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Fitoremediasi: Kiambang (*Salvinia molesta*) Mereduksi Polutan Limbah Pewarna Batik sebagai Sumber Belajar Pencemaran Lingkungan

Phytoremediation: Kiambang (Salvinia molesta) Reduces Batik Dye Waste Pollutants as a Learning Resource on Environmental Pollution

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Abstrak

Pewarnaan dalam proses pembuatan batik banyak menggunakan pewarna yang mengandung berbagai zat yang dapat menjadi polutan berbahaya bagi manusia dan biota lainnya. Namun demikian, terdapat berbagai organisme yang mampu mereduksi pengaruh pencemaran tersebut dengan prinsip remediasi khususnya yang dilakukan oleh beberapa jenis tumbuhan. Salah satu jenis tumbuhan yang berpotensi sebagai bioremediator adalah tanaman kiambang (*Salvinia molesta*). Tujuan penelitian ini adalah untuk mengetahui pengaruh kiambang (*Salvinia molesta*) dalam mereduksi polutan limbah pewarna batik sebagai sumber belajar pencemaran lingkungan. Penelitian ini adalah penelitian eksperimen, dengan metode yang digunakan adalah analisis deskriptif. Perlakuan yang digunakan terdapat dua, yaitu perlakuan berat kiambang yang berbeda dalam konsentrasi limbah yang sama, dan perlakuan berat kiambang yang sama dalam konsentrasi limbah cair yang berbeda. Penelitian dilakukan di Laboratorium Botani Jurusan Pendidikan Biologi FKIP Universitas Siliwangi selama enam bulan. Alat yang digunakan dalam penelitian ini antara lain wadah inkubasi 40 liter, neraca, gelas ukur, termometer, dan pH meter. Sedangkan, bahan yang digunakan dalam penelitian ini adalah limbah cair batik dari pengrajin batik di wilayah Kelurahan Cigeureung Kota Tasikmalaya dan tanaman kiambang. Pengumpulan data dilakukan dengan mengobservasi pertumbuhan kiambang dalam 4 kali pengamatan dalam kurun waktu 10 hari. Analisis data dilakukan berdasarkan sifat fisik dan kimiawi air limbah, dengan berbagai indikator seperti derajat keasaman/pH, *total suspended solid*, BOD, COD, kadar fenol, kadar *chrom total*, kadar amonium total, kandungan sulfida, kadmium, merkuri, dan nikel. Analisis secara kimiawi dilakukan di PT. Sucofindo (Persero) yang beralamat di Jalan Soekarno Hatta No. 217 Bandung. Berdasarkan analisis dan uji berbagai indikator, diketahui bahwa tanaman kiambang dapat menurunkan berbagai kandungan kimiawi polutan pada air limbah pada kedua perlakuan. Berdasarkan hasil tersebut, dapat disimpulkan bahwa tanaman kiambang dapat mengurangi polutan pada air limbah pewarnaan batik pada sampel air limbah pewarna batik di sentra batik Cigeureung Kecamatan Cipedes Kota Tasikmalaya.

Kata kunci: Air limbah; Batik; Fitoremediasi; *Salvinia molesta*

Abstract

The dyeing process in the batik-making process uses many dyes containing various substances that can be harmful pollutants for humans and other biota. However, various organisms can reduce pollution's effects with the principle of remediation, especially those carried out by several plants. One type of plant that has the potential as a bioremediator is the kiambang plant (Salvinia molesta). This study aimed to determine the effect of kiambang (Salvinia molesta) in reducing batik dye waste pollutants as a learning resource for environmental pollution. This study was an experimental study, with the method used being descriptive analysis. Two treatments were used: the treatment of different kiambang weights in the same waste concentration and the treatment of the same kiambang weight in different liquid waste concentrations. The study was conducted at the Botany Laboratory of the Department of Biology Education, Faculty of Teacher Training and Education, Siliwangi University, for six months. The tools used in this study included a 40-liter incubation container, a balance, a measuring cup, a thermometer, and a pH meter. Meanwhile, the materials used in this study were batik liquid waste from batik artisans in the Cigeureung Village, Tasikmalaya City, and the Kiambang plant. Data collection was carried out by observing the growth of kiambang in 4 observations within 10 days. Data analysis was carried out based on the physical and chemical properties of wastewater, with various indicators such as acidity/pH, total suspended solids, BOD, COD, phenol content, total chromium content, total ammonium content, sulfide content, cadmium, mercury, and nickel. Chemical analysis was carried out at PT. Sucofindo (Persero) is located at Jalan Soekarno Hatta No. 217, Bandung. Based on the analysis and testing of various indicators, it is known that the kiambang plant can reduce various chemical pollutant contents in wastewater in both treatments. Based on these results, it can be concluded that the kiambang plant can reduce pollutants in batik dyeing wastewater samples at the Cigeureung Batik Center, Cipedes District, Tasikmalaya City.

Keywords: *Batik; Phytoremediation; Salvinia molesta; Waste Water*

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INTRODUCTION

Batik is an Indonesian cultural heritage recognized internationally as Indonesia's national brand (Hakim, 2018), because batik has its characteristics and patterns according to its region of origin (Nugroho, 2020). The United Nations Educational, Scientific and Cultural Organization (UNESCO) recognized the many batik motifs in various regions as an intangible world cultural heritage (Hakim, 2018; Jannah & Muhimmatin, 2019; M. Larasati, 2021). As Indonesia becomes increasingly well-known as a batik producer, the demand for batik has also increased, resulting in the emergence of various batik companies in various regions, both managed by cooperatives and simply as small and medium enterprises (Aprilia & Adriani, 2022; Khasna, 2021; M. Larasati, 2021). One of the regions with a batik center in Indonesia, especially West Java, is Tasikmalaya City (Cahyanto et al., 2017).

Tasikmalaya City is a batik-producing area in West Java and has several well-known batik centers, namely the Parakannyasag area (Cahyanto et al., 2017) and Cigeureung, Cipedes District. Based on the results of observations that have been carried out, especially in the Cigeureung area, which is the largest batik center, it is known that there are 30 household-scale batik companies. With so many batik companies in the Cigeureung area, economically it will be able to become an economic commodity that can create jobs for the surrounding community (Jannah & Muhimmatin, 2019) and pass on the value of local batik wisdom to the younger generation (Hakim, 2018).

In addition to being a commodity, the presence of batik companies also has other impacts because the batik-making process will not be separated and avoid the coloring process that uses various synthetic dyes (Aprilia & Adriani, 2022; Kharisma Subagyo & Soelityowati, 2021; Yuliana, 2022), resulting in many pollutants in the form of heavy metals as a result of the coloring and washing process (Fatiha & Irawanto, 2021; Rosyidah & Rachmadiarti, 2023). Thus, the large number of batik companies in Cigeureung, Tasikmalaya City, can be estimated to hurt river water flow, becoming polluted by changing various indicators physically and chemically (Murniati et al., 2015).

The level of heavy metal pollution exposed to the environment, for example, from industrial waste and fertilizers, causes serious problems in nature because these metals cannot be naturally or biodegraded and accumulate at high levels (Fonseka et al., 2023; Rachmadiarti et al., 2022). Heavy metal pollution is not only a problem at the global level but also at the micro-scale environmental level. However, the severity and extent of pollution can vary from one place to another (Evitasari et al., 2020). At least 20 heavy metals contained in textile waste are classified as toxic waste, with half of them released into the environment, posing a significant risk to human health (George & Gabriel, 2017; Ashraf et al., 2019). Heavy metals commonly found in the environment, such as Cd, Pb, Co, Zn, and Cr, have phytotoxic properties at low concentrations and very high concentrations detected in wastewater (Rajkumar et al., 2012). These metals in sediments reach the food chain through aquatic plants and animals (George & Gabriel, 2017; Mustafa & Hayder, 2021; Rachmadiarti et al., 2022). In small amounts, certain heavy metals have positive properties as essential nutrients for healthy environmental life. However, large amounts of heavy metals can cause acute or chronic toxicity (poisoning) (George & Gabriel, 2017).

Problem-solving solutions regarding the restoration of polluted environments can be carried out in various ways, one of which is remediation using plants/phytoremediation (Chandanshive et al., 2016; Munfarida et al., 2020). Phytoremediation involves the use of various types of plants to absorb, accumulate, detoxify, and neutralise contaminants, whether in soil, sediment, wastewater, surface water, or groundwater, using physical, chemical, and biological processes (Fonseka et al., 2023). Phytoremediation is an in situ remediation technology that utilises the inherent abilities of living plants (Manousaki & Kalogerakis, 2011).

Several incidents of pollution caused by textile dyes have been reported by several researchers, thus providing a basis for using plants from various specific habitats (Chandanshive et al., 2016). One specific plant widely used as a phytoremediation agent is the Kiambang/*Salvinia molesta* (Munfarida et al., 2020; Mustafa & Hayder, 2021; Rachmadiarti et al., 2022). This plant can degrade textile dye waste effectively because it is supported by a dense root system that spreads in water and can grow naturally in various conditions, even in high salinity conditions (Chandanshive et al., 2016). The growth of *S. molesta* is easily adaptable to various conditions and acts as a remediation agent, making this plant a potential solution for degrading batik liquid waste, especially in the Cigeureung Batik Centre area, Cipedes District, Tasikmalaya City.

Efforts to use Kiambang/*S. molesta* plants that can absorb heavy metals, as stated by Fonseka et al., (2023), Ng & Chan (2017), and Nisa, (2024), show that this plant can absorb heavy metals in batik dyeing wastewater. Due to their fast growth properties, *S. molesta* plants are abundant in aquatic environments and can be used as phytoremediation agents. This can also be a learning material for students in Environmental Pollution courses, to analyse the role of S. molesta as a phytoremediation agent. Thus, this study aims to analyse the role of *S. molesta* in reducing batik dye waste pollutants in the Cigeureung River as a learning resource for environmental pollution.

METHOD

The research method used is an experimental method. The treatments used in this study consisted of two treatments. The first treatment was different volume weights of kiambang plants (*S. molesta*) planted in the same volume of batik dyeing waste. In contrast, the second treatment was the same volume weight of kiambang plants (*S. molesta*) in different volumes of batik dyeing waste referring to research by Fonseka et al., (2023), Ulfah et al., (2022), and Pribadi et al., (2016). These treatments are detailed as follows.

1. **The First Treatment Group**: Different treatments of the volume weight of the *S. molesta* plants planted in the same volume of liquid waste.
   Treatment A: 300 grams of *S. molesta* in 7 litres of liquid waste
   Treatment B: 250 grams of *S. molesta* in 7 litres of liquid waste
   Treatment C: 200 grams of *S. molesta* in 7 litres of liquid waste
2. **The Second Treatment Group**: The same weight-volume treatment of the *S. molesta* plants planted in different volumes of liquid waste.
   Treatment D: 150 grams of *S. molesta* in 2 litres of liquid waste
   Treatment E: 150 grams of *S. molesta* in 4 litres of liquid waste
   Treatment F: 150 grams of *S. molesta* in 6 litres of liquid waste

The tools used in this study included a 40-litre bucket, a 20-litre jerry can, an Ohaus scale, a 1-litre measuring cup, a thermometer, a pH meter, cutting tools, and stationery. The materials used included the kiambang plant (*S. molesta*) and batik dye waste obtained from several batik artisans in the Cigeureung area of Tasikmalaya City.

The research procedures carried out are listed in the flow diagram in Figure 1 below.

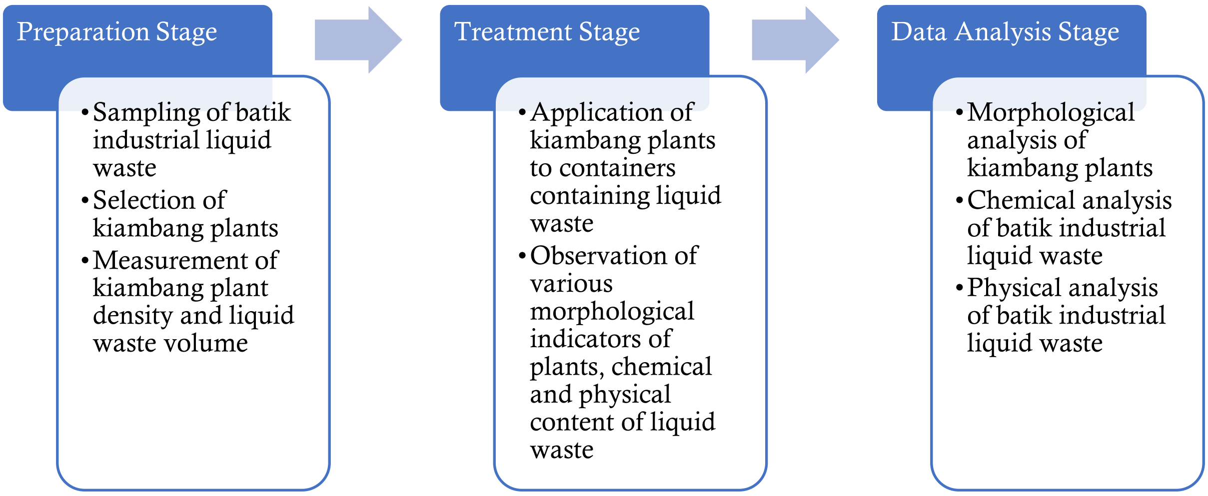

Figure 1. Research implementation flowchart

The data collection technique was carried out by observing the content of batik dye liquid waste through various indicators of physical and chemical water observation (Table 1), which include pH value, total suspended solid, BOD, COD, phenol content, total Chrom, ammonium content, sulfide content, oil & grease, cadmium content, mercury, and nickel. The duration of treatment was 10 days, with S. molesta plants applied to each treatment. At the same time, the data analysis technique was carried out by comparing the standard values of the chemical properties of batik dye wastewater, which included the values before and after treatment with S. molesta plants. The incubation of *S. molesta* plants in batik dye liquid waste was carried out at the Botany Laboratory of the Department of Biology Education, Universitas Siliwangi. In contrast, chemical properties were measured at PT. Sucofindo (Persero) is located at Jalan Soekarno Hatta No. 217, Bandung.

Table 1. Observation parameter indicators for the physical and chemical properties of batik dye wastewater

No.	Parameter	Unit	Quality standards	Description
Physical Parameters				
1	Water color	-	Clear	-
2	Water aroma	-	Odorless	-
Chemical Parameters				
1	Degree of acidity/ pH	-	6,00-9,00	
2	Level of Total Suspended Solid	mg/L	50	
3	BOD_5 days 20°C	mg/L	60	
4	COD by $K_2Cr_2O_7$ **	mg/L	150	
5	Level of Phenol**	mg/L	0,50	
6	Level of Total Chrom**	mg/L	1,00	
7	Level of Ammonium (NH_3-N)**	mg/L	8,00	
8	Level of Sulfide	mg/L	0,3	
9	Oil & Grease**	mg/L	3,00	
10	Level of Cadmium (Cd)	mg/L	-	
11	Level of Mercury (Hg)	mg/L	-	
12	Level of Nickel (Ni)	mg/L	-	

RESULT AND DISCUSSION

Result

Before batik dyeing, wastewater was treated with the kiambang plant (*S. molesta*), and its physical and chemical parameters were analysed. Testing based on physical parameters was conducted at the Botany Laboratory of Department of Biology Education, Universitas Siliwangi, while chemical parameter testing was conducted at the laboratory of PT. Sucofindo (Persero), with the results shown in Table 2 below.

Table 2. Results of analysis of various parameters of batik dye wastewater before treatment

No.	Parameter	Unit	Initial test results	Quality standards	Testing Method
Physical Parameters					
1	Water color	-	Cloudy	Clear	-
2	Water aroma	-	Smells fishy	Odorless	-
Chemical Parameters					
1	Degree of acidity/ pH	-	6,35	6,00-9,00	4500-H^+-B

No.	Parameter	Unit	Initial test results	Quality standards	Testing Method
2	Level of Total Suspended Solid	mg/L	107	50	2540 D
3	BOD_5 days 20°C	mg/L	115	60	5210 B
4	COD by $K_2Cr_2O_7$ **	mg/L	293	150	5220 B
5	Level of Phenol**	mg/L	0,117	0,50	5530 C
6	Level of Total Chrom**	mg/L	< 0,08	1,00	3111 B
7	Level of Ammonium (NH_3-N)**	mg/L	1,95	8,00	4500-NH_3-F
8	Level of Sulfide	mg/L	< 0,01	0,3	4500 S_2-D
9	Oil & Grease**	mg/L	5	3,00	5520 D
10	Level of Cadmium (Cd)	mg/L	< 0,003	-	3111 B
11	Level of Mercury (Hg)	mg/L	< 0,0008	-	3112 B
12	Level of Nickel (Ni)	mg/L	< 0,04	-	3111 B

*) Standard methods 22nd edition 2012, APHA-AWWA-WEF
**) Accreditation Parameters KAN No. LP-781-IDN

Based on the data in Table 2, many parameters exceeded the quality standards, including Total Suspended Solids, BOD, COD, Oil and grease, Cadmium (Cd), Mercury (Hg), and Nickel (Ni). Although the last three parameters were small, they should not be present. Therefore, based on the test results on the batik dye wastewater samples, the water samples were determined to be contaminated because they exceeded the established quality standards.

Analysis of the batik dye wastewater after treatment from October 10, 2022, to October 20, 2022, yielded the following results (Tables 3 and 4).

Table 3. Analysis Results After Treatment of the First Treatment Group

Parameter	Unit	Quality standards	Treatment			Testing Method *)
			A	B	C	
pH at Lab**	-	6,00-9,00	7,11	7,28	7,29	4500-H^+-B
Total Suspended Solid**	mg/L	50	64	47	30	2540 D
BOD_5 days 20°C	mg/L	60	18,21	15,13	10,09	5210 B
COD by $K_2Cr_2O_7$ **	mg/L	150	47,24	40,94	28,35	5220 B
Phenol**	mg/L	0,50	0,06	< 0, 005	< 0,006	5530 C
Chrom Total**	mg/L	1,00	< 0,04	< 0,04	< 0,04	3111 B
Ammonium Total (NH_3-N)**	mg/L	8,00	0,44	0,47	0,62	4500-NH_3-F
Sulfide	mg/L	0,3	< 0,01	< 0,01	< 0,01	4500 S_2-D
Oil & Grease**	mg/L	3,00	< 3	< 3	< 3	5520 D
Cadmium (Cd)	mg/L	-	< 0,003	< 0,003	< 0,003	3111 B
Mercury (Hg)	mg/L	-	< 0,0008	< 0,0008	< 0,0008	3111 B
Nickel (Ni)	mg/L	-	< 0,04	< 0,04	< 0,04	3112 B

*) Standard methods 22nd edition 2012, APHA-AWWA-WEF
**) Accreditation Parameters KAN No. LP-781-IDN
Description : Treatment A: 300 grams of *S. molesta* in 7 litres of liquid waste
Treatment B: 250 grams of *S. molesta* in 7 litres of liquid waste
Treatment C: 200 grams of *S. molesta* in 7 litres of liquid waste

Based on the analysis conducted before and after treatment in the first treatment group (Table 3), almost all parameters decreased depending on the number of kiambang (*S. molesta*) planted. Based on the measured parameters, treatment C can affect several parameters, including increasing the degree of acidity, decreasing the total suspended solid content, and decreasing the BOD and COD levels. Apart from these parameters, all treatments showed the same results.

Table 4. Analysis Results After Treatment of the Second Treatment Group

Parameter	Unit	Quality standards	Treatment			Testing Method *)
			D	E	F	
pH at Lab**	-	6,00-9,00	7,51	7,39	7,55	4500-H^+-B
Total Suspended Solid**	mg/L	50	29	41	72	2540 D
BOD_5 days 20°C	mg/L	60	8,86	7,25	20,26	5210 B
COD by $K_2Cr_2O_7$ **	mg/L	150	25,20	18,90	54,54	5220 B
Phenol**	mg/L	0,50	< 0,005	< 0,005	0,04	5530 C
Chrom Total**	mg/L	1,00	< 0,04	< 0,04	< 0,04	3111 B
Ammonium Total (NH_3-N)**	mg/L	8,00	< 0,05	< 0,05	0,63	4500-NH_3-F
Sulfide	mg/L	0,3	< 0,01	< 0,01	< 0,01	4500 S_2-D
Oil & Grease**	mg/L	3,00	< 3	< 3	< 3	5520 D
Cadmium (Cd)	mg/L	-	< 0,003	< 0,003	< 0,003	3111 B
Mercury (Hg)	mg/L	-	< 0,0008	< 0,0008	< 0,0008	3111 B
Nickel (Ni)	mg/L	-	< 0,04	< 0,04	< 0,04	3112 B

*) Standard methods 22nd edition 2012, APHA-AWWA-WEF
**) Accreditation Parameters KAN No. LP-781-IDN
Description: Treatment D: 150 grams of *S. molesta* in 2 litres of liquid waste
Treatment E: 150 grams of *S. molesta* in 4 litres of liquid waste
Treatment F: 150 grams of *S. molesta* in 6 litres of liquid waste;

Furthermore, based on the analysis carried out before and after treatment in the second group (Table 4), the results showed that almost all parameters experienced a decrease depending on the volume of batik dye liquid waste. Treatment D, which had a liquid waste volume of 2 litres, showed that all pollution parameters were smaller than those of treatments E and F, which had a larger liquid waste volume. Based on the measured parameters, it was known that treatment D could affect several parameters, including increasing the degree of acidity, decreasing the total suspended solid content, and decreasing the BOD and COD levels. Apart from these parameters, all treatments showed the same results.

Based on the results of the analysis that has been carried out as in Table 2, Table 3, and Table 4, it can be described as follows.

1. In the Total Suspended Solid (TSS) parameter, it was obtained from the first group treatment that the content of pollutants in the form of TSS experienced a significant decrease. The more *S. molesta* plants planted in the wastewater, the smaller the pollutant content will be. However, the pollutant content in treatment A, which has the least number of *S. molesta* plants, is still above the quality standard. Likewise, the TSS content experienced a significant decrease from the second group treatment. Thus, there is a correlation between the number of *S. molesta* plants and the decrease in the TSS parameter in the liquid waste of batik dye, as shown in Figure 2 below.

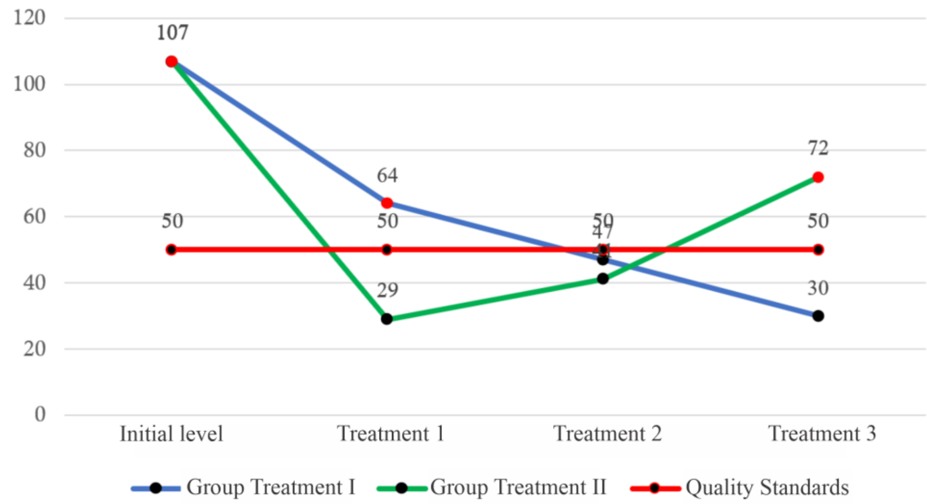

Figure 2. Graph of Total Suspended Solid (TSS) content in all treatment groups

In the pollutant indicator in the form of Total Suspended Solid (TSS), it is known that before the treatment of *S. molesta* plants, it was at 107 mg/L (Table 1), where this figure is greater than the established quality standard figure of 50 mg/L. After treatment using *S. molesta* plants in wastewater samples, in the First Treatment group (i.e. the treatment group providing different amounts of S. molesta in 7 litres of wastewater samples), it showed a continuous decrease with the addition of the amount of *S. molesta*. Based on Table 3 dan Figure 2, it is known that wastewater given treatment C (300 grams of S. molesta in 7 liters of liquid waste) has the most petite TSS figure of 30 mg/L, followed by treatment B (250 grams of *S. molesta* in 7 liters of liquid waste) with a TSS figure of 47 mg/L and treatment A (200 grams of *S. molesta* in 7 liters of liquid waste) with a TSS figure of 64 mg/L. Based on these results, the more *S. molesta* added to polluted waters correlates with a continuous decrease in TSS levels.

Similar results are also shown in Table 4 and Figure 2, namely the Second Treatment group with the same number of *S. molesta* plants, but differing in the volume of liquid waste. The lowest TSS levels were in treatment D (150 grams of *S. molesta* in 2 liters of liquid waste) with a figure of 29 mg/L, followed by treatment E (150 grams of *S. molesta* in 4 liters of liquid waste) with a figure of 41 mg/L and treatment F (150 grams of *S. molesta* in 6 liters of liquid waste) with a figure of 72 mg/L. Treatments D and E can reduce TSS levels below the established quality threshold. Based on these results, the amount of *S. molesta* added to polluted waters correlates with the reduction in TSS levels.

2. In the Biological Oxygen Demand (BOD) parameter, based on Table 2 and Figure 3, it is known that before the treatment of *S. molesta* plants, the BOD condition was at 115 mg/L, where this figure was greater than the set quality standard figure of 60 mg/L. After treatment using *S. molesta* plants in wastewater samples, the First Treatment Group showed a continuous

decrease with adding *S. molesta*. Based on Table 3 and Figure 3, it is known that wastewater given treatment C (300 grams of *S. molesta* in 7 liters of liquid waste) had the most petite BOD figure of 10.09 mg/L, followed by treatment B (250 grams of *S. molesta* in 7 liters of liquid waste) with a BOD figure of 15.13 mg/L and treatment A (200 grams of *S. molesta* in 7 liters of liquid waste) with a BOD figure of 18.21 mg/L. Based on these results, the more *S. molesta* added to polluted waters correlates with a continuous decrease in BOD levels.

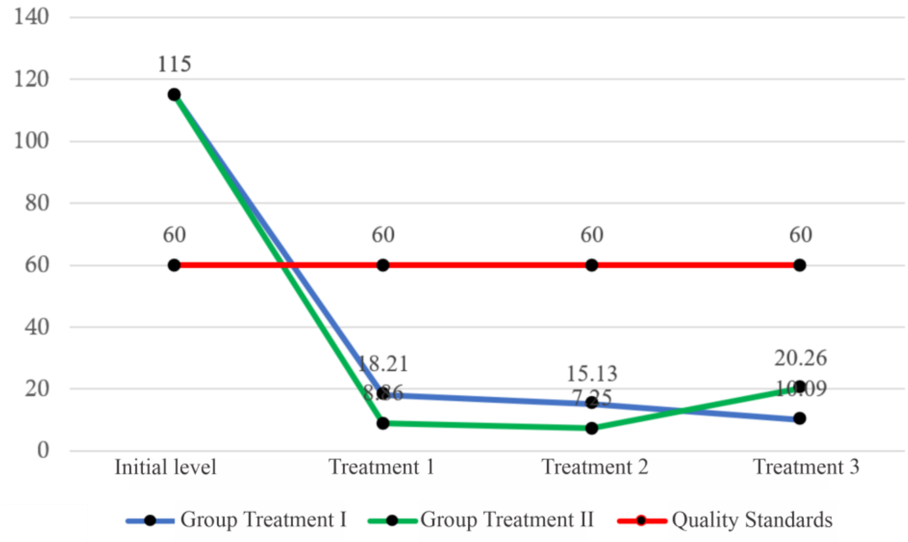

Figure 3. Graph of Biological Oxygen Demand (BOD) content in all treatment groups

Similar results are also shown in Table 4 and Figure 3, namely the Second Treatment group with the same number of kiambang plants, but differing in the volume of liquid waste. The lowest BOD levels were in treatment E (150 grams of *S. molesta* in 2 liters of liquid waste) with a figure of 7.25 mg/L, followed by treatment D (150 grams of *S. molesta* in 4 liters of liquid waste) with a figure of 8.86 mg/L and treatment F (150 grams of *S. molesta* in 6 liters of liquid waste) with a figure of 20.26 mg/L. All treatments from the First and Second Groups reduced BOD levels below the established quality threshold. Based on these results, the amount of *S. molesta* added to polluted waters correlates with the reduction in BOD levels.

3. In the Chemical Oxygen Demand (COD) parameter, it is known that before the treatment of *S. molesta* plants, the COD condition was at 293 mg/L (Table 2 and Figure 4), where this figure is greater than the set quality standard figure of 150 mg/L. After treatment using *S. molesta* plants in wastewater samples, the First Treatment group showed a continuous decrease with adding *S. molesta*. Based on Table 3 and Figure 4, it is known that wastewater given treatment C (300 grams of *S. molesta* in 7 liters of liquid waste) has the smallest COD number of 28.35 mg/L, followed by treatment B (250 grams of *S. molesta* in 7 liters of liquid waste) with a COD number of 40.49 mg/L and treatment A (200 grams of *S. molesta* in 7 liters of liquid waste)

with a COD number of 47.24 mg/L. Based on these results, the more *S. molesta* added to polluted waters correlates with a continuous decrease in COD levels.

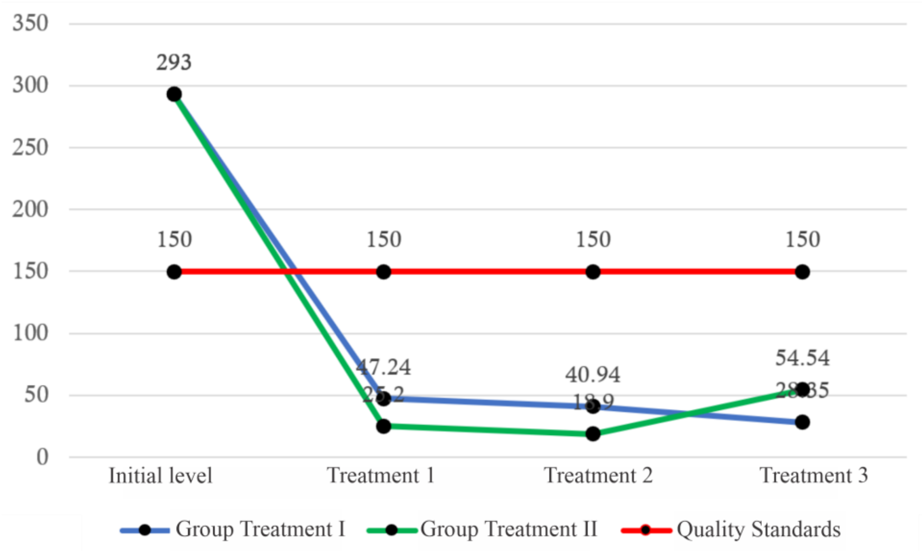

Figure 4. Graph of Chemical Oxygen Demand (COD) content in all treatments

Similar results were also shown in the application of *S. molesta* plants in the Second Treatment Group (Table 4 and Figure 4), namely that the wastewater given treatment E (150 grams of *S. molesta* in 4 liters of liquid waste) had the smallest COD number of 18.90 mg/L, followed by treatment D (150 grams of *S. molesta* in 2 liters of liquid waste) with a COD number of 25.20 mg/L and treatment F (150 grams of *S. molesta* in 6 liters of liquid waste) with a COD number of 54.54 mg/L. With such data, applying *S. molesta* plants in the First Treatment Group and the Second Treatment Group reduced COD levels below the quality standard number.

4. In the phenol content parameter, it is known that before the treatment of *S. molesta* plants, the phenol concentration was at 0.117 mg/L (Table 2 and Figure 5), where this figure was already above the established quality standard of 0.50 mg/L. After treatment using *S. molesta* plants in wastewater samples, the First Treatment group showed a continuous decrease with adding *S. molesta*. Based on Table 3 and Figure 5, it is known that the wastewater given treatment B (250 grams of S. molesta in 7 liters of liquid waste) and treatment C (300 grams of *S. molesta* in 7 liters of liquid waste) had phenol levels of <0.005 and <0.006, respectively, followed by treatment A (200 grams of *S. molesta* in 7 liters of liquid waste) whose phenol content was at 0.06.

   Similar results were also shown in the application of S. molesta plants in the Second Treatment Group (Table 4 and Figure 5), namely that the wastewater given treatment D (150 grams of *S. molesta* in 2 liters of liquid waste) and treatment E (150 grams of *S. molesta* in 4 liters of liquid waste) had a phenol content of <0.005, followed by treatment F (150 grams of *S. molesta* in 6 liters of liquid waste) with a phenol content of 0.04. With such data, applying *S. molesta* plants in the First Treatment Group and the Second Treatment Group reduced the phenol levels below the quality standard.

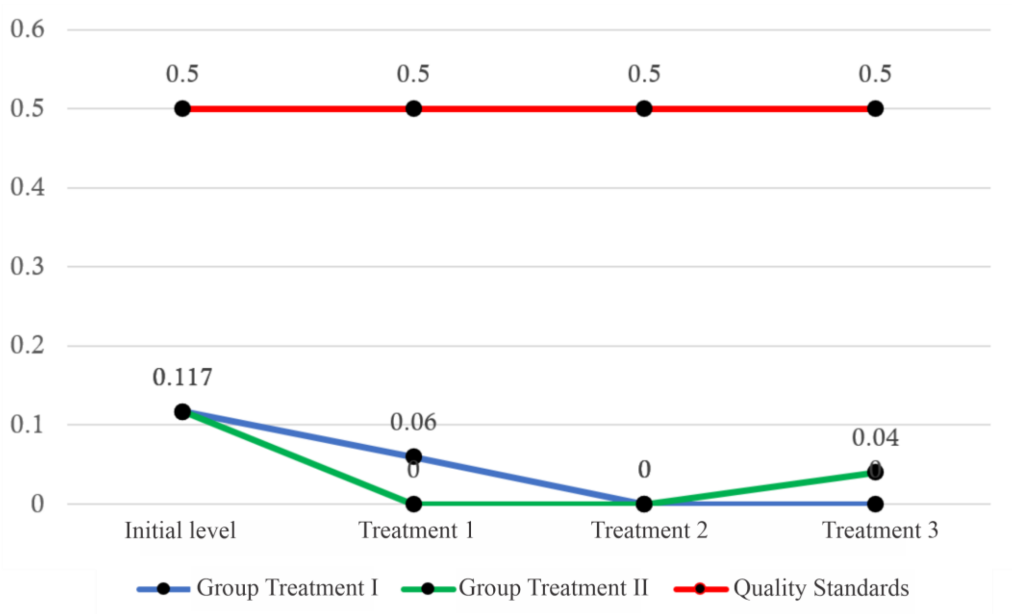

Figure 5. Graph of phenol content in both treatment groups

5. In the oil and grease parameters, based on Table 2 and Figure 6, it is known that the oil and grease content before treatment was at 5 mg/L, and it shows that it is at the threshold of the quality standard, 3.00 mg/L. After applying *S. molesta* plant treatment, it was known that in the First Treatment Group (Table 3 and Figure 6) and the Second Treatment Group (Table 4 and Figure 6), the oil and grease content were both at <3.00 mg/L. This result shows that applying *S. molesta* plants reduced the oil and grease levels in water samples contaminated with batik waste water.

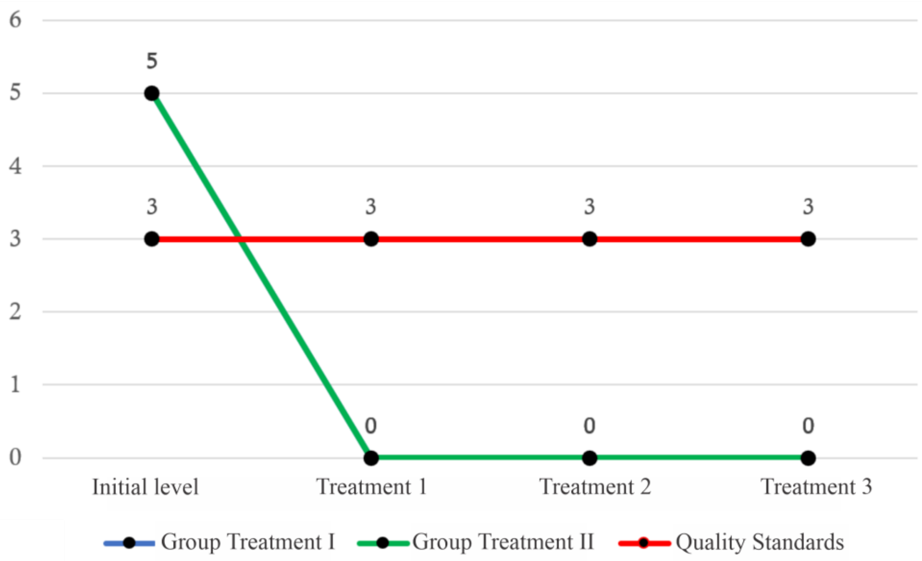

Figure 6. Graph of oil and grease content in all treatments

Discussion

Researchers have used the *S. molesta* plant in bioremediation processes for decades due to its ability to effectively and efficiently reduce various pollution indicators/parameters (Rawung et al., 2024). Based on previously presented research, it is known that the *S. molesta* plant can reduce various levels of water pollution caused by batik dye waste, such as Total Suspended Solids (TSS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Phenol, and oil and grease.

Total Suspended Solids (TSS) is a measure of the total of all solid particles suspended in water, typically measuring ≤ 2 µm in diameter (Musapana et al., 2020). These materials include sediment, various types of microalgae, bacteria, and organic waste (Bilotta & Brazier, 2008; Ng et al., 2017). Essentially, TSS levels in water are tolerable at a threshold of 50 mg/L. However, this level can increase if pollutants enter the water (Giardino et al., 2017).

TSS levels increase due to pollutants entering the waters as dye waste (Ibadulloh, 2019; D. A. Larasati et al., 2020). Larasati et al., (2020) explain that synthetic dyes containing various chemical compounds are often used in the batik dyeing process. These compounds can dissolve in wastewater and significantly contribute to increased TSS levels. Furthermore, Pratiwi et al. (2020) explain that one of the substances used in the batik-making process is wax, which functions to cover parts of the fabric that are not to be dyed. Unused or washed wax residue from the fabric can enter the wastewater and increase TSS. Wax is hydrophobic and tends to clump, forming suspended particles.

TSS levels in water can be reduced through bioaccumulator mechanisms by several aquatic plants such as Salvinia molesta. Several TSS phytoremediation mechanisms using aquatic plants include adsorption and mechanical filtration, where the roots and leaves of aquatic plants can physically trap various suspended particles (Musapana et al., 2020). Furthermore, another mechanism can occur through root absorption, where organic and inorganic particles are absorbed by plant roots and accumulated in plant tissue (Mustafa & Hayder, 2021). This study's results show that the effectiveness of *S. molesta* phytoremediation in reducing TSS levels in waters contaminated with batik waste depends on biomass. In line with the results of the study by Musapana et al., (2020), the higher the biomass of phytoremediation plants, the greater their ability to reduce TSS. In addition, increasing the surface area for filtration and absorption also affects the reduction of TSS levels.

The increase in BOD levels in water is closely related to the dissolved oxygen that microorganisms require to decompose organic matter under aerobic conditions over a specific period (Munfarida et al., 2020). This increase in BOD levels is triggered by several factors, including excessive organic pollution (Astuti & Indriatmoko, 2018) such as food waste, detergents, oil, and dye waste. Furthermore, other factors can also be caused by the direct discharge of liquid waste into rivers without prior treatment (Ulfah et al., 2022).

The phytoremediation mechanism by *S. molesta* that can reduce BOD levels in water is closely related to the degradation mechanism. Specifically, organic compounds dissolved in wastewater are absorbed by plants. Then, they are enzymatically broken down in plant tissue (Imron et al., 2019). Plant tissue in the roots, stems, and leaves becomes a place for the enzymatic breakdown of organic materials, especially in the roots and shoots that produce enzymes such as peroxidase and laccase to metabolise contaminants (Dhir, 2013).

Chemical oxygen demand (COD) measures the oxygen needed to oxidise organic and inorganic compounds in water (Munfarida et al., 2020; Ulfah et al., 2022). An increase in COD indicates water pollution, typically caused by excessive influx of organic and inorganic waste, difficult-to-degrade organic compounds, and decreased dissolved oxygen (DO) levels (Ng et al., 2017; Ulfah et al., 2022)

The decrease in chemical oxygen demand (COD) levels in batik wastewater after *S. molesta* treatment indicates that the plant has self-purification capabilities, namely the natural removal of pollutants through the process of destroying organic waste by microorganisms through the respiration process (Ulfah et al., 2022). The decrease in COD levels after *S. molesta* application to water contaminated with batik waste is closely related to the physical and biological mechanisms carried out by S. molesta in reducing COD levels.

The physical mechanisms that occur in *S. molesta* are closely related to its ability to filter organic particles by the surface of plant roots and leaves, as well as the slowing of water flow by plant biomass, which causes particulate sedimentation, thus impacting the reduction of COD (Favas et al., 2016). Then, the biological mechanisms carried out by plants, including *S. molesta*, are related to their ability to degrade organic and inorganic particles physiologically through various phases, namely phytoextraction/phytoaccumulation, phytostabilization, phytovolatization, phytodegradation, and phytofiltration/rhizofiltration (Ibañéz et al., 2018). Water polluted with batik waste usually contains various dyes, including lead (Pb) (Murniati et al., 2015). This batik dye element is difficult to degrade, thus increasing COD levels in the water. The application of *S. molesta* plants in waters as phytoremediation agents is related to the plant's ability to accumulate Pb in higher amounts in the root organs than in the leaves (Rachmadiarti et al., 2022), because *S. molesta* roots can immobilize various toxic ions and collect them in the roots. In addition, *S. molesta* roots also function as rhizofilters that can absorb various toxic Pb ions after the phytostabilization process, so this results in an increase in Pb levels in the roots caused by the Pb accumulation process in the roots (Ibañéz et al., 2018; Rachmadiarti et al., 2022).

In addition to chemical oxygen demand (COD), another parameter studied was phenol levels. The study results in both Group One (Table 3) and Group Two (Table 4) showed that phenol levels decreased significantly above the quality standard after *S. molesta* treatment was applied to batik wastewater samples. This indicates that *S. molesta* can reduce phenol levels in water contaminated with batik waste.

Phenolic compounds are aquatic pollutants with harmful effects and high toxicity, even at low concentrations. Phenolic compounds in waters contaminated with batik waste originate from the alcohol group used as a wax remover (Triwiswara, 2019). In addition to being found in batik industrial wastewater, phenolic compounds can also be found in the iron and steel, petrochemical (Varjani et al., 2018), pharmaceutical, resin synthesis, solvent, and lubricating oil industries (Varun et al., 2015).

Researchers have used plant root hairs as accumulators to remediate environmental phenol content. The results showed an efficient reduction in phenol levels due to the involvement of various peroxidase isoenzymes found in the root hairs (Ibañéz et al., 2015). Phytostabilisation mechanisms are thought to be involved in environmental phenol remediation, capable of controlling the movement of pollutants such as phenol (Srivastava, 2015).

Finally, the indicators measured in this study were oil and grease content. The results showed that the addition of *S. molesta* to water contaminated with batik waste decreased oil and grease content below the quality standard. These results were obtained in both the first and second treatment groups (Table 3 and Table 4).

The presence of oil and fat in waters contaminated with batik waste is caused by wax being used as a resisting agent in the production process (Triwiswara, 2019). Using wax as a resisting agent aims to prevent the penetration of other substances, usually dyes, into certain parts of the material's surface. In the context of batik production, wax functions to prevent the entry of dyes into unwanted areas. Therefore, after the dyeing process, the wax is removed so that the discharged waters will contain oil and fat (Cahyanto et al., 2017; Triwiswara, 2019).

The use of *S. molesta* as a phytoremediation agent to reduce oil and fat levels in waters contaminated with batik waste is closely related to phytoremediation mechanisms such as phytodegradation, phytostabilisation, and phytoextraction (Favas et al., 2016). The root features of *S. molesta* plants play an important role as filters for oil and fat particles suspended in water. Then, *S. molesta* can also absorb surfaces and absorb roots towards hydrophobic compounds such as oil and fat. The reduction in oil and fat levels in batik wastewater samples in this study is very much in line with the results of Triwiswara (2019) study, that the use of plant treatments can reduce oil and fat levels below the minimum threshold, so the use of aquatic plants such as *S. molesta* is highly recommended as phytoremediation agents for polluted waters.

The results of this research are projected as a learning resource for the Environmental Pollution course in the Department of Biology Education and the Environmental Physics course in the Department of Physics Education, Universitas Siliwangi. In the Environmental Pollution course, the research results are projected as one of the contents in the following topics: 1) Toxicology of Heavy Metals, Food, Drugs, and Pesticides; 2) Pollutants and Waste Characteristics; and 3) Water Pollution Project. Then, in the Environmental Physics course, the research results are projected to be one of the contents of soil and groundwater.

CONCLUSION

Based on the results of the research and discussion that have been presented, the conclusion obtained by this study is that the Kiambang plant (Salvinia Molesta) can reduce pollutants and reduce pollution levels in batik dye wastewater in the Cigeureung River in all indicators, namely pH value, total suspended solid, BOD, COD, phenol content, total Chrom, ammonium content, sulfide content, oil & grease. The density of *S. molesta* plants and the volume of batik wastewater influence the reduction rate of each waste component, and the speed of the phytoremediation process carried out by *S. molesta* plants. Therefore, artisans or batik company owners can use this plant for phytoremediation before the waste is discharged into the water.

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