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ASSESSMENT OF *PHRAGMITES AUSTRALIS* AND *TYPHA ANGUSTIFOLIA* EFFICACY FOR DOMESTIC SEWAGE TREATMENT DURING A PILOT SCALE STUDY OF CONSTRUCTED WETLAND

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ABSTRACT

Domestic wastewater poses significant environmental challenges particularly in developing countries. Conventional treatment methods often entail high operational costs and energy consumption. This research investigates the efficacy of two common macrophyte species, *Phragmites australis* (common reed) and *Typha angustifolia* (narrow-leaved cattail), in treating domestic wastewater within constructed wetlands (CWs) systems. The study focuses on monitoring changes in key physicochemical parameters, including pH, temperature, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD) chemical oxygen demand (COD), total alkalinity, chloride, Ca hardness and total hardness of inflow and outflow. Experimental setups utilizing horizontal subsurface flow configuration of constructed wetland and chambers were planted with these species aimed to assess their pollutant removal efficiencies. The main objective of the study was to evaluate the potential of these plant species in contributing to sustainable and cost-effective domestic wastewater treatment. Results generally indicate substantial reductions in organic matter and suspended solids, with varying degrees of nutrient removal, highlighting the role of these macrophytes.

Key words : Domestic wastewater, Constructed wetlands, *Phragmites australis*, *Typha angustifolia*, Phytoremediation, Physicochemical parameters.

Introduction

Constructed wetlands (CWs) are human-made systems specifically developed to replicate the natural treatment functions of wetlands by harnessing the interactions between wetland plants, soil substrates, and microbial communities to treat wastewater. These systems emulate the ecological mechanisms found in natural wetlands but operate in a managed and controlled setting. CWs can be categorized based on the predominant type of aquatic vegetation present, including free-floating, rooted emergent and submerged macrophytes (Brix and Schierup, 1989). Acting as engineered ecosystems, constructed wetlands are designed to filter wastewater and remove various pollutants prior to discharging treated water into natural environments. They integrate physical, chemical, and biological treatment processes to improve water quality

more effectively and efficiently than natural systems (Scholz *et al.*, 2007; Kadlec and Wallace, 2008). Due to their cost-effectiveness and simplicity, CWs are commonly implemented around the world as alternatives to traditional tertiary wastewater treatment methods (Kivaisi, 2002; Verhoeven *et al.*, 2006; Pathak and Jagetiya, 2022).

The rapid growth of the global population coupled with accelerating urban development has significantly increased domestic wastewater production. This type of wastewater typically contains elevated concentrations of organic compounds, suspended particles, and nutrients such as nitrogen and phosphorus, which, if released without adequate treatment, can cause serious harm to aquatic environments (Tchobanoglous *et al.*, 2014). While conventional centralized wastewater treatment plants (WWTPs) are generally effective, they require high financial investment, consistent energy input, and

technically skilled personnel, which limits their practicality in decentralized settings or under-resourced regions. Constructed wetlands (CWs) are engineered systems designed to treat wastewater by mimicking natural wetland processes. They leverage the interactions between plants, soil, and microorganisms to remove contaminants from water (Pathak and Jagetiya, 2024).

Several studies have confirmed that constructed wetlands are effective systems for the onsite treatment of both domestic/municipal and agricultural wastewater. These systems have been shown to successfully eliminate a wide range of contaminants, including suspended solids (SS), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrogen (N), phosphorus (P), trace metals, and pathogenic microorganisms present in wastewater (Rousseau *et al.*, 2004; Mitsch and Gosselink, 2007; Scholz *et al.*, 2007; Kadlec and Wallace, 2008; Pathak and Jagetiya, 2025).

As a sustainable and low-cost alternative, constructed wetlands (CWs) have gained attention for their ecological compatibility and efficiency in treating wastewater (Vymazal, 2007). These systems are designed to imitate the functions of natural wetlands by combining physical, chemical, and biological processes that involve substrates, microbial communities, and aquatic plants (Kadlec and Wallace, 2009). Certain indigenous bacterial strains possess plant growth-promoting properties, such as nitrogen fixation, phosphate solubilization, and production of growth hormones. These characteristics make them valuable candidates for biofertilizer development (Pathak and Jagetiya, 2024). Macrophytes, in particular, play an essential role by offering extensive surface areas for microbial colonization, enhancing oxygen transport to the root zone and facilitating nutrient uptake (Brix, 1997).

Among the many wetland plant species utilized in treatment systems, *Phragmites australis* (Poaceae) and *Typha angustifolia* (Typhaceae) stand out for their vigorous growth, resilience across a range of water conditions, and strong capacity to absorb pollutants (Brix and Schierup, 1989; Klomjek and Nitisoravut, 2005). *Phragmites australis*, commonly referred to as the common reed, possesses an extensive rhizome system that improves water flow through the substrate and facilitates oxygen movement, thereby enhancing aerobic microbial processes (Deva *et al.*, 2024). Likewise, *Typha angustifolia*, or narrow-leaved cattail, is a hardy emergent macrophyte known for producing substantial biomass and effectively removing contaminants such as nutrients and heavy metals from wastewater (Kantawanichkul *et al.*, 2009). Vegetation generally plays

a beneficial role in constructed wetlands, enhancing the removal efficiency of organic matter as well as nutrients such as nitrogen and phosphorus. Among the various plant species used worldwide, *Phragmites australis* (common reed) is the most widely adopted. Additionally, species from the genera *Typha* (including *T. latifolia*, *T. angustifolia*, *T. domingensis*, *T. orientalis* and *T. glauca*) and *Scirpus* (such as *S. lacustris*, *S. validus*, *S. californicus* and *S. acutus*) are frequently utilized in treatment wetland systems (Porwal and Jagetiya, 2019). The objective of this study was to carry out a detailed physicochemical assessment of domestic wastewater treatment using *Phragmites australis* and *Typha angustifolia* within constructed wetlands. By monitoring the variations in essential physicochemical indicators, the research was aimed to determine the pollutant removal performance of these macrophytes and enhance the current understanding and design of nature-based wastewater treatment technologies.

Materials and Methods

Experimental Setup and Plant species

The study was conducted using pilot-scale constructed wetland systems (horizontal subsurface flow (HSSF) to treat the domestic wastewater. Each CW unit with the dimensions of 1m x 0.6m x 0.6 (L x W x D), comprised a waterproof basin filled with a graded gravel and sand substrate, typically consisting of a bottom layer of coarse gravel, a middle layer of fine gravel and a top layer of sand. Four different sets of CWs have been established with the following configuration-

- **Set A (control):** unplanted wetland unit with only substrate to assess removal by physical and microbial processes without direct plant influence
- **Set B:** planted with *Phragmites australis*
- **Set C:** planted with *Typha angustifolia*
- **Set D:** co-planted with *Phragmites australis* and *Typha angustifolia*

Phragmites australis and *Typha angustifolia* seedlings were collected from local wetland areas and acclimatized before transplantation into the CW units. Plants were spaced appropriately to ensure optimal growth and coverage.

Wastewater Source and operation

Untreated domestic wastewater was collected from Gandhi Sagar Pond and introduced into the CWs chambers. The wastewater was fed intermittently at a controlled hydraulic loading rate (HLR) of (10 L m⁻² day⁻¹) and a hydraulic retention time (HRT) of 3 days with

gravity feed. The systems were operated under ambient environmental conditions.

Sample collection and Physicochemical analysis

Wastewater samples were collected on the monthly basis from the inflow (raw wastewater entering the CW chambers and the outflow (treated water discharged from each CW unit). Samples were collected as 24-hour composite samples, immediately transported to the laboratory in pre-cleaned bottles, and stored at 4 °C until analysis, typically within 24 hours. The following physicochemical parameters were analysed according to standard methods (APHA, 2017)-

- **pH:** measured using a digital pH meter
- **Temperature:** measured using a standard thermometer
- **Total Dissolved Solids (TDS):** gravimetric method after filtration
- **Dissolved Oxygen (DO):** azide modification of Winkler used
- **Biochemical Oxygen Demand (BOD):** 5-days BOD test
- **Chemical Oxygen Demand (COD):** closed reflux titrimetric method
- **Total alkalinity:** titration Method
- **Chloride:** argentometric used
- **Ca hardness:** EDTA titrimetric used
- **Total hardness:** EDTA titrimetric used

Data analysis

Mean concentrations, standard deviations and one factor ANOVA were calculated for each parameter in the inflow and outflow of all CW units. Percent pollutant removal efficiency (RE) was calculated using the formula-

$$RE\% = C_i (C_i - C_o) \times 100$$

Where,

C_i = Inflow concentration of the parameter

C_o = Outflow concentration of the parameter

Statistical analysis, such as ANOVA and t-tests, were performed to determine significant differences in removal efficiencies between the planted and unplanted units, and between the two plant species using MS Excel.

Results and Discussion

pH and temperature

The pH of domestic wastewater was monitored throughout the treatment process to evaluate the stability of chemical conditions favourable for microbial and plant

activity. The inflow pH of untreated domestic wastewater was found to range between 6.45 to 7.56, which is typical of residential sewage. After treatment in the constructed wetland units planted with *Phragmites australis* and *Typha angustifolia*, the outflow pH showed a slight decrease (non-significant), generally ranging from 7.05 to 7.55. This narrow and near-neutral pH range indicates that the system maintained favourable conditions for microbial degradation of organic matter and nutrient transformations (e.g., nitrification and denitrification), without creating an acidic or alkaline environment.

Previous studies have consistently demonstrated that constructed wetlands (CWs) can effectively maintain near-neutral pH conditions, which are conducive to microbial and plant activity during the treatment of domestic wastewater. For instance, Vymazal (2011) reported that CWs typically operate within a pH range of 6.5 to 8.5, depending on factors such as plant species, substrate type and operational conditions. This pH range supports essential microbial processes like nitrification and denitrification, as well as plant uptake of nutrients.

This study demonstrated a mild and significant difference between temperature of control chamber and chambers co-planted with both the test species. During present study observed inflow range of temperature 24.4°C to 44.5°C. After treatment in the constructed wetland units planted with *Phragmites australis* and *Typha angustifolia*, the outflow temperature showed decrease (significant), generally ranging from 17.67 to 35.67°C. Vymazal (2011) noted that CWs typically operate effectively within a temperature range of 20°C to 30°C, with microbial activity and pollutant removal efficiency peaking in this range. Similarly, Brix (1997) emphasized that temperature influences the metabolic rates of microorganisms and the uptake of nutrients by plants, thereby affecting the overall treatment efficiency. In colder climates, lower temperatures can reduce microbial activity, leading to decreased treatment efficiency. For instance, a study by Reed *et al.* (1995) found that the rate constants for pollutant degradation in CWs are temperature-dependent, with a decrease in temperature leading to a reduction in degradation rates. Therefore, maintaining an optimal temperature range is essential for sustaining the biological processes responsible for wastewater treatment in CWs.

Total dissolves solids (TDS)

The concentration of total dissolved solids (TDS) in the inflow and outflow samples was measured to assess the effectiveness of the constructed wetland system in reducing dissolved solids content. TDS levels in the raw

Table 1 : Monthly variation in physicochemical parameters of raw wastewater (municipal sewage) used as inflow in chambers of CWs.

Month	pH	Temperature (°C)	TDS (mg L ⁻¹)	DO (mg L ⁻¹)	BOD (mg L ⁻¹)	COD (mg L ⁻¹)	Total alkalinity (mg L ⁻¹)	Chloride (mg L ⁻¹)	Ca hardness (mg L ⁻¹)	Total hardness (mg L ⁻¹)
January	7.41	27.6	1200	8.41	110.4	144	454	278	179	181
February	6.92	25.7	1269	9.18	160.3	159	348	286	188	245
March	7.56	30.4	1300	9.98	226.6	165	460	300	200	262
April	7.28	34.7	1230	8.98	200.9	178	439	310	210	280
May	6.45	40.6	1190	8.17	235.6	162	395	275	223	240
June	7.49	44.5	1188	6.99	195.4	193	375	263	210	220
July	7.49	28.3	1100	6.64	184.3	208	365	242	178	209
August	7.17	31.4	1110	7.98	171.3	250	400	230	194	199
September	7.26	28.5	1157	9.19	156.5	190	449	243	199	200
October	7.54	29.4	1078	10.39	136.2	179	538	257	226	241
November	7.46	29.4	1198	10.9	98.4	128	555	274	238	245
December	7.28	24.4	1190	7.47	109.3	139	476	273	213	235

wastewater ranged from 1078 to 1300 mg L⁻¹, indicating a high concentration of inorganic salts, minerals, and organic matter. After treatment through the constructed wetland (C4) planted with *Phragmites australis* and *Typha angustifolia*, the TDS in the outflow decreased significantly, with final values ranging from 807.67 to 1055.33 mg L⁻¹. The observed reduction in TDS can be attributed to filtration through the wetland substrate, plant uptake of nutrients and ions, and microbial activity within the root zone (rhizosphere). The average TDS removal efficiency across all samples was approximately 40–50%, suggesting moderate effectiveness for non-volatile dissolved solids. A study by Brix (1997) highlighted the role of plant roots in enhancing the removal of dissolved solids by creating microenvironments that facilitate microbial activity and nutrient uptake. The presence of vegetation like *Phragmites* and *Typha* was found to significantly contribute to the reduction of TDS in CWs. *Typha* could tolerate TDS concentrations up to 2500 mg L⁻¹ (Valipour *et al.*, 2014).

Dissolved Oxygen (DO)

Dissolved Oxygen (DO) levels were measured at both the inlet and outlet of the constructed wetland to evaluate aerobic conditions and the extent of biological activity. DO in the inflow wastewater was generally low, ranging between 6.64 and 10.39 mg L⁻¹, indicating high organic loading and potential anaerobic conditions. In contrast, DO concentrations in the outflow increased, ranging between 8.10 and 13.83 mg L⁻¹, depending on plant type and sampling time. The increase in DO is largely due to oxygen transfer through the root systems of *Phragmites australis* and *Typha angustifolia*, which create localized aerobic microenvironments favourable

for microbial degradation of organic matter. Emergent plants with extensive aerenchyma (e.g. *Typha*, *Phragmites*, *Carex*, *Lythrum*, *Iris*) vary in efficiency of oxygen transport. Rapid growing species with dense root systems deliver more DO into the zone (Villaseñor Camacho *et al.*, 2010; Bridgham *et al.*, 2002). The DO level in water indicates the health of the aquatic ecosystems. The vital metabolism of aerobic organisms and respiration depends solely on the amount of oxygen dissolved in water (Sener *et al.*, 2020; Saha *et al.*, 2022, 2023).

Organic Matter Removal

Biochemical Oxygen Demand (BOD)

BOD is a key indicator of biodegradable organic matter in wastewater. In the present study, the inflow BOD levels of domestic wastewater were found to be in the range of 98.4 to 235.6 mg L⁻¹, reflecting a high organic load typical of untreated domestic outflow. After treatment through the constructed wetland system planted with *Phragmites australis* and *Typha angustifolia*, the outflow BOD levels dropped significantly to between 64.17 and 158.47 mg L⁻¹. In some of the studies, the observed BOD removal efficiency ranged from 70% to 85%, with the highest removal noted in wetlands with a longer hydraulic retention time and denser plant growth. The reduction is attributed to microbial degradation of organic compounds in the rhizosphere, oxygenation via plant roots and sedimentation of particulate matter (Vymzal *et al.*, 2010). High BOD values are attributed to the stagnation of water body leading to the absence of self-purification (Kataria and Bux, 2008; Sultana *et al.*, 2009; Jhansilakshmi and Reddi, 2014).



Fig. 1 : Physicochemical characteristics of inflow and outflow wastewaters of CW chambers.

Chemical Oxygen Demand (COD)

COD, which measures both biodegradable and non-biodegradable organics, was also significantly reduced by the constructed wetland system. The inflow COD values ranged from 128 to 250 mg L⁻¹, whereas outflow COD concentrations decreased to 67.33 to 247.33 mg L⁻¹.

¹. The COD reduction is primarily due to microbial oxidation processes enhanced by root zone oxygenation and plant-microbe interactions, as well as adsorption and physical filtration through the wetland substrate. The removal of COD is attributed to microbial degradation of substrate to the plant's roots (Greenway and Woolley,

1999; Vymazal, 2002; Steer *et al.*, 2003).

Total alkalinity

Total Alkalinity, which indicates the water's capacity to buffer against pH changes and neutralize acids, was moderately influenced by the constructed wetland system. The inflow alkalinity ranged between 348 and 555 mg L⁻¹ as CaCO₃, while the outflow levels dropped substantially to 159.33 to 428.00 mg L⁻¹. This removal efficiency implying that the wetland system effectively maintains a stable pH environment that supports microbial activity. The observed decline in alkalinity is largely due to microbial nitrification, a process that reduces alkalinity by converting ammonia into nitrate. Nonetheless, this reduction is partially balanced by alkalinity produced during denitrification and microbial degradation of organic compounds, demonstrating the system's ability to regulate acid-base interactions through both biological and chemical processes in the root zone and substrate. Alkalinity indicates the water's capacity to neutralize acids, which is primarily governed by the equilibrium between carbonic acid, bicarbonates, and carbonates (Chapman, 1996).

Chloride

The concentration of chloride in domestic wastewater is a key indicator of the presence of dissolved salts, commonly originating from household detergents, human waste and cleaning agents. In this study, the inflow chloride levels were found to be within the range of 230 to 310 mg L⁻¹, which is typical of untreated domestic sewage in urban areas. Following treatment in the constructed wetland planted with *Phragmites australis* and *Typha angustifolia*, the outflow chloride concentrations were reduced to 133.67 to 197.67 mg L⁻¹. The decrease in chloride concentration during monsoon months as observed in the present study might be due to dilution of water by rains (Saxena and Saksena, 2012; Shukla and Arya, 2018).

Calcium Hardness and Total Hardness

The calcium hardness of the inflow was found to be in the range of 178 to 228 mg L⁻¹ as CaCO₃, while the outflow levels dropped to 66.67 to 150.33 mg L⁻¹ as CaCO₃. Patel and Kanungo (2010) observed the percentage reduction ranged from 14.58-26.73% after the phytoremediation for calcium hardness.

The total hardness in untreated wastewater was observed to be between 181 and 280 mg L⁻¹ as CaCO₃. After treatment, the values reduced to 116.33 to 150.33 mg L⁻¹ as CaCO₃, with the 30–40% average removal efficiency. According to Patel and Kanungo (2010),

Lemna minor L. was able to reduce total hardness from domestic wastewater by less than 15%.

Conclusion

The results of this study indicate that CWs, incorporating *Phragmites australis* and *Typha angustifolia* are effective in improving the physicochemical properties of domestic wastewater through integrated biological, physical, and chemical processes. The pH values remained relatively stable within the ideal range of 6.8 to 7.5, supporting microbial communities vital for organic matter breakdown. Temperature variations, particularly higher levels during warmer seasons, positively influenced treatment performance by accelerating biological activity. Total Dissolved Solids (TDS) showed a moderate decline attributable to substrate filtration, nutrient uptake by plants, and microbial assimilation. Additionally, Dissolved Oxygen (DO) levels rose markedly in the treated outflow, suggesting the creation of aerobic zones favourable for microbial degradation. Significant reductions in organic pollutants were observed, with substantial BOD and COD removal. This highlights the efficient breakdown of organic matter via microbial metabolism, facilitated by oxygen transfer from plant roots and substrate filtration. An alkalinity reduction indicates that the constructed wetland system helps preserve a stable pH environment favourable for microbial processes. This decrease in alkalinity is mainly linked to nitrification, during which microbes oxidize ammonia to nitrate, consuming alkalinity in the process. Chloride levels dropped moderately, while calcium hardness and total hardness were also removed abstemiously to a substantial level, likely due to plant absorption and chemical interactions with the substrate media. In summary, the findings confirm that CW_s provide a sustainable, low-cost and eco-friendly solution for domestic wastewater treatment, especially in areas lacking centralized infrastructure. Although nutrient and inorganic ion removal was less efficient compared to organic matter reduction, the system still delivered notable improvements in outflow quality. To enhance performance particularly for non-biodegradable and salt-related parameters modifications such as increasing hydraulic retention time, incorporating diverse plant species, or optimizing substrate composition are recommended.

Author contribution

Sanju Prajapat was instrumental in the present research, contributing to its design by establishing objectives and methodologies. During implementation, they ensured adherence to protocols, and in the analysis phase, applied statistical methods to interpret the findings.

Dr. B.L. Jagetiya's involvement extended to crafting the manuscript, making the research accessible and impactful as the Research Supervisor.

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Competing interests

The authors declare no competing interests.

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