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# Implementation of two Distinct Plant Species in a Constructed Wetland System for Domestic Wastewater Treatment

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**ABSTRACT**

This study illustrates the efficacy of vertical flow-constructed wetlands (VFCWs) systems as a sustainable and ecologically sound approach for the treatment of domestic wastewater. The implementation of the VFCWs system demonstrated a high level of efficacy in the removal of organic matter (COD), ammonium (N-$NH_4^+$), and phosphate (P-$PO_4^{3-}$) from wastewater. The research utilized two plant species, namely *Azolla pinnata* (*A. pinnata*) and *Echinoderms amazonicus* (*E. amazonicus*), both of which exhibited remarkable capabilities in removing pollutants. The COD, N-$NH_4^+$ and P-$PO_4^{3-}$ removal efficiency of A. pinnata was found to be 87.6%, 89.7%, 89.7%, respectively. Meanwhile, *E. amazonicus* demonstrated removal efficiencies of 72.6% for COD, 79.7% for N-$NH_4^+$, and 90.0% for P-$PO_4^{3-}$. Meanwhile, *E. amazonicus* demonstrated removal efficiencies of 72.6% for COD, 79.7% for N-$NH_4^+$, and 90.0% for P-$PO_4^{3-}$. The results of this study indicated that both plant species could effectively treat domestic wastewater. In addition, it should be noted that the VFCWs system is very much below the QCVN 14:2015/BTNMT – Vietnamese National Standard for water quality discharge standards. This process guarantees that the wastewater that has undergone treatment adheres to the prescribed regulatory thresholds for pollutant concentration. The utilization of VFCWs in small and medium-sized wastewater treatment facilities can therefore be considered a financially viable and highly effective approach for the removal of pollutants.

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## 1. Introduction

The demand for clean water is on the rise due to the rapid expansion of urban areas, leading to an increased discharge of wastewater [1]. In these areas, the infrastructure is outdated, and most of the human waste is untreated, so it seeps into the ground or washes away, causing increasing levels of organic and microbial water pollution [2], [3]. The phenomenon has a detrimental impact on both the natural environment and the well-being of individuals. As reported by the Ministry of Construction, Vietnam (2019), the current total of operational centralized urban wastewater treatment plants stands at 43, boasting a collective designed capacity exceeding 926,000 $m^3$/day. Nevertheless, it is worth noting that a mere 13% of wastewater is currently being collected and subjected to processing procedures. The direct disposal of a substantial quantity of organic pollutants into the environment can result in pollution and the emergence of illnesses that pose a threat to the entire community [4], [5]. In addition, wastewater sources also affect surface water quality in rivers and lakes, which has decreased due to human activities, threatening clean water sources, human health and social progress [6]. Consequently, the presence of wastewater streams containing elevated levels of organic nutrients can lead to the phenomenon of eutrophication in aquatic ecosystems, thereby posing a significant risk to the survival and well-being of aquatic organisms [7], [8]. Hence, it is imperative to conduct thorough research and devise suitable domestic wastewater treatment systems that possess characteristics of user-friendliness, cost-effectiveness, and utilization of locally accessible materials. The development of the constructed wetlands (CWs) technology was motivated by the objective of enhancing treatment efficiency and promoting the advantages associated with the CWs system [9], [10].

Wetland technology has been classified into different wetland types, including surface flow, subsurface flow, and vertical and horizontal flows. The technology treatment procedure employed by CWs is founded upon the ecological interplay of various elements within a given aquatic ecosystem. CWs have demonstrated effective treatment of various types of wastewater, including domestic, industrial, livestock, and aquaculture wastewater, among others. Wetland technology refers to a wastewater treatment system that utilizes self-selected plants to replicate the properties of natural soil. This technology possesses the inherent benefit of being highly feasible to construct, making it particularly well-suited for deployment in natural settings. Additionally, it offers a manageable operational framework, necessitating reduced quantities of chemical substances. Moreover, its applicability is particularly pronounced in regions characterized by substantial land areas, particularly those of urban nature. Currently, the implementation of CWs, specifically VFCWs, has demonstrated notable efficacy in the removal of organic substances, suspended particulate matter, and various nutrients. The utilization of Colocasia esculenta in conjunction with VFCWs was a prevalent practice in the field of wastewater treatment. This approach aimed to effectively eliminate various pollutants, including Chemical Oxygen Demand (COD), Ammonium Nitrogen ($N\text{-}NH_4^+$), Nitrate Nitrogen ($N\text{-}NO_3^-$), and Total Phosphorous (TP). The removal efficiencies achieved for these pollutants were reported as 99.0%, 97.0%, 81.0%, and 89.0%, respectively, as documented in reference [11]. The treatment of organic substances involved a removal efficiency of 90% for biochemical oxygen demand ($BOD_5$) and an efficiency of over 80% for chemical oxygen demand (COD) [12]. Moreover, the utilization of Phragmites australis in constructed wetlands has been found to effectively reduce the presence of heavy metals such as zinc (Zn), nickel (Ni), copper (Cu), and chromium (Cr) in landfill leachate by approximately 41% to 56% according to the study referenced as [13]. The studies demonstrate the efficacy of CWs in the removal of pollutants, offering advantages such as high efficiency, cost-effectiveness in both operation and construction, and environmental compatibility [14]-[17].

The primary objective of this study was to investigate the utilization of two distinct plant species, namely *A. pinnata* and *E. amazonicus*, within wetland ecosystems for the purpose of wastewater treatment. *A. pinnata* is classified as a hydrophytic fern that exhibits floating characteristics, while *E. amazonicus* is an aquatic plant species that thrives submerged in water. Both species were selected based on their distinct attributes and capacity to enhance the process of pollution mitigation in wetland ecosystems. Due to its notable rate of growth and remarkable capacity for nutrient uptake, the plant *A. pinnata* emerges as a highly favorable option for the purpose of nitrogen and phosphorus removal from wastewater. In contrast, *E. amazonicus* is recognized for its significant capacity in the removal of organic contaminants. The objective of this study is to evaluate the effectiveness of wetland systems utilizing the prominent plant species *A. pinnata* and *E. amazonicus*. The effectiveness of the treatment will be evaluated in terms of its ability to remove pollutants and enhance the quality of water through the analysis of key parameters, including concentrations of COD, $N\text{-}NH_4^+$, and $P\text{-}PO_4^{3-}$. Consequently, the challenge is to develop a technique for treating wastewater for agricultural use at a reasonable cost. Based on available reports, it has been observed that the implementation of VFCWs technology exhibits efficacy in the treatment of water that has been contaminated [18], [19].

The aim of this study is to evaluate the effectiveness of two plant species, specifically *A. pinnata* and *E. amazonicus*, within the VFCWs model for the remediation of organic pollutants and nutrients present in domestic wastewater. The results obtained from this research project will enhance our understanding of the capacity of these plant species to improve the effectiveness of wetland systems for wastewater treatment. The result enables the implementation of enhanced strategies and pertinent approaches for the crucial protection of water resources.

## 2. Materials and Methods

### *2.1. Vegetation*

In this study, 2 types of plants were used: A. pinnata and E. amazonicus. The plants are collected, procured, and planted in laboratory tanks for further development and evaluation of their ability to remove pollutants. The initial root length of both plants was from 5 cm to 7 cm.

### *2.2. Feed wastewater characteristics*

The water sample for this study was collected at the domestic wastewater treatment plant of National University Dormitory in Di An, Binh Duong province, Vietnam. Wastewater was collected after biological basin of wastewater treatment system. All parameters were in accordance with National Technical Regulation on municipal wastewater (QCVN 14:2015/BTNMT) [20]. Table 1 shows the parameters and quality of the water used in the study.

**Table 1.** *Characteristics of wastewater treatment system*

| Parameters | Units | Feed wastewater | QCVN 14:2015/BTNMT, column A |
|---|---|---|---|
| pH | - | 7.1 – 7.77 | 6 – 9 |
| COD | mg/L | 100 – 150 | 75 |
| $N\text{-}NH_4^+$ | mg/L | 12 - 15 | 30 |
| $N\text{-}NO_3^-$ | mg/L | 0.07 – 0.09 | 6 |
| $P\text{-}PO_4^{3-}$ | mg/L | 9.5 – 10.5 | - |

### *2.3. VFCWs system's set up and operating conditions*

By using pumping systems, the water source was vertically raised by 21 centimeters within the tank of the VFCWs system. The experimental tank received water via a dosing pump, which functioned in accordance with pre-established design criteria including an inflow rate of 0.48 L/h, an organic loading rate of 0.1 kg $BOD_5/m^2$.day, and a hydraulic retention time of 23 hours. Each plant species was assigned two tanks in the VFCWs system, with each tank measuring 11.11 $cm^3$ (23 x 23 x 21 cm) in volume. The experimental methodology comprised the introduction of water into two test tanks that were furnished with a stratified filter medium. The initial stratum was composed of coarse gravel, measuring 6 cm in thickness, and having a diameter exceeding 2 cm. Following this, a 5 cm-thick layer of fine gravel with a diameter of 1 cm was applied. An 8-cm-thick layer of fine sand (0.5 cm in diameter) lay above this. A 2 cm-thick, stable water surface layer was situated atop the sand layer. Finally, the research specimen, illustrated in Figure 1, was positioned atop this uppermost stratum. The investigation was carried out utilizing a vertical flow configuration. In order to maintain the water level at a constant 2 cm throughout the duration of operation, a timer device was utilized in tandem with the pump.

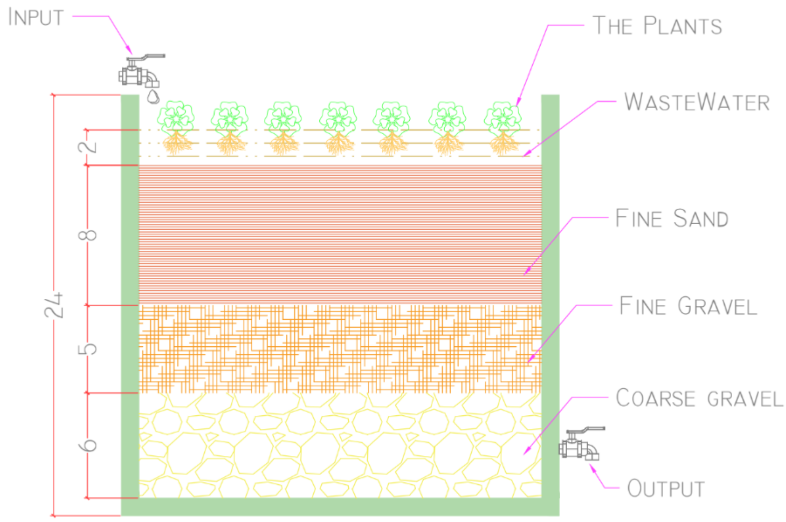


**Figure 1.** *Schematic diagram of the lab-scale wetland system*

### *2.4. Analysis methods*

Water samples were analyzed in the laboratory of Ho Chi Minh City University of Technology and Education to measure parameters such as pH, COD, $N\text{-}NH_4^+$ (mg/L), $N\text{-}NO_3^-$ (mg/L), and $P\text{-}PO_4^{3-}$

(mg/L). The standards of laboratory analysis are in accordance with the "Standard Methods for Water and Wastewater Testing" [21]. The removal efficiency of the vertical flow constructed wetlands system is calculated using formula (1).

$$Removal\ (\%) = \frac{C_i - C_e}{C_i} \times 100\% \quad (1)$$

Where:

$C_i$ is the concentration in influent, mg/L

$C_e$ is the concentration in effluent, mg/L

## 3. Results and Discussion

### *3.1. Chemical oxygen demand (COD) removal from wastewater*

During all phases of the research, the concentration of chemical oxygen demand (COD) in the influent exhibited a range of 100 to 150 mg/L. Based on the data presented in Figure 2, it can be observed that the average COD removal efficiencies for *A. pinnata* and *E. amazonicus* were 89.1% and 77.6% respectively.

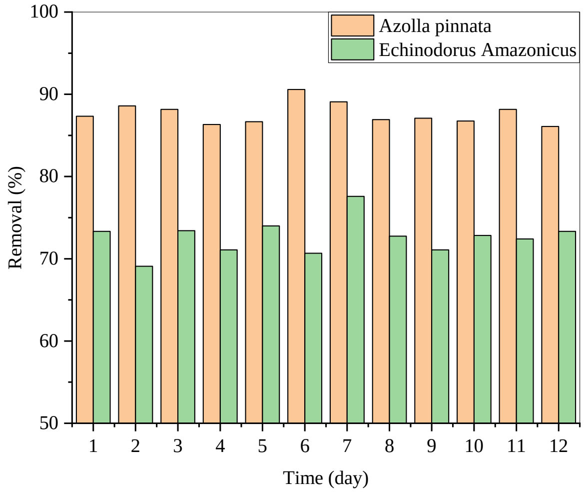


**Figure 2.** *The COD removal efficiency of A.Pinnata and E.Amazonicus in the VFCWSs.*

Additionally, the average COD effluent concentrations for *A. pinnata* and *E. amazonicus* were found to be 13.1 mg/L and 26.9 mg/L respectively. These values are following the requirements outlined in column A (75 mg/L) of the Vietnam National technical regulation on domestic wastewater (QCVN 14:2015/BTNMT) [20].

The primary mechanism for the removal of organic matter in the constructed wetland system was predominantly achieved through the processes of aerobic and anaerobic decomposition promoted by microorganisms. Additionally, sedimentation and filtration occurred between the layers of materials within the system [21], [22]. The reduction in COD concentration resulting from bioremediation can be ascribed to biological processes, particularly microbial activity, which is facilitated by the provision of oxygen and surface area by the root system of *A. pinnata* [23]. *E. amazonicus* and *A. pinnata* have different wastewater treatment efficiency due to differences in their root and leaf systems. In aquatic environments, *A. pinnata* has a well-developed root system that promotes beneficial microbial growth and improves nutrient cycling. Its broad leaves have a large surface area for interactions with water, facilitating gas exchange, which is essential for microbial activity. *E. amazonicus*, on the other hand, has a fibrous root system and long, narrow leaves that show adaptability to changing water levels. While both species can tolerate submerged conditions. *A. pinnata* is more aquatic adapted, which may affect its efficient nutrient uptake. The phytoremediation and nutrient assimilation abilities of *A. pinnata* contribute to its effectiveness. The efficiency of *E. amazonicus* is comparatively lower than that of A. pinnata, which can be attributed to various environmental factors including pH levels, light intensity, and concentration of organic matter in the water. Insufficient illumination can potentially exert a significant influence on the process of photosynthesis and its capacity to metabolize COD [24].

### *3.2. Fluctuation of pH in the system*

Figure 3 illustrates the variations in pH levels observed in both the influent and effluent. The pH of the influent was maintained within the range of 7.1 - 7.8, whereas the pH of the effluent varied between 6.9 and 7.6. The occurrence of substantial nitrification has been observed to lead to a decrease in pH, as demonstrated by equation (2) [22]. There was a lack of significant seasonal variation in pH observed within the two wetland systems. The promotion of contaminant elimination in CWs through microbial activity is facilitated by maintaining an appropriate pH level. The preferred pH range for the process of ammonification is documented to be between 6.5 and 8.5, as indicated by reference [25]. In contrast, the growth of nitrifying bacteria is reported to occur within a pH range of 7.5 to 8.6, as stated in reference [26]. The balanced chemical equation for the reaction between ammonia ($NH_3$) and oxygen ($O_2$) to produce nitric oxide (NO), water ($H_2O$), and hydrogen ions ($H^+$) is as follows:

$$2\ NH_3 + 3\ O_2 \rightarrow 2\ NO + 2\ H_2O + 4\ H^+ \quad (2)$$

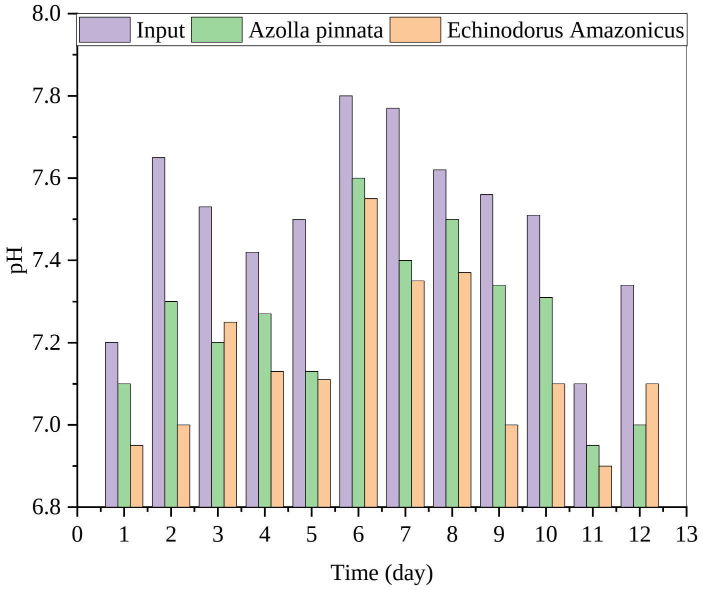


**Figure 3.** *pH variations in VFCWs with A. pinnata and E. amazonicus*

### *3.3. Nitrogen removal efficiency in the system*

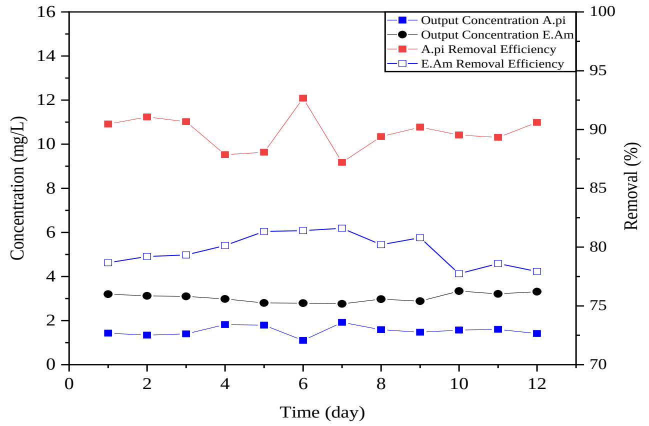


**Figure 4.** *Removal of N-$NH_4^+$ in VFCWs with A. pinnata and E. amazonicus*

Diverse plant species exhibit varying preferences for nitrogen absorption based on the specific forms of nitrogen available in the soil [27]. Additional processes, apart from those occurring in the soil, water column, and associated biofilms, experience enhancement due to the movement of nitrogen through plants [28]. During the experimental phase, the levels of nitrite were found to be significantly low in both the influent and effluent from the VFCWs. The study primarily focused on three forms of nitrogen, namely ammonia nitrogen, nitrite, and nitrate nitrogen [29]. According to a study conducted by [30], it was found that the mean percentage of $N\text{-}NH_4^+$ removal from domestic wastewater treated in VFCWs was 84.5%. The findings indicate that *A. pinnata* exhibited a greater reduction in ammonia nitrogen concentration compared to *E. amazonicus*, when both species were subjected to the same duration of time.

The removal of nitrate nitrogen is a crucial component of wastewater treatment due to its potential to cause detrimental effects on aquatic ecosystems and human health when present in high concentrations. The efficacy of nitrate-nitrogen ($N\text{-}NO_3^-$) removal in VFCWs may vary depending on the specific plant species employed. The efficacy of two specific plant species, namely *A. pinnata* and *E. amazonicus*, in VFCWs systems for the elimination of nitrate nitrogen ($N\text{-}NO_3$-) is depicted in Figure 5. Based on the results, it was observed that plant species *A. pinnata* demonstrated a success rate of 90.4% in the removal of $N\text{-}NO_3^-$ from the surrounding environment. Conversely, *E. amazonicus* exhibited a comparatively lower effectiveness of 72.6%. The remarkable effectiveness of nitrate nitrogen elimination observed in the *A. pinnata* can be attributed to its distinctive physiological properties. Based on the findings of scientific investigation, it has been determined that this particular botanical species exhibits a notable inclination towards the absorption and integration of nitrates. Consequently, this characteristic facilitates the efficient elimination of said pollutant from wastewater [31]. The denitrification processes are enhanced by the extensive root system of the plant species *A. pinnata*, which provides a substantial surface area for microbial activity [32]. In contrast, the plant species *E. amazonicus* exhibited a slightly diminished efficiency in removing nitrate nitrogen [33]. The potential cause for this phenomenon could be attributed to the reduced capacity of nitrate uptake or the structural variations in the roots of the plant, which in turn may impact the availability of oxygen for denitrification processes [34]. However, it is worth noting that plant species *E. amazonicus* exhibited significant potential for the removal of nitrate nitrogen in VFCWs systems, despite a slight decrease in removal efficiency.

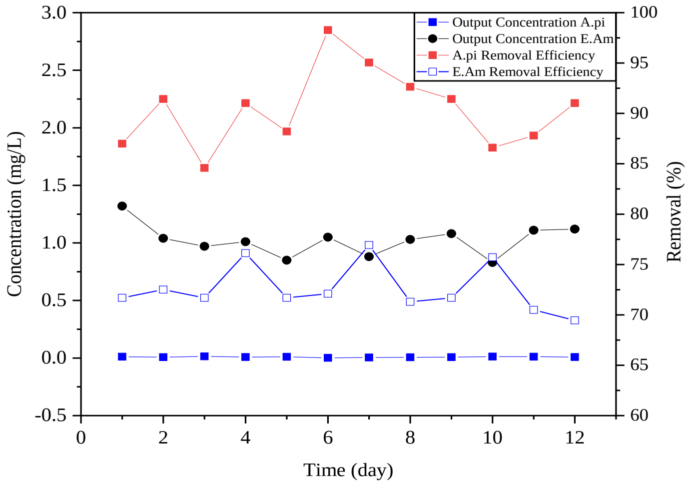


**Figure 5.** *Removal of $N\text{-}NO_3^-$ in VFCWs with A. pinnata and E. amazonicus*

### *3.4. Orthophosphate ($P\text{-}PO_4^{3-}$) removal*

The rate of phosphorus reduction in pilot scale VFCWs has been found to be substantial and of a high magnitude, as depicted in Figure 6. A combination of physical, chemical, and biological techniques is employed to eliminate $P\text{-}PO_4^{3-}$ in CWs. The elimination methods for $P\text{-}PO_4^{3-}$ are crucial and encompass various processes such as adsorption, precipitation within filter media, absorption by emerging plants, and biomass [35]. The soluble phosphorus present in subsurface flow wetlands will be transported along with the water flow. However, the phosphorus that is bound to particulate matter will be effectively captured and eliminated through filtration and interception mechanisms within the wetland substrate [30]. The mean mass removal efficiency for *A. pinnata* and *E. amazonicus* cultivated in VFCWs is 89.8% and 90.2%, respectively. This study presents a novel and cost-effective technique for the removal of P-$PO_4^{3-}$ in CWs.

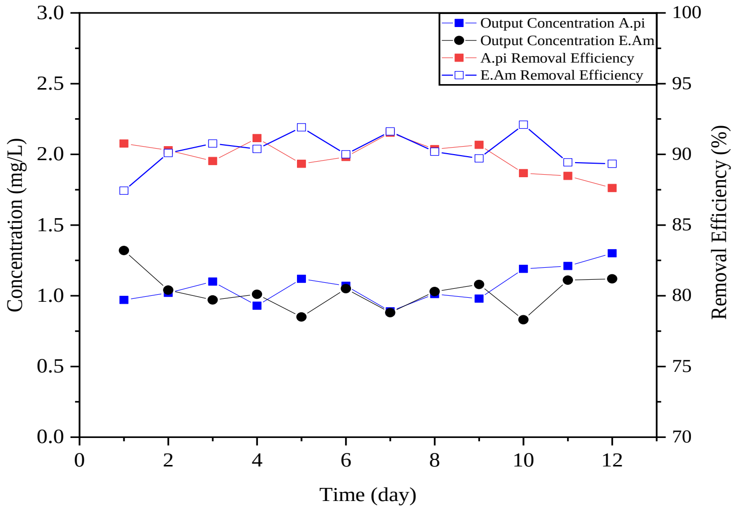


**Figure 6.** *Removal of P-$PO_4^{3-}$ in VFCWs with A. pinnata and E. amazonicus*

### *3.5. Comparison with other studies*

Comparing the results of the current study with findings from previous research reveals valuable insights into the effectiveness of *A. pinnata* and *E. amazonicus* in wastewater treatment. Several studies have investigated the wastewater remediation potential of various plant species as shown in Table 2.

**Table 2.** *Comparison with previous studies*

| Type of Wastewater | The plants | Removal Efficiency (%) | Reference |
|---|---|---|---|
| Rural community | Zantedeschia aethiopica | Organic matter: 60% | [36] |
| Tannery wastewater | Phragmites sp. | COD: 82%, N-$NH_4^+$: 96% | [37] |
| Domestic wastewater | Scirpus grossus | COD: 88.2%, N-$NO_3^-$: 72.9%, N-$NH_4^+$: 99.1%, P-$PO_4^{3-}$: 83.2% | [38] |
| Tannery wastewater | Nasturtium aquaticum | BOD: 98%, COD: 97% | [39] |
| Olive mill wastewater | Typha latifolia, Phragmites australis and Arundo donax | COD: up to 76.42% | [40] |
| Domestic wastewater | Typha latifolia and Commelina benghalensis | COD: 77%, N-$NO_3^-$: 79%, N-$NH_4^+$: 79%, P-$PO_4^{3-}$: 78% | [41] |
| Domestic wastewater | Scirpus grossus | N-$NH_4^+$: 84.7%, P-$PO_4^{3-}$: 71% | [42] |
| Municipal wastewater | Phragmites Australis and Cyperus Papyrus | COD: 69.9%, N-$NH_4^+$: 69.7%, | [43] |
| Municipal wastewater | Phragmites australis or Chrysopogon zizanioides | COD: 94%, N-$NH_4^+$: up to 63%, P-$PO_4^{3-}$: up to 95% | [44] |
| Swine wastewater | Typha latifolia and Canna hybrids | COD: 83.6%, TSS: 82.2%, TN: 94.4%; | [45] |
| Rural domestic sewage tailwaters | Ipomoea Aquas | COD: 46.7% | [46] |
| Domestic water | *A. pinnata* | COD: 87.6%, N-$NH_4^+$: 89.7%, N-$NO_3^-$: 90.4%, P-$PO_4^{3-}$: 89.7%. | This study |
| | *E. amazonicus* | COD: 72.6%, N-$NH_4^+$: 79.7%, N-$NO_3^-$: 72.6%, P-$PO_4^{3-}$: 90.2%. | |

## 4. Conclusions

The research showed that using *A. pinnata* and *E. amazonicus* improved the VFCWs system's water quality. *A. pinnata* removed significant amounts of COD (87.6%), ammonium nitrogen ($N\text{-}NH_4^+$), nitrate nitrogen ($N\text{-}NO_3^-$), and phosphate ($P\text{-}PO_4^{3-}$). *E. amazonicus* removed 72.6% COD, 79.7% $N\text{-}NH_4^+$, 72.6% $N\text{-}NO_3^-$, and 90.2% phosphate. Both plant species thrived in the experimental setup, but *A. pinnata* grew faster. *A. pinnata* is used for wastewater treatment due to its rapid growth, while *E. amazonicus* is chosen for its beauty and may be preferred in some cases. The findings also show that VFCWs' technology is environmentally sustainable and suitable for treating domestic wastewater contaminated by surface water or urban runoff. VFCWs' impressive results make them a viable option for cost-effective pollution treatment, cost reduction, and implementation in small to medium-sized treatment facilities. *A. pinnata* and *E. amazonicus* absorbed pollutants differently. *A. pinnata* absorbs more pollutants than *E. amazonicus*. Due to their different nitrogen absorption capacities, plant species selection in wastewater treatment systems is crucial. A. *pinnata* may remove ammonia nitrogen more efficiently, depending on system goals. Understanding plant species' nitrogen absorption preferences and capacities can help optimize wastewater treatment.

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## Conflict of Interest

The authors declare no conflict of interest.

## Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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