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Original Research Article

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

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Abstract

Increased water usage leads to higher levels of wastewater discharged into the river, which reduces river's quality as the amount of contaminants entering increases. One way to reduce the burden of contaminants discharged into the river is through phytoremediation with constructed wetlands in domestic wastewater (grey water). The objective of this study is to determine how the number of umbrella sedge plants, residence time, and media type affect domestic wastewater parameters, including BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solid), NH_3-N (ammonia), and PO_4 (orthophosphate). The study used a Randomized Block Design (RBD) with the following treatment factors: substrate type (activated carbon and quartz sand), number of plants (0, 4, 8, or 12 clumps), and retention time (0, 1, 2, 3, or 4 days). Statistical analysis was performed using a t-test, ANOVA, and regression at a 5% significance level. The results showed that activated carbon, 12 clumps of plants, and a residence time of four days were more effective in reducing TSS, BOD, COD, and phosphate content but less effective in reducing ammonia. Results from the fourth day showed that all pollutant levels were below quality standard limits and could be released into the river.

Keywords: Activated carbon ; constructed wetlands; grey water

1. Introduction

As the population grows, the demand for water increases, causing more wastewater to be discharged into rivers. Household waste contributes significantly to Indonesian river waters; in 2020, around 57.42% of Indonesian households dispose bathing, washing, and kitchen wastewater in sewers or rivers (Badan Pusat Statistik, 2020). Domestic wastewater comes from human activities and can be divided into black water, containing human feces, and grey water, coming from bathrooms, laundry rooms, and kitchens (Purwatiningrum, 2018). Grey water usually contains cleaning agents, such as soap; organic compounds; solid and dissolved dirt; and microorganisms. 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), as well as 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 housing because they can also serve as gardens and have aesthetic value (Rahmawati et al., 2022). Wetlands are categorized into two groups: constructed wetland 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 research uses the Horizontal Subsurface Flow constructed wetland type, which the media is submerged below the surface and the roots are submerged in wastewater. The artificial wetland system consists of three important components: aquatic plants; such as grasses and lilies, a media; as a place for plants to grow and a filter for pollutants (Swarnakar et al., 2022), and microorganisms; such as bacteria, fungi, and protozoa that live in the plant roots.

A variety of plants have been used in 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 right plants is crucial for supporting waste treatment because 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 parts of the plant. 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* plants are widely used in the phytoremediation of various types of liquid waste and parameters. It can reduce the COD and TSS content of palm oil mill effluent (Sa'at et al., 2017), as well as the ammonium, nitrate, and colour of 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*) show that umbrella sedge has the highest removal rate up to 91.18% for BOD, 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^{-}_{3}-N, and NH_4^+-N parameters, but PO_4^{-3}-P parameters increased in sandy media. Therefore, in this study, the author tried to compare umbrella sedge plant in different media to observe their reaction to the parameters found in greywater.

The substrate component in artificial wetlands acts as a medium for plant growth, pollutant treatment, also 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 (HRT) is usually related to the level of pollutant reduction in waste; a longer detention time increases the effectiveness of removal (Li et al., 2021). However, detention time effectiveness can differ due to wetland components such as the substrate and plants used, as well as external factors like the state of the environment. The number of days is adjusted according to household water usage needs, so in this study, one day was taken as the basis for comparison. A longer review was carried out 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 its 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 is to evaluate the impact of placing umbrella sedge plants in various media on greywater waste parameters, including orthophosphate present in soap waste. This study combines various elements, including the type of media used, the number of plants, and the number of residence times (in day), to maximize the reduction of grey water pollutants. The study aims 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 umbrella sedge (*Cyperus alternifolius*) plants obtained from around the river in Jekulo District, Kudus City. Research was conducted from August 2023 to March 2024 in an open field in Banjarsari Sub-district, Surakarta City. Effluent samples were collected from residential drains in Banjarsari Sub-district. 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 parameters of the domestic wastewater. The first factor is the substrate, which consists of activated carbon and quartz sand. The second factor is the number of plants, consisting of 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 is effluent exposure time, consisting of 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 involves preparing the necessary tools and materials. The preparation of materials was carried out using activated carbon and quartz sand media. The carbon and quartz sand from PT Bumi Kirana Asri were filtered using a sieve to obtain media particles sized 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 hours. Then, it was washed with water, dried, and stored in a closed, dry place. Before use, activated carbon and quartz sand are washed to remove dirt, then dried in the sun, and stored in a dry place.

The tool was prepared by assembling the research reactor in an 82-liter plastic box container with dimensions of 68 x 47.6 x 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 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 reactor's tilted shape. Figure 1 shows a sketch of the reactor design.

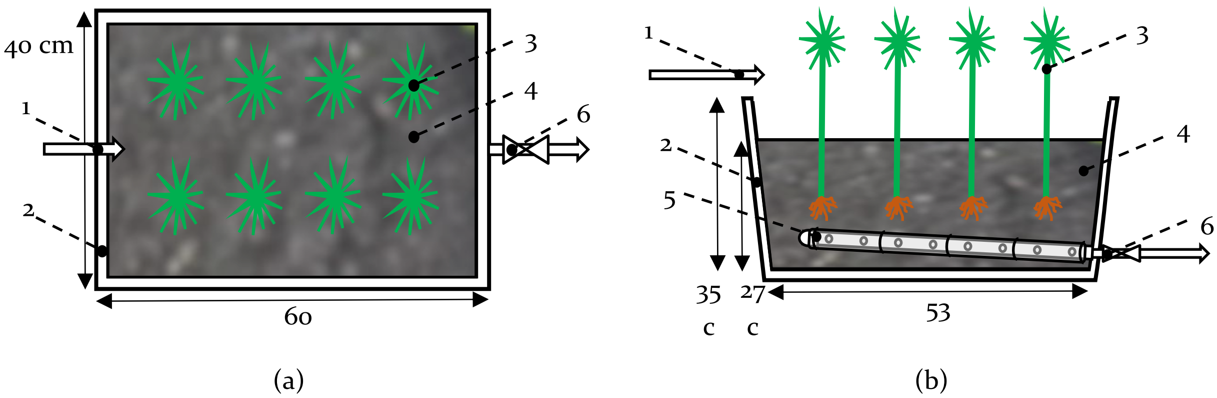


Figure 1. Layout from the top (A), and side view (B) of a CW reactor: (1) effluent inlet, (2) container, (3) umbrella sedge plant, (4) substrate, (5) ½-inch pipe assembly, (6) drain faucet

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. Then, plain water was introduced into the reactors approximately 20 L.

Acclimatization was carried out according to Azahra et al. (2015), by gradually introducing wastewater into the reactor's medium over a specified period of time. On the first five days, the reactor was given plain water. From the sixth to 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, so this concentration was chosen as the plants would start to wilt at higher concentrations.

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

2.5. Data Analysis

The data were analysed using IBM SPSS Statistics 22 and Microsoft Excel. IBM SPSS Statistics was used to perform statistical analyses, consisting of a T-comparison test, an ANOVA test, and a 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 test between the two media treatment samples (quartz sand and activated carbon). ANOVA was used to test for differences in the averages of 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 5% significance level, meaning that the results would be considered significant if the P-value < 0.05. The removal efficiency test was conducted using the equation (1), as referred to by Qomariyah et al. (2021), to determine the efficiency of wetlands in eliminating certain contaminants.

$$\%R = \frac{(Ci-Ce)}{Ci} x\ 100\% \quad (1)$$

Description

Ci : pollutant influent concentration (mg/L)

Ce : pollutant effluent concentration (mg/L) (Qomariyah et al., 2021)

3. Result and Discussion

3.1. Preliminary Test of Domestic Grey Water

Acclimatisation 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%, though 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 acclimatisation period, to determine the initial wastewater concentration. For the test, wastewater mixed with ordinary water in a 6:4 ratio was collected up to two liters. The results of 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

Source:

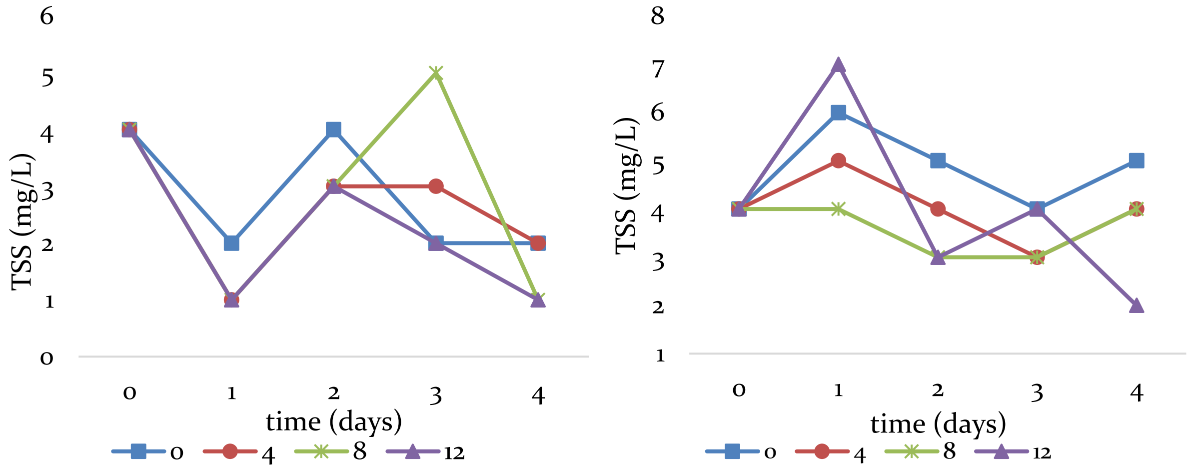
**Regulation of the Minister of Environment and Forestry of the Republic of Indonesia P.68/Menlhk-Sejten/2016 on Residential Wastewater Quality Standards (Kementrian Lingkungan Hidup dan Kehutanan, 2016).*

***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 is used as a reference for the grey water parameters prior to treatment in wetlands. This reference is also compared with the maximum levels specified in the relevant regulations. According to Minister of Environment Regulation No. 68 of 2016, the grey 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 carried out 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 the day 0 test. 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, 12 plants, as well as on day 4 with 8, 12 plants. The highest TSS reduction from each media treatment, number of plants, and residence time was with the activated carbon media (43.8%), followed by the 12 plants (28.13%), and the fourth day (34.38%).



(a) (b)

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 the 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 treatment is Y = 3.875 - 0.300X, and the residence time treatment is Y = 3.813 - 0.275X; both effects are negative, and the linear line formed to lead down. This decrease in TSS content is aligned with the findings of Kasman et al. (2018), who discovered that TSS content decreased with increased detention time and the number of mexican sword-plants.

The physical, biological, and chemical treatments in the reactor help reduce TSS. The media reduces TSS through filtration and adsorption, while plants absorb decomposition products through their roots. The activated carbon media reduces TSS more effectively than the quartz sand media because the pore size matches the size of the absorbed TSS and the surface area is wider, resulting in greater absorption capacity. The observation by Verayana et al. (2018) show that activated 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 the increasing number of roots, which reduce TSS. The roots capture TSS particles and degrade organic particles with the help of biofilms, while 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 content 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, 4 plants, and a one-day residence time (70.2% reduction). The lowest BOD content was 0.9 mg/L (98.8% reduction) in activated carbon with 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 residence day (95.87%).

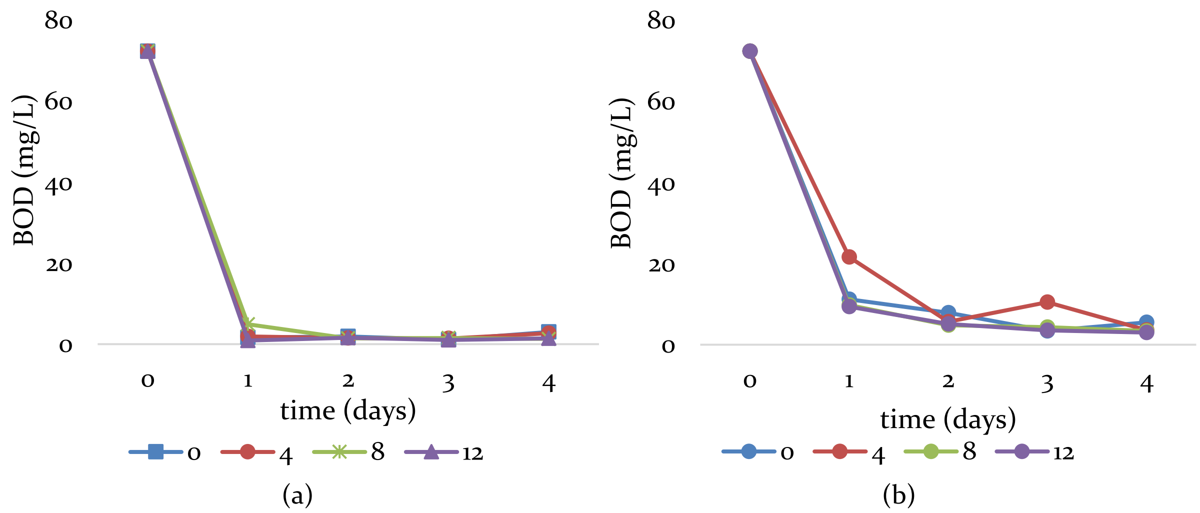


Figure 3. BOD content in domestic wastewater based on the number of plants used; (A) activated carbon media, (B) quartz sand media

The T-test statistical analysis revealed a significant difference in BOD content between activated carbon and quartz sand media (P=0.000). However, the results of 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 the BOD. The regression coefficient equations are Y = 5.900 - 0.624X for number of plants and Y = 7.681 - 1.336X for residence time. The effect of X on Y is negative, so the resulting linear line will slope downward.

The research of Puspita and Mirwan (2021) also showed a decrease in BOD content, demonstrating BOD removal up to 84.94% using Lembang plants (*Thypha angustifolia* L.) in a 9-day residence 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. Grey water's exposure to the media and plants effectively removes BOD from waste. There is 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), showed that activated charcoal bio sorbent from cocoa pods effectively reduces BOD content in CPO processing waste by up to 81.69%.

Further BOD removal is carried out by phyto treatment, which involves plants and microbes in the plant environment (Tangahu and Ningsih, 2016). Contaminants around the roots are caught by a biofilm, which attaches them to the roots. There, bacteria decompose the contaminants into simpler compounds. The amount of BOD reduction is related to the number of plants. The reactor with 12 plants is able to reduce BOD the most among other variations. Plants' photosynthesis process produces the oxygen needed by organisms to decompose organic matter and reduce BOD pollutants (Salsabila et al., 2024).

3.4. Effect on COD

COD is organic pollutant of chemical compounds contained in wastewater. COD measurements are conducted with the objective of ascertaining the requisite amount of oxygen necessary to facilitate the oxidation of organic compounds present within the wastewater. The COD content in grey water domestic waste demonstrates a decrease on the first day, followed by fluctuations until the fourth day. The highest COD measured at 55.5 mg/L in quartz sand media with four plants on day 3 (a 73.6% decrease). The minimum COD measured at 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 the activated carbon media (96.16%), in a 12 plants variation (93.49%), and residence time of four days (98.58%).

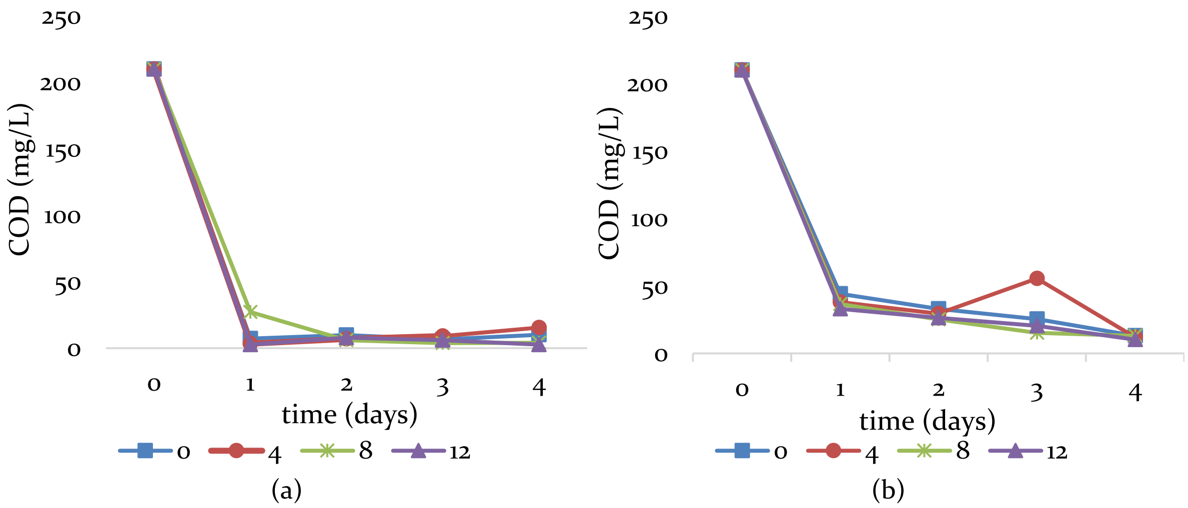


Figure 4. COD content in domestic wastewater based on the number of plants used; (A) activated carbon media, (B) quartz sand media

The result of the T-test analysis indicated a significant difference between the COD content in activated carbon and quartz sand media (P=0.000). The ANOVA test results of the treatment of the number of plants and the residence time showed no significant difference (P=0.66 and 0.43). 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 = 22.481-2.213X, and for residence time is Y = 25.131-3.273X. The direction of the influence of the independent variable on Y is negative, causing the linear line formed to lead down.

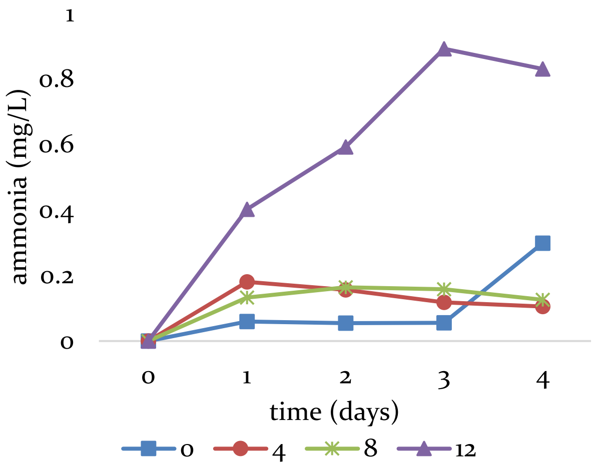
As the residence time of wastewater in the reactor increases, there is a decrease in pollutant levels. According to Salsabila et al. (2024), the highest COD concentration difference in wetlands was observed at a detention time of 12 days, resulting in a removal efficiency of 23.40-84.38% using *Salvinia rotundifolia* plants in grey water. 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.

The decline in COD is associated with a decrease in the amount of organic matter and chemical compounds present in the wastewater, resulting from the chemical oxidation process. Higher COD is due to the greater quantity of organic waste that must undergo oxidation, thereby necessitating a higher oxygen demand. Greater removal of COD in the 12 plants variations 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).

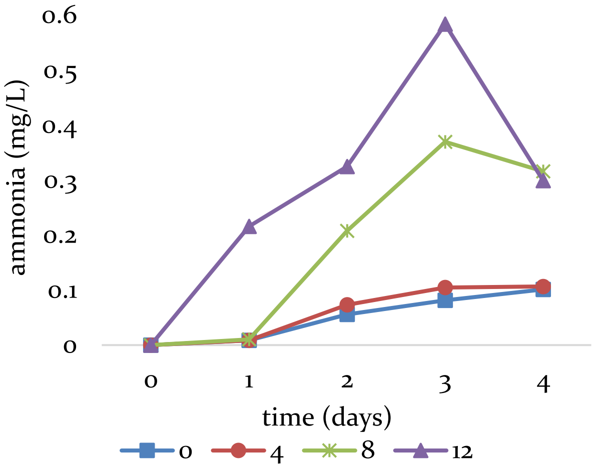
The media had a significant impact on the reduction of COD in wastewater. Activated carbon has been demonstrated to be more effective in reducing COD content in comparison to quartz sand of equivalent media size. Activated carbon is known for its ability to utilize adsorption power on its surface and pores, which in turn allows for further reduction of COD. The contact surface area between the activated carbon adsorbent and the pollutants is greater, thereby enabling nano activated carbon to reduce COD by up to 93.15%, in comparison with nano zeolite, which reduces COD by 85.11% (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 are taken to determine the level of ammonia in wastewater. The graph of ammonia in grey water shows an increase from the first to the fourth day. The highest content measured was 0.8934 mg/L in the activated carbon media with 12 plants on day three (a >100% increase), while the lowest content measured was 0.0089 mg/L in the quartz sand media with zero and four plants on day one (a 0% decrease). Ammonia increased the least in quartz sand media (1914.9%), in the control group (907.4%), and on day one (1332.7%).



(a)



(b)

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 variation 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 are $Y = -0.116 + 0.136X$ for the number of plants and $Y = 0.093 + 0.053X$ for residence time. Both have a positive effect on ammonia content, therefore the linear line formed will trend upward.

An increase in ammonia content in wastewater can be caused by several factors, one of which is an inadequate system for treating ammonia pollutants. This system uses anaerobic horizontal flow, allowing a lack of available oxygen. The horizontal flow system holds wastewater for observation, reducing the 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%).

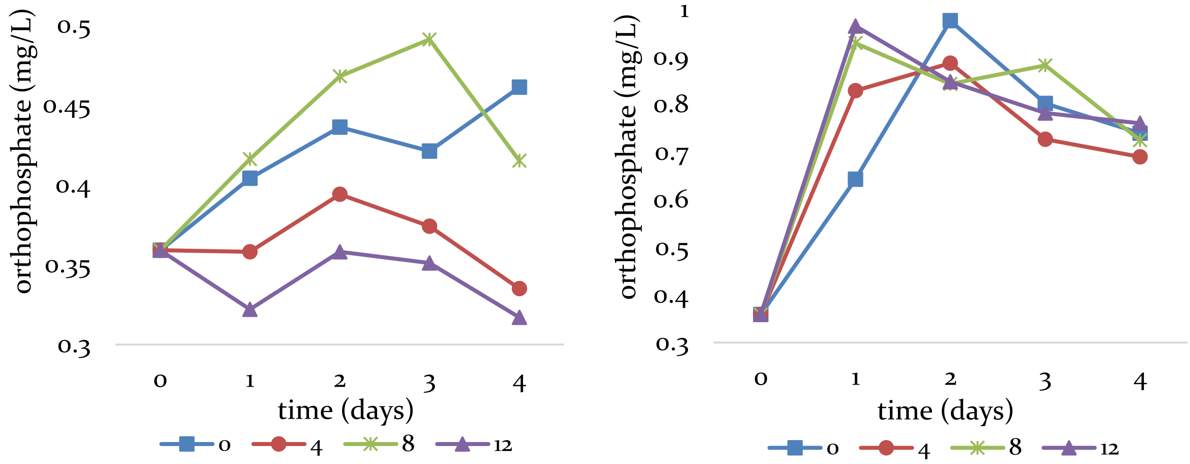
The effect of oxygen on nitrification is evident. While 12 plants variation require oxygen for high BOD and COD reduction, the occurrence of an oxygen deficit is inevitable. The degradation of organic matter by microorganisms reduces the dissolved oxygen; the higher the level of organic matter, the more oxygen is needed (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^+ will binds to OH^-, which loses its H^+ element and forms NH_3 and H_2O.

$$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$$ (Gumelar et al., 2017)

Processing results based on the media used show that both media increase 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), while ammonia is polar. Although quartz sand is a non-polar component due to the symmetry of its molecules, silicon and oxygen have polar bonds due to differences in electronegativity (Kurniawan, 2019).

3.6. Effect on Phosphate

A phosphate measurement is carried out to determine the level of orthophosphate contained in wastewater. Observation of the phosphate showed an increase at the beginning of the study, followed by a decrease on the following day. The highest content measured was 0.976 mg/L in quartz sand media with 0 plants on day 2 (a >100% increase), while the lowest content measured was 0.317 mg/L in activated carbon media with 12 plants on day 4 (an 11.7% decrease). The lowest increase in phosphate content was observed in activated carbon (10.1%), plant number 4 (60%), and on the fourth residence day (54.7%).



(a) (b)

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

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). Regression test results showed that the independent variables, 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.

The increase in phosphate occurs in both media and the different number of plants due to the less optimal 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 media and filtration by plants (Qomariyah et al., 2017). One way to optimize CW systems is to adjust the flow to increase efficiency. Research by Abou-Elela et al. (2013), showed that CW with vertical flow reduced phosphate by 68%, compared to 63% for those with horizontal flow.

The phosphate content begins with an increase and fluctuation, followed by a decrease on days three and four. This increase can be caused by 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 then converted into orthophosphate (Widyaningsih, 2023).

$$P_3O_{10}^{5-} + H_2O \rightarrow PO_4^{3-} + P_2O_7^{4-} + 2H^+$$

$$P_2O_7^{4-} + H_2O \rightarrow PO_4^{3-} + 2H^+ \text{ (Widyaningsih, 2023)}$$

Next, plants and bacteria around plant roots will 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. The findings of Novitasari et al. (2021) show that orthophosphate undergoes phytostabilisation in the root zone, rhizofiltration or adsorption into the roots and transport network, phytoextraction or absorption of orthophosphate ions by plants, phytodegradation by decomposing orthophosphate ions, and phytovolatilization by releasing orthophosphate ions into the atmosphere.

The phosphate observation results revealed differences between the two media. The quartz sand results showed a higher increase on day 1 compared to the activated carbon media results. This is due to filtration and adsorption occurring 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 concentration of 60% greywater, 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 in shaded conditions during acclimatization and data collection. Quantitative growth parameters include plant height, root length, stem diameter, number of leaves, wet weight, and dry weight, while qualitative plant development parameters include 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, so 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 if the generative phase begins at the same time for shaded and non-shaded umbrella sedge.

Another observation about this plant is that processing waste with the highest number of plants (12 clumps) resulted in the highest removal efficiency of TSS, BOD, and COD compared to other variations in the number of plants. This may be due 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 easily be 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, it would be worthwhile testing other parameters in domestic waste in artificial wetland systems.

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