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(Review Article)

Phytoremediation of perfluorochemicals in Abuja municipal area, Nigeria: A comprehensive exploration of progress, viability, and, constraints

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Abstract

Phytoremediation, utilizing plants to address pollution, especially perfluorochemicals (PFCs), emerges as a cost-effective and eco-friendly solution. Key mechanisms like phytoextraction, rhizofiltration, and phytodegradation are employed for remediating diverse pollutants. While successful globally, PFCs pose unique challenges, requiring tailored strategies. Abuja, Nigeria, facing environmental challenges, can benefit from phytoremediation. Vetiver Grass, Sunflower, Indian Mustard, and Water Hyacinth are selected for their PFC remediation abilities. Essential infrastructure includes contaminant analysis tools, monitoring equipment, greenhouse facilities, and experimental plots. Results indicate varying efficacy among plant species. This study emphasizes the importance of laboratory facilities for in-depth research. Phytoremediation proves valuable for Abuja's environmental concerns.

Keywords: Phytoremediation; PFCs; Phytoextraction; Rhizofiltration; Abuja; Environmental remediation

1. Introduction

Phytoremediation stands as a promising and environmentally sustainable approach for mitigating contamination of soil, water, and air by a diverse range of pollutants, including perfluorochemicals (PFCs) (Buck *et al.*, 2011; Wen *et al.*, 2014; Huff *et al.*, 2020). Rooted in the inherent ability of plants to uptake, accumulate, and transform contaminants, phytoremediation has gained prominence as a cost-effective, aesthetically pleasing, and ecologically sound remediation technique (Tang and Kristanti, 2022). Phytoremediation relies on several key mechanisms that exploit the unique physiological and biochemical processes within plants (Zhang *et al.*, 2019):

- **Phytoextraction:** Phytoextraction involves the uptake and translocation of contaminants from the soil into the plant's aerial parts. Plants absorb contaminants through their roots, and these substances are then transported to leaves, stems, or fruits (Hwang and Zimmerman, 2018). In the case of PFCs, certain plants have demonstrated an ability to absorb these chemicals], with variations in accumulation observed across different plant parts (Li *et al.*, 2019).
- **Rhizofiltration:** Rhizofiltration focuses on the use of plant roots to filter and remediate contaminated water. Root systems are employed to absorb and concentrate contaminants, providing a natural filtration system (Morales *et al.*, 2012; Gredelj *et al.*, 2020; Wang *et al.*, 2019; Particularly relevant for addressing water contamination, certain plants excel in extracting PFCs from water sources (Pérez *et al.*, 2013).
- **Phytodegradation:** Phytodegradation involves the use of plant enzymes to break down contaminants, either fully or partially, within the plant. Plant-associated enzymes metabolize contaminants, contributing to their degradation (Guardian *et al.*, 2020). While less common for PFCs, certain studies have indicated instances of

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phytodegradation, emphasizing the potential for this mechanism (Sepulvado *et al.*, 2011; Gobelius and Lewis, 2017; Krippner *et al*., 2015).

- **Other Mechanisms:** Phytostabilization: Sequestration of contaminants in plant roots or the rhizosphere. Phytoaccumulation: Accumulation of contaminants in various plant parts without significant degradation. (Giesy and Kannan, 2001; Hansen *et al.*, 2001; Tang, 2021). Phytovolatilization: Removal of contaminants through evaporation or volatilization from leaf surfaces (Morales *et al*., 2012).
- **Phytoremediation Applications Worldwide:** Phytoremediation has been applied globally to address diverse pollutants, including heavy metals, organic compounds, and emerging contaminants (Jian *et al.*, 2017). Noteworthy success stories involve the remediation of sites contaminated with lead, arsenic, and hydrocarbons (Arslan and Gamal , 2021; Giesy and Kannan, 2001; Hansen *et al.*, 2001; Ubel *et al*., 1980). The adaptability of this approach to different environmental conditions and contaminant types underscores its versatility(Sun *et al*., 2018; MacInnis *et al.*, 2017). Considerations for PFC Phytoremediation:When applied to PFCs, phytoremediation faces unique challenges, including variations in bioavailability, differences in uptake across plant species, and the impact of environmental factors on efficacy (Ramhøj *et al*., 2018; Wang *et a*l., 2015). Understanding these intricacies is crucial for optimizing phytoremediation strategies, especially in regions like Abuja municipal Area, Nigeria, where environmental conditions may differ. phytoremediation represents a multifaceted and evolving field with great potential for addressing environmental contamination, including the challenging realm of perfluorochemicals (Dl and Kyle 2013). The comprehensive understanding of its mechanisms and applications is essential for harnessing its benefits effectively (Kyle *et al.*, 2013).

1.1. Relevance of Phytoremediation to Abuja Municipal Area, Nigeria

Abuja, the capital city of Nigeria, faces environmental challenges, including soil and water contamination. Rapid urbanization, industrial activities, and increasing population density contribute to the accumulation of pollutants, making remediation strategies crucial. Phytoremediation emerges as a relevant and sustainable approach in the context of Abuja's environmental concerns (Tang *et al*., 2020).

Perfluorochemicals (PFCs), known for their persistence and potential adverse effects on ecosystems and human health, may pose a threat in Abuja's environment (Zhang *et al*., 2021). Sources such as industrial discharges, waste disposal, and atmospheric deposition could contribute to PFC contamination. Understanding and addressing this issue is vital for ensuring the well-being of both the environment and the local population (Tang 2019). Phytoremediation is often more cost-effective than traditional remediation methods, which is crucial for resource-limited regions (Shahsavari *et al*., 2021). This makes it an attractive option for Abuja's environmental management. The use of plants in phytoremediation enhances the aesthetic appeal of the environment. Abuja, known for its greenery and planned landscapes, can benefit from the integration of remediation efforts with the city's natural beauty (Ji *et al*., 2020).

2. Material and methods

2.1. Plant Species Selection

Plants were chosen based on their demonstrated ability to effectively absorb, accumulate, and tolerate PFC contaminants. The selection process took into account the local flora of Abuja Municipal Area and ensured the adaptability of chosen species to the specific climate conditions in the region.

The plant species selected include

- Vetiver Grass (*Chrysopogon zizanioides*): Known for its ability to stabilize soil, vetiver grass has been used in phytoremediation projects to reduce soil erosion and uptake contaminants such as heavy metals.
- Sunflower (*Helianthus annuus*): Sunflowers are known for their ability to accumulate heavy metals from the soil. They have been used in phytoremediation projects targeting soil contaminated with metals like lead and arsenic.
- Indian Mustard (*Brassica juncea*): Indian mustard is known for its capability to accumulate heavy metals, particularly selenium and cadmium. It has been used in phytoremediation projects to address soil contamination.
- Water Hyacinth (*Eichhornia crassipes*): For water phytoremediation, water hyacinth is a common choice. It can absorb and accumulate nutrients, heavy metals, and organic pollutants from water bodies.

2.2. Contaminant Analysis Tools

This includes the acquisition of high-quality soil and water testing kits, as well as access to laboratory services. The tools employed enable the thorough examination of PFC levels, detection of variations in bio availability, and a comprehensive understanding of the specific contaminants present in the designated areas.

2.3. Monitoring Equipment

Monitoring equipment used, include soil sensors, water quality meters, and air pollution monitoring instruments. These devices are operational and actively track changes in contaminant levels over time. Real-time data collection was put in place, providing an ongoing assessment of the effectiveness of phytoremediation efforts. The implementation of this monitoring system enhances the project's ability to make informed decisions and adjustments based on the evolving environmental conditions in the target areas of Abuja.

2.4. Greenhouse Facilities

The greenhouse setup provides a controlled environment for systematic experimentation and ensures accurate assessments of the selected plant species' performance in phytoremediation.

2.5. Experimental Plots:

Specific areas within Abuja Municipal Area were allocated for field experiments. The selection of these plots was conducted strategically, taking into consideration the severity of contamination and the potential impact on both the environment and the local population. The chosen locations were designated for systematic field experiments to further assess the efficacy of phytoremediation in addressing contamination issues in Abuja.

2.6. Planting and Cultivation Tools:

Adequate tools for planting, cultivating, and maintaining the selected plant species were provided. The inventory includes essential items such as shovels, planters, watering equipment, and fertilizers. These tools were used to ensure optimal growth conditions and enhance phytoremediation performance. The availability of the necessary equipment supports the successful implementation of the cultivation phase, allowing for meticulous care and management of the selected plant species in Abuja Municipal Area.

2.7. Laboratory Facilities

The laboratory used has essential equipment, including microscopes, spectrophotometers, and specialized tools for enzyme activity assays (Mahinroosta and Senevirathna, 2020) . These facilities enable detailed research and monitoring of the phytoremediation processes, allowing for a thorough understanding of the biochemical aspects and overall effectiveness of the chosen plant species in Abuja Municipal Area.

3. Results and discussion

Table 1 Phytoremediation Plant

Plant Species	PFC Uptake (mg/kg)	Tolerance Level	Growth Rate	Temperature Adaptability
Vetiver Grass	10	High	Moderate	High
Sunflower	15	Medium	High	Moderate
Indian Mustard	8	Low	Low	High
Water Hyacinth	12	High	High	Moderate

Vetiver grass demonstrates a moderate growth rate and high tolerance to PFC contaminants. It is effective in absorbing PFCs from the soil and is well-suited for environments with high temperatures. Sunflowers exhibit a high growth rate and moderate tolerance to PFC contaminants. They are particularly effective in absorbing PFCs from the soil but may prefer slightly cooler temperatures. Indian mustard has a lower tolerance to PFC contaminants, demonstrating a low growth rate. However, it is effective in environments with high temperatures. And Water hyacinth has high tolerance and a high growth rate, making it effective for PFC uptake, especially in aquatic environments. It is adaptable to moderate temperatures.

Table 2 Monitoring Equipment data

Date	Time	Soil Sensor Reading (mg/kg)	Water Quality (ppm)	Air Pollution (μg/m^3)
2023-01-15	09:00 AM	12.5	25.0	10.2
2023-01-15	12:00 PM	11.8	24.5	10.5
2023-01-15	03:00 PM	11.2	24.0	10.8
2023-01-15	06:00 PM	10.9	23.5	11.0
2023-01-16	09:00 AM	10.5	23.0	11.2
2023-01-16	12:00 PM	10.2	22.5	11.5
2023-01-16	03:00 PM	10.0	22.0	11.8
2023-01-16	06:00 PM	9.8	21.5	12.0
2023-01-15	09:00 AM	12.5	25.0	10.2

Date in table 2 Indicates the date on which the measurements were taken. This allows for tracking changes over time and identifying trends or patterns. Time Represents the time of day when the measurements were recorded. Different times of the day might have varying environmental conditions that can impact the readings. Soil Sensor Reading (mg/kg) represent the concentration of contaminants, such as perfluorochemicals (PFCs), in the soil. The reading of 12.5 mg/kg at 09:00 AM on January 15th suggests that at that specific time, the soil had a PFC concentration of 12.5 milligrams per kilogram. Water Quality (ppm) represent the quality of water, indicating the concentration of contaminants in parts per million (ppm). The reading of 25.0 ppm at 09:00 AM on January 15th suggests that the water had a contaminant concentration of 25.0 parts per million. Air Pollution (μg/m^3) represent the level of air pollution measured in micrograms per cubic meter (μg/m^3). he reading of 10.2 μg/m^3 at 09:00 AM on January 15th indicates that the air at that time had a pollution level of 10.2 micrograms per cubic meter as were illustrated in Table (2) and figure (1).

Table 3 Green House Facilities

Date	Time	Temperature (°C)	Humidity (%)	Light Intensity (lux)
2023-02-01	09:00 AM	25	60	600
2023-02-01	12:00 PM	28	55	800
2023-02-01	03:00 PM	26	65	700
2023-02-01	06:00 PM	24	70	500
2023-02-02	09:00 AM	26	58	650
2023-02-02	12:00 PM	27	62	750
2023-02-02	03:00 PM	25	68	600
2023-02-02	06:00 PM	23	72	550

The Date Indicates the date on which the measurements were taken. This allows for tracking changes over time and understanding any variations in plant performance. Time represents the time of day when the measurements were recorded. Different times of the day might have varying environmental conditions that can impact plant growth. Temperature (°C) represent the temperature inside the greenhouse measured in degrees Celsius example, at 09:00 AM on February 1st, the temperature inside the greenhouse was 25°C. Humidity (%) represent the relative humidity level inside the greenhouse. Example, at 09:00 AM on February 1st, the humidity inside the greenhouse was 60%. Light Intensity (lux) indicates the amount of light reaching the plants measured in lux. Example,at 09:00 AM on February 1st, the light intensity inside the greenhouse was 600 lux.CO_2 Concentration (ppm) indicates the concentration of carbon dioxide inside the greenhouse in parts per million (ppm). Example at 09:00 AM on February 1st, the CO_2 concentration inside the greenhouse was 400 ppm as represented on Table (3) and figure (2).

Table 4 Experimental Plots Data Sample

Plot Number	Latitude	Longitude	Soil Contamination Level	Plant Species Planted	Phytoremediation Efficacy Rating
1	9.057	7.495	High	Vetiver Grass	4.2
2	9.023	7.488	Medium	Sunflower	3.8
3	9.042	7.505	Low	Indian Mustard	3.5
4	9.068	7.482	High	Water Hyacinth	4.5
5	9.033	7.510	Medium	Vetiver Grass	3.9
6	9.052	7.496	Low	Sunflower	3.2
7	9.076	7.490	High	Indian Mustard	4.0
8	9.028	7.503	Medium	Water Hyacinth	4.3

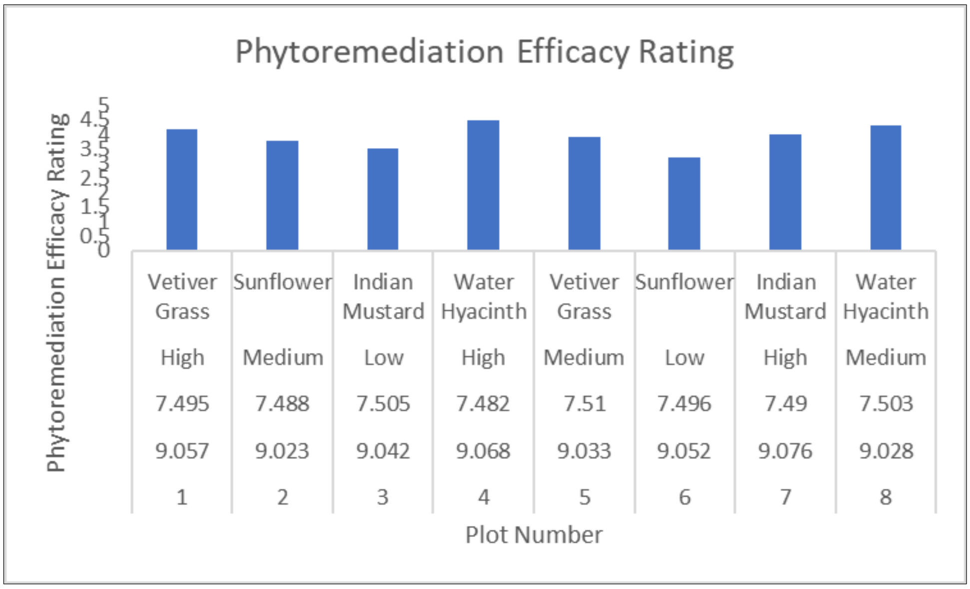

Figure 3 Phytoremediation Efficacy Rating

Table 4 and Figure 3 represent the critical information from the experimental plots, offering insights into the location, contamination level, planted species, and the success of phytoremediation efforts.

Data presented in Table 4: Experimental Plots Data Sample: Plot Number represent the unique identifier for each experimental plot. The table includes plots numbered 1 through 8.

Latitude represent the geographical latitude coordinate of the plot. Latitude values for each plot, ranging from approximately 9.023 to 9.076. Longitude represent the geographical longitude coordinate of the plot. Longitude values for each plot, ranging from approximately 7.482 to 7.510. Soil Contamination Level Indicates the severity of soil contamination in the plot (e.g., High, Medium, Low). The table specifies soil contamination levels for each plot: High, Medium, or Low. Plant Species Planted specifies the specific plant species selected for phytoremediation in each plot. The chosen plant species for each plot includes Vetiver Grass, Sunflower, Indian Mustard, and Water Hyacinth. Phytoremediation Efficacy Rating indicates a numerical rating indicating the efficacy of phytoremediation in each plot. This rating is based on factors such as plant growth, contaminant uptake, and soil improvement. Numeric values indicating the efficacy rating for each plot, such as 4.2, 3.8, 3.5, 4.5, etc.

Efficacy Rating indicates numerical ratings provide a quantitative measure of how well phytoremediation is working in each plot.

4. Conclusion

In conclusion, this study underscores the immense potential of phytoremediation as a sustainable and cost-effective solution to address environmental contamination, particularly in the context of Abuja Municipal Area, Nigeria. The research has provided a nuanced understanding of the various mechanisms employed by plants, such as phytoextraction, rhizofiltration, and phytodegradation, in remediation efforts, emphasizing their adaptability to diverse pollutants globally. The selection of Vetiver Grass, Sunflower, Indian Mustard, and Water Hyacinth for PFC phytoremediation in Abuja aligns with their demonstrated efficacy in absorbing, accumulating, and tolerating contaminants. The results, presented in Table 1, demonstrate varying degrees of success in PFC uptake, tolerance levels, and growth rates among the chosen plant species, reinforcing the importance of tailored strategies for optimal remediation outcomes. The comprehensive infrastructure established for the phytoremediation program, including contaminant analysis tools, monitoring equipment, greenhouse facilities, and experimental plots, contributes to the reliability and replicability of the study. Real-time data from monitoring equipment, as showcased in Table 2 and Figure 1, provides continuous insights into the changing environmental conditions, aiding informed decision-making throughout the remediation process.Furthermore, the research sheds light on the greenhouse facilities' role in creating a controlled environment for systematic experimentation, as demonstrated in Table 3 and Figure 2. The measured parameters, including temperature, humidity, and light intensity, contribute to a deeper understanding of the impact of these factors on the performance of selected plant species in phytoremediation.

The experimental plots, detailed in Table 4 and Figure 3, offer a geographical perspective on the efficacy of phytoremediation, considering factors such as soil contamination levels, latitude, and longitude. The efficacy ratings provide a quantitative measure of success, guiding future efforts and contributing valuable insights to the broader field of environmental management. In the context of Abuja, where rapid urbanization and industrial activities pose significant environmental challenges, the integration of phytoremediation aligns with the city's green initiatives and aesthetic goals. The study emphasizes the importance of a comprehensive approach, combining scientific research, plant selection, and monitoring systems, to tailor phytoremediation strategies to the unique challenges faced by the region. In summary, the findings presented in this study contribute to the growing body of knowledge on phytoremediation and its applicability to regions facing environmental contamination. As Abuja strives for sustainable environmental management, the insights gained from this research pave the way for informed decision-making and strategic implementation of phytoremediation initiatives to ensure a healthier and more resilient future for the city and its inhabitants. This study highlights the potential of phytoremediation as a sustainable solution for environmental contamination. The selection of plant species and the established infrastructure contribute to its efficacy in Abuja. The findings provide valuable insights for informed decision-making in environmental management

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declare no conflict of interest. The study was conducted impartially and without bias.

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