

Original Research Article

## Greywater Treatment Using Umbrella Sedge Plants and Activated Carbon Media with Constructed Wetland System

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### Abstract

Increased domestic wastewater discharge degrades river quality. This study evaluated phytoremediation using constructed wetlands with umbrella sedge plants to treat greywater prior to river discharge. Using a randomized block design, the study tested two substrates (activated carbon and quartz sand), plant quantity (0, 4, 8, or 12 clumps), and retention time (0 to 4 days) on key wastewater parameters: BOD, COD, TSS, ammonia (NH<sub>3</sub>-N), and orthophosphate (PO<sub>4</sub>). Data were analyzed via t-tests, ANOVA, and regression at a 5% significance level. Results indicated that a combination of activated carbon, 12 plant clumps, and a four-day retention time was the most effective in reducing TSS, BOD, COD, and phosphate, although it was less effective for ammonia. By the fourth day, all treated pollutant levels successfully met quality standards, making the water safe for river release.

**Keywords:** Activated carbon ; constructed wetlands; grey water

### 1. Introduction

With the increase in population, the demand for water is increasing, resulting in the discharge of more wastewater into rivers. Household waste significantly contributes to water quality in Indonesian rivers; in 2020, approximately 57.42% of Indonesian households disposed of bathing, washing, and kitchen wastewater in sewers or rivers (Badan Pusat Statistik, 2020). Domestic wastewater is generated by human activities and can be divided into black water, which contains human feces, and gray water, which is generated from bathrooms, laundry rooms, and kitchens (Purwatiningrum, 2018). Gray water usually contains cleaning agents, such as soap; organic compounds; solid and dissolved dirt; and microorganisms. The accumulation of these materials can negatively impact the river environment and its surroundings.

Constructed wetlands can be used for primary sewage treatment (Hasan and Suprapti, 2021) and secondary treatment for various liquid waste, such as domestic wastewater and leachate. Small-scale constructed wetlands are a good solution for treating domestic waste in residential areas because they can also serve as gardens and have aesthetic value (Rahmawati et al., 2022). Wetlands are categorized

into two groups: constructed wetlands with a free water surface (FWS) and subsurface flow (SSF) with directional flow systems, which are divided into two groups: horizontal subsurface flow constructed wetlands (HSSFCW) and vertical subsurface flow constructed wetlands (VSSFCW) (Alateeqi et al., 2023). This study used a horizontal subsurface flow constructed wetland, in which the medium was submerged below the surface, and the roots were submerged in wastewater. The artificial wetland system consists of three important components: aquatic plants, such as grasses and lilies, as a medium for plant growth and a filter for pollutants (Swarnakar et al., 2022); microorganisms, such as bacteria, fungi, and protozoa, that live in the plant roots.

A variety of plants have been used for phytoremediation, including aquatic and ornamental species. In Europe, ornamental plants such as *Canna indica*, *Typha latifolia*, and *Phragmites australis* are widely used as macrophytes in wetland treatment (Calheiros et al., 2007). In Indonesia, *Aglaonema* sp., *Sansevieria trifasciata*, *Agave* sp., and *Catharanthus roseus* are some of the ornamental plants commonly found that are capable of phytoremediation (Laela and Ammurabi, 2024). Selecting the appropriate plants is crucial for supporting waste treatment, as they must be resistant to toxins and changes in wetlands. *C. alternifolius* has received significant attention due to its ability to grow and thrive in poor environments. It is used as vegetation in artificial wetlands because it is cost-effective and easy to breed using seeds or plant parts. It also adds aesthetic value, beautifying the atmosphere and adding greenery to the area (Ebrahimi et al., 2013).

Previous studies have shown that *C. alternifolius* is widely used for phytoremediation of various types of liquid waste and parameters. It can reduce chemical oxygen demand (COD) and total suspended solids (TSS) content of palm oil mill effluent (Sa'at et al., 2017), as well as ammonium, nitrate, and color ink factory wastewater (Dolphen et al., 2019). It can also reduce the organic carbon, nitrogen, and phenol of olive mill wastewater while collecting heavy metal traces in its roots in the following order: Fe > Mn > Cu > Zn > B > Pb > Cr > Ni > Co > Cd (Goren et al., 2021). Additionally, it can collect heavy metals such as Fe, Cu, and Zn from shrimp farm wastewater (Chi-Tuan et al., 2021). Furthermore, Nguyen et al. (2023), observed that this plant can be reprocessed into biochar after Zn phytoremediation through pyrolysis, where biochar can reduce Methylene Blue up to 55.2 mg/g.

Observations made by Qomariyah et al. (2021) in soil media, among Mexican sword-plant (*Echinodorus palaefolius*), cattail (*Typha latifolia*), and umbrella sedge (*Cyperus alternifolius*), showed that umbrella sedge had the highest removal rate up to 91.18% for ;B; however its ability to reduce detergents in greywater is still lacking (Qomariyah et al., 2022). Another study by Ebrahimi et al. (2013) showed that *C. alternifolius* plants reduced COD, NO<sub>3</sub>-N, and NH<sub>4</sub><sup>+</sup>-N parameters, but PO<sub>4</sub><sup>3-</sup>-P parameters increased in sandy media. Therefore, in this study, the author attempted to compare umbrella sedge plants in different media to observe their reactions to the parameters found in greywater.

The substrate component in artificial wetlands acts as a medium for plant growth, facilitates pollutant treatment, and provides a place for biofilm attachment. One way to reduce organic pollutants in waste is to use activated carbon. Selecting plant substrates with activated carbon utilizes the adsorption process, whereby pollutants are absorbed by charcoal from the outside to the inside through its pores until they are bound inside the charcoal (Marhaini et al., 2021).

Detention time, also known as residence time, is the amount of time that waste remains in the reactor tank in contact with the treatment process units from the time it enters the inlet until it exits the outlet (Candra et al., 2023). Detention time (or hydraulic retention time - HRT) is usually related to the level of pollutant reduction in waste, and a longer detention time increases the effectiveness of removal (Li et al., 2021). However, detention time effectiveness can differ owing to wetland components, such as the substrate and plants used, as well as external factors, such as the state of the environment. The number of days was adjusted according to household water usage needs; therefore, one day was considered the basis for comparison in this study. A longer review was conducted over four days to determine the pollutant reduction over the next four days.

Although many studies have been conducted on waste and umbrella sedge, several parameters have been found to be less effective in their removal, such as detergent in the study by Qomariyah et al. (2022) and phosphate in the study by Ebrahimi et al. (2013). Therefore, the objective of this study was to evaluate the impact of placing umbrella sedge plants in various media on greywater waste parameters, including orthophosphate, which is present in soap waste. This study combined various elements, including the type of media used, the number of plants, and the number of residence times (in days), to maximize the reduction of grey water pollutants. The study aimed to determine the effectiveness of umbrella sedge plants in constructed wetlands with different types of media, numbers of plants, and residence times on domestic waste parameters, such as TSS, BOD, COD, ammonia, and phosphate.

## 2. Methods

### 2.1. Place and Time

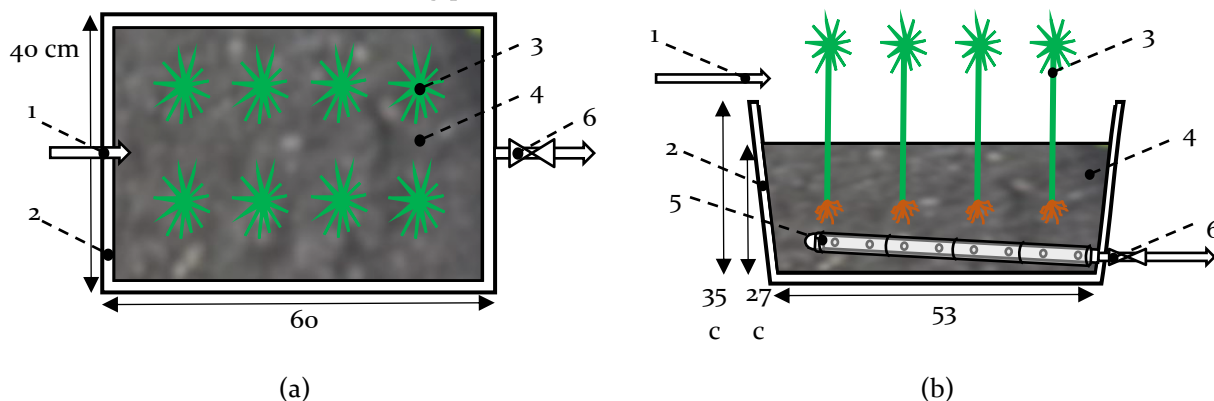
The study used *Cyperus alternifolius* plants obtained from around the river in the Jekulo District, Kudus City. Research was conducted from August 2023 to March 2024 in an open field in the Banjarsari Subdistrict, Surakarta City. Effluent samples were collected from residential drains in the Banjarsari Subdistrict. Water quality analysis was conducted at the Yogyakarta Public Health Laboratory (BB Labkemas).

### 2.2. Research Design

This study used an experimental method with a randomized block design (RBD). The independent variables were substrate type, number of plants, and residence time, and the dependent variable was the tested parameter of domestic wastewater. The first factor was the substrate, comprising activated carbon and quartz sand. The second factor was the number of plants, comprising control (0 clumps), 4 clumps, 8 clumps, and 12 clumps. All clumps were uniform in terms of the number of roots, stems, and leaves, stem height, and leaf color. The third factor was effluent exposure time, comprising 0, 1, 2, 3, and 4 days. The effluent parameters tested were total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, and orthophosphate. The CW treatment unit design uses a horizontal subsurface flow system and umbrella sedge plants.

### 2.3. Research Preparation

Research preparation involved preparing the necessary tools and materials. The materials were prepared using activated carbon and quartz sand. The carbon and quartz sand from PT Bumi Kirana Asri were filtered using a sieve to obtain particles with a size of 1–5 mm. The carbon was activated using 1 N HCl acid by soaking it in a 1:1 ratio of acid and carbon for 24 h. It was then washed with water, dried, and stored in a closed, dry place. Before use, the activated carbon and quartz sand were washed to remove dirt, dried in the sun, and stored in a dry place.



**Figure 1.** Layout from the top (A), and side view (B) of a CW reactor: (1) effluent inlet, (2) container, (3) umbrella sedge plant, (4) substrate, (5) 1/2-inch pipe assembly, (6) drain faucet

The tool was prepared by assembling a research reactor in an 82-liter plastic box container with dimensions of 68 × 47.6 × 41 cm. A 40 cm perforated ½-inch pipe wrapped in geotextile was placed in the center of the bottom of the container. A faucet was glued to the assembled pipe on the outside of the reactor using a rubber seal to prevent leakage. When the reactor was filled with the media, the pipe was tilted so that the end corresponding to the outside faucet was lower than the other side to allow water to escape and follow the tilted shape of the reactor. Figure 1 shows a sketch of the reactor design.

#### 2.4. Data Collection

The assembled constructed wetland reactors were filled with media up to 27 cm from the bottom of the container: four reactors contained activated carbon media, and four contained quartz sand media. Plants were transferred into the reactors, with four reactors containing 0, 4, 8, and 12 clumps of plants on each type of media. Plain water was then introduced into the reactors at a volume of approximately 20 L.

Acclimatization was conducted as described by Azahra et al. (2015) by gradually introducing wastewater into the reactor medium over a specified period. For the first five days, the reactor was filled with plain water. From the sixth to the twentieth day, plain water was replaced with wastewater at gradually increasing concentrations from 20% to 60%. If the plants could not adapt to the increase in concentration, as indicated by symptoms such as yellowing, wilting, and death, they were replaced, and the previous concentration was used. At a concentration of 60%, the plants appeared yellowed but survived; therefore, this concentration was chosen because the plants began to wilt at higher concentrations.

The first round of data collection or preliminary test was conducted after a 20-day acclimatization period. Wastewater in the reactors was replaced with 20 L of new 60% gray water, which was supplied to each reactor in batches. A 1-L sample of the gray water was collected using an HDPE plastic jerrycan and submitted to the BB Labkemas Yogyakarta laboratory for analysis of the initial concentration of TSS, BOD, COD, ammonia, and phosphate. Further observations were conducted over the course of four days, with samples collected every 24 h. A total of 34 wetland water samples were collected.

#### 2.5. Data Analysis

The data were analyzed using IBM SPSS Statistics 22 and Microsoft Excel. IBM SPSS Statistics was used to perform statistical analyses, including a t-test, analysis of variance (ANOVA) test, and regression. Microsoft Excel was used to calculate the removal efficiency percentage (%), as well as to create tables and graphs for visualization. A t-test was used to determine the significance of the difference between the two media treatment samples (quartz sand and activated carbon). ANOVA was used to test for differences in the averages of the four different variations in the number of plants (0, 4, 8, and 12 clumps) and residence time (1, 2, 3, and 4 days). Regression tests were performed to model the relationship between the dependent and independent variables. Each parameter was tested separately with the number of plants and days variables. Statistical tests were conducted at a significance level of 5 %, indicating that the results were considered significant if the p-value was < 0.05. The removal efficiency test was conducted using equation, described by Qomariyah et al. (2021) to determine the efficiency of wetlands in eliminating certain contaminants.

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

Where %R represents the percentage removal efficiency,  $C_i$  denotes the influent pollutant concentration (mg/L), and  $C_e$  indicates the effluent pollutant concentration (mg/L). This formulation is commonly used to assess the effectiveness of water or wastewater treatment systems by measuring the reduction in pollutant concentration before and after treatment; a higher %R value reflects a more efficient process, while a lower value indicates limited pollutant removal performance, as described by Qomariyah et al. (2021).

### 3. Result and Discussion

#### 3.1. Preliminary Test of Domestic Grey Water

Acclimatization conducted over a period of 20 days prior to data collection showed that umbrella sedge was resistant to waste concentrations of 0–40%. Yellowing of the leaves was observed when the grey water concentration reached 60%, although the plants were still able to survive. Rahmawan et al. (2023) conducted an RFT (Range Finding Test) with *Eichhornia crassipes* in laundry wastewater, and Gusmita et al. (2022) conducted an RFT with water jasmine plants in palm oil wastewater. These studies showed that a wastewater concentration of 60% was the maximum concentration for these plants. The preliminary test of greywater was conducted on day 0, after the acclimatization period, to determine the initial wastewater concentration. Wastewater mixed with ordinary water in a 6:4 ratio was collected up to 2 L for the test. The results for TSS, BOD, COD, ammonia, and phosphate contents are shown in Table 1.

**Table 1.** Preliminary test result domestic grey water

Parameter	Unit	Quality Standard	Result
TSS	mg/L	30*	4
BOD	mg/L	30*	72.4
COD	mg/L	100*	210
Amonia	mg/L	10*	<0.0089
Fosfat	mg/L	1**	0.359

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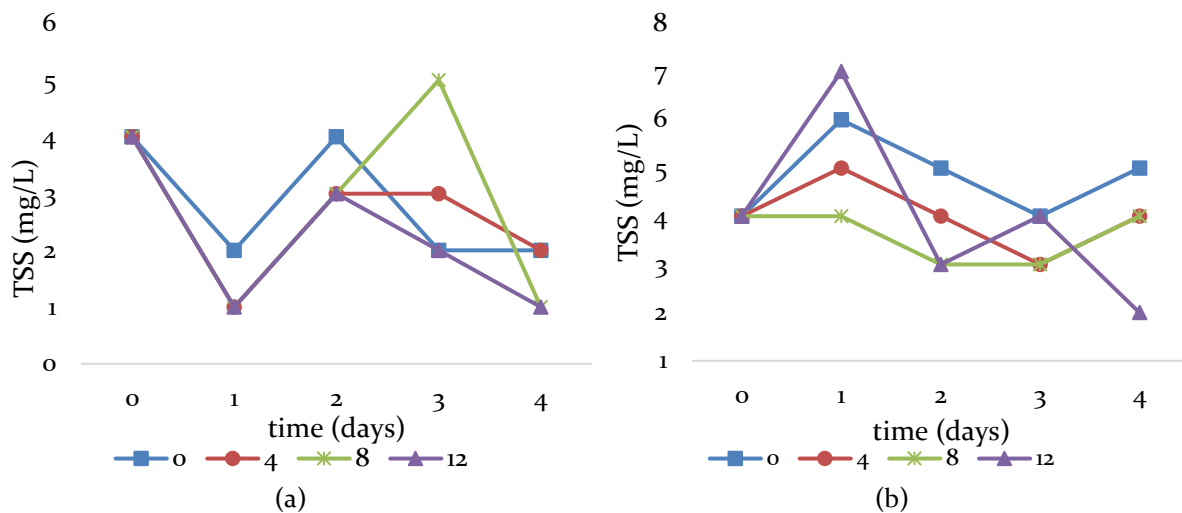
\*Regulation of the Minister of Environment and Forestry of the Republic of Indonesia P.68/Menlhk-Setjen/2016 on Residential Wastewater Quality Standards (Kementerian Lingkungan Hidup dan Kehutanan, 2016).

\*\*Government Regulation of the Republic of Indonesia No. 22 of 2021 regarding Implementation of Environmental Protection and Management (Presiden Republik Indonesia, 2021).

The preliminary analysis of the concentration was used as a reference for the gray water parameters prior to treatment in the wetlands. This reference was also compared with the maximum levels specified in the relevant regulations. According to Minister of Environment Regulation No. 68 of 2016, the gray water concentration in the initial test did not meet the quality standards for BOD and COD parameters. Meanwhile, the TSS and ammonia parameters, as defined in Minister of Environment Regulation No. 68 of 2016, and the phosphate parameter, as defined in Clean Water Standard Class III Government Regulation No. 22 of 2021, were still below the threshold. Based on these initial observations, treatment was conducted to determine whether the measured pollutant content could be reduced below the maximum level or maintained below the threshold.

#### 3.2. Effect on TSS

TSS measurements describe particles in water that cannot be dissolved. Observations of TSS content after treatment showed a decrease compared to day 0. As shown in the graph, there were fluctuations with the highest value of 7 mg/L (a 75% increase) occurring on day 1 with quartz sand media and 12 plants. The lowest value was 1 mg/L (a 75% decrease), which occurred on day 1 with activated carbon media and 4, 8, and 12 plants, as well as on day 4 with 8 and 12 plants. The highest TSS reduction from each media treatment, number of plants, and residence time was with activated carbon media (43.8%), followed by 12 plants (28.13%), and the fourth day (34.38%).



**Figure 2.** TSS content in domestic wastewater based on the number of plants used; (A) activated carbon media, (B) quartz sand media

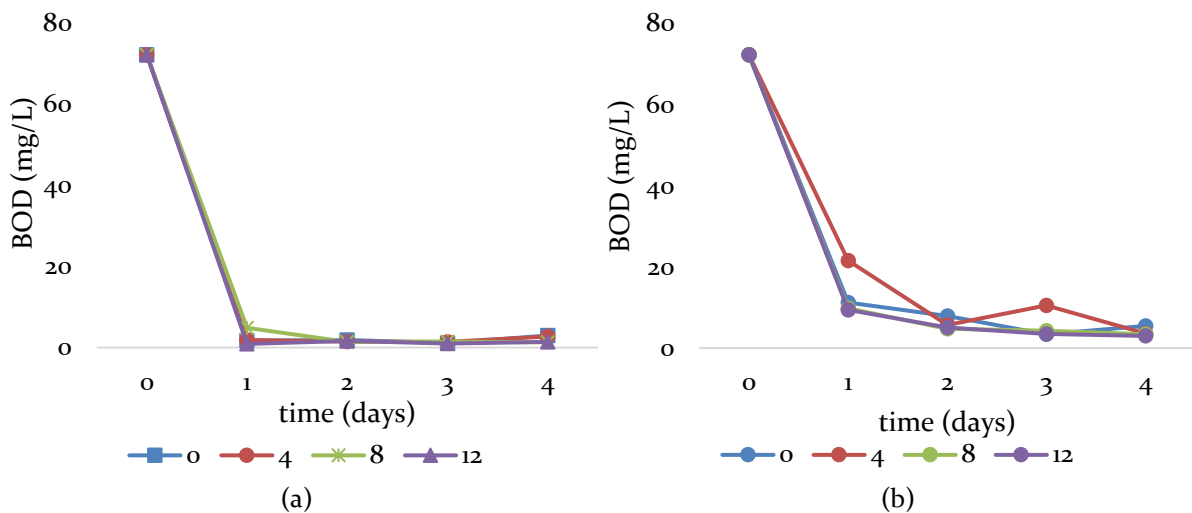
The T-test results revealed a significant difference in TSS content between the activated carbon substrate and quartz sand ( $P = 0.00$ ). However, the ANOVA test results for the treatments involving the number of plants and residence time did not show a significant difference ( $P = 0.57$  and  $0.67$ , respectively). Regression analysis showed no significant effect of the number of plants or residence time on TSS. The regression equation formed from the number of plants treated was  $Y = 3.875 - 0.300X$ , and the residence time treatment was  $Y = 3.813 - 0.275X$ ; both effects were negative and a linear line was formed to lead down. This decrease in TSS content is in accordance with the findings of Kasman et al. (2018), who discovered that TSS content decreased with increased detention time and number of Mexican sword plants.

Physical, biological, and chemical treatments in the reactor reduce TSS. The media reduces TSS through filtration and adsorption, whereas plants absorb decomposition products through their roots. The activated carbon medium reduces TSS more effectively than the quartz sand medium because the pore size matches the size of the absorbed TSS and the surface area is wider, resulting in greater absorption capacity. Verayana et al. (2018) show that activated observed charcoal activated with HCl has a larger pore morphology than activated charcoal activated with  $H_3PO_4$ . Additionally, the chemical composition of HCl-activated charcoal is higher than that of  $H_3PO_4$ -activated charcoal.

Plants with larger numbers are seen to reduce TSS more. This is related to an increasing number of roots, which reduce TSS. The roots capture TSS particles and degrade organic particles with the help of biofilms, whereas inorganic particles settle and accumulate at the bottom of the reactor. Biofilm-forming microorganisms, such as *Geobacter* and *Shewanella*, reduce suspended particles through biofilm aggregation, and *Lactobacillus plantarum* produces exopolysaccharides that enhance flocs, accelerating the sedimentation process and reducing TSS particles in wastewater (Amalludin et al., 2025).

### 3.3. Effect on BOD

A BOD measurement determines the amount of oxygen required for microorganisms to process or degrade the organic matter contained in wastewater. The results of the observations showed a drastic decrease in BOD on the first day and continued to fluctuate until the fourth day. The highest BOD content measured was 21.6 mg/L with quartz sand media, four plants, and a one-day residence time (70.2% reduction). The lowest BOD content was 0.9 mg/L (98.8% reduction) with activated carbon and 12 plants and a one-day residence time. The highest reduction in BOD content from each treatment occurred in the activated carbon media (97.48%), with 12 plants (95.87%), and on the fourth day of residence (95.87%).



**Figure 3.** BOD content in domestic wastewater based on the number of plants used; (A) activated carbon media, (B) quartz sand media

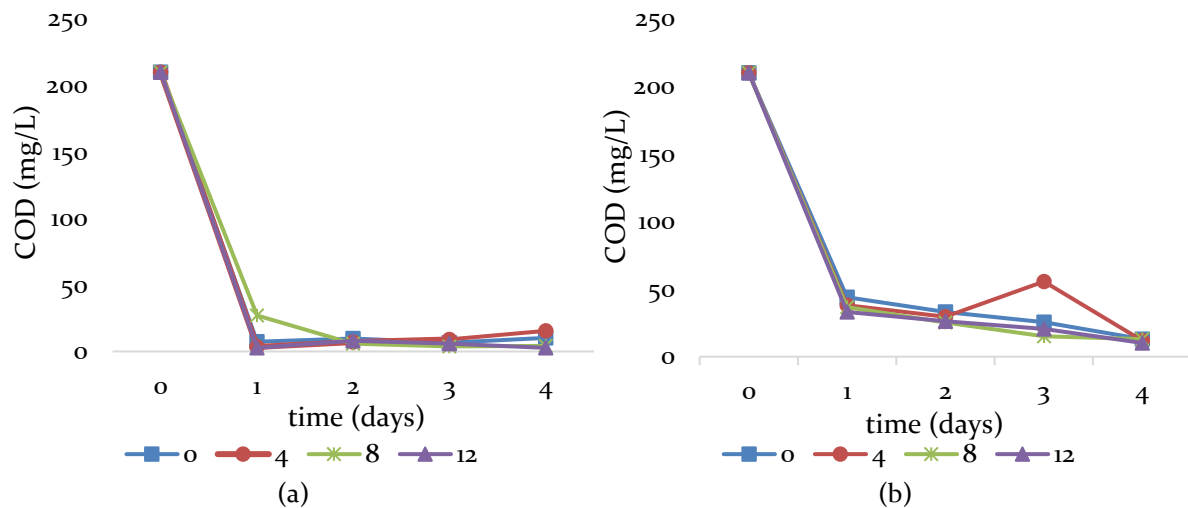
The results of the T-test statistical analysis revealed a significant difference in BOD content between activated carbon and quartz sand media ( $P=0.000$ ). However, the ANOVA test for the variables of number of plants and residence time showed no significant difference ( $P = 0.57$  and  $0.16$ , respectively). Regression analysis showed no significant effect of the number of plants and residence time on BOD. The regression coefficient equations were  $Y = 5.900 - 0.624X$  for the number of plants and  $Y = 7.681 - 1.336X$  for residence time. The effect of X on Y was negative; therefore, the resulting linear line will have a downward slope.

Puspita and Mirwan (2021) also showed a decrease demonstrated OD content, demonstrating BOD removal up to 84.94% using *Lembang* plants (*Thypha angustifolia* L) in a 9-day residu with time. Salsabila et al. (2024), using *Salvinia rotundifolia* plants resulted in BOD removal effectiveness of up to 72.73% in a 12-day residence time. Exposure of grey water to the media and plants effectively removes BOD from waste. There was a significant difference in BOD removal between the two types of media, indicating that activated carbon is more effective at reducing BOD levels in grey water waste because it captures more pollutants than quartz sand, which only filters them. Zein et al. (2020) demonstrated that activated charcoal biosorbent from cocoa pods effectively reduced BOD content in CPO processing waste by up to 81.69%.

Further BOD removal is achieved through phytoremediation, which involves plants and microbes in the plant environment (Tangahu and Ningsih, 2016). Contaminants around the roots are captured by a biofilm that attaches them to the roots. Bacteria decompose these contaminants into simpler compounds. The amount of BOD reduction is related to the number of plants. The reactor with 12 plants reduced the BOD the most among the other variations. Photosynthesis by plants produces, which is required to decompose organic matter and reduce BOD pollutants (Salsabila et al., 2024)..

### 3.4. Effect on COD

COD is an organic pollutant of chemical compounds contained in wastewater. COD measurements were conducted to determine the amount of oxygen necessary to facilitate the oxidation of organic compounds present in wastewater. The COD level in domestic grey water waste decreased on the first day and then fluctuated until the fourth day. The highest COD level was 55.5 mg/L in quartz sand media with four plants on day 3 (a 73.6% decrease). The lowest COD level was 2.7 mg/L in activated carbon media, with 12 plants on days 1 and 4 (a 98.7% decrease). The most significant decline in COD from each treatment was observed in activated carbon media (96.16%), with 12 plants (93.49%), and a residence time of four days (98.58%).



**Figure 4.** COD content in domestic wastewater based on the number of plants used; (A) activated carbon media, (B) quartz sand media

The results of the t-test analysis indicated a significant difference between the COD contents in the activated carbon and quartz sand media ( $P=0.000$ ). The ANOVA test results of the treatment of the number of plants and residence time showed no significant difference ( $P=0.66$  and  $0.43$ , respectively). The regression analysis of the variable number of plants and residence time demonstrated no significant effect on COD. The regression coefficient equation for the number of plants is  $Y = 22.481 - 2.213 X$ , and for residence time is  $Y = 25.131 - 3.273 X$ . The direction of the influence of the independent variable on Y is negative, causing the linear line formed to decrease.

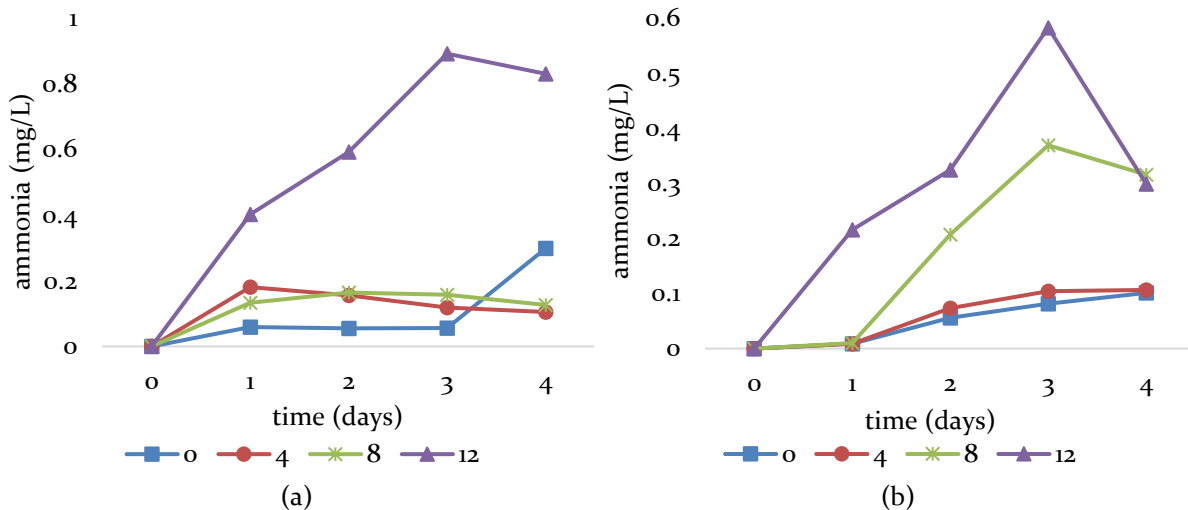
As the residence time of wastewater in the reactor increases, pollutant levels decrease. Salsabila et al. (2024) observed the highest COD concentration difference in wetlands after a retention time of 12 days, resulting in a removal efficiency of 23.40–84.38 using *Salvinia rotundifolia* plants (gr for water of gram per plant) treatment. Dewi et al. (2021), employing water lettuce (*Pistia stratiotes*) for the treatment of textile wastewater, also demonstrated a reduction in COD, particularly in the longest residence time of 9 days, exhibiting a 63.51% decrease.

A decline in COD is associated with a decrease in the amount of organic matter and chemical compounds present in wastewater, resulting from chemical oxidation. Higher COD is due to the greater quantity of organic waste that must undergo oxidation, thereby necessitating a higher oxygen demand. Greater COD removal in the 12 plants is due to two factors: first, an increase in the amount of oxygen produced through photosynthesis, and second, an increase in the number of available roots capable of absorbing more waste. The process of decomposition of waste is facilitated by the combined actions of plant roots and surrounding microorganisms, resulting in the breakdown of complex compounds and the subsequent production of substances that are capable of being absorbed by the aforementioned organisms (Rahmawan et al., 2023).

Media has a significant impact on COD reduction in wastewater. Activated carbon has been demonstrated to be more effective than quartz sand of equivalent media size in reducing COD content in comparison to quartz sand of equivalent media size. Activated carbon utilizes the adsorption power of its surface and pores, allowing for further COD reduction. The contact surface area between the activated carbon adsorbent and pollutants is greater, enabling nano-activated carbon to reduce COD by up to 93.15%, in comparison to zeolite-based COD by 85.1% (Munandar et al., 2016). Setiyanto et al. (2016), provides significant findings regarding the utilization of activated carbon media and mexican sword plants in reducing hospital waste, with a percentage reduction of up to 69.76%, which exceeds the effectiveness of other treatment methods.

### 3.5. Effect on Ammonia

Ammonia measurements were taken to determine the level of ammonia in wastewater. The graph of ammonia in grey water shows an increase from day 1 to day 4. The highest level measured was 0.8934 mg/L in the activated carbon medium with 12 plants on day 3 (a >100% increase), while the lowest level measured was 0.0089 mg/L in the quartz sand medium with zero and four plants on day 1 (a 0% decrease). Ammonia increased the least in the quartz sand medium (1914.9%), in the control group (907.4%), and on day 1 (1332.7%).

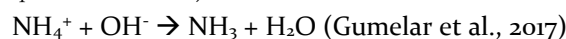


**Figure 5.** Ammonia content in domestic wastewater based on the number of plants used; (A) activated carbon media, (B) quartz sand media

The T-test results showed no significant difference in ammonia content between the activated carbon and quartz sand media ( $p = 0.257$ ). The ANOVA test results for the number of plants showed a significant difference in 12 plants variations after the Games-Howell post hoc test ( $p = 0.000$ ), while the ANOVA test results for the residence time showed no significant difference ( $p = 0.45$ ). Regression analysis of the independent variable, number of plants, showed a significant effect on ammonia content ( $P = 0.000$ ). However, the regression test results for residence time had no effect on COD ( $P = 0.138$ ). The regression equations were  $Y = -0.116 + 0.136X$  for the number of plants and  $Y = 0.093 + 0.053X$  for residence time. Both had a positive effect on ammonia content; therefore, the linear line formed trends upward.

An increase in ammonia content in wastewater can be caused by several factors, one of which is inadequate treatment of ammonia pollutants. This system uses anaerobic horizontal flow, resulting in a lack of available oxygen. The horizontal flow system holds wastewater for observation, thereby reducing pollutant content in several parameters; however, it is less suitable for reducing ammonia content. Abou-Elela et al. (2013), mentioned that the CW system with a vertical flow can reduce the ammonia content by a greater percentage (62.3%) than the artificial wetland system with a horizontal flow (57.1%).

The effect of oxygen on nitrification is evident. While 12 plant variations require oxygen for high BOD and COD reduction, the occurrence of an oxygen deficit is inevitable. The degradation of organic matter by microorganisms reduces dissolved oxygen; the higher the level of organic matter, the more oxygen is required (Rahmawan et al., 2023). An oxygen-deficient environment can cause a shift in water pH, affecting ammonia. Gumelar et al. (2017) observed that acidic wastewater undergoes adsorption of  $H^+$  ions by activated carbon, resulting in the formation of  $NH_3$  bonds. Acidic pH causes  $NH_4^+$  ionization; however, at alkaline pH,  $NH_4^+$  binds to  $OH^-$ , which loses its  $H^+$  element and forms  $NH_3$  and  $H_2O$ .

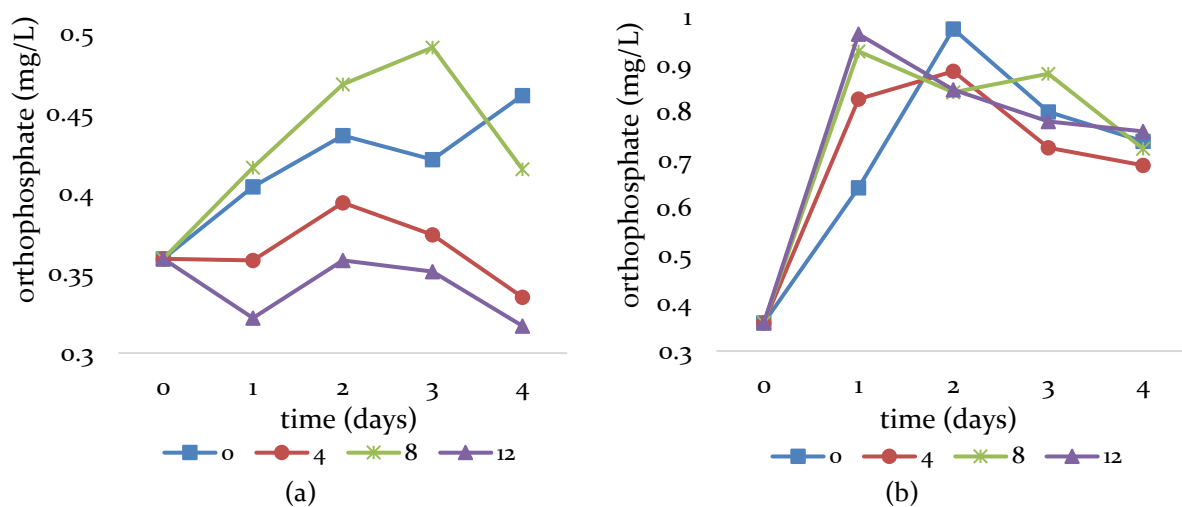


The processing results based on the media used reveal that both media increased ammonia levels, with activated carbon producing higher levels than quartz sand. This is because ammonia, which has polar bonds, does not easily bind to the non-polar bonds of activated carbon or quartz sand. Carbon-

based components are usually nonpolar and hydrophobic, allowing them to easily bind with other nonpolar components (Gawande et al., 2017), whereas ammonia is polar. Although quartz sand is a nonpolar component owing to the symmetry of its molecules, silicon and oxygen have polar bonds because of differences in electronegativity (Kurniawan, 2019).

### 3.6. Effect on Phosphate

Phosphate levels were measured to determine the level of orthophosphate in wastewater. Phosphate levels increased at the beginning of the study and decreased the following day. The highest phosphate level measured was 0.976 mg/L in quartz sand medium with one plant on day 2 (a >100% increase), while the lowest measured was 0.317 mg/L in activated carbon medium with 12 plants on day 4 (an 11.7% decrease). The lowest increase in phosphate level was observed in activated carbon (10.1%), in plant number four (60%), and on the fourth residence day (54.7%).



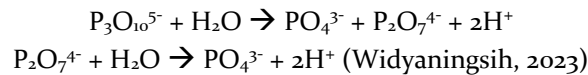
**Figure 6.** Orthophosphate content in domestic wastewater based on the number of plants used; (A) activated carbon media, (B) quartz sand media

The results of the t-test analysis revealed a significant difference in phosphate content between the activated carbon and quartz sand media ( $P = 0.000$ ). The ANOVA test results for the treatments involving the number of plants and residence time showed no significant difference ( $P = 0.985$  and  $0.914$ ). The regression test results showed that the independent variables, namely, the number of plants and residence time, had no significant effect on phosphate ( $P = 0.944$  and  $0.615$ ). The regression coefficient equations are  $Y = 0.603 - 0.003X$  for the number of plants and  $Y = 644 - 0.019X$  for residence time. Both equations have a negative effect on phosphate, and the resulting lines will slope downward. Additionally, it is known that 99% of the R square generated by the two treatments is influenced by factors outside the treatment of the number of plants and residence time.

An increase in phosphate was observed in both media and with different plant densities, likely due to the suboptimal system for removing phosphate pollutants. Ebrahimi et al. (2013), also conducted research using the same plants and sand media that resulted in an increase in phosphate content from 4.4 mg/L to 6.8 mg/L and a fluctuation in removal efficiency from 17%-23% to -2%-2%. CW systems have a limited effect on phosphorus reduction through retention or adsorption by the medium and filtration by plants (Qomariyah et al., 2017). Adjusting the flow can be used to optimize CW systems and increase their efficiency. Abou-Elela et al. (2013) showed that CW with vertical flow reduced phosphate by 68%, compared with 63% for those with horizontal flow.

The phosphate content initially increased and fluctuated, followed by a decrease on days three and four. This increase may be attributed to the breakdown of complex substances, such as sodium tripolyphosphate (STPP), a detergent, and bath soap builder, into simpler forms, such as orthophosphate.

STPP is converted into orthophosphate and pyrophosphate, which are subsequently converted into orthophosphate (Widyaningsih, 2023).



In addition, plants and bacteria around plant roots process the next stage of orthophosphate, either as auxiliary compounds for other processes or as nutrients that can be absorbed directly by plants and microbes. Novitasari et al. (2021) found that orthophosphate undergoes phytostabilization in the root zone, rhizofiltration or adsorption into the roots and transport networks, phytoextraction or absorption of orthophosphate ions by plants, phytodegradation by decomposing orthophosphate ions, and phytovolatilization by releasing orthophosphate ions into the atmosphere.

The phosphate adsorption results revealed differences between the two media. The quartz sand results showed a higher increase on day 1 than the activated carbon results. This is because filtration and adsorption occur directly on the surface of activated carbon. Wardhana et al. (2014), found that using plastic waste activated carbon for phosphate waste in a batch system, reduces phosphate by 45.45% in the longest time (150 minutes) with an adsorbent weight of 3 grams and 100-200 mesh size.

### 3.7. Plant Observation

During the greywater waste data collection period, observations of umbrella sedge plants showed that the plants grew well at a 60% grey water concentration, although some leaves turned yellow but did not fall off or wither. Umbrella sedge plants normally grow in open areas with direct sunlight but were able to survive under shaded conditions during acclimatization and data collection. Quantitative growth parameters included plant height, root length, stem diameter, number of leaves, wet weight, and dry weight, whereas qualitative plant development parameters included flowering and fruit formation Azhari et al. (2020). Over the course of 25 days of waste treatment, the plants grew an average of 5-7 cm in height, and the color of their stems and leaves darkened.

Umbrella sedge plants reproduce in two ways: flowering and sprouting (Kyambadde et al., 2004). The plants selected for data collection were still in the growth stage or vegetative phase; therefore, none had flowered, although some had sprouted. At the end of the study, observations showed that umbrella sedge shoots could grow well in quartz sand and activated carbon media. Additionally, flowers began to appear on several stems in different clumps, indicating the start of the generative phase through flowering. However, further research is needed to determine whether the generative phase begins at the same time for shaded and non-shaded umbrella sedge.

Another observation was that processing waste with the highest number of plants (12 clumps) resulted in the highest removal efficiencies of TSS, BOD, and COD compared to other variations in the number of plants. This may be attributed to the performance of the umbrella sedge roots, which are fibrous and spread out. Umbrella sedge roots are white when first appearing and turn red after growing longer, with thin root hairs forming around them. The growth direction of the roots differs among species, causing differences in their performance in treating pollutants (Qomariyah et al., 2021).

## 4. Conclusions

The application of *C. alternifolius* for phytoremediation in constructed wetlands for household greywater has been proven to effectively reduce several waste parameters. The combination of umbrella sedge plants and activated carbon media was more effective in reducing TSS, BOD, and COD. The number of umbrella sedge plants or the length of wastewater retention time did not affect the effectiveness of greywater removal, although the highest removal rates were achieved with the largest number of plants and the longest retention time. Therefore, it can be concluded that treatment with umbrella sedge is effective in reducing TSS, BOD, and COD in activated carbon media with 12 plants and a retention time of 4 days, although it is not effective in removing ammonia and orthophosphate.

This system can be easily adapted for processing individual household waste, thanks to the readily available plants and materials that do not require large areas of land. Although umbrella sedge plants assist in waste treatment and produce good results, further processing is needed to remove nutrients such as ammonia and phosphate. Adding other plants to the system, using different combinations of media, or different types of wetlands can provide a basis for further research. Additionally, testing other parameters in domestic waste in artificial wetland systems would be worthwhile.

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## Ethics Statement

This study did not involve human participants, animals, or sensitive data; therefore no ethical approval was required.

## CRedit Author Statement

**Nadya Aulia Azhari:** Idea Development, Investigation, Formal Analysis, Data Curation, Visualization, Manuscript Draft Preparation. **Sri Sumiyati:** Supervision, Research Design, Manuscript Review and Revision. **Badrus Zaman:** Supervision, Resources, Manuscript Review and Revision. **Nurandani Hardyanti:** Supervision, Manuscript Review and Revision. **Surya Prayoga:** Supervision, Resources, Manuscript Review

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