounds. Overall, the study demonstrates that both extract concentration and temperature are critical variables in optimizing phytocoagulant performance. The consistent efficacy of *Moringa oleifera*, coupled with its low CMC and favorable temperature, supports its potential as a viable alternative to chemical coagulants, such as aluminium sulphate. These outcomes highlight the value of phytochemical-rich extracts, particularly those high in saponins and terpenoids, due to their strong surfactant and pollutant-binding properties. Their performance highlights their potential role in sustainable water treatment strategies, particularly in oil-impacted and resource-limited regions such as the Niger Delta rural communities. Unlike synthetic coagulants, which can be costly and environmentally hazardous, plant-based alternatives are biodegradable, locally available, and eco-safe. It is recommended that *Moringa oleifera* and *Ficus exasperata* be developed and promoted as practical phytocoagulants for community-scale applications. Policymakers and

environmental practitioners can leverage these insights to develop sustainable and scalable treatment systems for oil-polluted waters, especially in resource-limited settings.

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#### Conflict of Interest Declaration

There is no conflict of interest associated with this work.

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