NATIONAL ENVIRONMENTAL SCIENCE ACADEMY (NESA)

International Journal on Environmental Sciences
http://nesa-india.org | http://journal.nesa-india.org/index/IJES
https://doi.org/10.53390/IJES.2026.17109
IJES 17(1): 103-107 **(2026)** • ISSN: 0976-4534

PHYTOREMEDIATION EFFICIENCY OF EMERGENT MACROPHYTES IN HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLANDS: A COMPARATIVE ASSESSMENT OF SPECIES-SPECIFIC POLLUTANT REMOVAL CAPACITY

Sachin Manohar Patil and Kailas P. Dandge

School of Environmental and Earth Sciences
K.B.C. North Maharashtra University, Jalgaon, Bambhori Pr. Chandsar, Maharashtra

Research Paper

Received: **18.03.2026** Revised: **08.04.2026** Accepted: **26.04.2026**

ABSTRACT

Constructed wetlands (CWs) utilizing macrophytes represent a sustainable and cost-effective approach for sewage treatment in developing regions. This pilot study evaluated the performance of selected macrophytes (*Typha latifolia*, *Phragmites australis*, and *Canna indica*) in a horizontal subsurface flow constructed wetland system for treating domestic sewage. The study was conducted over a 6-month period (March-August 2024) with a hydraulic retention time of 3 days. Water quality parameters including biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP), and fecal coliforms were monitored bi-weekly. Results demonstrated significant removal efficiencies: BOD (82-89%), COD (76-84%), TSS (85-92%), TN (68-75%), and TP (71-79%). *Typha latifolia* exhibited the highest overall performance with superior nutrient uptake capacity and biomass production (2.8 kg/m^2). Plant growth rates and physiological responses were monitored to assess stress tolerance and adaptation. The findings suggest that macrophyte-based constructed wetlands can effectively treat domestic sewage, providing an eco-friendly alternative to conventional treatment systems, particularly suitable for small communities and rural areas with limited infrastructure.

No. of Pages: 5 **References: 14**

Keywords: Constructed wetlands, macrophytes, sewage treatment, phytoremediation, wastewater management, Typha latifolia.

Introduction

Global water scarcity and increasing pollution of freshwater resources have necessitated the development of sustainable wastewater treatment technologies (Vymazal, 2011). Conventional sewage treatment systems, while effective, require substantial capital investment, operational costs, and technical expertise, making them impractical for many developing regions and rural communities (Kadlec & Wallace, 2009). Constructed wetlands (CWs) have emerged as viable alternatives that combine ecological engineering principles with natural treatment processes to achieve efficient pollutant removal at reduced costs (Wu et al., 2015).

Constructed wetlands are engineered systems designed to simulate natural wetland ecosystems for wastewater treatment through physical, chemical, and biological processes (Brix, 1997). These systems utilize the synergistic interactions between substrates, microorganisms, and vegetation to remove contaminants from wastewater (Zhang et al., 2014). Among the various components, macrophytes play a crucial role in enhancing treatment efficiency through multiple mechanisms including direct nutrient uptake, oxygen transfer to the rhizosphere, providing surface area for microbial biofilms, and physical filtration (Vymazal, 2013).

*Corresponding author: *sachincool98@gmail.com*

Macrophytes used in constructed wetlands are typically emergent species capable of tolerating waterlogged conditions and high pollutant concentrations (Tanner, 1996). Common species include *Typha* spp., *Phragmites australis*, *Scirpus* spp., and ornamental plants like *Canna* spp. (Greenway, 2005). The selection of appropriate plant species is critical for optimizing treatment performance and ensuring system sustainability under varying environmental conditions (Shelef et al., 2013).

Previous studies have demonstrated the effectiveness of macrophyte-based constructed wetlands for treating various types of wastewater, including domestic sewage, industrial effluents, and agricultural runoff (Vymazal & Kröpfelová, 2008; Stottmeister et al., 2003). However, most research has focused on temperate climates, and there remains a need for region-specific pilot studies to evaluate system performance under local environmental conditions and with indigenous or adapted plant species (Kivaisi, 2001).

The present study aims to evaluate the performance of three macrophyte species (*Typha latifolia*, *Phragmites australis*, and *Canna indica*) in a pilot-scale horizontal subsurface flow constructed wetland for treating domestic sewage. Specific objectives include: (1) assessing pollutant removal efficiency for key water quality parameters, (2) comparing the performance of different macrophyte species, (3) monitoring plant growth and biomass production, and (4) evaluating the feasibility of constructed wetlands as a decentralized sewage treatment option for small communities.

Materials and Methods

Study Site and Experimental Design

The pilot study was conducted at a rural wastewater treatment facility located in Maharashtra, India (19°N, 74°E) from March to August 2024. The climate is characterized as semi-arid with an average annual temperature of 25-28°C and rainfall of approximately 600 mm. The experimental setup consisted of nine horizontal subsurface flow (HSSF) constructed wetland units, each measuring 4 m × 2 m × 0.6 m (length × width × depth), arranged in a randomized block design with three replicates per treatment.

Constructed Wetland Configuration

Each wetland unit was constructed using reinforced concrete with a waterproof lining to prevent seepage. The substrate consisted of three layers: a bottom drainage layer of coarse gravel (20-30 mm diameter, 15 cm depth), a middle layer of medium gravel (10-15 mm diameter, 20 cm depth), and a top layer of fine gravel mixed with sand (5-10 mm diameter, 20 cm depth). The total substrate depth was 55 cm, with a water level maintained at 5 cm below the substrate surface. Inlet and outlet zones (40 cm each) consisted of coarse gravel to ensure uniform flow distribution and collection.

Macrophyte Selection and Establishment

Three macrophyte species were selected based on their documented wastewater treatment potential and local availability:

1. *Typha latifolia* L. (Common cattail) - emergent macrophyte, Typhaceae family
2. *Phragmites australis* (Cav.) Trin. ex Steud. (Common reed) - emergent macrophyte, Poaceae family
3. *Canna indica* L. (Indian shot) - emergent ornamental macrophyte, Cannaceae family

Uniform rhizomes or plantlets (n=25 per unit) were collected from established populations and transplanted into the wetland units in February 2024. A one-month establishment period was provided with reduced wastewater loading (50% of design load) before initiating the full-scale experiment. Three control units without vegetation were maintained for comparison.

Wastewater Characteristics and Loading

Domestic sewage from a nearby residential area (population ~500) was used as influent. The raw sewage was characterized by high organic content and nutrient concentrations typical of domestic wastewater. The wetland units were operated in continuous flow mode with a hydraulic retention time (HRT) of 3 days and an organic loading rate of 40 g BOD/m^2/day. Daily flow rate was maintained at 0.27 m^3/day per unit using flow meters.

Typical influent characteristics were: pH 7.2-7.8, BOD 180-240 mg/L, COD 320-450 mg/L, TSS 150-220 mg/L, TN 35-50 mg/L, TP 8-12 mg/L, and fecal coliforms 10□-10□ MPN/100 mL.

Sampling and Analytical Methods

Water samples were collected bi-weekly from inlet and outlet points of each wetland unit using acid-washed polyethylene bottles. Samples were transported to the laboratory in ice boxes and analyzed within 24 hours following standard methods (APHA, 2017). The following parameters were measured:

- pH and temperature: measured in situ using a portable pH meter (Hanna Instruments)
- Dissolved oxygen (DO): measured using a DO meter (Hanna HI-9146)

- Biochemical oxygen demand (BOD5): 5-day incubation method (APHA 5210 B)
- Chemical oxygen demand (COD): closed reflux colorimetric method (APHA 5220 D)
- Total suspended solids (TSS): gravimetric method (APHA 2540 D)
- Total nitrogen (TN): Kjeldahl digestion followed by spectrophotometry (APHA 4500-N)
- Total phosphorus (TP): acid digestion followed by ascorbic acid method (APHA 4500-P)
- Fecal coliforms: membrane filtration technique (APHA 9222 D)

Plant Performance Monitoring

Plant growth parameters were measured monthly for 15 randomly selected plants per wetland unit:

- **Plant height:** measured from substrate surface to the highest leaf tip
- **Stem diameter:** measured at 5 cm above substrate surface using digital calipers
- **Leaf count:** total number of living leaves per plant
- **Biomass production:** aboveground biomass harvested at the end of the study, dried at 70°C for 48 hours, and weighed

Tissue samples from roots and shoots were collected at the study conclusion for nutrient content analysis (N, P, K) using standard digestion and spectrophotometric methods.

Statistical Analysis

Data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY). Removal efficiencies were calculated as:

Removal efficiency (%) = [(Cin - Cout) / Cin] × 100

where Cin and Cout represent influent and effluent concentrations, respectively.

One-way analysis of variance (ANOVA) was performed to compare treatment efficiencies among different macrophyte species and control units, followed by Tukey's HSD post-hoc test for multiple comparisons. Pearson correlation analysis was used to examine relationships between plant growth parameters and pollutant removal rates. Statistical significance was set at $p < 0.05$.

Results

Water Quality Parameters and Removal Efficiency

The pilot-scale constructed wetlands demonstrated substantial removal of organic matter, nutrients, and fecal coliforms throughout the study period. Table 1 presents the mean influent and effluent concentrations along with removal efficiencies for different macrophyte treatments.

Table 1: Mean Water Quality Parameters and Removal Efficiencies in Constructed Wetlands.

Parameter	Influent Effluent (% Removal)	T. latifolia Effluent (% Removal)	P. australis Effluent (% Removal)	C. indica Effluent (% Removal)	Control
BOD (mg/L)	208 ± 28	23 ± 6 (89.0 ± 2.3)[a]	28±7 (86.5±2.8)[ab]	37±9 (82.2 ± 3.1)[b]	58 ± 12 (72.1 ± 4.2)[c]
COD (mg/L)	384 ± 52	62 ± 14 (83.9 ± 2.6)[a]	71 ± 16 (81.5±3.2)[ab]	92 ± 18 (76.0±3.7)[b]	124 ± 24 (67.7 ± 4.5)[c]
TSS (mg/L)	186 ± 34	15 ± 5 (91.9 ± 2.1)[a]	18 ± 6 (90.3 ± 2.4)[ab]	28 ± 8 (84.9 ± 3.0)[b]	42 ± 11 (77.4 ± 4.1)[c]
TN (mg/L)	42 ± 7	11 ± 3 (73.8 ± 3.4)[a]	12 ± 3 (71.4 ± 3.8)[ab]	14 ± 4 (66.7 ± 4.2)[b]	18 ± 5 (57.1 ± 5.1)[c]
TP (mg/L)	9.8 ± 1.6	2.1 ± 0.6 (78.6 ± 3.2)[a]	2.4 ± 0.7 (75.5 ± 3.6)[ab]	2.8 ± 0.8 (71.4 ± 4.0)[b]	3.6 ± 0.9 (63.3 ± 4.8)[c]
Fecal coliforms (log MPN	6.2 ± 0.4	2.8 ± 0.5 (3.4 log reduction)[a]	3.0 ± 0.5 (3.2 log reduction)[a]	3.3 ± 0.6 (2.9 log reduction)[a]	4.1 ± 0.7 (2.1 log reduction)[a]

Note: Values represent means ± standard deviation (n = 12 sampling events × 3 replicates). Different superscript letters indicate statistically significant differences ($p < 0.05$) among treatments based on Tukey's HSD test.

Organic Matter Removal

All vegetated wetlands achieved high removal rates for both BOD and COD. *Typha latifolia* systems demonstrated the highest BOD removal efficiency (89.0 ± 2.3%), significantly outperforming control units (72.1 ± 4.2%, $p < 0.001$). The removal efficiency followed the order: *T. latifolia* > *P. australis* > *C. indica* > Control. Similar trends were observed for COD removal, with *T. latifolia* achieving 83.9% removal compared to 67.7% in unvegetated controls.

Suspended Solids Removal

TSS removal was highly efficient across all treatments, with vegetated systems achieving 85-92% removal. Both *T. latifolia* and *P. australis* performed comparably (91.9% and 90.3%, respectively; $p > 0.05$), significantly exceeding the performance of *C. indica* (84.9%) and control units (77.4%). The physical filtration capacity of the gravel substrate, enhanced by root system development, contributed to effective particle removal.

Discussion

Treatment Performance and Mechanisms

The pilot study demonstrated that macrophyte-based horizontal subsurface flow constructed wetlands can effectively treat domestic sewage, achieving removal efficiencies comparable to or exceeding conventional secondary treatment systems. The observed BOD removal rates (82-89%) align with previous studies reporting 75-95% removal in similar systems (Vymazal, 2011; Wu et al., 2015). The superior performance of vegetated systems compared to unvegetated controls confirms the critical role of macrophytes in enhancing treatment processes.

Multiple synergistic mechanisms contribute to pollutant removal in constructed wetlands. Organic matter degradation occurs primarily through aerobic and anaerobic microbial metabolism (Stottmeister et al., 2003). Macrophytes enhance this process by releasing oxygen through roots, creating oxidized microsites in the otherwise anaerobic substrate where aerobic bacteria can degrade organic compounds (Brix, 1997). The extensive root systems also provide large surface areas for biofilm development, increasing overall microbial activity.

Species-Specific Performance

Typha latifolia emerged as the superior species for wastewater treatment in this study, demonstrating highest removal efficiencies for all measured parameters except TSS, where performance was comparable to *P. australis*. Several factors contribute to *T. latifolia*'s enhanced performance. First, its vigorous growth and high biomass production (4.73 kg/m^2) indicate robust metabolic activity and nutrient uptake capacity. Second, Typha species are characterized by well-developed aerenchyma tissue facilitating efficient oxygen transport to roots, thereby enhancing rhizosphere oxidation and supporting aerobic microbial processes (Brix, 1997).

Conclusion

This pilot study demonstrates that macrophyte-based horizontal subsurface flow constructed wetlands provide effective treatment for domestic sewage, achieving substantial removal of organic matter, nutrients, and pathogens. *Typha latifolia* emerged as the optimal species, combining high treatment efficiency with robust growth and biomass production. The superior performance of vegetated systems compared to unvegetated controls confirms the essential role of macrophytes in enhancing treatment through multiple mechanisms including oxygen transfer, nutrient uptake, and biofilm support.
The study supports the feasibility and sustainability of constructed wetlands as decentralized wastewater treatment solutions, particularly for small communities and rural areas lacking conventional infrastructure. These systems offer ecological, economic, and social benefits including low capital and operating costs, minimal energy consumption, simple operation, aesthetic value, and potential for habitat creation. The findings provide valuable baseline data for designing and implementing constructed wetland systems in similar climatic and socioeconomic contexts.

References

1. **American Public Health Association** (APHA). (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association.
2. **Brix, H.** (1997). Do macrophytes play a role in constructed treatment wetlands? Water Science and Technology, 35(5), 11-17. https://doi.org/10.1016/S0273-1223(97)00047-4
3. **Greenway, M.** (2005). The role of constructed wetlands in secondary effluent treatment and water reuse in subtropical and arid Australia. *Ecological Engineering*, 25(5), 501-509. https://doi.org/10.1016/j.ecoleng.2005.07.008
4. **Kadlec, R. H., & Wallace, S. D.** (2009). Treatment wetlands (2nd ed.). CRC Press. https://doi.org/10.1201/9781420012514
5. **Kivaisi, A. K.** (2001). The potential for constructed wetlands for wastewater treatment and reuse in developing countries: A review. *Ecological Engineering*, 16(4), 545-560. https://doi.org/10.1016/S0925-8574(00)00113-0

6. **Shelef, O., Gross, A., & Rachmilevitch, S.** (2013). Role of plants in a constructed wetland: Current and new perspectives. Water, 5(2), 405-419. https://doi.org/10.3390/w5020405

7. **Stottmeister, U., Wießner, A., Kuschk, P., Kappelmeyer, U., Kästner, M., Bederski, O., Müller, R. A., & Moormann, H.** (2003). Effects of plants and microorganisms in constructed wetlands for wastewater treatment. Biotechnology Advances, 22(1-2), 93-117. https://doi.org/10.1016/j.biotechadv.2003.08.010

8. **Tanner, C. C.** (1996). Plants for constructed wetland treatment systems—A comparison of the growth and nutrient uptake of eight emergent species. *Ecological Engineering*, 7(1), 59-83. https://doi.org/10.1016/0925-8574(95)00066-6

9. **Vymazal, J.** (2007). Removal of nutrients in various types of constructed wetlands. Science of the Total Environment, 380(1-3), 48-65. https://doi.org/10.1016/j.scitotenv.2006.09.014

10. **Vymazal, J.** (2011). Plants used in constructed wetlands with horizontal subsurface flow: A review. Hydrobiologia, 674(1), 133-156. https://doi.org/10.1007/s10750-011-0738-9

11. **Vymazal, J.** (2013). Emergent plants used in free water surface constructed wetlands: A review. *Ecological Engineering*, 61(Part B), 582-592. https://doi.org/10.1016/j.ecoleng.2013.06.023

12. **Vymazal, J., & Kröpfelová, L.** (2008). Wastewater treatment in constructed wetlands with horizontal sub-surface flow. Springer. https://doi.org/10.1007/978-1-4020-8580-2

13. **Wu, H., Zhang, J., Ngo, H. H., Guo, W., Hu, Z., Liang, S., Fan, J., & Liu, H.** (2015). A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation. *Bioresource Technology*, 175, 594-601. https://doi.org/10.1016/j.biortech.2014.10.068

14. **Zhang, D. Q., Jinadasa, K. B. S. N., Gersberg, R. M., Liu, Y., Ng, W. J., & Tan, S. K.** (2014). Application of constructed wetlands for wastewater treatment in developing countries—A review of recent developments (2000-2013). *Journal of Environmental Management*, 141, 116-131. https://doi.org/10.1016/j.jenvman. 2014.03.015