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Effectiveness of *Ipomoea aquatica* Forssk. on Decreasing COD and BOD Content Leachate using the Constructed Wetland Method at the Lempeni Landfill, Lumajang District

Efektivitas *Ipomoea aquatica* Forssk. terhadap Penurunan Kadar COD dan BOD Air Lindi dengan Metode *Constructed Wetland* di TPA Lempeni, Kabupaten Lumajang

FAHIMA AULIA ZAHRO[1], KHOIRON KHOIRON[1*]

[1]Public Health Program, Faculty of Public Health, Jember University (Universitas Jember), Jl. Kalimantan No. 37, Jember Regency, East Java, 68121, Indonesia
*Email: khoiron@unej.ac.id

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ABSTRAK

Lindi merupakan cairan hasil dekomposisi sampah yang menyebabkan ancaman lingkungan yang serius akibat kadar chemical oxygen demand (COD) dan biochemical oxygen demand (BOD) yang sangat tinggi. Studi ini menganalisis kinerja Ipomoea aquatica Forssk. (kangkung air) dalam menurunkan level COD dan BOD pada lindi dari Tempat Pembuangan Akhir (TPA) di Fasilitas Pengolahan Sampah Lempeni dengan memanfaatkan sistem lahan basah konvensional. Pendekatan eksperimen menggunakan desain kelompok kontrol pretes-postes tunggal, dengan sampel lindi masukan diambil dari instalasi pengolahan lindi TPA Lempeni. Temuan eksperimen mengindikasikan penurunan COD mencapai -2,8% di kelompok kontrol, 7.6% di kelompok perlakuan 1, 14% di kelompok perlakuan 2, serta 19,4% di kelompok perlakuan 3. Sementara itu, penurunan BOD tercatat sebesar 8,6%, 50,1%, 52,4%, dan 63,7% untuk kelompok kontrol, perlakuan 1, perlakuan 2, dan perlakuan 3 secara berurutan. Hasil tersebut membuktikan bahwa penerapan Ipomoea aquatica bersama teknologi lahan basah buatan mampu meningkatkan secara nyata efektivitas pengurangan zat pencemar organik di lindi, sehingga menonjolkan nilai potensialnya sebagai solusi fitoremediasi yang ramah lingkungan untuk penanganan limbah cair.

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ABSTRACT

Leachate, a liquid resulting from waste decomposition, poses a serious environmental threat due to its high levels of chemical oxygen demand (COD) and biochemical oxygen demand (BOD). This study examined the performance of *Ipomoea aquatica* Forssk. (water spinach) in reducing COD and BOD levels in leachate from the Lempeni Waste Processing Facility using a constructed wetland system. An experimental approach was employed with a single-group pretest-posttest control design, and the leachate samples were collected from the Lempeni Landfill Leachate Treatment Plant. The findings indicated COD reductions of -2.8% in the control group, 7.6% in treatment group 1, 14% in treatment group 2, and 19.4% in treatment group 3. Meanwhile, BOD reductions were recorded at 8.6%, 50.1%, 52.4%, and 63.7% for the control, treatment 1, treatment 2, and treatment 3, respectively. These results demonstrate that applying *Ipomoea aquatica* in conjunction with constructed wetland technology significantly enhances the removal of organic pollutants from leachate, highlighting its potential as an environmentally friendly phytoremediation solution for liquid waste management.

1. INTRODUCTION

1.1 Background

To this day, waste management remains a significant issue in Indonesia. The increasingly wasteful consumption habits of the public have accelerated the accumulation of waste year after year. This situation has positioned Indonesia as the second-largest waste-producing country in the world. According to a report from the Ministry of Environment and Forestry (KLHK, 2021), the amount of waste generated in 2021 reached 30,429,174.09 tons per year, with the majority originating from households. Of that total, approximately 64.78% has been appropriately managed, while the remaining 35.22% remains unaddressed, posing serious risks to public health and the environmental ecosystem.

Landfills serve as waste management facilities before waste is released into nature, in compliance with established safety standards. The waste compaction process in landfills produces a liquid called leachate. This liquid ranges in color from murky to dark. It contains various pollution indicators, such as organic matter, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), pH, and total dissolved solids (TDS). Leachate forms when waste piles are mixed with rainwater or groundwater, and it contains organic and inorganic compounds and pathogenic microorganisms that can contaminate the environment. Therefore, leachate from landfills must be treated before being discharged into river waters, as stipulated in the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia (KLHK, 2016).

Ineffective leachate treatment can be identified by elevated chemical oxygen demand (COD) and biochemical oxygen demand (BOD) levels. COD refers to toxic organic substances that microorganisms can break down through oxidation into CO_2 and H_2O. The safe environmental threshold for COD is 300 mg/L. On the other hand, BOD represents the amount of oxygen microorganisms require to break down organic matter in the water. To prevent environmental pollution, BOD levels must meet applicable quality standards, which are set at below 150 mg/L (Ramadhani & Asrifah, 2020).

In addition to leachate treatment plants, an alternative approach for further leachate processing is the constructed wetland method. This technique involves creating an artificial ecosystem that mimics the natural water filtration mechanisms of wetlands, with plants serving as agents that break down waste products, making it more environmentally sustainable (Astuti et al., 2017). A study by Siswoyo et al. (2020) showed that implementing the constructed wetland method using water hyacinth plants significantly reduced BOD, COD, cyanide, and TSS by 97.9%, 84.4%, 99.87%, and 45.6%, respectively. Meanwhile, research by Kasman et al. (2022) reported that canna lilies and water lettuce in constructed wetlands also effectively reduced BOD and COD levels by 84% and 86%.

Ipomoea aquatica Forssk., commonly known as water spinach, is one of the plants that shows potential as a medium for wastewater treatment. According to Ngirfani & Puspitarini (2020), water spinach's ability to produce oxygen can aid the breakdown of organic matter in wastewater. This process is related to its capacity to absorb organic substances resulting from microbial decomposition while supplying the oxygen required. A study by Salim (2021) found that using the constructed wetland method with water spinach in ecoprint industry wastewater reduced TSS, BOD, and TDS levels by 50%, 47%, and 29%, respectively. In addition to its effectiveness in reducing pollutants, water spinach has economic value, is easy to obtain, and requires minimal maintenance, making it well-suited for leachate treatment using the constructed wetland method.

The Lempeni Landfill in Lumajang Regency is still struggling to manage leachate effectively. Laboratory test data from 2017 to 2022 indicate that COD and BOD concentrations in the leachate consistently exceed the maximum limits set by Ministerial Regulation No. 59 of 2016, 300 mg/L for COD and 150 mg/L for BOD. Another obstacle is the selection of plant species used as media in the wetland pond, as some currently used species tend to have relatively short lifespans. The wetland at The Lempeni Landfill currently uses canna lilies, elephant grass, and water hyacinth. Therefore, this study aims to evaluate the performance of *Ipomoea aquatica* Forssk. (water spinach) in reducing COD and BOD levels in leachate through the constructed wetland approach.

1.2 Research Objectives

The general objectives of this research are to analyze the COD and BOD levels in leachate at the Lempeni Landfill before and after the constructed wetland treatment, and also to analyze the reduction difference in COD and the reduction difference in BOD levels in leachate at the Lempeni Landfill after the constructed wetland treatment.

2. METHOD

2.1 Tools and Materials

The tools and materials used in this study include a rectangular plastic container, a water faucet, medical trash bags, gravel, paddy soil, *Ipomoea aquatica* Forssk (water spinach) plants, and 306 liters of leachate.

2.2 Research Procedure

This research is an experimental study using a pretest–posttest–only control group design. It was conducted from February to March 2023. The sample used was inlet leachate from the wetland unit of the leachate treatment plant at Lempeni Landfill. The research objects were COD and BOD levels.

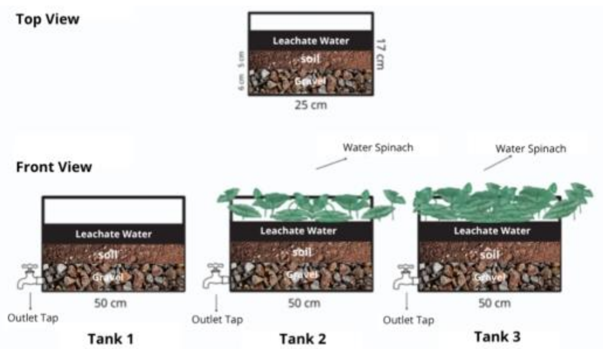


Figure 1. Constructed wetland scheme

The wastewater required for this study totaled 306 liters, sourced from the leachate treatment plant at the Lempeni Landfill in Lumajang Regency. This amount consisted of 54 liters for acclimatization and 252 liters for treatment. During acclimatization, 9 liters of leachate were added to each tank, with 6 tanks used in this stage, each containing *Ipomoea aquatica* Forssk. plants. For the constructed wetland treatment process, 21 liters of leachate were added to each tank. This stage involved 12 tanks, each with 4 treatments and 3 replications.

The constructed wetland treatment mechanism in this study was divided into five stages. The preparation stage involved using rectangular reactor tanks measuring 50 cm in length, 25 cm in width, and 17 cm in height. The tanks were filled with gravel (4–5 cm in diameter), a five cm-thick layer of soil, and water spinach plants (*Ipomoea aquatica*) with the following characteristics: 2–5 leaves/stems, dense roots, 2–3 weeks old, weighing approximately 5 grams, and stem length of about 46 cm. The next stage was acclimatization, a 6-day period for plant adaptation, during which 9 liters of leachate were flowed into each tank. This was followed by the leachate treatment stage using the constructed wetland method over seven (7) days, with three replications. The COD and BOD sample tests were conducted on the 7th day. The next step was sample collection, carried out in accordance with SNI 6989.59.2008, the Wastewater Sampling Method, using the grab sampling method. The final stage involved measuring COD levels according to SNI 6989.2-2019 and BOD levels according to SNI 6989.72-2009 (BSN, 2008; BSN, 2009; BSN, 2019).

2.3 Data Analysis

The research data were analyzed using SPSS software, which included the one-way analysis of variance (ANOVA) and paired-samples t-test. This study included four types of treatments: the control group, experimental group 1 (gravel, soil, and leachate), experimental group 2 (gravel, soil, leachate, and 4 *Ipomoea aquatica* Forssk. plants), and experimental group 3 (gravel, soil, leachate, and 8 *Ipomoea aquatica* Forssk. plants). The one-way ANOVA was used to determine whether there were significant differences in average COD and BOD levels after the constructed wetland treatment. If the significance value $\alpha < 0.05$, then H_0 is rejected, indicating a significant difference between treatment groups in COD and BOD levels. Conversely, if $\alpha > 0.05$, then H_0 is accepted, meaning there is no significant difference in COD and BOD levels among the groups.

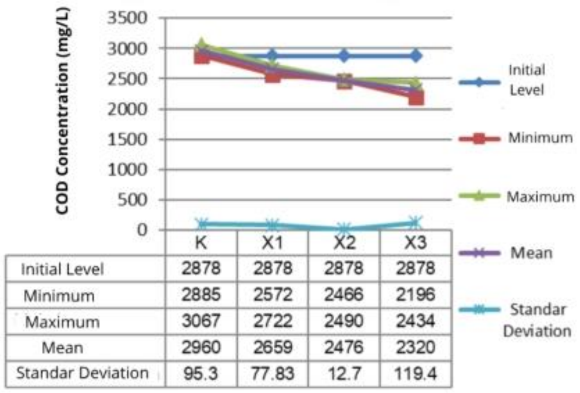
Meanwhile, the paired samples test was used to compare two related samples. In this study, the test aimed to identify differences in COD levels before and after treatment within each group (control and experimental) and to determine differences in BOD levels before and after treatment within each group.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 COD Levels Before and After Constructed Wetland Treatment

Based on the research findings, a comparison of COD levels using the constructed wetland treatment method, along with the initial COD levels in each experimental group, can be seen in Figure 2.



	K	X1	X2	X3
Initial Level	2878	2878	2878	2878
Minimum	2885	2572	2466	2196
Maximum	3067	2722	2490	2434
Mean	2960	2659	2476	2320
Standar Deviation	95.3	77.83	12.7	119.4

Figure 2. COD levels After constructed wetland treatment

Figure 2 shows that the minimum values in all groups decreased, falling below the initial COD levels prior to the constructed wetland treatment. The mean and maximum values in groups X_1, X_2, and X_3 were also lower than the initial COD levels before treatment. In contrast, the control group showed an increase, with values above the initial COD levels prior to the constructed wetland treatment.

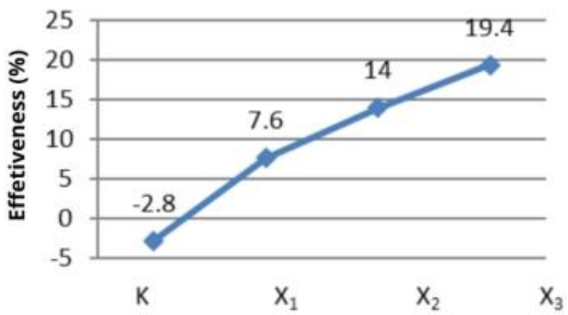


Figure 3. COD reduction effectiveness in the control group (K), experimental group 1 (X_1), experimental group 2 (X_2), and experimental group 3 (X_3)

Figure 3 shows the effectiveness of COD reduction in each group: 7.6% in experimental group 1 (X_1), 14% in experimental group 2 (X_2), and 19.4% in experimental group 3 (X_3). Meanwhile, the control group showed no reduction. Among all groups, the highest reduction was achieved by experimental group 3 (X_3), with an effectiveness of 19.4%, in which COD levels decreased from 2,878 mg/L to 2,320 mg/L. In contrast, the lowest effectiveness was observed in the control group (K), which actually showed an increase of 2.8%, with COD levels rising from 2,878 mg/L to 2,960 mg/L.

A normality test was conducted for the experimental groups using the Shapiro–Wilk test, as the sample sizes were less than 50. The test results showed p-values of 0.424 for the control group (K), 0.484 for experimental group 1 (X_1), 0.380

for experimental group 2 (X_2), and 0.852 for experimental group 3 (X_3). These values were greater than $\alpha = 0.05$, indicating that the data in each group were usually distributed. Meanwhile, the paired samples test results showed significance values of 0.276 for the control group (K), 0.040 for X_1, 0.000 for X_2, and 0.015 for X_3. Since the significance values for groups X_1, X_2, and X_3 were less than $\alpha = 0.05$, it can be concluded that leachate treatment at the Lempeni Landfill using *Ipomoea aquatica* Forssk. had a significant effect in reducing COD levels in the treatment groups.

3.1.2 BOD Levels Before and After Constructed Wetland Treatment

Leachate treatment through constructed wetlands has been shown to reduce BOD levels. The decrease in BOD levels across experimental groups varied with the number of plants and the size of the media used. Based on the research results, a comparison of BOD levels in the constructed wetland treatment relative to the initial BOD levels in each experimental group is shown in Figure 4.

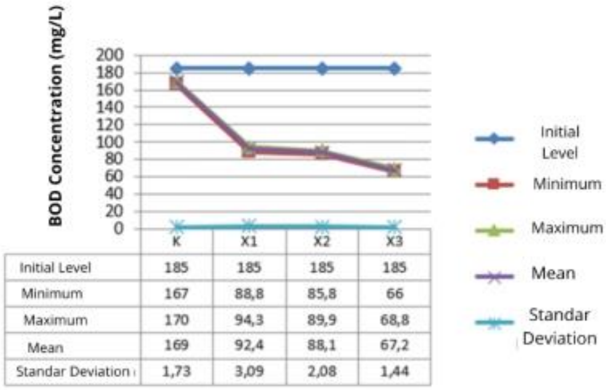


Figure 4. BOD levels after constructed wetland treatment

Figure 4 shows that the minimum, maximum, and mean values decreased across all groups. This reduction is indicated by BOD levels falling below the initial levels prior to the constructed wetland treatment. The highest minimum, maximum, and mean values were observed in the control group (K): 167 mg/L, 170 mg/L, and 169 mg/L, respectively. Meanwhile, the lowest minimum, maximum, and mean values were observed in Experimental Group 3 (X_3), with values of 66 mg/L, 68.8 mg/L, and 67.2 mg/L, respectively.

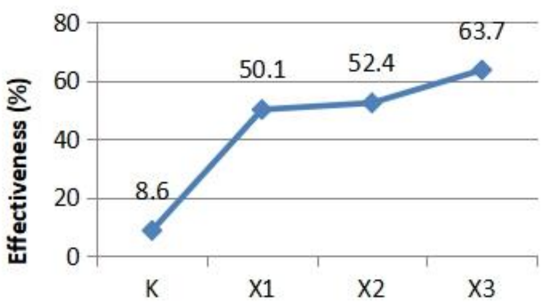


Figure 5. Effectiveness of BOD reduction in the control group (K), experimental group 1 (X_1), experimental group 2 (X_2), and experimental group 3 (X_3).

Figure 5 shows the effectiveness levels in each group, namely 8.6% in the control group (K), 50.1% in experimental group 1 (X_1), 52.4% in experimental group 2 (X_2), and 63.7% in experimental group 3 (X_3). Among these four groups, the highest effectiveness was found in experimental group 3 (X_3) at 63.7%. This reduction corresponds to a decrease in BOD levels from 185 mg/L to 67.2 mg/L. Meanwhile, the lowest effectiveness was observed in the control group (K) at 8.6%, with BOD levels decreasing from 185 mg/L to 169 mg/L.

In this study, the statistical test used for the experimental groups was the Shapiro-Wilk normality test, as the sample sizes were less than 50. The analysis results showed p-values of 0.000, 0.093, 0.654, and 0.537 for the control group (K), experimental group 1 (X_1), experimental group 2 (X_2), and experimental group 3 (X_3), respectively. All values were greater than $\alpha = 0.05$, indicating that the data in the experimental groups were normally distributed. Since the data were normally distributed, a paired samples test was conducted to determine the effect of *Ipomoea aquatica* Forssk. plants on the reduction of BOD levels in each experimental group. The results of the paired-samples test showed significance values of 0.004 for the control group (K), and 0.000 for experimental groups 1 (X_1), 2 (X_2), and 3 (X_3). All these values were less than $\alpha = 0.05$. Therefore, it can be concluded that leachate treatment at the Lempeni Landfill using *Ipomoea aquatica* Forssk. (water spinach), as the media significantly reduces BOD levels across all treatment groups.

3.1.3 Difference in Average Reduction of COD Levels between the Control Group and Experimental Groups

The measurements in this study aimed to determine differences in the reduction of COD levels in leachate from Lempeni Landfill across groups. The groups used in this study received different treatments. The four groups studied were the control group (K), which contained only leachate; experimental group 1 (X_1), which contained gravel, soil, and leachate; experimental group 2 (X_2), which contained gravel, soil, leachate, and four water spinach plants; and experimental group 3 (X_3), which contained gravel, soil, leachate, and eight water spinach plants. The COD levels after treatment for these four groups are shown in Table 1.

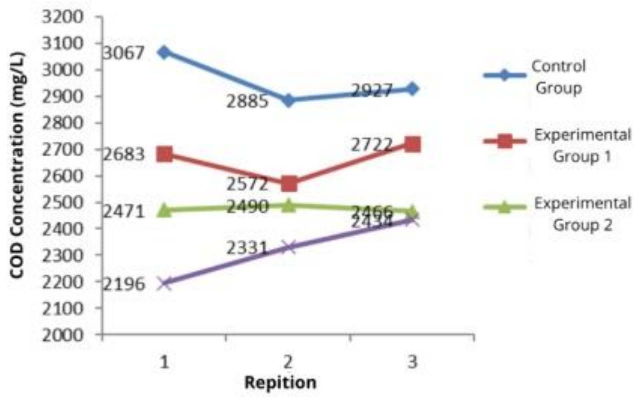


Figure 6. Difference in COD level reduction after constructed wetland treatment

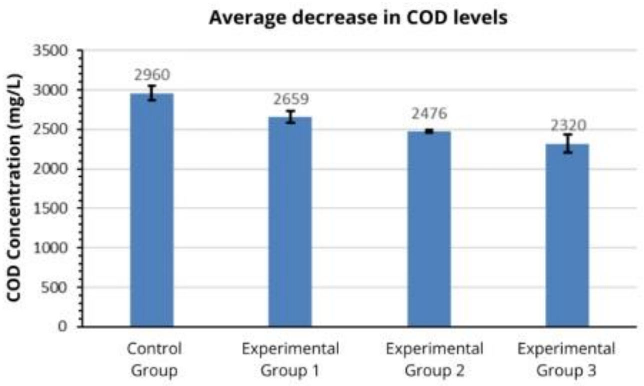


Figure 7. Average decrease in COD levels after constructed wetland treatment

Based on Figures 6 and 7, the average COD levels were 2,960 mg/L in the control group (K), 2,659 mg/L in experimental group 1 (X_1), 2,476 mg/L in experimental group 2 (X_2), and 2,320 mg/L in experimental group 3 (X_3). In the control group, the highest recorded COD level was 3,067 mg/L, while the lowest was 2,927 mg/L. In experimental group 1 (X_1), the highest COD level reached 2,722 mg/L, and the lowest was 2,572 mg/L. For experimental group 2 (X_2), the highest COD level was 2,490 mg/L, and the lowest was 2,466 mg/L. Meanwhile, in experimental group 3 (X_3), the highest COD level recorded was 2,434 mg/L, and the lowest was 2,196 mg/L. From these measurements, it can be concluded that the COD levels after treatment in each group still did not meet the leachate water quality standard of 300 mg/L, as regulated in the Minister of Environment and Forestry Regulation Number 59 of 2016.

The statistical test used for the experimental groups in this study was the Shapiro-Wilk normality test, chosen because the sample sizes were less than 50. Based on this test, the p-values for the control group, experimental group 1 (X_1), experimental group 2 (X_2), and experimental group 3 (X_3) were 0.424, 0.484, 0.380, and 0.852, respectively. All these values are greater than α = 0.05, so it can be concluded that the experimental groups' data in this study were usually distributed.

Based on these results, differences in COD reduction between the control group (K), experimental group 1 (X_1), experimental group 2 (X_2), and experimental group 3 (X_3) were analyzed using a one-way ANOVA. One requirement for this test is that the data must be homogeneous. The homogeneity test on COD data across groups yielded a p-value of 0.199 (> 0.05), indicating that the COD data within each group were homogeneous. The one-way ANOVA is an alternative to the independent-samples t-test when analyzing more than two independent samples. The significance value obtained from this test was 0.000, which is less than the α = 0.05 level. Therefore, it can be concluded that there are significant differences in COD reduction between the control group (K), experimental group 1 (X_1), experimental group 2 (X_2), and experimental group 3 (X_3).

Table 1. Tukey HSD test results for differences in COD levels

Group	Control	Experiment 1	Experiment 2	Experiment 3
Kontrol	-	0.011*	0.001*	0.000*
Experiment 1 (X1)	0.011*	-	0.115	0.006*
Experiment 2 (X2)	0.001*	0.115	-	0.199
Experiment 3 (X3)	0.000*	0.006*	0.199	-

Note: (*) indicates a significant difference

Based on Table 1, the control group differs significantly from experimental groups 1, 2, and 3. Experimental group 1 differs considerably from the control group and experimental group 3. Experimental group 2 differs substantially from the control group. Meanwhile, experimental group 3 differs considerably from the control and experimental group 1. These differences are significant ($p < 0.05$), indicating differences among the experimental groups.

3.1.4 Difference in Average Decrease of BOD Levels in Control and Experimental Groups

The media components applied in the experimental groups are one factor contributing to the success in reducing BOD levels in leachate. Each group in this study received different treatments. The four groups studied included the control group, experimental group 1 (X_1), experimental group 2 (X_2), and experimental group 3 (X_3). The BOD levels after treatment in these four groups are shown in Figure 8.

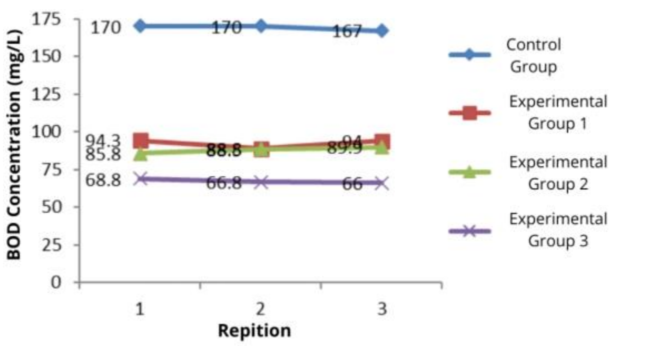


Figure 8. Difference in BOD level reduction after constructed wetland treatment

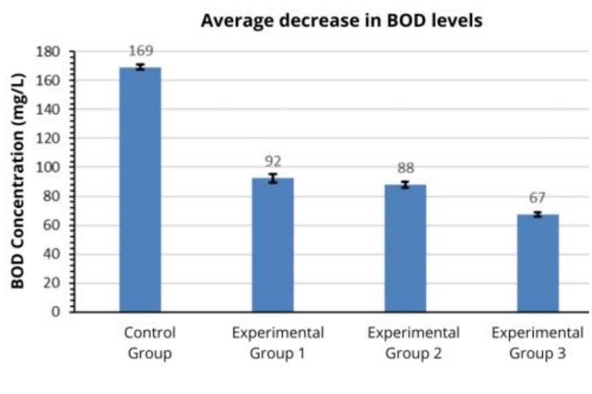


Figure 9. Average decrease in BOD levels after constructed wetland treatment

Based on Figures 8 and 9, the average BOD levels were 169 mg/L for the control group, 92.4 mg/L for experimental group 1 (X_1), 88.1 mg/L for experimental group 2 (X_2), and 67.2 mg/L for experimental group 3 (X_3). In the control group, the highest BOD level was 170 mg/L, while the lowest was 167 mg/L. In experimental group 1 (X_1), the highest BOD level was 94.3 mg/L, and the lowest was 88.8 mg/L. In experimental group 2 (X_2), the highest BOD level was 89.9 mg/L, and the lowest was 85.8 mg/L. In experimental group 3 (X_3), the highest BOD level recorded was 68.8 mg/L; the lowest was 66 mg/L. Based on these measurements, it can be concluded that the BOD levels after treatment in groups X_1, X_2, and X_3 have met the leachate quality standard of 150 mg/L, as set forth in the Regulation of the Minister of Environment and Forestry Number 59 of 2016.

This study used the Shapiro-Wilk normality test because the sample size analyzed was less than 50. The test results showed p-values of 0.000 for the control group, 0.093 for experimental group 1 (X_1), 0.654 for experimental group 2 (X_2), and 0.537 for experimental group 3 (X_3). These values exceed $\alpha = 0.05$, so the data in the experimental groups are normally distributed. Based on this, the difference in BOD reduction between the control group (K) and the X_1, X_2, and X_3 groups was analyzed using a one-way ANOVA, assuming homogeneity of variances. The homogeneity test for BOD levels showed a p-value of 0.305 (> 0.05), indicating that the data from each group are homogeneous. The one-way ANOVA yielded a p-value of 0.000 (< 0.05), so H0 was rejected, and Ha accepted. Therefore, there is a significant difference in BOD reduction between the control group (K), experimental group 1 (X_1), experimental group 2 (X_2), and experimental group 3 (X_3).

Table 2. Tukey HSD test results for differences in BOD levels

Group	Control	Experiment 1	Experiment 2	Experiment 3
Control	-	0.000*	0.000*	0.000*
Experiment 1 (X1)	0.000*	-	0.151	0.000*
Experiment 2 (X2)	0.000*	0.151	-	0.000*
Experiment 3 (X3)	0.000*	0.000*	0.000*	-

Note: (*) show signs of significance

Based on Table 2, the control group shows a significant difference from all experimental groups. Experimental group 1 shows a substantial difference between the control and experimental groups 3. Meanwhile, experimental group 2 differs significantly from the control and experimental group 3. Furthermore, experimental group 3 has a significant difference from all other groups. These differences are indicated by significance values smaller than $\alpha = 0.05$, suggesting important differences between the treatment groups.

3.2 Discussion

3.2.1 COD Levels Before and After Constructed Wetland Treatment

Chemical oxygen demand (COD) is the amount of oxygen microorganisms require to oxidise organic matter in leachate. Based on the research results for each experimental group, the COD levels in Lempeni Landfill leachate decreased. The COD reduction in experimental tank one was 7.6%, in tank two 14%, and in tank three 19.4%. This decrease in COD levels indicates that the organic matter in the leachate can be broken down into simpler compounds by microorganisms present in the constructed wetland. This reduction is also supported by the root systems of aquatic plants, which can produce oxygen to serve as an energy source for microorganisms in their metabolic processes. The more aerobic bacteria that grow around plant roots in the constructed wetland during oxidation, the greater the potential for lower COD levels in the leachate. The biological mechanism that utilises roots as a growth medium for microbes requires sufficient oxygen, so the denser and deeper the plant roots, the larger the rhizosphere zone in the constructed wetland to support microbial activity (Hidayah & Aditya, 2017). The rhizosphere zone is the area of soil surrounding plant roots. Bacteria in the rhizosphere confer many benefits to plants. Therefore, a higher level of interaction between bacteria and plants can accelerate the absorption of COD in leachate by plants (Januar & Sari, 2023). The longer the plant roots, the greater the capacity of rhizosphere bacteria to degrade the organic matter in the leachate. The degraded organic matter is then used in the plant's photosynthesis process. This treatment process is called phytoremediation (Purnomo & Anggraini, 2022).

The constructed wetland treatment in this study was combined with filtration. Experimental group 1 was treated only with filtration. This method was used to reduce turbidity and separate suspended solids contained in the leachate. The gravel used in the reactor tank served as an inorganic medium for the filtration treatment of leachate, during which suspended solids settled to the bottom of the reactor tank. As a result, the leachate discharged through the outlet stream would be clearer than the untreated leachate (Riyanti et al., 2019). This research aligns with the study by Wulandari et al. (2020), which found that gravel is highly effective at settling dissolved solids in leachate. The pile of gravel forming cavities within the reactor tank facilitates sedimentation. In addition, gravel serves as a surface for microbial growth during the decomposition of organic matter in the leachate.

In addition to gravel, soil was used as a medium for plant growth and microbial attachment in the constructed wetland treatment in this study. The soil used was paddy field soil from rice cultivation. Paddy soil from rice cultivation contains a higher amount of smectite minerals compared to non-rice paddy soil. Smectite is one of the components of soil clay minerals. Clay minerals enhance nutrient availability and improve soil fertility (Mufriah, 2022). Generally, fertile soil has a high organic matter content. A high level of organic matter in the soil will optimise the growth of soil microorganisms. Organic matter in the soil serves as an energy source for microorganisms in their metabolic processes (Bolly & Apelabi, 2022). This aligns with the findings of Hidayah & Aditya (2017), who stated that the flow of domestic wastewater through soil media in constructed wetlands has a positive impact. A change in organic matter content indicates this, specifically an increase in soil organic carbon (C-organic) from 1.85% to 1.91% after the wastewater flow was applied. The increase in soil C-organic content is directly proportional to improved soil fertility. Organic carbon in soil plays a vital role in supporting the decomposition of wastewater.

Plants play a crucial role in the success of leachate treatment using constructed wetlands. In this study, the aquatic plant used in experimental groups 2 and 3 was *Ipomoea aquatica* Forssk. (water spinach). Water spinach is an aquatic plant that is resistant to pollution. It is commonly used as a biofilter to reduce the organic matter and heavy metal content of soil or water. The plant organs that play an essential role in the decomposition of pollutants in leachate are the leaves and roots. Water spinach has long, cylindrical stems and a high water-absorption capacity. As a result, the plant tends to grow with multiple branches and spread out. The numerous branches form broad, strong roots (Nadila, 2020). Root absorption processes result in the highest concentration of pollutants in roots compared to leaves and stems. The parenchyma tissue in water spinach acts as a pathway for oxygen produced by the roots, allowing nutrients from the water and soil to be absorbed quickly (Hapsari et al., 2018). The plant's resistance to COD in leachate is evident from the research observations, which showed that water spinach exhibited good growth. Strong root development, increased leaf number, and longer petioles indicate that water spinach is tolerant of pollutants in leachate from the Lempeni Landfill. The high level of pollutants absorbed by the plant, particularly the leaves, is indicated by several leaves turning yellow on the fourth day of the study. This is consistent with the findings of Kandowangko et al. (2017), who reported that reduced green colouration in plants is caused by heavy metal accumulation in leaves, which damages chloroplast structure and results in necrosis at the edges and tips of leaves.

3.2.2 BOD Levels Before and After Constructed Wetland Treatment

Biochemical oxygen demand (BOD) is the amount of oxygen microorganisms use as a nutrient source during the decomposition of organic matter. The research results showed that the BOD levels in the leachate from the Lempeni Landfill decreased across all experimental groups. The effectiveness of BOD reduction was recorded at 8.6% in the control tank, 50.1% in experimental tank 1, 52.4% in experimental tank 2, and 63.7% in experimental tank 3. This decrease indicates that the organic matter in the leachate was increasingly reduced. The leachate treatment at the Lempeni Landfill utilized the synergy between water spinach (*Ipomoea aquatica*), microorganisms, gravel, and soil. The organic matter entering the reactor tank underwent sedimentation, then was broken down into simpler compounds through absorption by microorganisms and water spinach roots (Januar & Sari, 2023). The lowest reduction occurred in the control group. Nevertheless, the control group still showed decreased BOD levels, attributed to the natural decomposition of organic matter. Ryanita et al. (2020) explained that decomposition in the control group can still occur, albeit not optimally, through the activity of microorganisms and the diffusion of oxygen from the air into the domestic wastewater.

The organic matter measured in BOD includes readily degradable compounds. The decomposition of this organic matter occurs aerobically and involves oxygen. The organic content in the leachate is utilized by water spinach as a nutrient source and to support photosynthesis. Enhanced plant growth supports increased microorganism activity. Microorganisms require an adequate oxygen supply to break down organic matter. Oxygen transfer occurs via plant roots and the air that passes through the stem, following diffusion through the leaf pores of the water spinach (Wimbaningrum et al., 2020). According to Januar & Sari (2023), the rhizosphere is the primary zone for microbial interaction, with about 15% of the root surface area serving as the interaction site. The most commonly found microorganisms in the rhizosphere zone are *Actinomycetes* and *Pseudomonas.* Furthermore, research by Cahyana & Aulia (2019) indicated that aerobic zones within the reactor tank are found in the roots and rhizosphere, which are rich in oxygen. The increased oxygen levels in this aerobic zone support the proliferation of microorganisms, thereby optimizing the decomposition of organic matter. Therefore, plants play a vital role in reducing BOD levels. The growth is inversely related to BOD levels in the leachate within the reactor tanks. In addition to producing oxygen, plants also help slow water flow in the reactor tanks, further enhancing sedimentation.

The selection of plants in experimental groups 2 and 3 was a key factor in successfully reducing BOD levels in the leachate. Water spinach is a plant resistant to pollutants. The pollutants absorbed by the water spinach are used as nutrients in its metabolic processes (Ngirfani & Puspitarini, 2020). Water spinach is used in the reactor tank as a phytoremediation medium. The reduction in BOD levels across the experimental groups indicated the effectiveness of water spinach in this study, as shown in Figure 4.3. The reduction in BOD levels was accompanied by the growth of water spinach, including an increase in leaf count. In experimental group 2 (X_2), the initial number of leaves ranged from 15 to 20 and increased to 44 to 50 by the end of the study. In experimental group 3 (X_3), the initial number of leaves ranged from 22 to 28, and increased to 79 to 87 by the end. The rapid growth of water spinach was influenced by sustained photosynthesis within the constructed wetland. Ryanita et al. (2020) stated that photosynthesis leads to more leaves and longer stems. This condition accelerates the absorption of organic matter in the leachate and enhances its degradation by microorganisms around the plant roots. In addition to plant growth, observations also found reduced leachate volume in each reactor tank. Based on measurements of the distance between the scum layer and the leachate surface, a reduction of 2–3 cm in leachate quantity was recorded in each tank. This surface water evaporation was caused by plants undergoing a process known as phytovolatilization.

3.2.3 Reduction in COD Levels

The research results showed that the average COD levels after treatment in the control group and experiments 1, 2, and 3 were 2,960 mg/L, 2,659 mg/L, 2,476 mg/L, and 2,320 mg/L, respectively. These values remain above the quality standard threshold set by the Regulation of the Minister of Environment and Forestry Number 59 of 2016, which is 300 mg/L. Although the COD levels in the leachate at Lempeni Landfill have not yet met the required standard, the constructed wetland method using water spinach *(Ipomoea aquatica)* as the plant medium has proven effective in reducing COD concentrations across all treatment groups. The high COD levels indicate a substantial amount of organic matter resulting from the decomposition of accumulated waste at the Lempeni Landfill.

Based on the pollution index calculation, which is obtained by dividing the parameter values in the study by the standard quality values at the landfill, the results for the control group, experiment 1, experiment 2, and experiment 3 were 9.87, 8.86, 8.3, and 7.73, respectively. The COD levels in all four groups fall into the moderate pollution category, as the Pollution Index for COD levels is below 10. According to Januar & Sari (2023), a pollution index (PI) for leachate water parameters in the range of $5.0 < PIj \leq 10$ is classified as moderate pollution. Furthermore, the results of the one-way ANOVA test showed a significance value of 0.000 < 0.05, thus H0 is rejected. This result indicates a significant difference in the reduction of COD levels among the experimental groups. Several factors influence this variation. Kasman et al. (2018) suggest that differences in COD reduction among groups are influenced by media, plant species, retention time, and environmental conditions surrounding the constructed wetland. The number of plants can influence the density of components within the reactor tank. A greater number of plants can increase oxygen production, enhancing microorganisms' activity in the rhizosphere. The denser and deeper the plant roots, the wider the rhizosphere zone within the constructed wetland (Hidayah & Aditya, 2017). The rhizosphere zone is the area of soil surrounding plant roots with a high concentration of bacteria. Generally, bacteria in the rhizosphere positively impact plants, as frequent interactions between plants and bacteria can optimize the absorption of COD in leachate water (Januar & Sari, 2023).

The difference in COD reduction is evident in the results of leachate treatment at the Lempeni Landfill using the constructed wetland method with water spinach (*Ipomoea aquatica*) as the plant medium. With a retention time of 7 days, the lowest COD level was recorded at 2,320 mg/L in experimental group 3, which had the highest number of water spinach plants, totaling eight. This finding is consistent with the study by Abdi et al. (2018), which reported differences in COD reduction among groups A, B, C, and D, which were influenced by the number of plants. In group D, with 30 water lettuce plants and a retention time of 2 days, COD levels were reduced by 109.38 mg/L. This was due to the reactor tank's higher plant density than other groups and the appropriate selection of aquatic plants for phytoremediation in the constructed wetland process. The release of exudates from plants can increase the amount of easily degradable organic matter, providing a surface for microorganisms to attach. Generally, exudates consist of organic acids, polysaccharides, amino acids, and other organic components. The amount of exudates varies with environmental conditions around the plants and the type of plant used in the constructed wetland (Widiyanti et al., 2020). The study by Daroini & Arisandi (2020) found that the presence of leaves, bark, and twigs in the leachate can increase its organic content. This aligns with the finding that the control group experienced increased COD levels due to leaves from other plants falling into the reactor tank.

Although experimental group 3 (X_3) achieved the lowest COD level in the leachate treatment at Lempeni Landfill, it did not show a significant reduction across all replications. The most significant COD reduction among the four experimental groups was found in experimental group 2 (X_2). This can be seen in Figure 6, where COD reduction in each replication of experimental group 2 (X_2) was consistent. This condition may be influenced by the uneven growth of water spinach plants across replications within the experimental tanks. Such variations can affect the nutrients plants absorb as they break down the leachate's organic matter into simpler compounds. his finding is in line with the research by Nitasari & Wahidah (2020), which showed differences in leaf number growth rates among water spinach plants grown in the same soil medium, particularly in group C (8 plants), with two replications of 3 and 4 plants, respectively. Furthermore, the two replications showed differences in plant height growth in the same soil medium in group C (8 plants), with heights of 3 cm and 2.8 cm. In addition, the surrounding conditions of the reactor tank may also influence the COD levels in the leachate.

In addition to plants' role in reducing COD levels, the use of filtration media in treatment processes also contributes to COD reduction in landfill leachate. The purpose of filtration is to separate or remove colloids and suspended solids in the leachate from the Lempeni Landfill. The smaller the pore size of the filtration media, the more effective the filtration process becomes in performing its function. The filtration medium used in this study was gravel measuring 4–5 cm. This type of gravel falls under the category of medium gravel, with a porosity percentage of 40%. Porosity refers to the percentage of soil volume not occupied by solids in the leachate. The higher the gravel's porosity, the larger its surface area and the greater the number of particles. A larger surface area increases the absorption capacity and helps prevent clogging in the leachate treatment process (Sirajuddin & Saleh, 2020).

Soil is another medium used in the filtration process. Compared to gravel, soil has a higher density, which causes more solids in the water to settle. This condition aligns with findings by Al Kholif et al. (2019), who stated that soil media has a greater density than gravel when used in domestic wastewater treatment. Thus, using soil combined with *Bintang Air* (*Cyperus papyrus*) plants in a constructed wetland for five days reduced COD levels by 90.34%. A similar statement was also made in the study by Khoiriah & Stighfarrinata (2023), which found that the thickness and pore size of the filtration media can influence filtration performance. The greater the media thickness, the greater the surface area available to separate solids from water. Moreover, the smaller the particle size of the filtration media, the greater the surface area available for adsorption.

3.2.4 Reduction in BOD Levels

The research showed that the average BOD levels after treatment in the control group and experiments 1, 2, and 3 were 169 mg/L, 92.4 mg/L, 88.1 mg/L, and 67.2 mg/L, respectively. The BOD values in all these groups were already within the threshold set by the Regulation of the Minister of

Environment and Forestry Number 59 of 2016, which is 150 mg/L. This condition indicates that the organic matter in the leachate has undergone optimal degradation. BOD levels meeting quality standards indicate that the organic matter has been efficiently degraded. Based on the calculation of the Pollution Index Evaluation, obtained by dividing the parameter values in the study by the quality standard values at the landfill, the results for the control group, experiment 1, experiment 2, and experiment 3 were 1.13, 0.62, 0.60, and 0.45, respectively. The BOD levels in the three experimental groups are considered good (meeting quality standards) because their Pollution Index values are less than 1. Meanwhile, the control group falls into the light pollution category with a Pollution Index between 1.0 and 5.0.

The results of the one-way ANOVA test showed a p-value of 0.000 (< 0.05), indicating differences in BOD reduction among the experimental groups. This difference is evident in comparisons between the control and experimental groups 1, 2, and 3, all of which show a significance value of 0.000. Similarly, comparisons between experimental group 1 and the control group, as well as between experimental group 3 and the control group, and between experimental group 3 and the control, experiment 1, and experiment 2 also produced significance values of 0.000. In contrast, the comparison between experimental groups 1 and 2 yielded a p-value of 0.151 (> 0.05), indicating no significant difference between the two groups. This non-significance is due to the significance value exceeding the α threshold of 0.05.

The differences in BOD reduction among the groups are influenced by various factors, such as the media used, the amount of media, and the environmental conditions surrounding the reactor tanks. The significant BOD reduction in experimental group 3, which reached 67.2 mg/L, was caused by using more water spinach plants than in the other groups, as well as by the combination of constructed wetland treatment through both filtration and phytoremediation within the reactor tanks. *Ipomoea aquatica* Forssk. (water spinach) is a plant capable of surviving in poor-quality water. Water spinach is classified as a hyperaccumulator plant. The plant organs involved in the biofiltration process of water spinach for polluted water are the leaves and roots. The leaves function to collect absorbed substances for processing through photosynthesis. Mitochondria within the leaves carry out decomposition processes to reduce pollutant content in the leaves.

In addition to leaves, the roots of water spinach play a crucial role in absorbing pollutants in the leachate. The root morphology of water spinach, characterized by its long, dense, branched, and fibrous nature, enables it to have a high accumulation capacity. Roots also transport absorbed substances to other organs, resulting in higher pollutant concentrations in roots than in leaves and stems (Widyawati & Kuntjoro, 2021). Furthermore, the intensity of sunlight entering the reactor tanks affects plant growth by facilitating oxygen production, which supports microbial activity. Therefore, the constructed wetland treatment in breaking down easily degradable organic matter is supported by the filtration process using gravel, soil, microorganisms, and plants (Kasman et al., 2018). His condition aligns with the research by Munthe et al. (2021), which found that treating laundry wastewater with *Ipomoea aquatica* Forssk. (water spinach) plants resulted in a reduction in BOD across three repetitions within 7 days. The highest BOD reduction was observed in group D (30 water spinach stems), amounting to 24.2 mg/L. In comparison, the lowest reduction occurred in group B (10 water spinach stems), which experienced an increase in BOD levels reaching 104.2 mg/L.

The reduction of BOD levels in leachate through constructed wetland treatment in each group indicates the breakdown of organic matter into simpler compounds. The organic matter that settles at the bottom of the reactor is decomposed by microorganisms attached to the roots of the water spinach plants (Wimbaningrum et al., 2020). This sedimentation occurs because gravel is used as the filtration medium. The small size of the gravel increases microbial growth due to its large surface area and reduced pore spaces (Saputra, 2018). The use of filtration media supports a better BOD reduction process compared to groups that do not combine phytoremediation and filtration in the constructed wetland leachate treatment This is consistent with the study by Oktavia et al. (2021) which found that treating tofu industry wastewater using soil media and Typha latifolia plants can reduce BOD levels by 72%, whereas reactors without media showed only a 53% reduction. Besides plants, soil also plays a role in treating tofu wastewater. Using soil helps absorb acidic odors from tofu wastewater, ensuring that the treatment process does not produce unpleasant smells that could disturb the comfort of the local community around the study area.

4. CONCLUSION

Based on the findings on the application of *Ipomoea aquatica* Forssk. in a constructed wetland system for treating leachate at the Lempeni Landfill, Lumajang Regency, it can be concluded that the incorporation of this macrophyte both before and after the wetland units substantially enhanced organic pollutant removal across all experimental groups, as reflected in consistent declines in COD and BOD concentrations; specifically, COD was reduced by 7.6%, 14.0%, and 19.4% in experimental groups 1, 2, and 3, respectively, while BOD decreased by 8.6%, 50.1%, 52.4%, and 63.7% across the control and experimental groups, indicating progressively stronger treatment performance with increased system complexity. This trend is further supported by the observed mean COD concentrations, which declined from 2,960 mg/L in the control to 2,659 mg/L, 2,476 mg/L, and 2,320 mg/L in experimental groups 1, 2, and 3, respectively, alongside corresponding reductions in mean BOD from 169 mg/L to 92.4 mg/L, 88.1 mg/L, and 67.2 mg/L, thereby confirming that the most pronounced improvements in leachate quality were achieved in experimental group 3, whereas the control exhibited the least effective removal.

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