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Efficiency of Constructed Wetlands with Indigenous Umbrella Sedge for Rural Domestic Wastewater Treatment in Northern Vietnam

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ABSTRACT: Plants plays a crucial role in the treatment mechanisms of constructed wetlands (CW). In this study, the indigenous umbrella sedge (*Cyperus alternifolius*) was employed for the treatment of rural domestic wastewater in northern Vietnam, a region characterized by a tropical monsoon climate. The CW system was designed with a planting density of 105 plants/m² on a substrate composed of gravel, stones, and sand. The experiment was conducted over a period of 60 days, with a wastewater inflow of 100 L/day and sampling performed every three days. The results indicated that the removal efficiencies of COD, TSS, NH_4^+, TN, and TP were 67.0 ± 5.5%, 61.7 ± 6.0%, 66.6 ± 8.4%, 71.8 ± 5.8%, and 68.0 ± 10.3%, respectively. The effluent quality consistently met the Vietnamese standard QCVN 14:2025/BTNMT, Column B. These findings highlighted the potential of indigenous plant-based CW systems as an effective and sustainable approach for domestic wastewater treatment in rural areas of Vietnam.

KEYWORDS: Constructed wetlands; indigenous umbrella sedge; domestic wastewater; Northern Vietnam

1. Introduction

Constructed wetland (CW) technology offered several advantages, including low investment and operational costs, the utilization of indigenous plant species, and compatibility with the surrounding environment and landscape [1]. In addition, CW systems were capable of removing organic matter, nutrients (N and P), and pathogenic microorganisms, thereby contributing to public health protection. Numerous studies in Vietnam demonstrated the effectiveness of this technology in treating wastewater containing heavy metals, as well as effluents from craft villages and livestock farming [2–4].

Plants played a central role in pollutant removal within CWs through their root structures, which facilitated filtration, reduced flow velocity, and provided a favorable habitat for microbial communities [5]. Plant roots released oxygen and exudates that supported nitrification processes and enhanced biodegradation. Beyond nutrient uptake, heavy metal absorption, and microclimate regulation, plants also contributed aesthetic value, provided biomass, and offered potential applications in soil remediation [5, 6]. Different climatic regions possessed dominant plant species that could be effectively applied in CWs. The use of indigenous species not only ensured high adaptability to local climate, soil, and water conditions but also helped maintain ecological balance and minimized the risk of biological invasion. Furthermore, locally available plants were often inexpensive, resistant to pests and environmental fluctuations, and thereby enhanced both treatment performance and the long-term sustainability of CW systems.

Umbrella sedge (*Cyperus alternifolius*), an aquatic plant belonging to the family Cyperaceae, was commonly found in tropical and subtropical regions and demonstrated strong growth under flooded conditions. This species was highly valued in CW systems due to its rapid growth rate, high tolerance to pollution, and dense, extensive root system, which enhanced mechanical filtration and provided favorable conditions for microbial development. In a study conducted in Yazd, Iran, CWs planted with *Cyperus alternifolius* achieved removal efficiencies of 83% for COD, 81% for NO_3^--N, 47% for NH_4^+-N, and 10% for PO_4^{3-} after a hydraulic retention time of four days [7]. Another study in Italy reported different treatment performances, with removal efficiencies of 70–72% for BOD_5, 61–67% for COD, 47–50% for TN, and 43–45% for TP [8]. In Vietnam, umbrella sedge had been applied for the treatment of piggery wastewater and effluents from traditional noodle-making villages [9, 10]. *Cyperus alternifolius* achieved removal efficiencies of BOD_5: 75.3%, COD: 69.0%, TN: 53.9%, NH_4^+–N: 58.3%, NO_3^-–N: 62.8%, and PO_4^{3-}–P: 43.3–62.9% [11, 12]. However, treatment performance varied considerably depending on wastewater characteristics and local environmental conditions.

Domestic wastewater in rural Vietnam was often mixed with effluents from household livestock farming and small-scale food processing, resulting in complex compositions distinct from typical municipal wastewater. To date, no study had evaluated the treatment performance of indigenous umbrella sedge in CWs for rural domestic wastewater in northern Vietnam. The region experienced a tropical monsoon climate with four distinct seasons: a cool and dry winter (November–January), a humid spring with frequent drizzle (February–April), a hot and rainy summer (May–July), and a mild autumn (August–October). Such climatic variability, characterized by large fluctuations in temperature, humidity, and rainfall, strongly influenced plant growth and treatment performance in CW systems. This study provided detailed information on the treatment efficiency of CWs planted with indigenous *Cyperus alternifolius* and established a scientific basis for the application of this technology in environmental protection in Vietnam.

2. Materials and Methods

2.1. Materials.

Domestic wastewater was collected from An Vi village, Trieu Viet Vuong commune, Hung Yen province (20°50'28.8"N, 105°58'19.7"E). The influent concentrations of COD, TSS, NH_4^+, TN, and TP were approximately 1.8, 1.6, 2.1, 2.2, and 2.1 times higher than the permissible limits of QCVN 14:2025/BTNMT (Column B), respectively (Table 1). This indicated that the raw domestic wastewater exhibited moderate to high organic and nutrient loads, which were typical of rural households lacking centralized treatment systems.

Table 1. Domestic wastewater quality in rural Northern Vietnam.

Parameter	Unit	Value	QCVN 14:2025/BTNMT, Column B
pH	–	7.2	6 – 9
COD	mg/L	161.8 ± 14.5	90
TSS	mg/L	95.5 ± 9.7	60
NH_4^+	mg/L	17.2 ± 2.9	8
TN	mg/L	64.6 ± 7.8	30
TP	mg/L	12.4 ± 1.6	6

Note: QCVN 14:2025/BTNMT is the latest Vietnamese regulation on domestic wastewater. Column B defines permissible limits for discharges into water bodies not used for domestic supply.

Indigenous umbrella sedge (*Cyperus alternifolius*) was collected from the banks of the Red River in Hung Yen province, located in northern Vietnam, which has a tropical monsoon climate. The plants were cultivated in the CW system for two months to allow stable establishment prior to the commencement of the experiment.

2.2. Experimental setup.

A horizontal subsurface flow constructed wetland was designed with dimensions of 1.4 × 0.6 × 0.8 m (length × width × height). The substrate consisted of a mixture of yellow sand, limestone, and gravel. Indigenous umbrella sedge was planted at an initial density of 105 plants/m². Wastewater was fed into the system using a dosing pump at a flow rate of 100 l/day. The experiment was conducted in two phases. In Phase 1, which lasted four weeks, the influent wastewater concentration was gradually increased to 0, 25, 50, and 100% of the actual domestic wastewater.

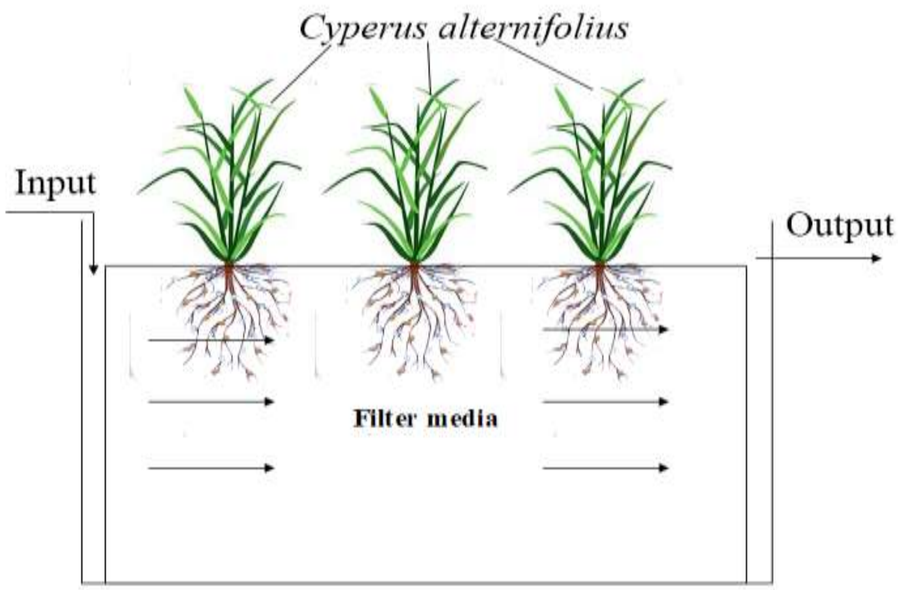

Figure 1. Experimental setup of the constructed wetland system.

The purpose of Phase 1 was to acclimate the plants and activate the system. Phase 2 lasted 60 days, during which domestic wastewater was continuously supplied to the constructed wetland. Samples were collected every three days, and both influent and effluent were analyzed for COD, TSS, NH_4^+, TN, and TP. The experiment was conducted under the tropical monsoon climate of northern Vietnam, characterized by an average temperature of 26–32 °C, relative humidity of 75–85%, average daily sunshine of 11.5–13 hours, and monthly rainfall ranging from 150 to 250 mm.

2.3. Water quality analysis.

The concentrations of pollutants in the wastewater were measured using standard analytical methods. Chemical Oxygen Demand (COD) was analyzed using the potassium dichromate ($K_2Cr_2O_7$) titration method. Total Suspended Solids (TSS) were determined by filtration through a glass fiber filter. Ammonium (NH_4^+) was measured using the Nessler reagent colorimetric method at a wavelength of 410 nm. Total Nitrogen (TN) was determined by catalytic reduction with Devarda's alloy. Total Phosphorus (TP) was analyzed using the spectrophotometric method with ammonium molybdate.

3. Results and Discussion

3.1. COD removal.

The results showed that the influent COD concentration was 161.8 ± 14.5 mg/l, approximately 1.8 times higher than the QCVN 14:2025/BTNMT, Column B standard (90 mg/l). In the CW system, plants contributed to COD removal primarily by transporting oxygen to the rhizosphere, providing surfaces for aerobic microorganisms to degrade organic matter, and reducing flow velocity, thereby enhancing sedimentation and COD removal [5]. After treatment, COD decreased to 53.3 ± 9.6 mg/l, corresponding to an average removal efficiency of 67.0 ± 5.5%, and consistently remained below the regulatory threshold (Figure 2).

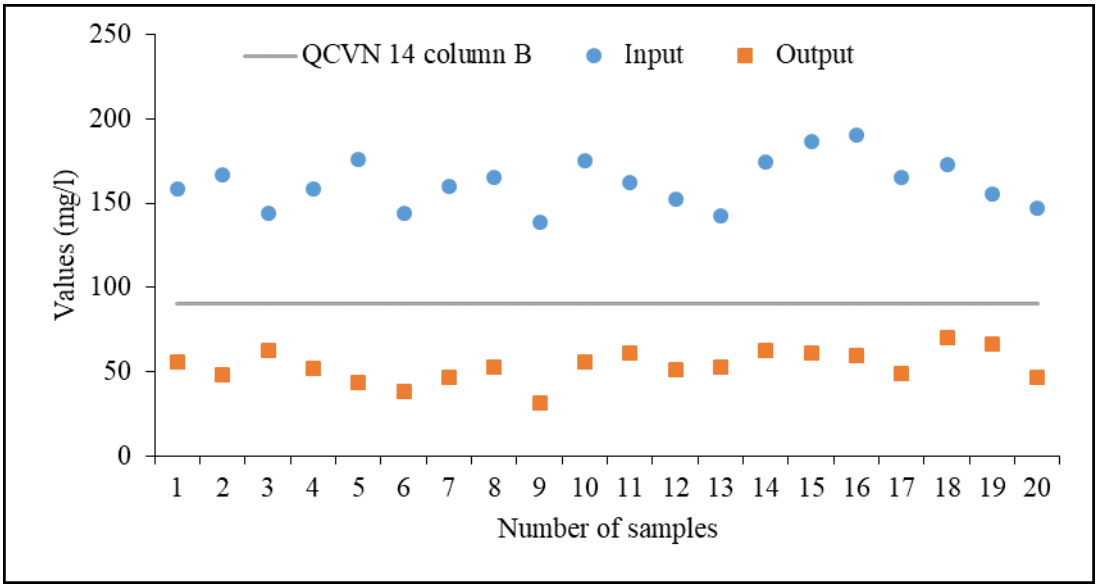

Figure 2. COD removal efficiency of the constructed wetland planted with indigenous umbrella sedge.

Previous studies also reported COD removal efficiencies above 60% in CWs treating domestic wastewater [13, 14], whereas another study reported much lower efficiencies of 16–33% [15]. In Vietnam, *Cyperus alternifolius* achieved a COD removal efficiency of 69.0% when treating swine wastewater [11]. Such discrepancies may be attributed to differences in CW design and experimental conditions. Overall, the COD removal efficiency observed in this study was comparable to previously published findings, indicating that the indigenous umbrella sedge was well suited for COD treatment in domestic wastewater.

3.2. TSS removal.

The results indicated that the influent TSS concentration averaged 95.5 ± 9.7 mg/l, approximately 1.6 times higher than the QCVN 14:2025/BTNMT, Column B standard (60 mg/l). Plants in the CW played a crucial role in TSS removal by reducing flow velocity, providing surfaces for particle retention, stabilizing sediments, and supporting microbial degradation of organic matter [10]. After treatment, the TSS concentration decreased to 36.3 ± 4.9 mg/l, which was below the permissible limit (Figure 3), corresponding to a removal efficiency of 61.7 ± 6.0%. These findings demonstrated that, despite considerable fluctuations in influent TSS, the CW system consistently maintained stable effluent quality in compliance with discharge standards.

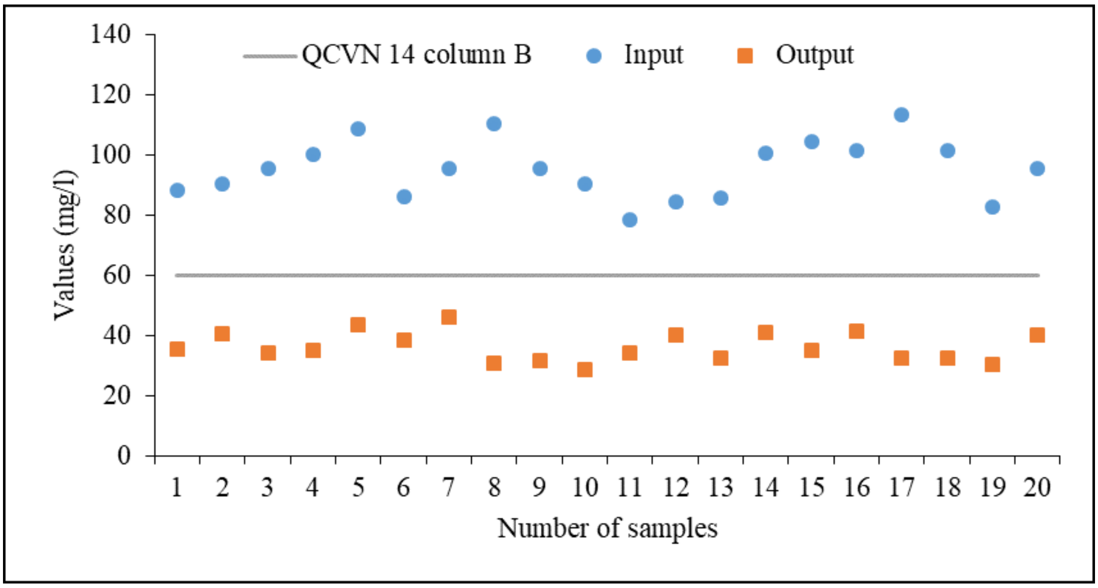

Figure 3. TSS removal efficiency of the constructed wetland planted with indigenous umbrella sedge.

3.3. NH_4^+ removal.

The analysis revealed that the influent NH_4^+ concentration averaged 17.2 ± 2.9 mg/l, approximately 2.2 times higher than the QCVN 14:2025/BTNMT, Column B standard (8 mg/l). After treatment, NH_4^+ decreased to 5.6 ± 0.9 mg/L, corresponding to an average removal efficiency of 66.6 ± 8.4%. The effluent concentration consistently remained below the regulatory threshold, indicating that the CW system effectively and stably removed ammonium (Figure 4). In CWs, plants can utilize NH_4^+ as a nutrient source [16]. The observed NH_4^+ removal efficiency was notably higher than previously reported in Vietnam, where C. alternifolius achieved 58.3% NH_4^+ removal in urban domestic wastewater and 42.8% in swine wastewater treatment systems [11, 12]. In this study, umbrella sedge exhibited normal growth without additional fertilization, which not only reduced operational costs but also ensured effective NH_4^+ removal from domestic wastewater.

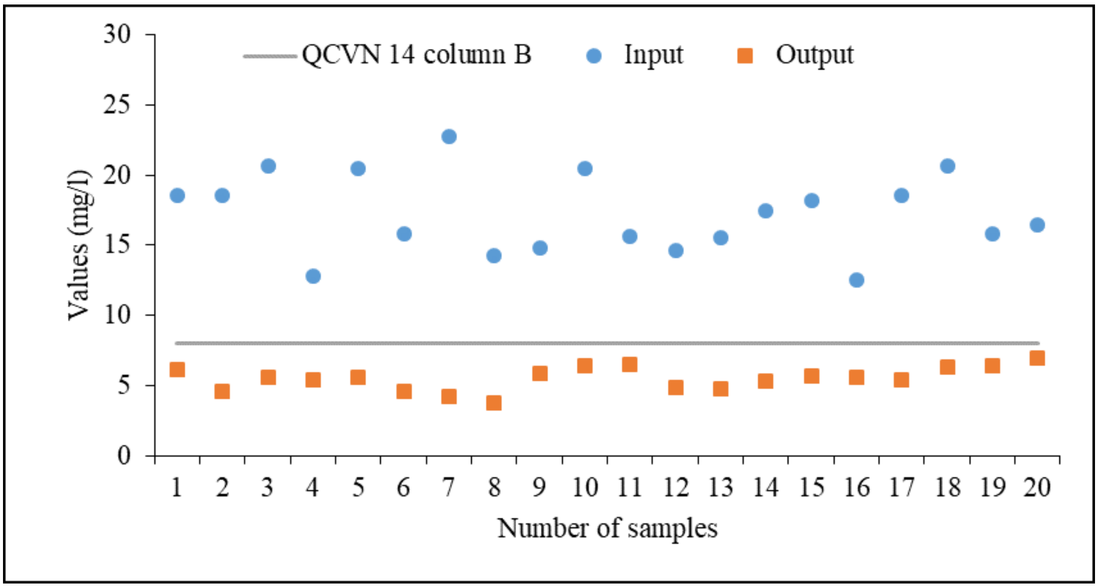

Figure 4. NH_4^+ removal efficiency of the constructed wetland planted with indigenous umbrella sedge.

3.4. TN removal.

The results showed that the influent TN concentration was approximately 2.2 times higher than the QCVN 14:2025/BTNMT, Column B standard (30 mg/l). The removal of TN in CWs primarily occurs through microbial nitrification–denitrification processes in combination with plant uptake [17]. After treatment, TN decreased to 18.0 ± 2.8 mg/l, which was below the permissible limit, with an average removal efficiency of 71.8 ± 5.8%. Previous studies in Vietnam reported lower TN removal efficiencies, such as 56.2% for CWs planted with *Typha orientalis* L. [18].

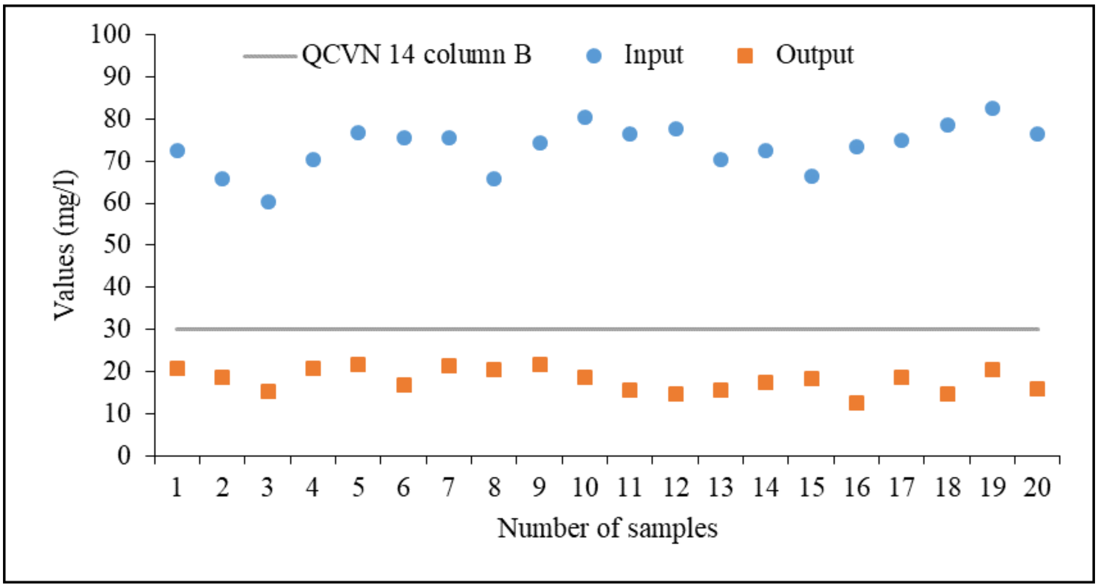

Figure 5. TN removal efficiency of the constructed wetland planted with indigenous umbrella sedge.

Similarly, the CW system planted with *Brachiaria mutica* achieved a removal efficiency of only 58.6% [19]. In addition, *Cyperus alternifolius* demonstrated a TN removal efficiency of 53.9% in domestic wastewater under similar climatic conditions [12]. These findings suggest that CWs planted with indigenous umbrella sedge in Vietnam exhibited superior TN removal efficiency compared to systems with other plant species.

3.5. TP removal.

The results showed that the influent TP concentration averaged 12.4 ± 1.6 mg/l, approximately 2.1 times higher than the QCVN 14:2025/BTNMT, Column B standard (6 mg/l). After treatment, TP decreased to 3.9 ± 1.0 mg/l, below the permissible limit, corresponding to an average removal efficiency of 68.0 ± 10.3%. The primary mechanisms of TP removal involved adsorption and precipitation onto the $CaCO_3$-rich substrate (limestone), combined with uptake by plants and microbial activity [20]. Plants have been reported to contribute 22.5–59.6% of TP removal in CWs [21]. Removal efficiencies of up to 77% have been achieved with Canna generalis, and 78.2–89.8% with systems planted with Myriophyllum aquaticum [21]. In contrast, systems using *Phragmites communis, Typha orientalis*, and *Dracaena fragrans* achieved lower TP removal efficiencies of only 48% [22]. In Vietnam, *Cyperus alternifolius* demonstrated moderate TP removal efficiencies of 43.3% in swine wastewater and 62.9% in urban domestic wastewater [11, 12]. These findings indicate that different plant species exhibit varying effectiveness in TP removal. In this study, the umbrella sedge-based CW consistently achieved effluent TP concentrations within the discharge standard, demonstrating the feasibility and long-term effectiveness of this indigenous species for phosphorus removal from domestic wastewater in Vietnam.

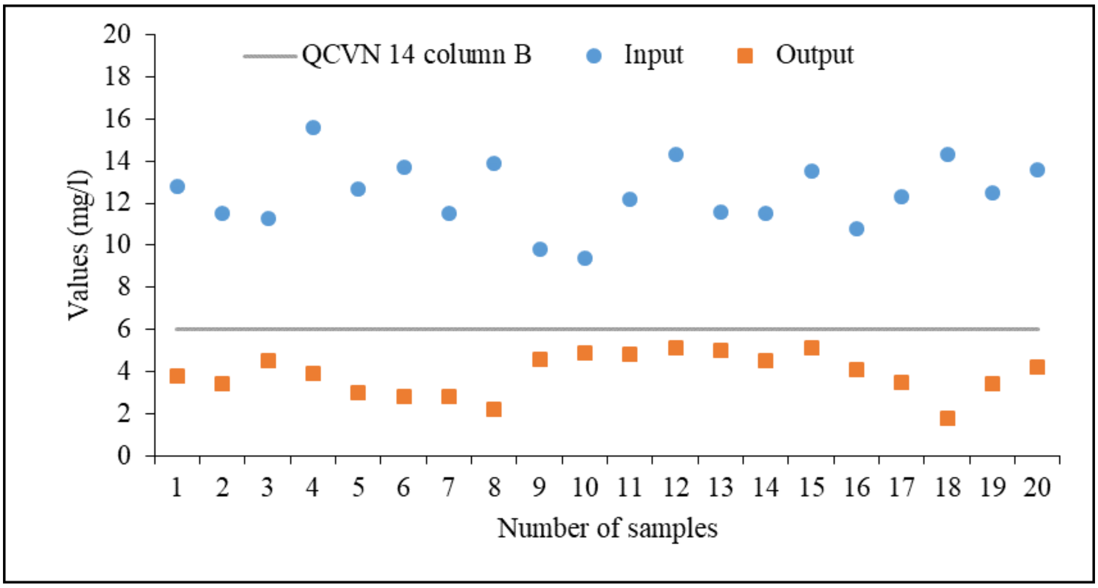

Figure 6. TP removal efficiency of the constructed wetland planted with indigenous umbrella sedge.

The tropical monsoon climate of northern Vietnam, characterized by four distinct seasons with relatively mild winters (14.5–26.9 °C) and consistently high humidity, exerted a moderate influence on CW performance. Unlike CW systems in temperate regions, which experience severe declines in performance during freezing winters, the warm winter conditions in Vietnam sustained microbial activity and plant growth throughout the year, resulting in only minor seasonal variations in pollutant removal [2]. The use of the indigenous *Cyperus alternifolius* further enhanced system stability, as this species was well adapted to local climatic fluctuations, maintaining oxygen release and nutrient uptake efficiency under both wet and dry seasonal conditions. Therefore, CWs planted with native macrophytes represented a cost-effective and climate-resilient solution for rural wastewater treatment in Vietnam.

4. Conclusions

This study demonstrated the effectiveness of indigenous umbrella sedge in treating rural domestic wastewater in northern Vietnam. The quality of untreated wastewater exceeded the permissible standards by 1.6–2.2 times, whereas after treatment, removal efficiencies ranged from 61.7% to 71.8%. The effluent concentrations of COD, TSS, NH_4^+, TN, and TP were 53.3 ± 9.6 mg/L, 36.3 ± 4.9 mg/L, 5.6 ± 0.9 mg/L, 18.0 ± 2.8 mg/L, and 3.9 ± 1.0 mg/L, respectively, all of which met the QCVN 14:2025/BTNMT, Column B standard. These findings provide a strong scientific basis for the broader application of indigenous plant species in CW technology for wastewater treatment in rural areas of Vietnam, contributing to environmental improvement, water resource protection, and sustainable development.

Acknowledgments

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Author Contribution

Nguyen Van Thanh: Conceptualization, Methodology, Data Analysis, Writing; Pham Thuong Giang: Methodology, Data Collection, Data Analysis, Writing; Bui Thi Kim Anh: Supervision, Funding; Nguyen Thi Thu Thuy: Methodology, Data Collection; Dang Dinh Kim: Supervision.

Competing Interest

The authors declare no competing interests.

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