KNOWLEDGE FLAME
E-ISSN: 3049-1541
International Multidisciplinary Research Journal (KF-IMRJ)
(An International Indexed & Peer Reviewed Journal
Impact Factor: 5.292 https://knowledgeflame.in PRGI Reg. No. MAHMUL/2024/89852

Efficacy of *Lemna minor* in Municipal Wastewater Phytoremediation

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Abstract:

The findings from a study on the use of the aquatic macrophyte *Lemna minor* (common duckweed) for the phytoremediation of municipal wastewater. The research, conducted in Chhatrapati Sambhajinagar, Maharashtra, demonstrates that *Lemna minor* is a highly effective, low-cost, and sustainable solution for improving sewage water quality.

Over a seven-day treatment period, the plant significantly reduced concentrations of key pollutants across various wastewater concentrations (20% to 100%). Notable results include reductions in Chemical Oxygen Demand (COD) by up to 65.6%, Biochemical Oxygen Demand (BOD) by up to 71.5%, and Total Nitrogen by up to 69.3%. Nitrate removal was nearly 100% in lower concentrations. The treatment also successfully lowered levels of suspended and dissolved solids, sulphates, and chlorides, while shifting the water's pH towards neutral. These findings confirm the potential of *Lemna minor*-based systems for decentralized wastewater management, particularly in resource-limited regions, as a viable green alternative to conventional, capital-intensive methods.

Background and Study Relevance:

Rapid urbanization has led to increased municipal wastewater generation, posing significant threats to public health and aquatic ecosystems. While effective, conventional treatment methods are often expensive and energy-dependent, limiting their application in economically constrained areas. Phytoremediation, the use of plants to remove or degrade environmental contaminants, has emerged as a cost-effective and ecologically sustainable alternative.

The aquatic plant *Lemna minor*, or duckweed, is recognized for its rapid growth, high nutrient uptake capacity, and resilience in polluted environments. It is known to absorb substantial amounts of nitrogen (N), phosphorus (P), and heavy metals. This study aimed to provide localized research by evaluating the efficiency of *Lemna minor* in treating municipal sewage under the specific climatic conditions and wastewater composition of Chhatrapati Sambhajinagar, Maharashtra. The primary objective was to quantify its effectiveness in reducing key water quality indicators such as BOD, COD, total nitrogen, and total phosphorus.

Experimental Design and Methodology:

The study was designed to measure the phytoremediation potential of *Lemna minor* on domestic wastewater under controlled conditions.

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- **Location and Duration:** The experiment was conducted from April to July 2023 in Chhatrapati Sambhajinagar, Maharashtra, utilizing wastewater collected from a local pond.
- **Experimental Setup:** 200 grams (fresh weight) of *Lemna minor* were introduced into a rectangular cement tank (195 cm x 145 cm x 75 cm) filled with untreated wastewater. The plants were allowed to grow for seven days under natural sunlight.
- **Wastewater Concentrations:** The experiment was conducted using five different concentrations of municipal sewage, diluted with water, to assess performance under varying pollutant loads: Set I (20%), Set II (40%), Set III (60%), Set IV (80%), and Set V (100%).
- **Parameters Analyzed:** Physicochemical parameters of the wastewater were analyzed before and after the seven-day treatment period using standard methods outlined by the American Public Health Association (APHA, 1989). Key parameters included:

◦ pH and Electrical Conductivity (EC)
◦ Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and Total Solids (TS)
◦ Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)
◦ Nutrients: Nitrates (NO_3^-), Phosphates (PO_4^{3-}), Ammoniacal Nitrogen (NH_4OH), and Total Kjeldahl Nitrogen (TKN)
◦ Ions: Sulphates (SO_4^{2-}) and Chlorides (Cl^-)

Analysis of Untreated Wastewater (Baseline)

The initial analysis confirmed that pollutant levels increased directly with sewage concentration. The 100% concentration (Set V) represented the baseline for raw municipal sewage, highlighting its high contamination load and the need for treatment.

- **pH and EC:** The wastewater was slightly acidic, with pH values ranging from 6.2 to 6.6. Electrical Conductivity (EC) increased from 262 µS/cm in 20% concentration to 812 µS/cm in 100% concentration, indicating a high load of dissolved inorganic salts.
- **Solids:** Total Suspended Solids (TSS) ranged from 26 mg/L to 125 mg/L, and Total Dissolved Solids (TDS) ranged from 42 mg/L to 209 mg/L, contributing to turbidity.

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- **Organic Load:** Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels were high, reaching 106 mg/L and 215 mg/L, respectively, in undiluted sewage. These levels significantly exceed permissible discharge limits and indicate substantial organic pollution.
- **Nutrients:** Concentrations of nitrogen and phosphorus were elevated, with total nitrogen reaching 52.5 mg/L and phosphates reaching 12 mg/L. These high nutrient levels are a primary cause of eutrophication in water bodies.

The following table summarizes the initial physicochemical characteristics of the untreated wastewater across the five concentration sets.

Table 1: Initial Physicochemical Characteristics of Municipal Sewage

Parameter	Unit	Set I (20%)	Set II (40%)	Set III (60%)	Set IV (80%)	Set V (100%)
pH		6.2	6.3	6.4	6.5	6.6
EC	µS/cm	262	321	490	647	812
TSS	mg/L	26	50	74	103	125
TDS	mg/L	42	80	122	165	209
TS	mg/L	68	130	196	268	334
BOD	mg/L	21	43	64	85	106
COD	mg/L	45	91	129	181	215
NO_3^-	mg/L	0.1	0.5	1.3	1.6	3.1
PO_4^{3-}	mg/L	2.1	4.8	7.3	10.1	12
SO_4^{2-}	mg/L	14.9	29.8	44	61	75
Cl^-	mg/L	7.5	15.2	21.8	34	41
NH_4OH	mg/L	4	7.8	12.2	14.3	18
TKN	mg/L	11	21.5	32	42.1	52.5

Post-Treatment Results and Efficacy:

Treatment with *Lemna minor* resulted in substantial improvements in water quality across all tested concentrations. The plant demonstrated a multi-faceted ability to absorb dissolved pollutants, trap suspended particles, and facilitate the degradation of organic matter.

- **pH Neutralization and EC Reduction:** The pH shifted towards a neutral range (6.5 to 7.2). EC saw a significant decline, with a maximum reduction of 497 µS/cm in the 100% concentration set, indicating effective removal of dissolved ions.
- **Solids Removal:** TSS and TDS were effectively reduced. For instance, in the 100% concentration, TSS dropped from 125 mg/L to 66 mg/L, and TDS dropped from 209 mg/L to 158 mg/L. This is attributed to particle trapping and nutrient absorption.

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- **Organic Load Reduction:** A significant decrease in organic pollutants was observed. In the 100% sewage, BOD fell by 49.2% (from 106 to 53.8 mg/L) and COD fell by 65.6% (from 215 to 74 mg/L). This points to efficient assimilation of organic nutrients and enhanced microbial degradation.
- **Nutrient Removal:** The most significant finding was the effective removal of nitrogen and phosphorus. Nitrates were reduced to nearly zero in lower concentrations. In the 100% sewage, total nitrogen was reduced by 69.3% (from 52.5 to 16.1 mg/L), and ammoniacal nitrogen was reduced by 61% (from 18 to 7 mg/L). This high nutrient uptake capacity is crucial for mitigating eutrophication.

The following table details the final water quality parameters after the seven-day treatment.

Table 2: Final Physicochemical Characteristics after Treatment

Parameter	Unit	Set I (20%)	Set II (40%)	Set III (60%)	Set IV (80%)	Set V (100%)
pH		6.5	6.9	7.0	7.1	7.2
EC	µS/cm	170	140	230	289	315
TSS	mg/L	17	22	51	62	66
TDS	mg/L	27	43	83	107	158
TS	mg/L	44	65	134	169	224
BOD	mg/L	7.7	15.0	19.1	24.2	53.8
COD	mg/L	17	34	53	64	74
NO_3^-	mg/L	0	0	0	0.2	0.5
PO_4^{3-}	mg/L	0.4	1.3	2.1	4.7	4.9
SO_4^{2-}	mg/L	5.1	10.2	15.0	19.9	27
Cl^-	mg/L	5.1	11.0	14.5	21.2	29
NH_4OH	mg/L	1.1	2.4	3.5	4.2	7.0
Total Nitrogen	mg/L	3.1	7.0	9.1	13.2	16.1

Quantitative Analysis of Pollutant Reduction:

The percentage reduction in contaminants provides a clear measure of *Lemna minor*'s efficiency. The plant showed high removal rates across most parameters, although efficiency was slightly lower in the 100% concentration set for some metrics, suggesting that very high pollutant loads might require longer retention times.

Table 3: Percentage Reduction in Key Physicochemical Parameters

Parameter	Set I (20%)	Set II (40%)	Set III (60%)	Set IV (80%)	Set V (100%)
EC	35.11%	56.39%	53.06%	55.33%	61.21%
TSS	34.62%	56.00%	31.08%	39.81%	47.20%
TDS	35.71%	46.25%	31.97%	35.15%	24.40%
BOD	63.33%	65.12%	70.16%	71.53%	49.25%
COD	62.22%	62.64%	58.91%	64.65%	65.58%
NO_3^-	100.00%	100.00%	100.00%	87.50%	83.87%

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PO_4^{3-}	80.95%	72.92%	71.23%	53.47%	59.17%
SO_4^{2-}	65.77%	65.77%	65.91%	67.38%	64.00%
NH_4OH	72.50%	69.23%	71.31%	70.63%	61.11%
TKN	71.82%	67.44%	71.56%	68.65%	69.33%

Conclusion:

The study demonstrates that *Lemna minor* is highly effective for the phytoremediation of municipal wastewater. The significant reductions achieved in organic load (BOD, COD), nutrients (nitrogen, phosphorus), and solids confirm its potential as a sustainable and low-cost treatment technology.

Key Implications of the study:

- **Viable Green Alternative:** The findings position duckweed-based systems as an eco-friendly alternative to conventional wastewater treatment, which is often inaccessible in developing regions.
- **Eutrophication Control:** The plant's high efficiency in removing nitrogen and phosphorus is critical for protecting natural water bodies from nutrient-induced ecological damage.
- **Decentralized Treatment:** *Lemna minor*'s ease of application makes it suitable for decentralized, small-scale treatment systems in rural or resource-limited communities.
- While the overall performance was robust, the study notes that treatment efficiency for certain pollutants was less pronounced at the highest sewage concentrations. Future research is recommended to optimize operational parameters like plant density and water retention time to maximize removal efficiency, particularly for higher pollutant loads.

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