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The Combination of Filter and Constructed Wetland for Home Industry Batik Wastewater Treatment

Diana Rahayu[1*], Andri Arthono[2], Adinda Rizki Virginia[3], Elviana[4], Reskiana Saefuddin[5], Alimuddin[6]

[1,2,3] Civil Engineering, Faculty of Science and Technology, Institut Sains dan Teknologi AL-Kamal, Jakarta, Indonesia

[4]Packaging Engineering Technology, Faculty of Industry Technology, Politeknik Negeri Media Kreatif, Jakarta, Indonesia

[5] Research Center for Limnology and Water Resources, Badan Riset dan Inovasi Nasional, Jakarta, Indonesia

[6]Civil Engineering, Faculty of Technology and Science, Universitas Ibn Khaldun, Bogor, Indonesia

[1*]dianarahayu@ista.ac.id, [2]andriarthono@ista.ac.id, [3] adinda.rizki.v@ista.ac.id, [4]elviana@polimedia.ac.id, [5] resk001@brin.go.id, [6]alimuddin@uika-bogor.ac.id

ABSTRACT

The batik industry produces liquid waste, with up to 80% of the total water used ultimately discharged into the environment. This wastewater contains heavy metals, suspended solids, oil, and grease. However, the majority of the batik industry in Indonesia operate on a small-scale basis and discharge its effluent without prior treatment, posing a significant risk of environmental pollution and threatening ecosystems and human health. Consequently, this study aims to test the application of a nature-based solution constructed wetland as an alternative for batik wastewater treatment. An experimental method was employed, utilizing a laboratory-scale constructed wetland system integrating filters and phytoremediation. The dimensions of the constructed wetland reactor used in this study were 25 cm x 25 cm x 40 cm, with a layered configuration of 5 cm gravel, 10 cm coconut coir, 10 cm coconut shell activated carbon, 5 cm sand, an 8 cm water level, and a 3 cm freeboard. The tested parameters were BOD, COD, TSS, oil, and grease. The removal efficiency percentage was calculated. The results from a 24-hour retention time showed that in the control reactor (CWs_A), the values decreased by 14% for BOD, 14% for COD, 8% for TSS, and 4% for oil and grease. In the reactor vegetated with Amazon Frogbit (*Limnobium laevigatum*) (CWs_B), the reduction was 7% for BOD, 7% for COD, 38% for TSS, and 15,5% for oil and grease. The results were not yet significant in the reduction of all observed parameters, indicating the necessity for further research development.

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1. INTRODUCTION

Over six thousand batik industries are now operational across 27 provinces in Indonesia (Diyah et al., 2023). The batik industry has experienced significant growth since UNESCO recognized it as an Intangible Cultural Heritage of Humanity (Heraningsih et al., 2023; Siregar et al., 2020). However, behind the beautiful motifs and embedded cultural value, the dyeing and washing processes generate a substantial volume of wastewater (Indrayani & Rahmah, 2018) amounting to up to 80% of the total water used in production (Dewi et al., 2022). The synthetic dyes utilized in batik production are predominantly environmentally hazardous due to their heavy metal content, including Chromium (Cr), Copper (Cu), Cadmium (Cd), Manganese (Mn), Lead (Pb), and Nickel (Ni) (Dini et al., 2023). Notably, only about 5% of the dyes used adhere to the fabric, while the remainder is discharged as effluent (Febrianti et al., 2023).

Meanwhile, the majority of batik industries in Indonesia remain small-to-medium-scale enterprises (SMEs) which lack adequate wastewater treatment infrastructure, resulting in the direct release of untreated effluent into aquatic environments (Liwun et al., 2020). Consequently, there is an urgent need for innovation in sanitation solutions for areas where the implementation of centralized or conventional wastewater treatment systems is unfeasible (Sánchez et al., 2023). There is a critical demand for treatment processes that are not only more cost-effective and affordable but also easier to maintain. Implementing pre-treatment can lessen the detrimental impact of batik wastewater on the environment. Standard treatment practices employ a multi-barrier approach—physical, chemical, and biological—whose objective is the removal of pollutants such as suspended solids, colloids, and dissolved organic and inorganic substances. Physical methods include techniques such as screening, sedimentation, filtration, centrifugation, and flotation. Meanwhile, phytoremediation is an example of a biological treatment method (Kencana & Radityaningrum, 2022). Phytoremediation utilizes plants to detoxify contaminated soil or water. This technique is not only economical and practical but also efficient in neutralizing pollutants like heavy metals and organic compounds. An additional advantage is its ecological benefit, contributing to environmental restoration. By improving soil conditions and the population of pollutant-degrading microbes, the plant's absorption and purification processes can be maximized, resulting in cleaner water (Dwi Prasetyo et al., 2022; Mahardika, 2025). The Constructed Wetlands method is a system that combines physical and biological approaches in water treatment (Sánchez et al., 2022).

Constructed wetlands are specifically engineered with design features such as optimized dimensions and selected aquatic plant species to enhance treatment effectiveness (Pérez et al., 2024). These systems utilize vegetation to cleanse wastewater by breaking down harmful substances (Khajah & Ahmed, 2024; Baehaqi & Alicia, 2025) and a substrate that functions as a medium for microbial development, plant growth, and pollutant retention. Substrates like sand and massive gravel are favored due to their abundant availability, low cost, and high pollutant retention capacity (Cakin et al., 2024).

In addition to sand and gravel, this research will also employ substrates comprising activated carbon from coconut shell (Rusdianto et al., 2022) and coconut coir (Amira et al., 2022). Many researchers have utilized Constructed Wetlands (CWs) to find effective formulas for the use of materials and appropriate aquatic plants. For instance, measurements taken by (Hapsari et al., 2018) used water spinach to reduce lead (Pb) levels. Similarly, (Dwi Prasetyo et al., 2022) measured reductions in pH and TDS using Salvinia molesta, Marsilea crenata, and Azolla pinnata plants. Therefore, the primary objective of this study is therefore to assess the performance of an integrated multi-media filter (using sand, coconut shell activated carbon, coconut coir, and gravel) and constructed wetland system, which utilizes Amazon Frogbit (Limnobium laevigatum), in treating wastewater by reducing concentrations of COD, BOD, TSS, and oil & grease. State of the are in this study is the use of Amazon frogbit as a phytoremediation agent, which has not been implemented in previous research. The research focuses on the organic and suspended solids parameters that are most relevant to the performance of CWs.

2. METHOD

This research utilized a pre-experimental methodology, employing a design structure that incorporated both pre-test and post-test measurements within a single group (Indraswari et al., 2023). Two treatment containers were used, comprising a control and a variant with the addition of 80 grams of Amazon Frogbit (*Limnobium laevigatum*) characterized by a minimum of three leaf blades. Each container had a volume of 25 liters, with a filter volume to batik wastewater ratio of 1,07 : 1, and was observed for 24 hours. Samples were collected at a 24-hour retention time (3 samples): wastewater at the inlet, wastewater from the control reactor (CWs_A), and wastewater from the amazon frogbit reactor (CWs_B) for parameter testing.

2.1 Study

The batik wastewater sample was collected from one of the Batik home industry in Jakarta, geographically located at coordinates 106°50'45" East Longitude and 06°13'34" South Latitude. All observations for this study took place in the laboratory facilities of the Civil Engineering department at the Institute Science and Technology AL-Kamal, Jakarta. Meanwhile, water parameter testing was performed at the laboratory of PT. Unilab Perdana.

2.2 Substrate and Vegetation

The filter media used in this study consisted of sand, coconut shell charcoal, dried coconut coir soaked in water to remove tannins, and gravel with a diameter of 1-3 cm. The filter media were arranged in a reactor measuring 25 cm x 25 cm x 40 cm. Figure 1(a) illustrate the reactor for the control CWs system comprised the subsequent filter layers, arranged from bottom to top. The first layer consisted of 5 cm of gravel (10-30 mm). The second layer was sand with a thickness of 5 cm. The third layer was 10 cm thick of dried coconut coir.

The fifth and sixth layers were activated charcoal made from coconut shell, with a 10 cm thickness and an 8 cm depth of batik wastewater, as well as a 3 cm freeboard. As illustrated in Figure 1(b), the vegetation used was Amazon Frogbit (Limnobium laevigatum) with a fresh weight of 80 grams, a minimum of three leaf blades, and a root length of 0.5-1 cm. The selection of 80 grams for the plants used was based on the length and width of the CWs and the size of the plants. After weighing, the appropriate weight for the plants was 80 grams. Before being introduced into the CWs reactor, the plants were washed with water to remove residual soil from the previous growth medium. The filter configuration was identical to that of the CWs_A reactor**.**

(a) (b)

Figure 1. Filter configuration and depth (a) CWs-A left unplanted during the whole phases (b) CWs_B was planted with amazon frogbit (*Limnobium laevigatum*)

2.3 Experiment Setup and Operation

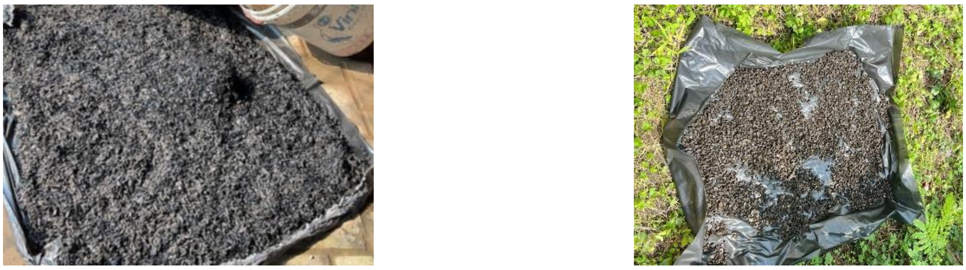
This experiment was conducted at the Civil Engineering laboratorium in the Institute Sains and Technology AL-Kamal, Jakarta, Indonesia. A detailed overview of the methodology, including a schematic of the experimental design, is provided in Figure 23 System CWs_A and CWs_B were prepared in parallel. Each system consisted of substrates was placed under the bottom layer and two CWs in series (CWs_A and CWs_B). The CWs was packed with plastic tub (L 250 × W 250 × H 400 mm, 25 litres) Each reactor was filled with 19 L of filter media and 18 L of wastewater. The CWs specifications are presented in the **Tabel 1** below.

Table 1. Specification of CWs

Parameters	Unit	Value
CWs length	cm	25
CWs width	cm	25
CWs high	cm	40
Volume of CWS	cm3	24963,5
	L	25,0
Volume of filter	cm3	19202,7
	L	19

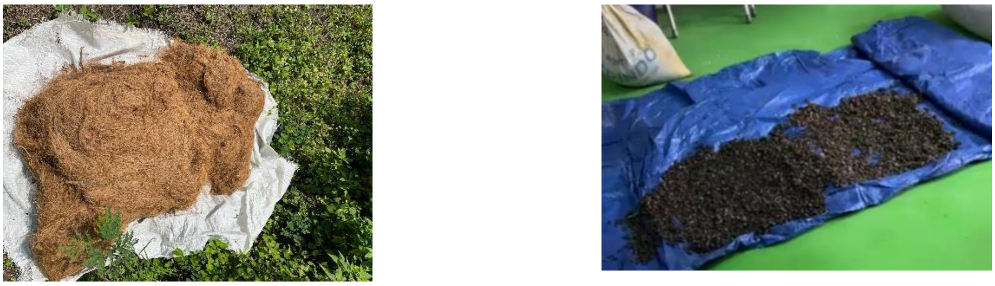
Parameters	Unit	Value
Volume of waste water	L	18
Average detention time	hour	0,88
Average water discharge	L/ hour	21
Retention time	hour	24
Vegetation weight per CWs	gram	80

Batik wastewater from a 120 L tank was fed by gravity from a storage tank into the CWs reactor tanks at an average flow rate of 21 L/hour. The study was conducted over 50 days, comprising a 14-day period for vegetation (Amazon Frogbit) seedling cultivation period; a 10-day for plant acclimatization phase; a 13-day period for initial filter preparation in the CWs reactors, following flow rate calculation, and observational setup; and the last 18-days were for water parameter testing phase. Filters made from sand, gravel, dried coconut fiber, and coconut shell charcoal are repeatedly washed and dried before being installed in the CWs. This removes impurities such as mud from the sand and dirt, reduces the black color of the water from the coconut shell charcoal, and reduces the yellow color from the dried coconut fiber. The selection of 80 grams for the plants used was based on the length and width of the CWs and the size of the plants. After weighing, the appropriate weight for the plants was 80 grams. Washing and drying the filter as shown in the **Figure 2** below.



(a) Coconut shell charcoal

(b) Gravel



(c) Dried coconut fiber

(d) Sand

Figure 2. Washing and drying the filter

The plant acclimatization process is essential to allow plants to adapt and thrive in their new media and environment (Kencana & Radityaningrum, 2022). In this study, plant acclimatization consisted of two stages: 50% and 100% acclimatization, with each phase lasting 5 days.

2.4 Sampling and Analysis

Influent (inflow) and effluent (outflow) water samples were collected from each treatment unit to determine the effectiveness of the constructed wetland–based treatment system. Sampling was conducted once after the system reached a 24-hour hydraulic retention time (HRT), ensuring that the collected samples represented the stabilized operating condition of the reactor. Subsequent laboratory analyses were performed to characterize the wastewater quality before and after treatment. The assessed parameters included biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and oil and grease. Each parameter was analyzed in strict accordance with the applicable Indonesian National Standards (SNI), namely SNI 6989.72:2009 for BOD, SNI 6989.15:2019 for COD, SNI 6989.3:2019 for TSS, and SNI 6989.10:2011 for oil and grease. Compliance with these standardized methods ensured the reliability, accuracy, and comparability of the analytical results. The overall performance of the integrated filtration–phytoremediation reactor was quantified using removal efficiency, which reflects the percentage reduction of pollutant concentration between influent and effluent. The removal efficiency for each parameter was calculated using Equation (1), allowing for a systematic evaluation of the reactor's capability in improving wastewater quality.

$$\textbf{Removal Efficiency (\%)} = \mathbf{(Co - Cs / Co) \times 100\ \%} \qquad \text{(Amira et al, 2022)}$$

Where:
C0 = initial parameter concentration
Cs = parameter concentration after treatment

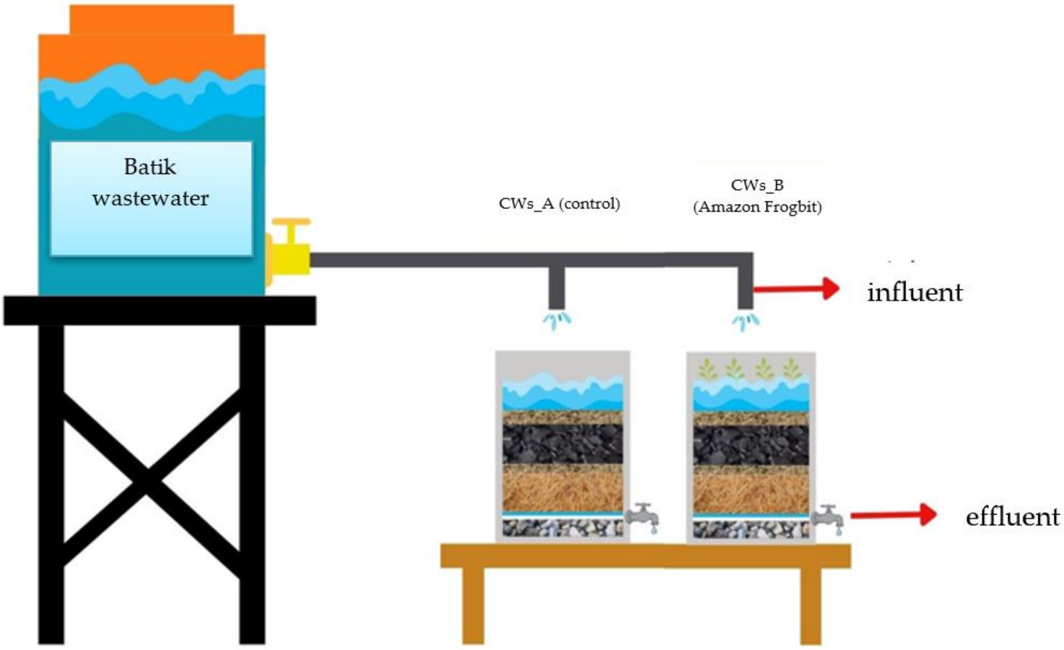


Figure 3. Diagram of Vertical Flow and constructed wetland (CW) systems used for wastewater treatment

3. RESULTS AND DISCUSSION

3.1 Home Industry Batik Wastewater Characteristics

After the Constructed Wetland Model for Home Industry Batik Wastewater Treatment is installed as shown in the **Figure 4**. Next, the wastewater quality characteristics of the influent are tested first.

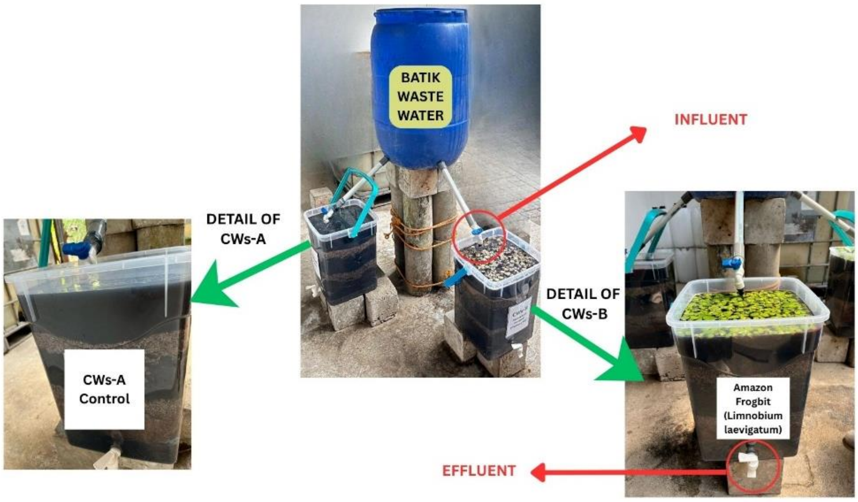


Figure 4. Constructed wetland model for home industry batik wastewater treatment

The concentration values of batik wastewater from a home-based batik production industry (X) in South Jakarta, the analytical results in Table 1 show that the effluent concentrations for key parameters—BOD, COD, TSS, and oil & grease—far surpass the regulatory limits stipulated in Indonesian Ministry of Environment and Forestry Regulation No. P.16/Menlhk/Setjen/KUM.1/4/2019, Annex II. The measured values for these pollutants were substantially higher, at 4,035 mg/L, 10,088 mg/L, 1,623 mg/L, and 946 mg/L, respectively.

According to (Kiswanto et al., 2019) wastewater from the batik industry is predominantly dominated by dyes such as Remazol Black, Red, and Golden Yellow, which generally contain stable, non-biodegradable organic compounds. The stability of these compounds complicates natural degradation processes, particularly at high concentrations, thereby potentially increasing pollutant parameters and causing contamination of aquatic environments.

Table 2. Wastewater Influent Test Results

No.	Parameter	Unit	Result*	Quality Standard** (mg/L)
1	BOD	mg/L	4.035	60
2	COD	mg/L	10.088	150
3	Suspended Solid (TSS)	mg/L	1.623	50
4	Oil and Grease	mg/L	946	3

Source : *Analysis Source PT Unilab Perdana, 2025
**The Minister of Environment and Forestry of the Republic of Indonesia No. P.16/Menlhk/Setjen/KUM.1/4/2019, Annex II.

3.2 Concentration of Treatment Parameters in the Integrated Filter and Constructed Wetland System

Effluent from the integrated filter and constructed wetland treatment system was sampled at the outlet of each reactor. Laboratory analysis results indicated a reduction in parameter concentrations in both the CWs_A and CWs_B reactors following a 24-hour hydraulic retention time (HRT) treatment period, compared to the unprocessed influent concentrations.

Table 2. Concentration of BOD in each reactor

Reaktor	Quality Standard* (mg/L)	C_0**	Cs**	% R
CWs_A			3488	14%
CWs_B	60	4035	3754	7%

Source: *The Minister of Environment and Forestry of the Republic of Indonesia No. P.16/Menlhk/Setjen/KUM.1/4/2019, Annex II
**Analysis Source PT Unilab Perdana, 2025
Where: C_0 = initial parameter concentration
C_s = parameter concentration after treatment
%R = removal efficiency

Biochemical Oxygen Demand (BOD) is an analytical parameter that reflects the amount of dissolved oxygen consumed by microorganisms during the aerobic degradation of organic matter in water (Safitri et al., 2023). In wastewater treatment engineering, BOD serves as a fundamental indicator of organic pollution levels because it represents the biodegradable fraction of organic contaminants present in the wastewater. Accordingly, the BOD removal efficiency provides a direct measure of a treatment system's ability to decompose and stabilize organic compounds, thereby indicating the overall effectiveness of the biological processes within the reactor (Salim, 2021).

A comparative assessment of the influent and effluent values presented in **Table 2** demonstrates that the CWs_A configuration achieved a higher reduction in BOD concentration compared to the CWs_B system. This suggests that CWs_A possessed a more efficient microbial degradation environment potentially due to differences in substrate composition, hydraulic behavior, or plant–microbe interactions—which collectively enhanced the removal of biodegradable organic matter.

Table 3. Concentration of COD in each reactor

Reaktor	Quality Standard* (mg/L)	C_0**	Cs**	% R
CWs_A			8719	14%
CWs_B	150	10088	9384	7%

Source: *The Minister of Environment and Forestry of the Republic of Indonesia No. P.16/Menlhk/Setjen/KUM.1/4/2019, Annex II
**Analysis Source PT Unilab Perdana, 2025
Where C0 = initial parameter concentration
Cs = parameter concentration after treatment
%R = removal efficiency

As presented in **Table 3**, the COD concentration in reactor CWs_A decreased by 14% from the initial concentration (C_0), whereas in reactor CWs_B, the reduction was only 7%. The decline in BOD and COD concentrations during the treatment process, as suggested (Sandhika et al, 2022) is likely attributable to the degradation of compounds and biomass in the wastewater into simpler forms by microorganisms within the plant-based biofiltration system. These degradation byproducts are subsequently absorbed by plant roots as nutrients, leading to a reduction in BOD and COD concentrations with increased hydraulic retention time within the system.

Table 4. Concentration of TSS in each reactor

Reaktor	Quality Standard* (mg/L)	C_0**	Cs**	% R
CWs_A	50	1623	1500	8%
CWs_B			1000	38%

Source: *The Minister of Environment and Forestry of the Republic of Indonesia No. P.16/Menlhk/Setjen/KUM.1/4/2019, Annex II
**Analysis Source PT Unilab Perdana, 2025
Where: C0 = initial parameter concentration
Cs = parameter concentration after treatment
%R = removal efficiency

A more substantial reduction in TSS concentration was observed in reactor CWs_B compared to CWs_A, amounting to 38% on **Table 4.** TSS removal in constructed wetlands is principally governed by two mechanisms: particle interception by plant roots and stems, and sedimentation. These processes were responsible for reducing the initial concentration of 1,623 mg/L to a final value of 1,000 mg/L. (Salim, 2021) within this context, the plant root system contributes significantly by stabilizing the substrate material at the base of the tank. This stabilization not only enhances sedimentation efficiency but also minimizes the potential for particle resuspension. Furthermore, suspended particles with high density and large size undergo gravitational settling as they pass through the plant root zone.

A similar trend was observed for oil and grease concentrations (Table 5), which decreased by 4% in reactor CWs_A and 15.5% in reactor CWs_B. In batik wastewater, the fabric processing and wax-removal (lorodan) stages generate organic waste in the form of wax and starch paste (Safamaura & Afany, 2025) thereby elevating oil and grease concentrations. The constructed wetland system CWs_B proved more effective in reducing oil concentration due to the presence of plant roots, which absorb organic and inorganic pollutants in the form of dissolved ions. These ions are subsequently translocated to the stems via the xylem vascular tissue and then distributed to the leaves (Fitriani Nur & Isworo Slamet, 2020).

Table 5. Concentration of oil and grease in each reactor

Reaktor	Quality Standard* (mg/L)	C_0**	Cs**	% R
CWs_A			909	4%
CWs_B	3	946	800	15,5%

Source: *The Minister of Environment and Forestry of the Republic of Indonesia No. P.16/Menlhk/Setjen/KUM.1/4/2019, Annex II
**Analysis Source PT Unilab Perdana, 2025
Where: C0 = initial parameter concentration
Cs = parameter concentration after treatment
%R = removal efficiency

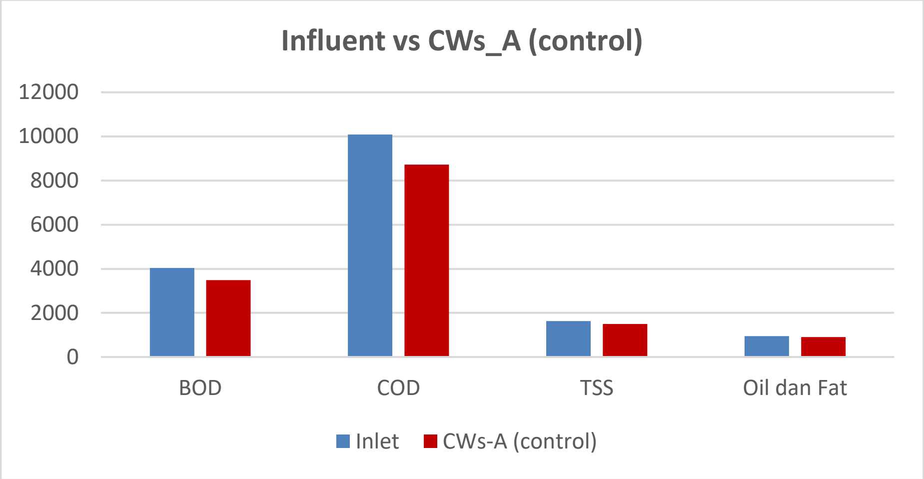


Figure 5. Comparative analysis of pollutant removal efficiency

A comparison of initial parameter concentrations with those in CWs_A revealed that the most effective reduction achieved by this reactor was for BOD and COD, both decreasing by 14%. This was followed by an 8% reduction in TSS and a 4% reduction in oil and grease, as illustrated in **Figure 5.** Conversely, a comparison between the influent and CWs_B effluent concentrations, detailed in **Figure 6,** showed that the most substantial reduction was in the TSS parameter (38%), followed by oil and grease (15.5%). The BOD and COD parameters were reduced by 7% each.

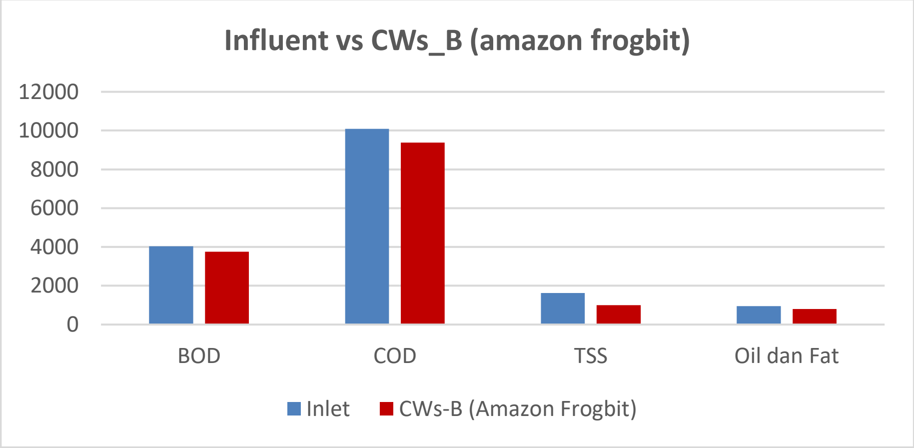


Figure 6. Comparison of initial concentration of parameters with CWs_B

Based on **Figure 6**, the pollutant removal efficiency observed in this study can be attributed to the filtration process utilizing various media with specific functions. Silica sand media played a role in removing physical pollutants such as turbidity, Total Suspended Solids (TSS), and odor. Meanwhile, activated carbon was effective in eliminating odor, color, gaseous chemicals, heavy metals, and organic impurities. Coconut coir media also demonstrated potential as a biosorbent and bioaccumulator for heavy metals. In addition to filtering coarse particles and providing mechanical stability a role shared with activated carbon the sand media, along with gravel, functioned to filter suspensions and solids in the liquid waste (Kencana & Radityaningrum, 2022).

Aquatic plants contributed significantly to reducing environmental pollutant levels. Several studies, including (Oktorina et al., 2020), confirm that these plants enhance wastewater quality through decomposition mechanisms. One primary mechanism is phytostabilization, wherein plants immobilize contaminants by converting them into non-toxic compounds without absorbing them into their tissues. The conversion products are then bound and preserved (immobilized) on the root surface. This immobilization ensures that pollutants are stably bound to the roots, preventing them from being easily dislodged and carried away by water flow. This stabilization process is reinforced by rhizodegradation the degradation of pollutants in the root zone (rhizosphere) mediated by the activity of symbiotic microorganisms associated with the plant roots (Yunita & Asmoro, 2023). Furthermore, (Sukono et al., 2020) add that the decomposition rate in the rhizome zone is slower than in other parts of the plant. This is because the process heavily relies on the performance of microorganisms that consume and degrade organic material gradually.

3.3 Recommendation

The combined filter and wetland treatment system reduced pollution but failed to meet KLHK's required discharge standards. This shortfall is likely due to the fact that a critical Range Finding Test (RFT) was not conducted prior to the study. An RFT is an essential preliminary stage designed to determine the optimal pollutant concentration range that the test plants can effectively absorb (Kencana & Radityaningrum, 2022). This necessity was underscored during the plant acclimatization phase, where the plant leaves discolored and wilted after only two days, indicating inadequate tolerance to the initial wastewater strength. Therefore, a more complex treatment process integrating chemical, biological, and physical methods is required to achieve significant concentration reductions and ensure compliance with applicable quality standards. This would allow for the safe discharge of effluent into water bodies without causing environmental damage.

4. CONCLUSION

In terms of removal efficiency, the most effective reduction in reactor CWs_A was observed for BOD and COD, both at 14%. In contrast, the comparison between the inlet and reactor CWs_B showed the highest reduction was for TSS (38%), followed by oil and grease (15.5%). Despite these reductions, the treated effluent from both systems did not meet the KLHK standards, which stipulate maximum permissible concentrations of 60 mg/L for BOD, 150 mg/L for COD, 50 mg/L for TSS, and 3 mg/L for oil and grease. The insignificant decrease in BOD and COD parameter values in this study could be due to the absence of cutting of aquatic plant roots at the pre-treatment stage (Anggraini & Purnomo, 2022). After conducting this research, further research is needed regarding the innovation of special treatment for the use of coconut shell charcoal in order to eliminate the black color effect when mixed with wastewater in addition to treatment only by washing and drying repeatedly. There are many factors that need to be considered to ensure that the research can be conducted optimally, such as determining an effective and efficient reactor scale for reducing pollutant concentrations, conducting measurements in several stages including incorporating chemical treatment processes, and, lastly, selecting the appropriate aquatic vegetation for pollutant removal.

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