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Domestic Wastewater Influent Treatment in Reservoir B of Lampung University Using Constructed Wetlands (CWs)

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Abstract

This study aims to analyze the effectiveness of the Constructed Wetlands (CWs) method in improving the water quality of domestic wastewater before it enters Resevoir (Embung) B at Lampung University. Reservoir B, which has the largest storage capacity on campus, also receives domestic wastewater (grey water) from residential areas and a terminal. The CWs method was applied using bamboo water (*Equisetum hyemale*) and water jasmine (*Echinodorus palaefolius*), with and without the addition of moss. Water quality parameters such as pH, TSS, BOD, COD, NH_3-N, TDS, EC, temperature, and DO were tested. The results show that the combination of bamboo water with moss (P3) and water jasmine with moss (P4) was the most effective in reducing pollutant concentrations, with several parameters such as TSS, pH, and NH_3-N meeting the domestic wastewater quality standards in accordance with Government Regulation No. 22 of 2021. Although BOD and COD did not fully meet the standards, there was a significant reduction compared to initial conditions. These findings suggest that the CWs system has potential as an eco-friendly and cost-effective technology for domestic wastewater treatment, especially in small-scale environments such as campuses or residential areas.

Keywords: Constructed wetlands (CWs), Domestic wastewater, Grey water, Reservoir.

1. Introduction

Reservoirs (embung) are a type of waterbody that is intentionally designed and built by humans. Reservoirs are usually used to increase the aesthetic value of a location or as a means of storing water (Zhou *et al.*, 2021). In addition, the benefits of making reservoirs are in controlling the volume of groundwater storage and helping to maintain groundwater flow as one of the activities to modify the hydrological cycle (Sun *et al.*, 2019). The construction of reservoirs is also useful as a recreational destination that offers natural beauty in the form of flora and fauna while also having an important role in environmental conservation efforts (Elhassan *et al.*, 2021).

Lampung University has 4 reservoirs spread evenly across the campus area, including reservoir A, located in the middle of the area with an area of 0.5 Ha, reservoir B located near the student dormitory (Rusunawa) and adjacent to residential areas and terminals with an area of 0.96 Ha, reservoir C located at the Faculty of Medicine with an area of 0.31 Ha, and reservoir D located at the Faculty of Engineering with an area of 0.38 Ha. By creating reservoirs in the campus area, the government hopes that the reservoirs can function as rainwater harvesting areas for reserves during the dry season, water resource conservation, and local tourist parks for students and residents (PUPR, 2021).

Reservoir B is close to the student dormitory and is one of the reservoirs with the largest water storage volume (22,936 m^3) compared to the other 3 reservoirs. Besides collecting rainwater, Reservoir B is also filled with domestic wastewater (grey water) from residential areas, terminals, and dormitories. Grey water (GW) is wastewater from household activities. Grey water is considered wastewater with a low pollutant content compared to wastewater from industrial activities (South & Nazir, 2016). However, this waste must undergo a process before entering the water body (reservoir) so the pollutant content does not accumulate and pollute the waters around the reservoir.

Water pollution control needs to be carried out to reduce the negative impacts. Water pollution control is carried out to ensure water quality in accordance with quality standards (Government Regulation No. 22 year 2021) concerning the implementation of environmental protection and management. On the other hand, there is an accumulation of waste due to the non-functioning of the waste filter on the reservoir inlet channel. Without handled immediately, this condition will damage the function of the reservoir and has the potential to cause disease due to the microbes and parasites produced (Sutriati & Ginting, 2012).

One of the most widely used water waste treatment methods is constructed wetlands. Construted wetland is an artificial wetland as a place for waste treatment which is a waste treatment process by imitating the water purification process in natural wetlands or swamps (Sutyasmi & Susanto, 2013) and where construted wetland can reduce the harmful effects of waste, as well as contribute to water conservation efforts (Suswati & Wibisono, 2013). The CWs method has great potential for use in developing countries with tropical and subtropical climates as an alternative to wastewater treatment (Qing *et al.*, 2015). Waste treatment using the CWs method has been applied to black water waste, especially in the absorption of nitrogen, where nitrogen is the primary pollutant in that waste (Li *et al.*, 2021). This method is simple, and the energy used is only sourced from domestic wastewater. In addition, planting aquatic plants in the installation will add aesthetic value to reservoir B. This method's maintenance cost is relatively low, it is highly efficient, and it is easy to operate. This study aimed to analyze the application of the Constructed Wetlands (CWs) method by creating a pilot project for improving input wastewater (influent) in Reservoir B, Lampung University.

2. Methods

2.1 Study site

The study was conducted from July to October 2024. The domestic wastewater samples tested came from Reservoir B Lampung University with coordinates 5°21'56.86"S, 105°14'20.07"T, and an altitude of 114 masl (Figure 1). The CWs method testing was conducted at the Laboratory of Water and Land Resource Engineering, Lampung University. Wastewater sampling was carried out in the morning (07.00) and afternoon (17.00), assuming a higher volume of waste produced. The water collected amounted to 48 liters and was divided into 4 treatments.

Figure 1. Sampling location.

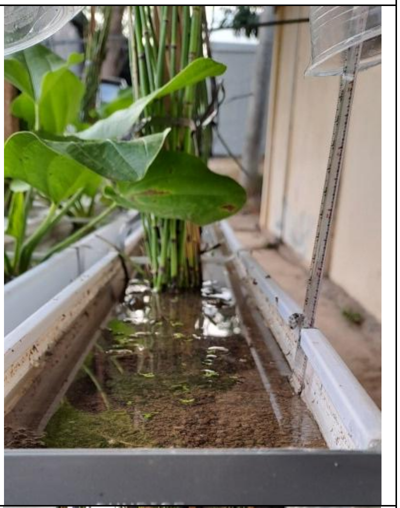
To support the research, the tools used were a simple CWs reactor made of gutters with dimensions of length, width, and height in a sequence of 200 x 12 x 10 cm, a 1-liter measuring cup, a 5-liter bucket, and a ruler. In addition, the measuring tools used included pH-2Pro Digital LCD pH meter, A1 E-1 TDS EC meter 3 in 1, smart sensor AR8210 Dissolved Oxygen (DO) meter, TA318 digital thermometer hygrometer weather indoor and outdoor, solar power meter, manual bench scales. The materials used were samples of domestic wastewater, water bamboo plants (*Equisetum hyemale*), water jasmine (*Echinodorus palaefolius*), soil from water channel sediments, and planting media with a mixture of compost and burnt rice husks.

The independent variables used in this study were plant species, planting media conditions, and observation duration. The dependent variables observed included water quality parameters such as pH, Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Ammonia (NH_3-N), Total Dissolved Solids (TDS), Electrical Conductivity (EC), temperature, and Dissolved Oxygen (DO).

2.2 Experimental design

The duration of the test used was 4 days. The test was carried out using a reactor designed with 2 treatments. The treatments used were different types of aquatic plants and planting media conditions (Table 1). The CWs reactor design is shown in Figure 2. Using plants in the CWs method requires the acclimatization of the plants to clean the plants from dirt on the stems, roots, and leaves (Nadhifah *et al.*, 2019). After that, the plants were allowed to grow in the reactor for about 2 weeks before applying the treatment.

Table 1. Treatment combinations

Initial treatment	Plants variety	Media condition	Picture
1	*Equisetum hyemale*	Without mossy on the surface of planting media	
2	*Echinodorus palaefolius*	Without mossy on the surface of planting media	

Initial treatment	Plants variety	Media condition	Picture
3	*Equisetum hyemale*	Mossy on the surface of planting media	
4	*Echinodorus palaefolius*	Mossy on the surface of planting media	

Figure 2(a) shows the CWs design used. Figure 2(b) is a vertical view of the method used. The height of the planting medium used was 6 cm, and the planting distance between plants was 80 cm in each treatment.

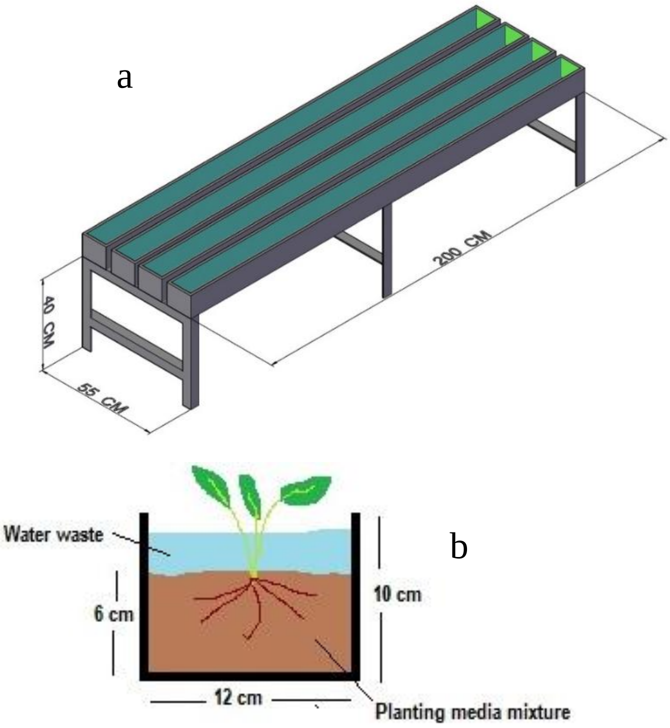


Figure 2. (a) Longitudinal section and (b) cross section of the CWs Reactor.

2.3 Observation, measurement, and analysis

Before the measurement was carried out, observations were made on the characteristics of domestic wastewater (influent) flowing into Reservoir B, Lampung University, for one week. These observations were carried out every morning from 06.00 to 07.00 and in the afternoon from 16.00 to 18.00. The parameters observed included pH, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and the height of the wastewater flow.

After the wastewater characteristics were obtained, testing was carried out using a CWs reactor. The wastewater used in the test (influent) was collected directly for one day. Furthermore, the wastewater was divided and flowed to each treatment. During the test, the water was observed every morning (08.00-09.00) and afternoon (16.00-18.00) with parameters of pH, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), water evaporation, and Dissolved Oxygen (DO). Observations were made by taking water samples in each treatment following SNI 6989.59:2008 and measuring the values for each parameter. In addition to water observations, microclimate observations around the test location were carried out using parameters such as air temperature, humidity, and radiation intensity.

This study not only involved direct observation but also analysis of wastewater samples before and after the application of the CWs method in the laboratory. The parameters analyzed included Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Ammonia (NH_3-N). Total Suspended Solids (TSS) were analyzed using the gravimetric method (SNI 6989.3-2019). Chemical Oxygen Demand (COD) and Total Ammonia (NH_3-N) were analyzed using the Spectrophotometric method. Biological Oxygen Demand (BOD) was analyzed using the SNI 6989.72:2009 method.

3. Results and Discussion

3.1 Influent characteristics observation

The characteristics of domestic wastewater influent were measured for 7 days before the CWs model was designed. The results of observations of wastewater characteristics in the influent of reservoir B are shown in Table 2.

Table 2. Characteristics of wastewater in the influent of reservoir B

Date	Water level (cm)	Temperature (°C)	pH	EC (µs/cm)	TDS (ppm)
(a) Morning observation					
16/07/2024	0.5	23.6	7.93	316	77.5
17/07/2024	0.5	25.4	7.64	226	134
18/07/2024	1.3	25.9	7.51	232	116
19/07/2024	1.3	26.2	7.69	303	151
20/07/2024	0.5	23.6	7.5	103	125
21/07/2024	1.3	29.9	8.38	304	152
22/07/2024	1.3	25.5	7.5	212	150
Average	1.0	25.7	7.7	242.3	129.4
(b) Afternoon observation					
16/07/2024	1.3	27.1	7.99	292	146
17/07/2024	1.2	26.9	7.7	327	163
18/07/2024	1.3	27.5	7.61	314	157
19/07/2024	1.3	27.9	7.79	299	149
20/07/2024	1	2	8.25	294	147
21/07/2024	1.2	28.9	8.2	290	145
22/07/2024	1.3	29	7.32	247	126
Average	1.2	24.2	7.8	294.7	147.6

Based on Table 2, the height of wastewater is higher in the afternoon, indicating an increase in the volume of influent entering the system. In addition, the Electrical Conductivity (EC) and Total Dissolved Solids (TDS) values also increased compared to the morning, indicating that more domestic waste is produced in the afternoon. Conversely, the influent temperature tends to be higher in the morning, which is influenced by weather conditions around the observation environment. Meanwhile, the influent pH value is in the range of 7.7–7.8, indicating neutral conditions.

3.2 Microclimate conditions during observation

Based on microclimate data during the Constructed Wetlands (CWs) method testing (Table 3), the average air temperature in the morning was recorded at 31.0°C, while in the afternoon, it was higher, namely 33.3°C. The increase in temperature in the afternoon is in line with the higher intensity of solar radiation, where the average radiation in the morning reached 90.6 W/m². In comparison, in the afternoon, it increased to 222.4 W/m². In addition, the average relative humidity in the morning was recorded at 59.0%, while in the afternoon it decreased to 53.0%. This decrease in humidity can be associated with an increase in air temperature and solar radiation intensity in the afternoon, which causes an increase in the evaporation rate in the environment around the CWs system.

Table 3. Microclimate condition during testing

Date	Temperature (°C)	Relative Humidity (%)	Solar Radiation (W/m^2)
Morning observation			
29/10/2024	31.9	57	88.3
30/10/2024	31.2	58	88.8
31/10/2024	30.6	59	120.9
01/11/2024	30.4	62	64.3
Average	31.0	59	90.6
Afternoon observation			
28/10/2024	35.2	49	372.8
29/10/2024	34.5	52	487.6
30/10/2024	31.9	53	24
31/10/2024	31.7	58	5
Average	33.3	53	222.4

Environmental factors, especially microclimate conditions such as temperature, humidity, and solar radiation intensity, play an important role in the wastewater treatment process using CWs. Higher temperatures in the afternoon can affect microbial activity in the CWs system, which plays a role in the decomposition and absorption of pollutants. Zhao *et al.* (2022) state that environmental conditions, including temperature and humidity, greatly influence microbial activity in the waste decomposition process. The microclimate dynamics around the CWs system are important in evaluating the effectiveness of domestic wastewater treatment in Reservoir B of Lampung University.

3.3 Water quality condition during experiment

Water quality parameters such as pH, temperature, TDS, EC, and DO can be used as indicators to assess the effectiveness of the CWs system in treating domestic wastewater before it enters the water body (Reservoir B). The diversity of values during testing can reflect the activity of microorganisms, decomposition of organic compounds, and oxidation rates. Periodic parameter monitoring is essential to evaluate the stability and efficiency of the system in improving wastewater quality.

Figure 3a shows the change in pH values for 87 hours from 4 treatments. The variation in pH values produced showed a consistent fluctuation in the four treatments. The highest pH value was achieved by Treatment 4 at 22 hours, which was 8.58. This increase was most likely influenced by the photosynthetic activity of water jasmine and moss plants, which can reduce the concentration of dissolved CO_2, thereby increasing the pH (Liu *et al.*, 2019). Water jasmine plants have extensive canopy growth and high photosynthetic intensity, contributing to the stability of the system's pH. In addition, the activity of microorganisms is influenced by the pH conditions of the planting medium in the pH range of 5-7 (Fajar *et al.*, 2022). In general, the pH trend showed a uniform fluctuating pattern. The final pH values of each treatment were: Treatment 1 (7.73), Treatment 2 (7.74), Treatment 3 (7.69), and Treatment 4 (7.70). In addition to biological factors, the decrease in water volume contributed to changes in pH values. Figure 3f shows that the water volume decreased drastically from 12 liters to only 2.5–4 liters at the end of the observation.

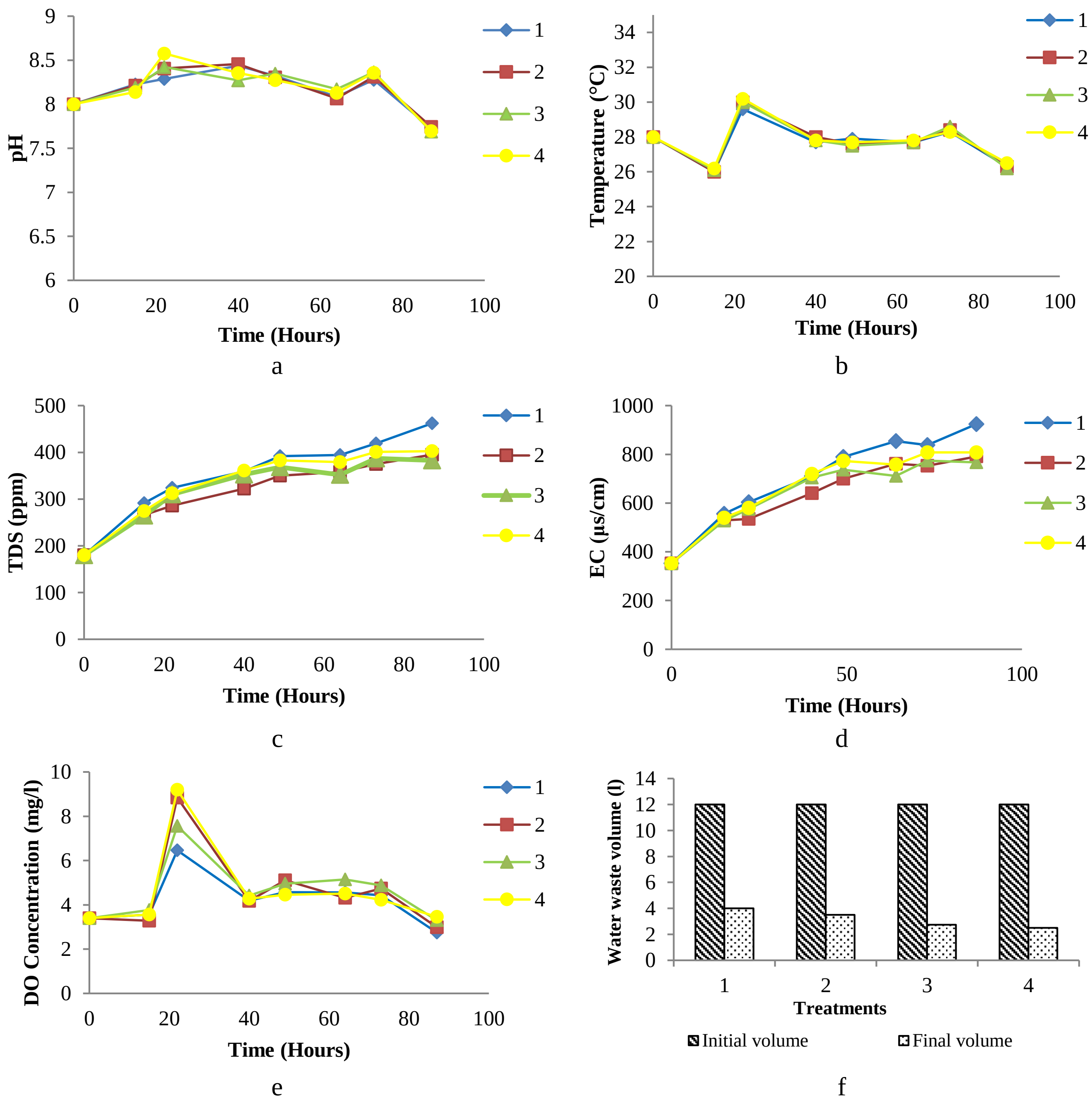


Figure 3. Changes in the values of (a) pH, (b) temperature, (c) TDS, (d) EC, (e) DO, and (f) volume of wastewater in the CWs test results.

Figure 3b shows the variation in wastewater temperature in line with changes in ambient temperature (Table 3). The decrease in waste temperature at hour 15 was most likely due to the lower ambient temperature in the morning. Conversely, the increase in waste temperature at hour 22 coincided with the higher ambient temperature during the day. This shows that the temperature of waste in an open system is greatly influenced by the ambient air temperature, especially since the media is in an open condition without thermal protection. High or low ambient temperatures can affect the occurrence of chemical reactions, reaction rates, and the activity of aquatic microorganisms (Ramadani *et al.*, 2021).

During 87 hours of observation, the Total Dissolved Solids (TDS) value increased in all treatments (Figure 3c), but the highest increase occurred in treatments without moss (Treatments 1 and 2), which reached up to 462 ppm. In contrast, treatments with moss on the top layer of the media (Treatments 3 and 4) showed lower TDS accumulation, namely 383 and 386 ppm. This indicates that the presence of moss plays an important role in inhibiting the increase in dissolved substances. Despite experiencing greater volume shrinkage (Figure 3f), TDS in the treatment with moss remained lower, strengthening the assumption that moss can actively absorb dissolved substances and maintain water quality despite evaporation or water shrinkage. This process likely involves bioaccumulation and the activity of microorganisms associated with moss. Vymazal (2010) stated that plants and microbes in the CWs system can absorb nutrients and dissolved ions effectively. Thus, the presence of moss not only helps stabilize TDS, but also provides resilience to CWs systems against fluctuations in water volume due to evaporation, making it an essential component in improving wastewater treatment efficiency.

Electrical Conductivity (EC) values (Figure 3d) increased in all treatments. The initial EC value of 353 µS/cm became 766.5–924 µS/cm. The highest increase was recorded in the treatment without moss (treatment 1), while the lowest occurred with a layer of moss on the top of the media (treatment 3). This pattern indicates that moss contributes to reducing dissolved ions, directly impacting the decrease in EC. One of the causes is thought to be due to the reduction in water volume during observation (Figure 3f). When water evaporates, and no new water is added, the concentration of dissolved substances will automatically increase, which is then reflected in the increase in EC values. Treatments without moss (1 and 2) appear to experience a sharper increase in EC compared to treatments 3 and 4, which use moss on the top of the planting media. In this case, moss plays an important role in helping to absorb nutrient ions and other compounds through adsorption and assimilation mechanisms (Bačkor *et al.*, 2023), thereby suppressing the rate of increase in EC in the Constructed Wetlands (CWs) system.

During 87 hours of observation, DO concentration increased sharply to a peak at hour 22, especially in treatments using moss and plants, with the highest value in treatment 4 (water jasmine with moss) of 9.19 mg/L. This shows that the presence of moss and plant species such as water jasmine can increase photosynthesis and enrich dissolved oxygen in water. The percentage of oxygen increases with increasing pH value (Ginghină *et al.*, 2020). Furthermore, DO decreases gradually, presumably due to reduced water volume due to evaporation, transpiration, and increased oxygen consumption by microorganisms. Overall, combining plants and mossy media effectively maintains oxygen quality in the Constructed Wetlands system (Hassan *et al.*, 2021).

In general, the combination of plant types and mossy planting media plays a role in maintaining water quality. Water bamboo plants with moss are more effective in reducing EC and TDS, while water jasmine tends to have a more substantial effect on pH stabilization and increasing DO. These findings indicate the importance of selecting the appropriate combination of plants and planting media to improve the overall performance of the Constructed Wetlands system.

3.4 Effectiveness of constructed wetlands

Reservoir B of Lampung University is a water body in the class 3 water category. The explanation in government regulation No. 22 of 2021 states that class 3 water is intended for freshwater fish farming and livestock and can be used for irrigation water (Government Regulation, 2021). The quality standards are based on these regulations to test the effectiveness of applying the CWs method in this study, with water quality specifications for class 3. The water observed was wastewater before treatment and water after treatment. The test results are shown in Table 4.

The observation results showed an increase in water quality after treatment. Based on comparing the initial value before treatment and referring to the domestic wastewater quality standards in PP No. 22 of 2021 (Table 4). The water temperature in all treatments ranged from

26.2°C to 26.5°C, remaining within the tolerance limit of environmental temperature deviation, where it does not interfere with the biological processes occurring in the system. A visible change occurred in the TSS parameter, where the initial value was 46.92 mg/L (already below the quality standard of 100 mg/L). However, after treatment, the value dropped to 16.21 mg/l (Treatment 2) and 18.58 mg/l (Treatment 4), indicating the ability of water jasmine plants to trap suspended particles. Although not stated explicitly, the results of similar studies show that the influence of water jasmine plants used in wastewater treatment from a landfill has the potential to improve water quality including TSS content in waste through absorption by stems, roots, and sedimentation in the planting medium (Sari *et al.*, 2019).

Table 4. Results of wastewater testing before and after application of the CWs method

Parameter	Quality Standard (PP No. 22, 2021)	Initial Treatment Value	Final Value in the Treatments			
			1	2	3	4
Temperature (°C)	Dev.3	28	26,3	26,3	26,2	26,5
TSS (mg/l)	100	46,92	39	16,21	24,78	18,58
BOD (mg/l)	6	37	129	105	22	59
COD (mg/l)	40	105	360	300	60	130
NH3-N (mg/l)	1,9	12,26	1,4	1,13	1,58	1,61
pH	6 - 9	8	7,73	7,74	7,69	7,70
TDS (mg/l)	1000	180	462	395	383	402,5
DO (mg/l)	3	3,4	2,74	2,98	3,30	3,46

In BOD and COD, only Treatment 3 (water bamboo with moss) showed a decrease, where the BOD value dropped from 37 to 22 mg/l, and the COD from 105 to 60 mg/l, although it did not meet the quality standards (BOD ≤ 30 mg/L; COD ≤ 100 mg/L). On the contrary, in Treatments 1 and 2 (without moss), the values increased, indicating that plants alone were insufficient to suppress organic compounds optimally. A decrease in value also occurred in ammonia (NH_3-N), from 12.26 mg/l to 1.0 mg/l, approaching the quality standards in Treatment 3 (1.58 mg/l) and Treatment 4 (1.61 mg/l). The decrease in value shows the important role of plants and moss in absorbing or degrading nitrogen compounds through biological processes (Van Der Wal et al., 2005). The pH value remained stable in the range of 7.69–7.74 and was still within safe limits (6–9), indicating no disturbance to the system's balance.

TDS values increased from 180 mg/l to a maximum of 462 mg/l (Treatment 1), but were still far below the standard of 1000 mg/l. Treatments 3 and 4 (with moss) showed a lower increase in TDS, indicating the role of moss in absorbing dissolved ions. In the DO parameter, only Treatments 3 and 4 managed to maintain dissolved oxygen levels above the minimum limit of 3 mg/l, at 3.30 and 3.46 mg/l, respectively, indicating environmental conditions that support aerobic microorganisms. Treatment 3 (water bamboo with moss) was the most effective in reducing pollutant concentrations and approaching the standard for most parameters, followed by Treatment 4 (water jasmine with moss). These results indicate that the combination of plants and moss has greater potential to increase the effectiveness of the constructed wetlands (CWs) system compared to using plants alone.

4. Conclusion

Based on the research results, the Constructed Wetlands (CWs) method with the treatment of water bamboo and water jasmine plants, with mossy and moss-free planting media, is efficacious in improving the quality of domestic wastewater before entering Reservoir B, Lampung University. The combination of water bamboo with moss (P3) and water jasmine with moss (P4) treatments showed the best results, with several parameters such as TSS, pH, and NH3-N having met the domestic wastewater quality standards based on government regulation No. 22 of 2021. Although several other parameters, such as BOD and COD, have not fully reached the quality standard threshold, the concentration has decreased significantly compared to the initial conditions. This shows that the CWs system has good potential as an environmentally friendly and low-cost alternative technology for domestic wastewater treatment, especially on a small scale, such as in a campus or residential areas.

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