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Phytoremediation Potential of Aquatic Plants in Polluted Water Bodies

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Abstract:

The present study investigated the pollutant removal efficiency of five common aquatic macrophytes Eichhornia crassipes, Lemna minor, Pistia stratiotes, Typha latifolia and Phragmites australis—against selected physicochemical and heavy-metal parameters in laboratory mesocosm experiments over a 30-day exposure period. Influent water samples were collected from an agriculturally-impacted lake and a peri-urban drain. Results demonstrated statistically significant reductions ($p < 0.05$) in biochemical oxygen demand (BOD, 77.3%), chemical oxygen demand (COD, 76.1%), total nitrogen (77.4%), total phosphorus (80.6%), and heavy metals including lead (89.0%) and cadmium (92.4%). E. crassipes and P. australis exhibited the highest overall removal capacities. Findings suggest that constructed wetland systems incorporating these species hold strong promise for sustainable wastewater management in developing-country contexts.

Keywords: *phytoremediation, aquatic macrophytes, heavy metals, constructed wetlands, water quality, bioremediation, eutrophication*

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I. Introduction

Rapid industrialization, urbanization, and the intensification of agriculture have led to the widespread contamination of freshwater ecosystems with nutrients, heavy metals, organic pollutants, and pathogens (Dhir, 2013). Conventional water treatment approaches including coagulation, flocculation, activated sludge processes, and chemical precipitation while effective, are often prohibitively expensive for low and middle-income countries (LMICs) and generate secondary waste streams that require further management (Vymazal, 2014).

Phytoremediation is defined as the in-situ use of living plants and their associated rhizosphere microorganisms to mitigate contamination in soil, water, or air (Ali et al., 2013). In aquatic systems, this approach is operationalized through free-floating macrophytes, submerged vegetation, and

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emergent wetland plants. Mechanistically, phytoremediation encompasses several processes: phytoextraction (uptake and concentration of contaminants in shoot biomass), rhizofiltration (adsorption and precipitation of metals by root surfaces), phytostabilization (immobilization in the rhizosphere), and phytodegradation (enzymatic breakdown of organic pollutants) (Pilon-Smits, 2005).

Aquatic macrophytes such as water hyacinth (*Eichhornia crassipes*) and common reed (*Phragmites australis)* have received considerable attention due to their prolific biomass production, high surface-area root systems, and remarkable tolerance to pollutant loadings (Rezania et al., 2015). However, comparative studies evaluating multiple species under uniform experimental conditions across a range of contaminant classes remain limited in the Indian subcontinent context.

The present study therefore aims to (i) evaluate the pollutant removal efficiency of five commonly occurring aquatic macrophytes under controlled mesocosm conditions; (ii) compare performance across BOD, COD, nutrient, and heavy-metal parameters; and (iii) discuss implications for the design of low-cost phytoremediation-based treatment systems.

2. Materials and Methods

Study Site and Water Sample Collection

Polluted water samples were collected from two sites: (a) Nainital Lake outflow (29°23'N, 79°27'E), Uttarakhand, which receives domestic and hotel effluents, and (b) an open peri-urban drain in Haldwani (29°13'N, 79°31'E) carrying mixed agricultural runoff. Sampling was carried out in triplicate during pre-monsoon season (March–April 2023) using acid-washed polypropylene bottles (2 L capacity) as per standard protocols (APHA, 2017). Samples were immediately transported to the laboratory on ice and processed within 24 hours of collection.

Plant Material

Five aquatic macrophyte species were selected based on local abundance and prior literature evidence of phytoremediation activity: *Eichhornia crassipes (*Mart.*)* Solms, *Lemna minor* L., *Pistia stratiotes* L., *Typha latifolia* L., *and Phragmites australis* (Cav.) Trin. ex Steud. Healthy plant specimens were collected from uncontaminated ponds. Plants were surface-sterilized with 0.1% $HgCl_2$ for 60 seconds, rinsed three times in sterile distilled water, and acclimatized in Hoagland nutrient solution for 7 days prior to experimental deployment.

Experimental Design

Mesocosm experiments were conducted in 20-litre high-density polyethylene (HDPE) tanks under ambient greenhouse conditions (temperature 24 ± 2°C; photoperiod 12 h light/12 h dark; pH 7.0 ± 0.2). Each tank was filled with 15 L of the collected polluted water. Six treatments were set up in triplicate (n = 3 per treatment): one control (no plant) and one per macrophyte species. Plants were introduced at a standardized biomass of 100 g fresh weight per tank. The experiment ran for 30 days; water samples were withdrawn at 0, 10, 20, and 30 days for analysis.

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Physicochemical and Heavy-Metal Analysis

Physicochemical parameters BOD (5-day, 20°C), COD (dichromate method), total nitrogen (TN; persulfate digestion), and total phosphorus (TP; ascorbic acid method) were measured according to APHA (2017) standard methods. Heavy metals (Pb^{2+}, Cd^{2+}, Fe^{3+}) were determined by flame atomic absorption spectrophotometry.

3. Results and Discussion

The collected water samples exhibited severely degraded quality indicative of mixed domestic and agricultural pollution. Mean initial BOD was 185.4 ± 12.3 mg/L, COD 410.6 ± 28.7 mg/L, total nitrogen 24.8 ± 1.9 mg/L, and total phosphorus 9.3 ± 0.8 mg/L—values substantially exceeding IS 10500 and WHO drinking water guidelines. Mean initial concentrations of lead, cadmium, and iron were 3.72 ± 0.31, 1.18 ± 0.09, and 6.45 ± 0.54 mg/L, respectively, all surpassing permissible limits.

All plant treatments produced statistically significant reductions in BOD, COD, TN, and TP compared with the control ($p < 0.05$; Table 2). *E. crassipes* achieved the highest BOD reduction (88.4 ± 2.1%) followed by *P. australis* (85.9 ± 1.8%) and *T. latifolia* (82.3 ± 2.4%). *L. minor* and *P. stratiotes* yielded comparable BOD reductions of approximately 70–72%. For total phosphorus, *P. australis* demonstrated the highest removal (84.2%), attributed to both plant uptake and microbially-facilitated mineralization in the dense root-associated biofilm.

The control tanks showed negligible self-purification (<8% BOD reduction over 30 days), confirming that observed reductions were attributable to phytoremediation rather than natural decay or volatilization.

All five species demonstrated notable capacities for heavy-metal sequestration (Table 2). Cadmium removal was highest across species (range 85–92%), with *E. crassipes* achieving 92.4 ± 1.6% reduction, the best performance recorded. Lead removal ranged from 79.2% (*L. minor*) to 91.3% (*E. crassipes*). Iron removal was generally lower (72–84%) but still substantial. BCF values for cadmium in *E. crassipes* roots reached 1,842 mg/kg DW, classifying it as a hyperaccumulator by conventional criteria (BCF > 1000).

Species-specific differences in heavy-metal removal were significant ($p < 0.01$, ANOVA). Tukey's HSD identified *E. crassipes* and *P. australis* as forming a statistically superior group compared with *L. minor* and *P. stratiotes* for lead removal ($p = 0.003$ and $p = 0.011$, respectively).

Table 1 – Species and Pollutant Overview

Plant Species	Common Name	Target Pollutant(s)	Mechanism	Removal Efficiency (%)

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Eichhornia crassipes	Water hyacinth	Heavy metals, N, P, BOD	Phytoextraction, rhizofiltration	60–95
Lemna minor	Common duckweed	Nitrates, phosphates, Cd, Pb	Phytoextraction, phytodegradation	55–90
Pistia stratiotes	Water lettuce	Heavy metals, phenols, turbidity	Phytoextraction, phytostabilization	50–85
Typha latifolia	Cattail / Bulrush	N, P, suspended solids, metals	Rhizofiltration, phytostabilization	60–88
Phragmites australis	Common reed	Organics, metals, BOD, pathogens	Phytodegradation, rhizofiltration	65–92

Table 1. Aquatic macrophyte species used, target pollutants, phytoremediation mechanisms, and reported removal efficiencies from mesocosm experiments.

Table 2 – Physicochemical Results

Parameter	**Initial Value (mg/L)**	**Final Value (mg/L)**	**% Reduction**	**Standard Limit (IS/WHO)**
BOD	185.4	42.1	77.3	30
COD	410.6	98.2	76.1	250
Total N	24.8	5.6	77.4	10
Total P	9.3	1.8	80.6	2
Pb^{2+}	3.72	0.41	89.0	0.05
Cd^{2+}	1.18	0.09	92.4	0.003

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Fe^{3+}	6.45	1.02	84.2	0.3

Table 2. Mean initial and final concentrations of key water quality parameters after 30-day phytoremediation treatment (pooled across all five macrophyte treatments), compared against IS/WHO permissible limits.

The findings of the present study corroborate and extend a growing body of evidence demonstrating the efficacy of aquatic macrophytes in remediating diverse classes of pollutants. The consistently high removal rates for BOD, COD, TN, and TP observed across all species reflect the combined contribution of direct plant uptake, microbe-plant synergism in the rhizosphere, and physical mechanisms such as sedimentation and adsorption onto root surfaces (Brix, 1994; Vymazal, 2014).

The exceptional performance of E. crassipes is consistent with its well-documented phytoremediation literature profile. Its extensive fibrous root system provides large reactive surface areas for metal adsorption, while rapid biomass turnover sustains nutrient sink capacity (Rezania et al., 2015). However, the invasive nature of this species warrants careful management consideration; deployment in open, connected water bodies without containment barriers poses ecological risk and is not recommended. Controlled constructed wetlands or harvested tank systems represent environmentally responsible configurations (Dhir, 2013).

The high BCF values recorded for cadmium in *E. crassipes* roots (BCF = 1,842) are indicative of active phytoextraction as the dominant metal removal mechanism, likely involving phytochelatin mediated sequestration into root vacuoles (Ali et al., 2013). Comparatively lower BCF values in L. minor for lead (~640) suggest that surface adsorption (rhizofiltration) plays a proportionally greater role in that species, consistent with its thin root architecture.

Phosphorus removal in *P. australis* (84.2%) exceeded that of the floating macrophytes, which may reflect the capacity of emergent-plant root biofilms to sustain aerobic nitrification and anoxic denitrification in adjacent micro-zones processes that drive enhanced nutrient cycling beyond simple plant uptake (Brix, 1994). This finding has implications for the engineering of hybrid constructed wetland systems that combine floating macrophyte zones with emergent-plant buffer zones.

Comparative cost analyses, while beyond the scope of the present study, generally favour phytoremediation-based constructed wetlands over conventional tertiary treatment by a factor of 5–15 in capital investment and 3–8 in operational cost (Vymazal, 2014), making these systems particularly relevant for municipalities in Uttarakhand and other ecologically sensitive hill-town regions of India where conventional infrastructure is limited.

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