Efficacy of Duckweed (Lemna spp.) in Phyto-remediation of Wastewater: A Comprehensive Review

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***Abstract*—This review investigates the efficacy of duckweed (*Lemna* spp.) in the phytoremediation of wastewater. Duckweed demonstrates remarkable capabilities in removing pollutants such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients (nitrogen and phosphorus), heavy metals, and pathogens. Its removal efficiencies are typically 60–75% for BOD, 54–70% for COD, and over 90% for nitrogen and phosphorus. With rapid growth, high biomass productivity, and low operational cost, duckweed presents a viable alternative for decentralised wastewater treatment, particularly in rural or semi-urban areas. Furthermore, harvested duckweed biomass can be used for animal feed or bioenergy production. This review evaluates pollutant removal efficiencies, economic feasibility, limitations, and potential solutions, positioning duckweed as a sustainable solution for wastewater management**

***Index Terms*—Duckweed, Lemna spp., phytoremediation, wastewater treatment, nutrient removal, biomass utilisation, ecological sanitation**

I INTRODUCTION

Wastewater management is a pressing global issue, especially in resource-limited regions facing rising environmental pollution. Conventional treatment methods, though effective, often require high costs, energy, and complex infrastructure, making them impractical for rural and semi-urban areas. This has spurred demand for sustainable, cost-effective, and eco-friendly alternatives. Phytoremediation, using plants to remove contaminants from water and soil, offers a promising solution. Duckweed (Lemna spp.), a small, free-floating aquatic plant, has emerged as a standout option due to its exceptional pollutant removal abilities, rapid growth, and versatile biomass applications. Duckweed efficiently removes various wastewater pollutants, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients like nitrogen and phosphorus, heavy metals, and pathogens. It achieves removal efficiencies of 60–75% for BOD, 54–70% for COD, and over 90% for nitrogen and phosphorus. Its low maintenance needs and high biomass productivity make it ideal for decentralised wastewater treatment systems. Furthermore, duckweed's biomass can be repurposed for animal feed, biofertilizer, or bioenergy, adding economic and ecological value. Despite these advantages, challenges such as sensitivity to environmental conditions, biomass management, and scalability must be addressed to unlock its full potential. This review examines duckweed's efficacy in phytoremediation, focusing on its pollutant removal efficiency, economic viability, and practical applications. By assessing its strengths, limitations, and possible solutions, the study underscores duckweed's potential as a sustainable wastewater management solution, particularly in resource-constrained settings. With its ability to tackle pollution while offering additional benefits, duckweed represents an innovative approach to addressing global wastewater challenges

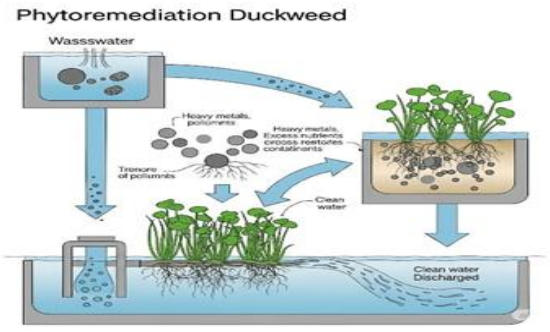

Fig: Phytoremediation, using plants to remove contaminants

II METHODOLOGY:

A. Phytoremediation and Role of Duckweed

Phytoremediation involves the use of green plants to remove, degrade, or contain contaminants in water or

soil. Duckweed-based systems employ mechanisms such as phytoextraction, phytostabilisation, rhizofiltration, and phytodegradation.

a) Botanical and Ecological Features of Duckweed**:** Duckweed belongs to the Lemnaceae family and thrives in nutrient-rich, slow-moving freshwater. Key characteristics include:

- Rapid biomass accumulation
- Minimal nutrient requirements
- Tolerance to a wide pH range
- Low maintenance and harvesting ease

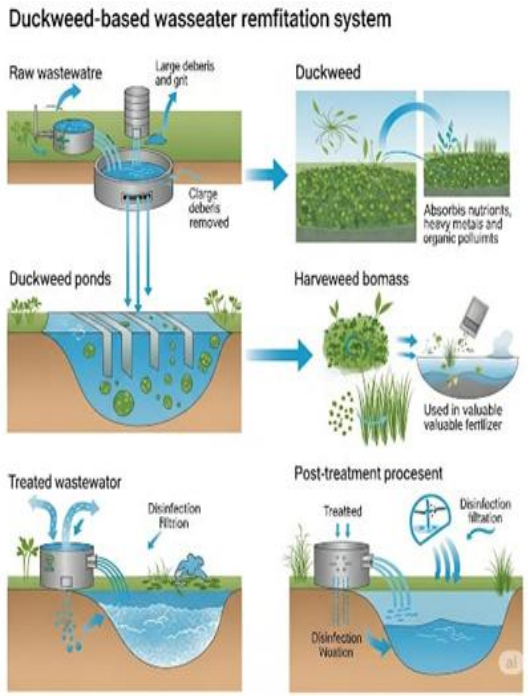

Fig: Duckweed-based systems employ mechanisms

b) Pollutant Removal Efficiency:

The table shows the pollutant removal over time (Days) for BOD, COD, Nitrate, Phosphate, along with the duckweed coverage percentage:

Day	BOD (mg/L)	COD (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	% Duckweed Coverage
0	220	420	35	8.5	0%
2	180	360	28	6.9	40%
4	135	290	20	5.4	70%
6	95	220	13	3.7	90%
8	60	150	7	2.1	100%
10	35	90	3	0.9	100%

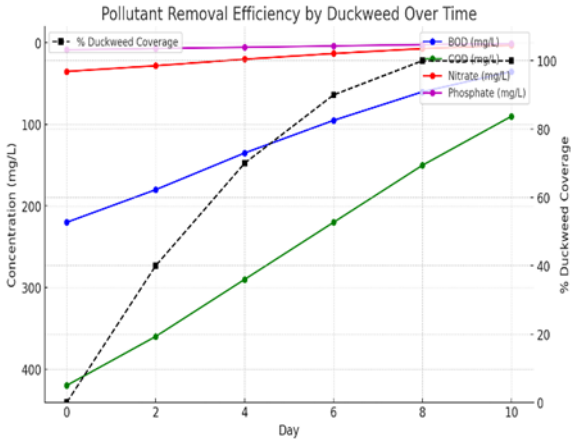

Fig: Pollutant Removal Efficiency Graph

The above graph shows pollutant concentrations (BOD, COD, Nitrate, Phosphate) decreasing over time as duckweed coverage (%) increases. The left Y-axis shows pollutant concentrations (in mg/L) and is inverted for better visualisation of removal, while the right Y-axis shows the % duckweed coverage.

c) Nutritional Composition of Duckweed Biomass**:**

Component	*Range (% dry weight)*	Maximum (%)	References
Protein	30–35	44.52	Peer-reviewed articles
Fat	4–8	—	—
Starch	2–6	—	—
Fiber	15–20	—	—
Ash	10–15	—	—

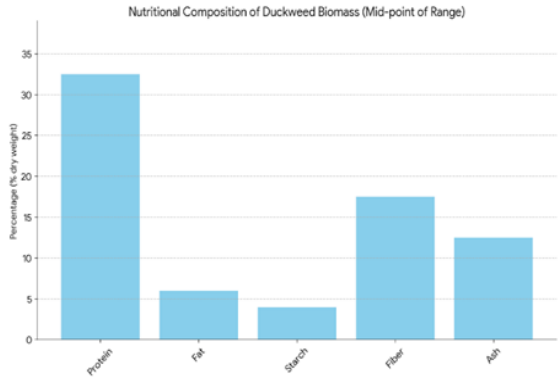

Fig: Nutritional Composition of Duckweed Biomass

III APPLICATIONS OF DUCKWEED-BASED SYSTEMS:

I Wastewater Treatment: Municipal, domestic, and aquaculture effluents.

II Biomass Utilization: Protein-rich feed for fish, poultry, livestock.
III Bioenergy: Anaerobic digestion of biomass for biogas production.
IV Carbon Sequestration: Effective CO_2 fixation in aquatic ecosystems.

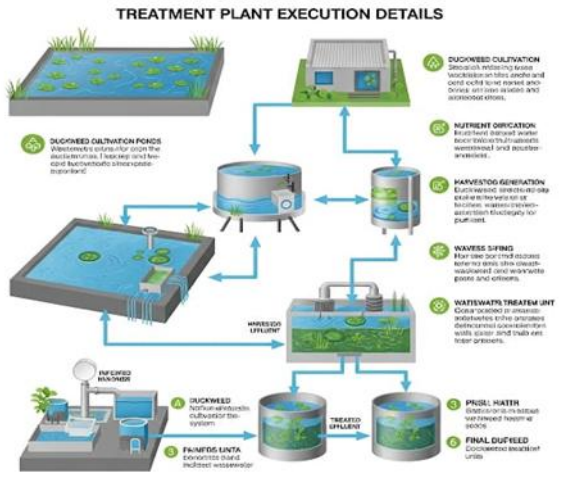

Figure: Treatment System

IV CHALLENGES AND LIMITATIONS:

- Risk of invasiveness in natural ecosystems.
- Requirement for regular harvesting to maintain performance.
- Sensitivity to heavy metal toxicity in extreme concentrations.
- Potential for odour and mosquito breeding if not maintained properly.

I. COST-EFFECTIVENESS COMPARISON

Parameter	Duckweed System	Conventional System
Capital Cost	Low	High
Operational Cost	Very Low	Moderate to High
Energy Requirement	Minimal	High
Maintenance	Low	High
Resource Recovery (Biomass Use)	Yes	Limited

V DISCUSSION

The findings suggest duckweed is a promising candidate for wastewater remediation in developing regions. With superior removal efficiencies and low operational inputs, duckweed-based phytoremediation offers a green, affordable, and scalable solution. However, to transition from experimental to commercial scale, issues related to harvesting automation, ecological impacts, and regulatory approval must be addressed. Further research should focus on genetically improved strains and integrated systems with algae or microbial consortia.

VI CONCLUSION

Duckweed (*Lemna* spp.) provides a sustainable and low-cost phytoremediation solution for wastewater treatment. Its potential in pollutant removal, biomass utilization, and ecological safety makes it a valuable tool in achieving circular economy goals in sanitation. Future studies must bridge the gap between pilot-scale studies and full-scale implementations for broader adoption.

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