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Original Research Article

Effectiveness of *Pistia stratiotes* and *Limnocharis flava* for Chromium Removal From Batik Wastewater

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Abstract

The batik industry has the potential to cause environmental problems owing to wastewater containing hazardous pollutants, particularly Cr, which is difficult to degrade. Therefore, appropriate management efforts are required, one of which is phytoremediation. This study aimed to determine the effectiveness of *Pistia stratiotes* and *Limnocharis flava* in reducing Cr concentrations based on variations in fresh weight and analyze their accumulation capacity through the bioconcentration factor (BCF) and translocation factor (TF). This study employed an experimental method with variations in fresh weight and a contact time of 7 days, using a completely randomized factorial design. Cr concentrations were measured using atomic absorption spectrophotometry (AAS) and analyzed using the Aligned Rank Transform (ART), followed by post hoc pairwise comparison tests. The highest removal efficiency was achieved by *P. stratiotes* (55.57%), while *L. flava* reached 42.73%. Fresh weights of 100 g and 250 g showed significant effects compared to the control. Both plants exhibited good Cr accumulation, indicated by BCF > 1 and TF < 1,suggesting a phytostabilization mechanism. These findings indicate that both species have strong potential as effective phytoremediators for Cr-contaminated wastewater.

Keywords: Batik industry; Chromium; Limnocharis flava; Phytoremediation; Pistia stratiotes

1. Introduction

The batik industry not only contributes to the regional and national economy but also has the potential to cause environmental problems due to the liquid waste it generates if not managed properly. Industrial liquid waste originates from production activities and is characterized by turbid color, high pH, and organic and inorganic pollutants, including heavy metals (Cu, Pb, Cr, Ni, Zn, Cd) (Syafrudin et al., 2020; Sumardiono et al., 2023; Marendra et al., 2024). Chromium (Cr) is a heavy metal commonly found in batik waste (Deliza et al., 2021; Dini et al., 2023; Safamaura and Afany, 2025). The presence of Cr is closely related to the use of synthetic dyes and mordants in the dyeing process (Kencana and Radityaningrum, 2022; F. L. Sasongko et al., 2023; Tampubolon et al., 2021). Cr is toxic, persistent, and bioaccumulative; therefore, its long-term accumulation in the environment can impact aquatic organisms, aquatic ecosystems, and even humans (A`yunina et al., 2022; Rachmawati et al., 2025).

Therefore, its presence in the environment is an important issue that needs to be addressed and managed to minimize the resulting impact, one of which is through the application of phytoremediation technology.

Phytoremediation is a waste treatment technology that utilizes the ability of plants to absorb, stabilize, and break down organic and inorganic pollutants in water or soil (Astuti and Rosemalia, 2022; Mohebi and Nazari, 2021). Phytoremediation is widely recognized as an environmentally friendly, low-cost, and effective technology for reducing large amounts of pollutants compared to other conventional treatment methods (Syafrudin et al., 2018; Prastitianti and Purwanti, 2024). This technology works through several main mechanisms, including phytoextraction, rhizofiltration, phytostabilization, rhizodegradation, and phytovolatilization (Alfakihuddin et al., 2023). These mechanisms are generally used to assess the ability to accumulate and translocate pollutants in plants using the bioconcentration factor (BCF) and translocation factor (TF)(Córdoba-Tovar et al., 2025). The effectiveness of phytoremediation is closely related to the concept of hyperaccumulation, which is the ability of plants to extract and accumulate specific minerals or metals within their biomass (Wibowo et al., 2025).

Based on this, the selection of phytoremediation plants is an important factor because each plant has different absorption, translocation, and remediation mechanisms for pollutants (Tan et al., 2023). Aquatic plants such as water hyacinth, water jasmine, water lettuce, and water spinach have been reported to have potential as phytoremediators owing to their higher absorption and translocation capabilities compared to non-hyperaccumulator plants (Marendra et al., 2024).

Aquatic plants, such as *Pistia stratiotes* and *Limnocharis flava*, have extensive fibrous root systems, which are believed to be capable of absorbing and accumulating heavy metals from wastewater and polluted water (Billah et al., 2020). This potential is also due to the presence of chelating agents in the form of phytochelatins, which are the plant's response to pollutant exposure (Aulya et al., 2020). This ability is evidenced by the findings of Billah Moelyaningrum and Ningrum (2020), who reported that the effectiveness of reducing Cr concentration using *Pistia stratiotes* reached 67.7%, as well as Irmawanty *et al.* (2023), who showed that Cr concentration decreased from 0.219 mg/L to 0.041 mg/L after treatment using *Limnocharis flava*. The ability of *P. stratiotes* and *L. flava* to remediate heavy metals has been reported in several studies. However, direct comparisons of the effectiveness of both plants in reducing Cr in batik wastewater are still limited. Additionally, studies on the dominant phytoremediation mechanisms based on bioconcentration and translocation factors are still rarely conducted.

Based on the aforementioned context, this study aimed to analyze and evaluate the effectiveness of *Pistia stratiotes* and *Limnocharis flava* in reducing Cr concentration in batik industry wastewater with variations in the wet weight of the plants. The bioconcentration factor (BCF) and translocation factor (TF) values were also analyzed to determine the dominant phytoremediation mechanisms and identify the appropriate plant species for environmental remediation. The research results are expected to fill the gap in studies comparing the absorption capabilities and phytoremediation mechanisms of the two types of plants, expand the examination of the potential of plants as phytoremediators, and serve as scientific recommendations for sustainable waste management and the recovery of contaminated environments.

2. Methods

2.1 Research Location and Time

Wastewater samples were obtained from the production process of a batik industry in Surakarta City. The sample was taken directly from the residual dye effluent solution before it entered the drainage system, thus representing fresh liquid waste. Sampling was conducted over one production cycle, starting from morning until evening on the same day, to illustrate the characteristics of the waste generated during the production process. The experimental design, including acclimatization, waste exposure, and analysis of Cr concentration, was conducted at the Greenhouse of the Biology Sub-section and the Chemistry Sub-section of the Integrated Laboratory Unit of Universitas Sebelas Maret. The research was conducted over a period of three months, from October to December 2025.

2.2 Research Design and Data Collection

This study was an experimental study with a laboratory-scale batch system designed based on a completely randomized factorial design. The treatment factors included the types of plants *Pistia stratiotes* and *Limnocharis flava*, as well as variations in the wet weight of the plants (0, 100, 150, 200, 250, 300, and 400 g). The range of plant wet weight was chosen based on previous studies that showed that biomass significantly affects the effectiveness of metal removal in phytoremediation systems (Rahayuningtyas, et al., 2018; Oktaviani et al., 2020; Huntoyungo et al., 2025). Batch reactors in the form of plastic tubs measuring 39 × 31.5 × 12 cm for *P. stratiotes* and cylindrical containers with a diameter of 20 cm and a height of 19 cm for *L. flava*, each filled with 5 liters of liquid waste without dilution or nutrient addition. The size of the tank for *P. stratiotes* was determined proportionally to the volume and characteristics of the floating plant, allowing for optimal interaction between the root system and the waste medium. The research was conducted in a laboratory with environmental parameters following natural conditions, without special control over aeration, light intensity, or dissolved oxygen (DO).

The phytoremediation process began with the acclimatization of the plants for 7 days, with water replacement every two days (Oktaviani et al., 2020; Sariti, 2023; Parwati and Hendri, 2025). Subsequently, they were exposed to liquid waste for 7 days, as it has been reported that plants can optimally absorb pollutants within a minimum of 7 days (Baroroh et al., 2018). Each treatment was conducted in two repetitions (duplo) based on the Federer experimental design approach. The concentration of Cr in post-treatment water samples and plant tissues was analyzed using an atomic absorption spectrophotometer (AAS) at a wavelength of 357.9 nm, referring to SNI 6989-84:2019, after undergoing wet digestion. The pH was measured using a pH meter and the temperature was measured using an integrated temperature sensor on the total dissolved solids (TDS) meter. The morphology of the plants was visually observed and measured using a tape measure. These parameter measurements were conducted to support the interpretation of the phytoremediation results.

2.3 Data Analysis Procedure

Effectiveness of Removal

Cr removal effectiveness is determined using the equation in the study by Widodo *et al.* (2018) (Equation 1):

$$E\ (\%) = \frac{[C0 - C1]}{C0} \times 100\% \quad (1)$$

In Eq. (1), E (%) represents the value of the actual pollutant removal effectiveness. **Co represents** the initial concentration of the pollutant (mg/L), while **C1 represents** the final concentration of the pollutant (mg/L) post-phytoremediation, measured after the treatment period.

Conversion of Chromium Concentration

The concentration of Cr metal (mg/L) in plant tissue was converted to (mg/kg) using the following equation (Mahlungulu et al., 2023) (Equation 2):

$$C\ sample\left(\frac{mg}{kg}\right) = C\ AAS\ \left(\frac{mg}{L}\right) \times \frac{Vs}{Ws} \quad (2)$$

In Eq. (2), the concentration of Cr in plant tissues is calculated in terms of biomass, where **C AAS represents** the pollutant concentration from the AAS instrument readings, **Vs represents** the final volume of the destruction solution (mL), and **Ws represents** the weight of the sample from each plant tissue used (g).

Bioconcentration Factor (BCF)

The bioconcentration factor was calculated using the following equation (Siyar et al., 2022) (Equation 3):

$$BCF = \frac{C_{plant\ tissue}}{C_{water}} \quad (3)$$

In Eq. (3), BCF is calculated based on the dry weight of the plant (DW). **C root/leaf represents** the concentration of the heavy metal Cr in the roots or leaves of the plant (mg/kg DW), and **C water represents** the concentration of the heavy metal Cr in the water.

Based on the results obtained, the bioconcentration factor (BCF) can be categorized as follows (Basri et al., 2024): BCF value < 1: Accumulator; BCF = 1: Indicator; BCF > 1: Excluder

Translocation Factor (TF)

The translocation factor can be calculated using the following equation (Siyar et al., 2022) (Equation 4):

$$TF = \frac{C_{leaves}}{C_{roots}} \quad (4)$$

In Eq. (4), TF is calculated based on the dry weight of the plant (DW). **C leaf represents** the concentration of heavy metal Cr in the plant leaves (mg/kg DW), and **C roots** represents the concentration of heavy metal Cr in the roots.

Based on the resulting values, the translocation factor (TF) can be categorized as follows (Zain and Sitogasa, 2025): TF value < 1: phytoextraction; TF > 1: phytostabilization.

Statistical Analysis

Data analysis in this study was conducted using R-based statistical software with a non-parametric statistical approach, namely Aligned Rank Transform (ART) at a significance level of α = 5%. The ART method was chosen because the research data did not meet the assumptions of parametric tests (normality and homogeneity of variance) and allowed for the analysis of main effects and interactions between factors while still using the ANOVA analysis framework (Durner, 2019). If the analysis results show a significant effect, further analysis or post hoc tests in the form of pairwise comparisons using the Bonferroni correction will be conducted.

3. Result and Discussion

3.1 Initial Characteristics of Batik Industrial Wastewater

The characteristics of liquid waste produced by each batik industry can vary depending on the batik process, amount of water, type of dye, and additional chemicals used during production (Zakaria et al., 2023). The potential differences in this regard underline the importance of identifying the waste characteristics of an industry to determine the extent of the pollutant load generated, both for the environment and for plants as phytoremediation agents. In addition, the phytoremediation capacity of plants can also vary, and one of the factors that influences this is the level of contamination in their environment (Córdoba-Tovar et al., 2025). The initial characteristics of the batik industrial wastewater in this study are presented in Table 1.

Table 1. Initial characteristics of batik industrial wastewater

No	Parameter	Measurement Result	Quality Standard
1.	Temperature (°C)	32.3	38°C**
2.	pH	7.9	6.0 – 9.0*
3.	Chromium (mg/l)	0.3768	1*

Description: (*) Regulation of the Minister of Environment of the Republic of Indonesia Number 5 of 2014; (**) Regional Regulation of Central Java Province Number 5 of 2012.

The batik waste in this study originated from the dyeing process, which was identified to contain heavy metals that could pose a danger to the environment and organisms if discharged directly into water bodies. This waste has a thick black and murky color due to the use of dyes such as remazol (Larasati et al., 2020), and it has a pungent odor suspected to be caused by the use of kerosene in the dye paste production. The remazol dye's property of being easily soluble but difficult to decompose naturally can lead to increased water turbidity and reduced sunlight penetration efficiency, thereby affecting the photosynthesis process, aquatic ecosystem functions, and increasing the accumulation of complex heavy metals that can poison aquatic biota and inhibit plant growth (Al-Mahbashi et al., 2022; Dewi et al., 2021).

The results of the measurement of the physicochemical parameters of the water (Table 1) showed a temperature of 32.3°C and a pH value of 7.9, indicating that the wastewater was in a basic condition, which was suspected to be caused by the use of sodium bicarbonate ($NaHCO_3$) during the production process (Oktavina and Imtihani, 2023). The temperature and pH of the wastewater are important parameters because the temperature of the wastewater can affect the growth, metabolism, and survival of plants as phytoremediation agents, as well as determine the solubility level and the rate of chemical reactions present in the wastewater. Meanwhile, the increase in pH value (basic condition) of the liquid waste can also affect the survival of plants and the solubility level of heavy metals, which tends to decrease and cause more metals to be in the form of precipitates, ultimately potentially affecting the effectiveness of the phytoremediation process (Bahute et al., 2024).

The detected chromium concentration was 0.3768 mg/L, which meets the environmental quality standard of 1 mg/L. The presence of Cr in this waste is produced by the use of reactive dyes or metal-type catalysts in the production process (Astuti *et al.*, 2023; Fatiha et al., 2025). Although the detected Cr levels still meet environmental quality standards, its presence still needs to be monitored, considering the continuous production activities in the batik industry and the potential for increased Cr metal accumulation in water bodies and the risk of metal biomagnification from organisms to higher trophic levels, including humans, over time (Nurhayati et al., 2020; Allifah *et al.*, 2025; Pratama et al., 2025). Therefore, efforts to manage the waste must continue to minimize the long-term toxic effects of Cr pollution, both ecologically and environmentally. One of the efforts that can be undertaken is phytoremediation, where its effectiveness is greatly influenced by the initial characteristics of the waste, including temperature, pH value, and heavy metal contamination.

3.2 Effectiveness of Chromium (Cr) Removal by *Pistia stratiotes* and *Limnocharis flava* Plants

The effectiveness of chromium (Cr) heavy metal reduction by *P. stratiotes* and *L. flava* is presented in Table 2.

Table 2. Initial and final concentrations of chromium (Cr) metal and removal effectiveness after 7 days

No	Treatment (g)	Co (mg/L)	*P. stratiotes*		*L. flava*	
			C1 (mg/L)	E (%)	C1 (mg/L)	E (%)
1.	0 (Control)	0.3768	0.3363	10.75	0.3953	0
2.	100		0.1674	55.57	0.2470	34.45
3.	150		0.2506	33.49	0.2273	39.68
4.	200		0.2341	37.87	0.2448	35.03
5.	250		0.2091	44.51	0.2353	37.55
6.	300		0.2603	30.92	0.2158	42.73
7.	400		0.2638	29.99	0.2375	36.97

Description: numbers in yellow indicate the highest effectiveness value for reduction; C: concentration (Co = initial concentration; C1 = final concentration); E: effectiveness.

Table 2 shows that both plants can be used to reduce Cr concentration in batik wastewater with varying effectiveness values among the treatments. *P. stratiotes* produced a higher removal efficiency (55.57 %), while *L. flava* achieved 42.73%. The small difference in Cr concentration compared to the initial concentration in both plants (Table 2) is suspected to be related to the non-essential nature of Cr, which makes it unnecessary for macrophytes in their physiological mechanisms, resulting in limited absorption (Zahari et al., 2021). Meanwhile, the control treatment (without plants) resulted in a lower removal efficiency compared to the treatment with plants, indicating that the presence of plants affects the Cr concentration in the waste through phytoremediation mechanisms, particularly through the active absorption process by plant tissues (Zain and Sitogasa, 2025).

Although descriptively *P. stratiotes* shows a higher effectiveness value in removing Cr compared to *L. flava*, the analysis results using the ART test indicate that the significance value obtained is 0.72 (> 0.05), which can be interpreted as no significant difference between *P. stratiotes* and *L. flava* in remediating Cr in batik waste. Therefore, both plants are considered to have the same ability to remediate Cr. This absorption capability is supported by a fibrous root system that can expand the area for absorbing the nutrients contained in their growing media, including Cr (Hasnunidah and Wiono, 2019), and is consistent with the findings reported by Rahman *et al.* (2021) that plants with a fibrous root system have better absorption capabilities compared to a taproot system.

Furthermore, the findings reported by Bahute et al. (2024) and Huntoyungo et al. (2025) indicate that the Cr remediation capability of *P. stratiotes* and *L. flava* is related to the presence of chelating agents, one of which is phytochelatin compounds that function as metal-binding agents through the formation of complex compounds in the form of phytochelatin-metal (Amalia et al., 2023). The removal of Cr concentration can also occur due to the absorption and translocation of metals from the medium to plant tissues, which begins with the direct interaction between the contaminated medium and the roots. It is then translocated to other organs through the vascular tissue before being localized within the plant tissues and cells to minimize its toxic effects on plant metabolism (Masruroh and Purnomo, 2024). The mechanism of metal absorption by plants can be determined by analyzing Cr content in plant tissues. The results of the Cr concentration analysis in plant tissues are presented in Figures 1 and 2, which were subsequently used to analyze the chromium (Cr) absorption mechanism in both plants.

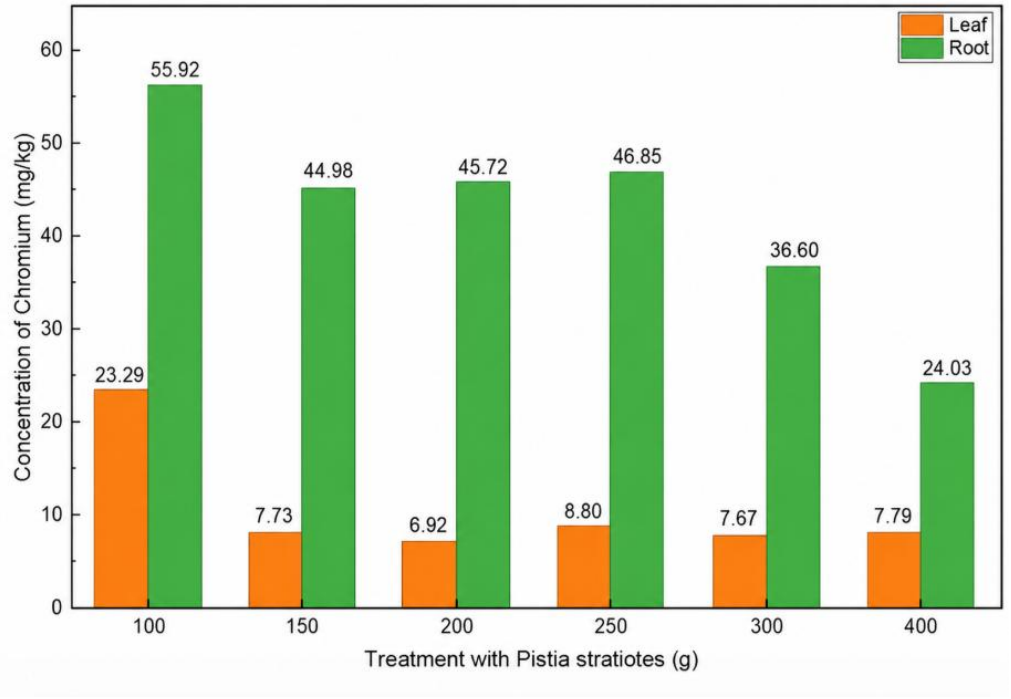


Figure 1. Concentration of heavy metal chromium (Cr) in the tissues of *P. stratiotes*

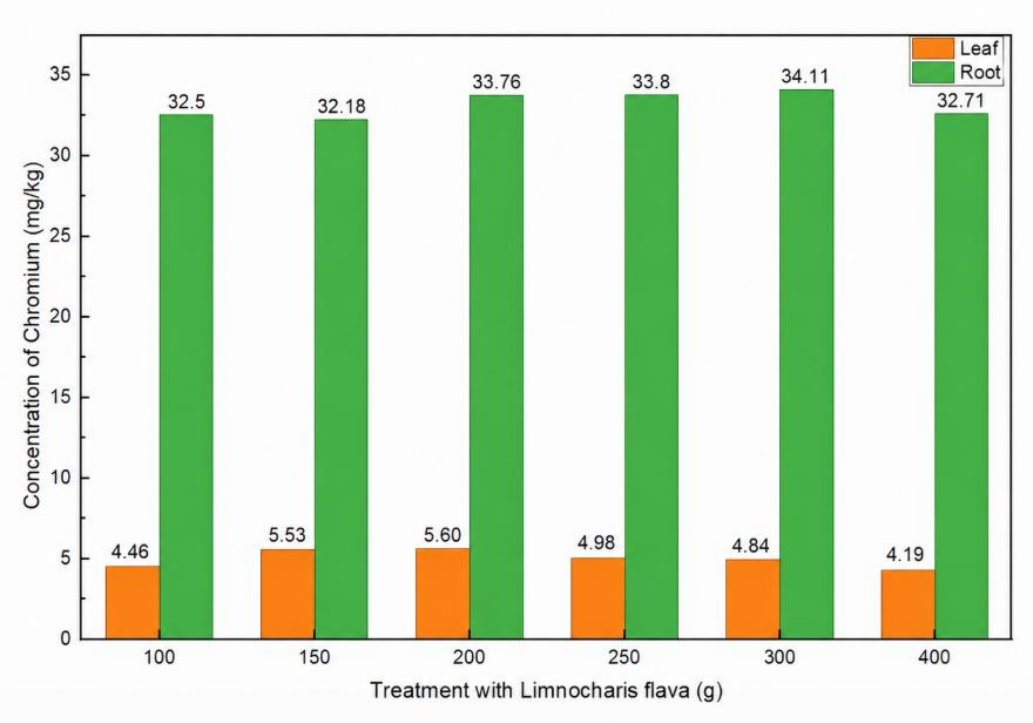


Figure 2. Concentration of heavy metal chromium (Cr) in the tissues of *L. flava*

Figures 1 and 2 show that the accumulation of Cr in the roots of both plants is higher than that in their leaves. These findings are consistent with those of Mirjankar *et al.* (2023) on *P. stratiotes* and Amalia et al. (2023) on *L. flava*, who reported that the root parts of plants accumulate higher levels of heavy metals than the above-ground organs, such as leaves and stems. The high accumulation of Cr in plant roots is fundamentally caused by their function as absorbing and supplying organs for nutrients and other elements present in their growth medium (Wajong, et al., 2022). Although leaves produce lower accumulation values, they still play a role in metal management through excretion and localization mechanisms, both actively and passively, through the process of abscission (Samosir et al., 2023). Based on the description, it can be concluded that the accumulation of Cr metal can occur in all parts of the plant, but it is more dominant in the roots, which is suspected to be related to the formation of phytochelatin compounds as a plant defense response to heavy metals.

In addition, the effectiveness of Cr removal and accumulation can also be influenced by the physicochemical factors of the water, such as temperature and pH of the wastewater. The measurement results of the wastewater temperature in each reactor showed daily fluctuations, ranging from 28.1 to 32.2°C. These daily fluctuations during the phytoremediation process can be influenced by surrounding environmental conditions, such as sunlight intensity and weather at the time of measurement (Violita et al., 2020). These daily fluctuations also occurred in the water pH parameter, which ranged from 7.48 to 7.72. Although fluctuating, the pH values in this study remained within the tolerance limits for aquatic life, thus not hindering the phytoremediation process. The fluctuation in pH values was suspected to be related to the photosynthetic activity of plants, which can affect the ion balance in the water (Soheti et al., 2020; Violita et al., 2020).

Based on these results, it can be concluded that the apu wood and genjer plants have relatively the same ability to absorb Cr. The effectiveness of metal removal is determined not only by the physiological and biological characteristics of the plants but also by environmental conditions, such as pH and temperature, which need to be controlled for optimal phytoremediation.

3.3 The Impact of Plant Biomass on Chromium Effectiveness Removal

Figure 3 shows how plant biomass affects the effectiveness of chromium (Cr) removal.

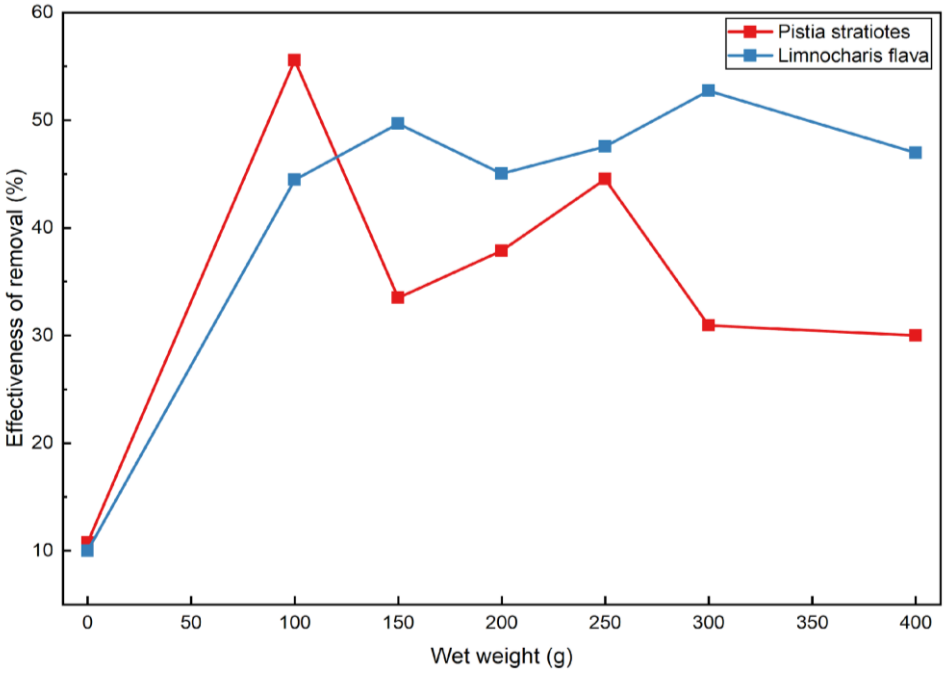


Figure 3. Effectiveness of Cr metal removal based on plant biomass variation

Source: research results (2025)

Figure 3 shows that the highest chromium removal efficiency by *P. stratiotes* occurred at an initial biomass of 100 g, reaching 55.57% (Table 2), while the highest efficiency for *L. flava* occurred at a biomass of 300 g, amounting to 42.73% (Table 2). The results of the statistical analysis show that variations in biomass significantly affect the effectiveness of chromium removal ($p < 0.05$). However, the post hoc test results indicate that significant differences only occur between the control treatment (0 g) and the biomass of 100 g and 250 g, while other biomass variations do not show significant differences ($p > 0.05$). These results indicate that an increase in plant biomass is not always accompanied by a proportional increase in chromium removal efficiency, which is in line with the findings of (Ahmed et al., 2019), who reported that an imbalance in the ratio between the amount of plant biomass and pollutant concentration can reduce the absorption efficiency per unit mass.

The pattern of Cr removal effectiveness that is relatively constant at a biomass of 100 g–400 g, ranging from 30% to 45%, is suspected to be related to several factors, including the limited absorption capacity of the plants, particularly in the root system, the simultaneous adsorption-desorption processes, the physiological adaptation of the plants to metal exposure, and changes in the chemical conditions of the medium (Mahmudha et al., 2025). Additionally, the increase in plant density within a single reactor is suspected to cause competition among plants, thereby limiting the root expansion area and the absorption effectiveness of the plants. These findings are consistent with those of Rahayuningtyas et al. (2018) and Lestari (2023), who reported that phytoremediation with lower biomass treatment tends to yield higher removal efficiency compared to treatments with higher biomass and density. Lidiana et al. (2022) also reported that an increase in plant weight can impact the plant's ability to absorb and reduce metals.

Based on this description, these results indicate that the effectiveness of phytoremediation is not only influenced by the amount of biomass but also by the capacity of the space, the system's load-bearing capacity, and the density of plants in the processing unit. Therefore, these factors need to be thoroughly considered to optimize the application of phytoremediation as a waste treatment method.

3.4 Bioconcentration Factor (BCF) and Translocation Factor (TF) Values of Chromium (Cr) in *Pistia stratiotes* and *Limnocharis flava*

The mechanism of chromium phytoremediation by *P. stratiotes* and *L. flava* was analyzed based on the values of the bioconcentration factor (BCF) and translocation factor (TF), as shown in Table 3. The BCF value describes the plant's ability to accumulate metals from the medium into plant tissues, whereas the TF value indicates the plant's ability to translocate metals from the roots to the leaves (Taufikurahman et al., 2017).

Table 3. Results of bioconcentration factor (BCF) and translocation factor (TF) calculations for *P. stratiotes and L. flava*

Type of Plant	Treatment	BCF		TF
		Root	Leaf	
P. stratiotes	100	334.05	139.13	0.42
	150	179.49	30.87	0.17
	200	195.28	29.56	0.15
	250	224.05	42.06	0.19
	300	140.61	29.47	0.21
	400	91.07	29.51	0.32
L. flava	100	131.56	26.61	0.14
	150	141.58	24.71	0.17
	200	137.91	22.38	0.17
	250	143.63	23.82	0.15
	300	158.04	18.57	0.14
	400	137.71	15.86	0.13

The bioconcentration factor (BCF) values presented in Table 3 indicate that chromium (Cr) accumulation in both plants primarily occurs in the roots. *P. stratiotes* exhibited BCF values ranging from 91.07–334.05 in the roots and 29.51–139.13 in the leaves, whereas in *L. flava*, the BCF values for roots and leaves ranged from 131.56–158.04 and 15.86–26.61, respectively. Thus, both plants showed BCF values > 1 and were categorized as accumulator plants, meaning plants capable of effectively absorbing and storing heavy metals in their bodies (Basri et al., 2024; Martind and Wiratno, 2025). These findings are consistent with previous research on aquatic macrophytes used as heavy metal remediation agents (Samal and Dash, 2024; Soenardjo and Mentari, 2023; Zain and Sitogasa, 2025).

The high BCF value produced by the roots compared to the leaves indicates that the roots are the main tissue for storing heavy metal Cr from wastewater. This pattern is also consistent with the interaction between the roots and the wastewater medium and the fibrous root system's ability to provide a large surface area for metal adsorption and absorption processes (A. S. Sasongko et al., 2020). The accumulation of Cr in root tissues can also be related to the process of metal adsorption on root cell walls and subsequent sequestration in vacuoles as a plant protection mechanism involving root exudation and chelation by phytochelatins (Priantoro et al., 2025; Sharma et al., 2020). Root exudation is the process of releasing metabolites containing organic acids from the roots to increase Cr bioavailability by forming soluble metal complexes, thus facilitating metal uptake into plants (Ongon'g et al., 2020; Priantoro et al., 2025).

The translocation factor (TF) values for both plants were relatively low, ranging from 0.15–0.42 for *P. stratiotes* and 0.13–0.17 for *L. flava*. A TF value < 1 indicates limited Cr distribution from the roots to the upper parts (leaves and stems) and suggests that this phytoremediation process occurs through a phytostabilization mechanism. This finding aligns with the research of Bakshe and Jugade (2023), which is characterized by lower metal deposition in the canopy section. Similar findings have also been reported by previous studies, namely Chedadi *et al.* (2024) on *P. stratiotes* and Davis *et al.* (2023) on *L. flava*. According to Chocobar-Ponce *et al.* (2022), the limited mobility of Cr metal can be attributed to the

reduction process of Cr (VI) to Cr (III), with Cr (III) tending to bind to functional groups on the cell wall (–COOH, –OH, –SH), thus reducing the translocation of Cr from the roots to other parts.

Although Cr accumulation was mostly detected in the roots, it was also found in leaf tissues. These findings indicate the potential risk of bioaccumulation and biomagnification, particularly at higher trophic levels, if post-phytoremediation biomass is not managed properly, especially in *L. flava*, which is commonly consumed as a food plant. This potential danger aligns with the research of Ongon'g *et al.* (2020), who found that the entry of toxic metals, even in low concentrations, has a negative impact on human health, with the effects only being detected and known after several years of exposure to the metals. Therefore, biomass harvested from the phytoremediation system should not be used for consumption and requires proper post-treatment management, such as incineration, gasification, or pyrolysis, to prevent secondary contamination and biomagnification.

3.5 Morphological Changes in *Pistia stratiotes* and *Limnocharis flava*

Exposure to batik industrial wastewater results in significant morphological changes in *P. stratiotes* and *L. flava*, characterized by the appearance of phytotoxic symptoms such as chlorosis and necrosis on day 3, which became more severe by day 7 of observation. The phytotoxic symptoms in *P. stratiotes* are marked by a slight yellowing of the leaves (chlorosis), followed by dry brown discoloration at the tips and edges of the leaves as an early indication of necrosis, as reported by Wahyuno et al. (2020). In contrast, the toxicity symptoms found in *L. flava* not only include chlorosis and necrosis but also leaf edge curling and stem rot. The symptoms of leaf curling are suspected to be related to nutrient deficiency conditions due to the accumulation of harmful elements, including Cr, which exceeds the plant's tolerance limits, potentially disrupting physiological processes, including inhibiting nutrient absorption, ultimately causing damage to the plant's metabolism (Baroroh et al., 2018). The symptoms of plant damage are shown in Figure 4.

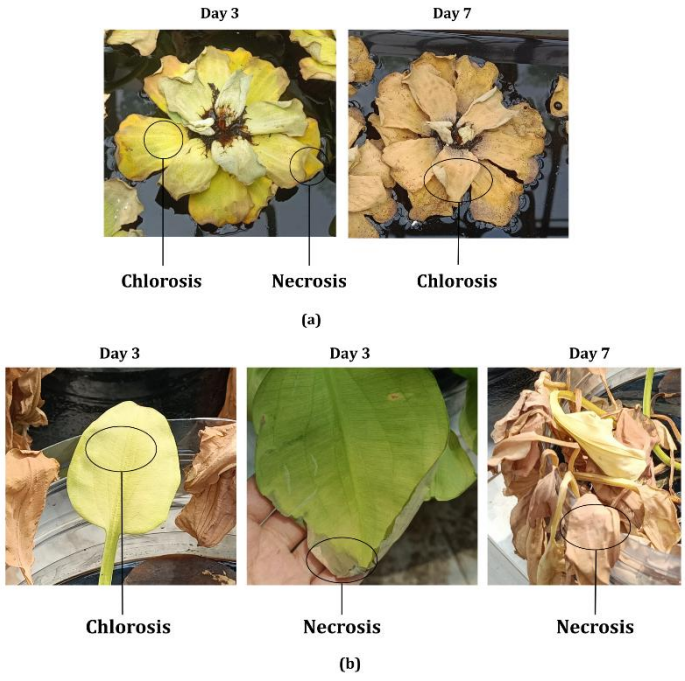


Figure 4. Signs of plant damage on days 3 and 7 of phytoremediation (a) *P. stratiotes* plant group, (b) *L. flava* plant group.

The symptoms of morphological damage in *P. stratiotes* and *L. flava* are closely related to physiological disturbances caused by the accumulation of Cr in plant tissues. The accumulation of Cr metal has the potential to increase the production of free radicals or reactive oxygen species (ROS), leading to oxidative stress and various physiological problems, including the inhibition of antioxidant

enzyme activity and even death in all plant tissues (Syafrudin et al., 2018; Ahmed et al., 2021). Additionally, the decrease in physical growth parameters, such as leaf width shrinkage, is believed to be caused by the inhibition of mitotic cell division and a reduction in the size of palisade cells and mesophyll tissue (Oktaviani et al., 2024). Physical changes were also observed in the roots and stems of the plants. At the root level, metal stress inhibits root growth due to the limited translocation of photosynthates from leaves to roots (Riyazuddin et al., 2022), whereas at the stem level, Cr metal stress can potentially disrupt stem cellular metabolism, leading to a reduction in stem size (Riyazuddin et al., 2022).

Quantitatively, metabolic damage also impacted the reduction in the wet weight of plants post-phytoremediation (Table 4). *P. stratiotes* experienced a decrease in wet weight of up to 70%, while *L. flava* experienced a decrease of 65%. The decrease in wet weight in both plants is suspected to be related to the decline in the plants' physiological functions, which can disrupt biochemical processes and growth, such as root and shoot growth, and affect the condition of the plant cells, ultimately contributing to the decrease in wet weight of both plants (Saud et al., 2022). Additionally, the decrease in wet weight is also suspected to be related to the use of waste concentration without dilution, as reported by Siregar and Lestari (2024) and supported by Yustiningsih et al. (2019), who stated that the higher the waste concentration, the less optimal the plant growth will be.

The impact of Cr exposure on the wet weight of plants is also consistent with previous observations of morphological changes. The decrease in wet weight in *P. stratiotes* plants is suspected to be related to damage to leaf and root tissues, resulting in the loss of plant organ mass. Meanwhile, in *L. flava*, the decrease in wet weight is also suspected to be related not only to damage to leaf and root tissues but also to the loss of stem turgor pressure caused by the reduced ability of the plant to absorb water (Priya and Shankar, 2020), which indirectly contributes to the decrease in organ mass.

Table 4. Average wet weight of *P. stratiotes* and *L. flava* after phytoremediation

No	Initial wet weight (g)	*P. stratiotes*		*L. flava*	
		Final wet weight (g)	Decrease (%)	Final wet weight (g)	Decrease (%)
1.	0	0	0	0	0
2.	100	39.5	61	42.5	58
3.	150	48.0	68	57.5	62
4.	200	74.0	63	70.0	65
5.	250	97.5	61	109.0	56
6.	300	107.0	64	127.0	58
7.	400	122.0	70	161.0	60

Description: Numbers in yellow indicate the highest effectiveness value for reduction.

Based on this description, it can be concluded that heavy metal Cr stress in plants causes metabolic damage and morphological changes in both *P. stratiotes* and *L. flava*. This physiological damage to plants ultimately reduces their ability to absorb metals from the medium, thereby affecting the effectiveness of absorption. Therefore, periodic harvesting of damaged plants needs to be done to optimize the remediation process and prevent the return of pollutants to the environment (leaching).

4. Conclusions

The plants *Pistia stratiotes* and *Limnocharis flava* were found to be effective in reducing Cr concentrations. The highest reduction effectiveness was observed in *P. stratiotes* (55.57 %) with a wet weight of 100 g, while *L. flava* showed 42.73% effectiveness with a wet weight of 300 g. The wet weight of both plants significantly affected the removal efficiency, especially in the 0-100 g and 0-250 g treatments. Both plants exhibited good Cr accumulation capabilities (BCF > 1), with the highest accumulation in the root section (TF < 1), indicating that phytoremediation occurred through a phytostabilization mechanism.

These results indicate that *P. stratiotes* and *L. flava* have the potential to be used as phytoremediators in the management of batik industry wastewater.

Further research is recommended to evaluate the performance of plant species on a field scale, as well as to examine the effects of contact time and environmental factors, such as light intensity, aeration, and dissolved oxygen, on the effectiveness of phytoremediation. Additionally, the use of non-food plants and the management of post-phytoremediation biomass warrant further investigation to minimize potential health risks and reduce secondary pollution.

Ethics Statement

This research did not involve human subjects, identifiable personal data, and there were no animal experiments. All data used in this research were obtained from direct field observations at waste management and industrial facilities, as well as secondary data from public databases and available literature sources. The preparation of this manuscript was assisted by artificial intelligence (AI) tools in a limited capacity for language editing and enhancing writing clarity. This study was conducted in accordance with relevant institutional guidelines and standard research ethics, ensuring data integrity, transparency, and responsible reporting of results**.**

CRediT Author Statement

Nurafni Rindiani: Idea Development, Research Design, Investigation, Data Curation, Formal Analysis, Visualization, Manuscript Draft Preparation. **Hashfi Hawali Abdul Matin:** Supervision, Result Verification, Manuscript Review and Revision. **Siti Rachmawati:** Supervision, Result Verification, Manuscript Review and Revision. **Budiyono Budiyono:** Result Verification, Manuscript Review and Revision.

References

A`yunina, U., Moelyaningrum, A.D. and Ellyke, E. 2022. Pemanfaatan arang aktif tempurung kelapa (Cocos Nucifera) untuk mengikat kromium (Cr) (study pada limbah cair batik). Jurnal Kesehatan Lingkungan Indonesia, 21(1), 93–98.

Ahmed, A.S., Hassan, A.M. and Nour, M.H. 2019. Physicochemical studies on removal performance of Pb +2 from simulated wastewater by Chitosan/Activated carbon composite. International Journal of Recent Research in Life Sciences (IJRRLS), 6(3), 23–38. www.paperpublications.org.

Ahmed, A., Sara Taha, A., Sundas, R.Q. and Man-Qun, W. 2021. Heavy metals and pesticides toxicity in agricultural soil and plants: ecological risks and human health implications. Toxics, 9, 42.

Al-Mahbashi, N.M.Y., Kutty, S.R.M., Bilad, M.R., Huda, N., Kobun, R., Noor, A., Jagaba, A.H., Al-Nini, A., Ghaleb, A.A.S. and Al-Dhawi, B.N.S. 2022. Bench-scale fixed-bed column study for the removal of dye-contaminated effluent using sewage-sludge-based biochar. Sustainability (Switzerland), 14(11)

Alfakihuddin, M.L.B., Sunartaty, R., Satriawan, D., Purnomo, T., Sahabuddin, E.S., Drsini, Pasanda, O.S., Dewadi, F.M., Ningsih, E., Bani, G.A., Hutauruk, T.R. and Andayani, S. 2023. Pengendalian limbah industri (Pertama). PT Global Eksekutif Teknologi.

Allifah, A.N.A., Jamdin, Z., Natsir, A.N. and Rosmawati T. 2025. Pola sebaran logam berat kromium (Cr) di Perairan Tulehu Maluku Tengah. BIOTROPIC The Journal Od Tropical Biology, 9(1), 21–33.

Amalia, S., Fasya, A.G., Hasanah, U., Rosydul, M., Hs, A. and Artikel, R. 2023. Efektifitas limnocharis flava dan hydrilla verticillata sebagai fitoremediator logam tembaga. Alchemy: Journal of Chemistry, 11, 43–50.

Astuti, D., Awang, N., Othman, M.S. Bin, Kamaludin, N.F.B., Meng, C.K. and Mutalazimah, M. 2023. Analysis of heavy metals concentration in textile wastewater in batik industry center. Jurnal Penelitian Pendidikan IPA, 9(3), 1176–1181.

Astuti, D. and Rosemalia, I. 2022. Review: Penurunan BOD (Biological Oxygen Demand) limbah cair domestik dengan fitoremediasi. Jurnal Unitek, 15(1), 59–72.

Aulya, N.R., Ristanto, R.H., Nurazizah, M., Febryaningrum, S., Muthiah, A., Fauziyah, F. and Nabila, T. 2020. Efektivitas pistia stratiotes dan salvinia molesta sebagai agen fitoremediasi limbah Sungai Ciliwung. Spizaetus : Jurnal Biologi Dan Pendidikan Biologi, 1(1), 21–26.

Bahute, F.O., Nakoe, M.R. and Jusuf, H. 2024. Tanaman genjer (Limnocharis Flava) sebagai agen penyerap logam berat mangan (Mn) dari limbah cair industri tahu. Jurnal Kolaboratif Sains, 7(6), 2228–2238.

Bakshe, P. and Jugade, R. 2023. Phytostabilization and rhizofiltration of toxic heavy metals by heavy metal accumulator plants for sustainable management of contaminated industrial sites: A comprehensive review. Journal of Hazardous Materials Advances, 10(February), 100293.

Baroroh, F., Handayanto, E. and Irawanto, R. 2018. Fitoremediasi air tercemar tembaga (Cu) menggunakan salvinia molesta dan pistia stratiotes serta pengaruhnya terhadap pertumbuhan tanaman brassica rapa. Jurnal Tanah Dan Sumberdaya Lahan, 5(1), 689–700. http://jtsl.ub.ac.id

Basri, S.A.A., Samawi, M.F. and Fahruddin. 2024. Bioconcentration and translocation of heavy metals in Mangrove Avicennia sp. and Rhizophora sp. in Diesel Powel Plant. Ecological Engineering and Environmental Technology, 25(9), 223–230.

Billah, A.R., Moelyaningrum, A.D. and Ningrum, P.T. 2020. Phythoremediasi Chromium Total (Cr-T) menggunakan kayu apu (Pistia stratiotes L.) pada limbah cair batik. Jurnal Biologi Udayana, 24(1), 47.

Chedadi, M., Moussaoui, A. El, Bassouya, M., Jawhari, F. zahra, Zoufri, I., Barnossi, A. El, Asmi, H. El, Ammari, M., Merzouki, M. and Bari, A. 2024. Capacity of an aquatic macrophyte, Pistia stratiotes L., for removing heavy metals from water in the Oued Fez River and their accumulation in its tissues. Environmental Monitoring and Assessment, 196(11), 1–12.

Chocobar-Ponce, S., Prado, C., Tabernero, R., Ilina, N., Pagano, E., Ramallo López, J.M., Mizrahi, M.D. and Rosa, M. 2022. The reduction of Cr (VI) in Salvinia minima, possible involvement of an h-type thioredoxin. Environmental Science and Pollution Research, 29(3), 3958–3966.

Córdoba-Tovar, L., Marrugo-Madrid, S., Castro, L.P., Tapia-Contreras, E.E., Marrugo-Negrete, J. and Díez, S. 2025. Exploring the phytoremediation potential of plant species in soils impacted by gold mining in Northern Colombia. Environmental Science and Pollution Research, 32, 3795–3808.

Davis, L.M.M., Hidayati, N., Firdaus, A.M., Talib, C., Rini, D.S., Juhaeti, T., Syarif, F. and Gunawan, I. 2023. Uptake and translocation of lead and cadmium in wild-found plant species from Bekasi and Karawang, West Java, for phytoremediation. IOP Conference Series: Earth and Environmental Science, 1201(1)

Deliza, D., Syukri, A., Wulanda, M.N. and Sartika, D. 2021. Detection of metal elements within Inductively Couple Plasma Emission Jambi batik waste and views as Muslim education. Journal of Physics: Conference Series, 1869(1)

Dewi, A., Rustanti, E.I., Pratiwi, H., Nerawati Diana, A.T. and Narwati. 2021. Application of tamarindus indica seed extract as bio-coagulant to removal suspended solids and colors. International Journal of Public Health Science, 10(2), 324–329.

Dini, L., Kusumadewi, R.A. and Hadisoebroto, R. 2023. Adsorpsi logam berat krom (Cr) dan zat warna dengan adsorben kulit pisang kepok dalam air limbah batik. Jurnal Reka Lingkungan, 11(1), 37–48.

Durner, E. 2019. Horticulturae effective analysis of interactive effects with non-normal data using the aligned rank transform, ARTool and SAS ® University Edition. Horticulturae, 5(57), 2–13.

Fatiha, I.I., Firdhausi, N.F. and Zummah, A. 2025. Potensi tumbuhan melati air (Echinodorus radicans) terhadap penurunan kadar timbal (Pb) dan tembaga (Cu) pada limbah cair home industry batik di Desa Sendang Kabupaten Lamongan. Bioscientist : Jurnal Ilmiah Biologi, 13(1), 176–196.

Hasnunidah, N. and Wiono, W.J. 2019. Botani tumbuhan tinggi. In Graha Ilmu. Graha Ilmu.

Huntoyungo, D.R., Jusuf, H. and Maksum, T.S. 2025. Perbedaan efektivitas tanaman kayu apu dan kangkung air sebagai fitoremediator dalam menurunkan kadar kromium total (Cr) pada limbah cair industri sablon nokturnal di Kabupaten Bone Bolango Differences in the Effectiveness between Water lettuce and wate. Jurnal Kolaborasi Sains, 8(6), 2711–2719.

Irmawanty, Rijal, M., Syamsiah and Samputri, S. 2023. Arbes river water quality based on heavy metal content as well as the potential of Limnocharis Flava, Pistia Stratiotes, and Hydrilla Verticillata as phytoremediator agents. Journal of Sustainability Science and Management, 18(4), 138–151.

Kencana, E.M. and Radityaningrum, A.D. 2022. Kombinasi filtrasi dan fitoremediasi untuk pengolahan limbah cair industri batik. Dampak, 19(2), 56–65.

Larasati, D.A., Alkian, I., Arifan, F. and Sari, S.R. 2020. Batik home industry wastewater treatment using UVC/Ozon Oxidation Method: case study in Cibelok Village, Pemalang, Indonesia. IOP Conference Series: Earth and Environmental Science, 448(1)

Lidiana, R., Suprayogi, D. and Nengse, S. 2022. Kemampuan tanaman genjer (Limnocharis Flava) dalam menurunkan kadar logam berat timbal pada air limbah artifisial. Jukung (Jurnal Teknik Lingkungan), 8(1), 72–83.

Mahlungulu, A., Kambizi, L., Akinpelu, E.A. and Nchu, F. 2023. Levels of heavy metals in grapevine soil and leaf samples in response to seasonal change and farming practice in the Cape Winelands. Toxics, 11(2)

Mahmudha, S., Nugraha, F., Idris, M., Masriah, I. and Lestari, D. 2025. Fitoremediasi in vitro logam Pb dan Cu menggunakan eceng gondok (Eichhornia crassipes): strategi ramah lingkungan dan berkelanjutan. INSOLOGI: Jurnal Sains Dan Teknologi, 4(3), 502–511.

Marendra, S.M.P., Widiatmono, B.R. and Sari, E. 2024. Comparison effectiveness of phytoremediation in reducing BOD and COD (Study Case: Batik Alam Industry, Pasuruan). Jurnal Sumberdaya Alam Dan Lingkungan, 11(1), 20–29.

Martind, D.Y. and Wiratno, E.N. 2025. Analisis konsentrasi logam berat kadmium (Cd) pada air, sedimen, dan akar mangrove avicennia marina di Kawasan Mangrove Wonorejo, Surabaya, Jawa Timur. Water and Marine Pollution Journal: PoluSea, 3(2), 32–44.

Masruroh, S. and Purnomo, T. 2024. Analisis kandungan logam berat tembaga (Cu) pada tumbuhan akuatik sebagai indikator pencemaran di Sungai Brantas Mojokerto. LenteraBio : Berkala Ilmiah Biologi, 13, 131–140.

Mirjankar, M.R., Pattar, S.V., Gaddigal, A.T., Shivappa, P., Poojari, P.B., Ganeshkar, M.P., Goder, P.H. and Kamanavalli, C.M. 2023. Phytoremediation of copper contaminated water using pistia stratiotes and emphasis of thermal stability in response to metal stress. Water Conservation Science and Engineering, 8(1), 1–14.

Mohebi, Z. and Nazari, M. 2021. Phytoremediation of wastewater using aquatic plants, A review. Journal of Applied Research in Water and Wastewater, 8(1), 50–58.

Nurhayati, I., Vigiani, S. and Majid, D. 2020. Kromiun (Cr), COD dan BOD limbah cair laboratorium dengan pengenceran,koagulasi, dan adsobsi. Fe), 14(1), 74–87.

Oktaviani, L., Nilandita, W. and Suprayogi, D. 2020. Tanaman apu-apu terhadap kadar logam Zn berdasarkan variasi jumlah tanaman. Jurnal Teknik Lingkungan, 6(1), 44–52.

Oktaviani, R., Mukarlina and Linda, R. 2024. Growth respone of bara variety (Capsicum Frustencens) to heavy metal stress of cadmium sulfate ($CdSO_4$). Jurnal Biologi Tropis, 24(1), 343–351.

Oktavina, W.R. and Imtihani, H.N. 2023. Formulasi dan evaluasi suspensi granul effervescent ekstrak kitosan cangkang kepiting bakau (Scylla serrata) dengan perbandingan natrium bikarbonat. Journal of Islamic Pharmacy, 8(2), 62–67.

Ongon'g, R.O., Edokpayi, J.N., Msagati, T.A.M., Tavengwa, N.T., Ijoma, G.N. and Odiyo, J.O. 2020. The potential health risk associated with edible vegetables grown on Cr (VI) polluted soils. International Journal of Environmental Research and Public Health, 17(2)

Parwati, S. and Hendri, M. 2025. Pengaruh tumbuhan air genjer (Limnocharis flava L), mata lele (Lemna minor L) dan paku air (Azolla pinnata R.Br) serta bobot biomassa terhadap kualitas limbah cair tahu. 12(1), 22–36.

Prastitianti, D. and Purwanti, I.F. 2024. Kajian Fitoremediasi Air Tanah Tercemar Lindi Tpa Dengan Kandungan Logam (Studi Kasus: Fitoremediasi Fe Dan Besi Di Lahan Bekas Tpa Keputih). Jurnal

Purifikasi, 23(1), 17–26.

Pratama, C.G., Prayogo, P. and Isroni, W. 2025. Analysis of Chromium (Cr) Heavy Metal Content in Sediments and Mangrove Roots Avicennia marina in the Wonorejo Mangrove Ecosystem Area Surabaya. Journal of Marine and Coastal Science, 14(1), 58–68.

Priantoro, E.A., Suryaatmana, P., Sumiarsa, D., Widyarani, Butar, E.S.B. and Sembiring, T. 2025. Fitoremediasi Logam Berat Sistem Lahan Basah Terapung Menggunakan Tanaman Akar Wangi (Chryzophogon zizanioides (L.) Roberty) sebagai Hiperakumulator Phytoremediation of Heavy Metals in Floating Wetland System using Vetiver (Chryzophogon zizanioides (L.) R. Jurnal Teknologi Lingkungan, 26(1), 1–14.

Priya, M. and Shankar, S.R. 2020. Effect of Heavy Metals on Growth and Development of Cultivated Plants with Reference to Cadmium, Chromium and Lead-A Review Effect of Heavy Metals on Growth and Development. Journal of Stress Physiology & Biochemistry, 16(3), 2020.

Rachmawati, S., Matin, H.H.A., Azzam, A.K., Arifiandita, D.M., Nurcahyo, F.D., Manullang, R.H. and Susatio, R. 2025. Analysis of heavy metal pollution of chromium (Cr) and nickel (Ni) in soil at Putri Cempo Landfill, Indonesia. BIO Web of Conferences, 155, 04002.

Rahayuningtyas, I., Wahyuningsih, N.E. and Budiyono. 2018. PENGARUH VARIASI LAMA WAKTU KONTAK DAN BERAT TANAMAN APU-APU (Pistia stratiotes L.) TERHADAP KADAR TIMBAL PADA IRIGASI PERTANIAN. Jurnal Nair, 6(6), 2356–3346. http://ejournal3.undip.ac.id/index.php/jkm

Rahman, F., Ihsan, M., Ilfan, F. and Rodhiyah, Z. 2021. Fitoremediasi untuk menurunkan kadar logam merkuri (Hg) pada lahan bekas penambangan emas tanpa izin di kabupaten Sarolangun, Jambi. Jurnal Ilmiah Teknik Lingkungan, 13(2), 48–54. envirotek.upnjatim.ac.id.

Riyazuddin, R., Nisha, N., Ejaz, B., Khan, M.I.R., Kumar, M., Ramteke, P.W. and Gupta, R. 2022. A comprehensive review on the heavy metal toxicity and sequestration in plants. Biomolecules, 12(1), 1–26.

Safamaura, R.S. and Afany, M.R. 2025. Pengaruh Limbah Cair Industri Batik Terhadap Kualitas Air Sungai Loji Di Pekalongan. Jurnal Tanah Dan Sumberdaya Lahan, 12(1), 153–158.

Samal, K. and Dash, R.R. 2024. Experiments and modeling to develop a Pistia stratiotes based Floating Vegetated System (FVS) for the removal of heavy metals (Pb, Zn, Cr, Cu, Ni). Science of the Total Environment, 926(January), 171981.

Samosir, A.M., Syarifah, M. and Sulistiono, S. 2023. Akumulasi Logam Berat Tembaga Dan Timbal Pada Mangrove Rhizopora Mucronata Di Karangsong, Indramayu. Jurnal Teknologi Perikanan Dan Kelautan, 14(1), 101–112.

Sariti. 2023. Penentuan Kadar Logam Berat Timbal (Pb) Menggunakan Metode Kombinasi Remediasi Genjer (Limnocharis flava) Dan Adsorpsi Zaeolit Alam dengan Variasi Konsentrasu. In Universitas Islam Negeri Maulana Malik Ibrahim Malang.

Sasongko, A.S., Cahyadi, F.D., Yonanto, L., Islam, R.S. and Destiyanti, N.F. 2020. Kandungan Logam Berat di Perairan Pulau Tunda Kabupaten Serang Banten. Manfish Journal, 1(02), 90–95.

Sasongko, F.L., Ghufronudin, G. and Nurhadi, N. 2023. Partisipasi Stakeholders Dalam Pengelolaan Dampak Pencemaran Sungai Jenes Surakarta. Jurnal Sosial Ekonomi Dan Humaniora, 9(2), 135–146.

Saud, S., Wang, D., Fahad, S., Javed, T., Jaremko, M., Abdelsalam, N.R. and Ghareeb, R.Y. 2022. The impact of chromium ion stress on plant growth, developmental physiology, and molecular regulation. Frontiers in Plant Science, 13(Cd)

Sharma, A., Kapoor, D., Wang, J., Shahzad, B., Kumar, V., Bali, A.S., Jasrotia, S., Zheng, B., Yuan, H. and Yan, D. 2020. Chromium bioaccumulation and its impacts on plants: An overview. Plants, 9(1), 1–17.

Siregar, L.P.A. and Lestari, W. 2024. Kemampuan Tanaman Air Sebagai Fitoremediator Limbah Cair Pabrik Pengolahan. 14(1), 45–54.

Siyar, R., Doulati Ardejani, F., Norouzi, P., Maghsoudy, S., Yavarzadeh, M., Taherdangkoo, R. and Butscher, C. 2022. Phytoremediation Potential of Native Hyperaccumulator Plants Growing on

Heavy Metal-Contaminated Soil of Khatunabad Copper Smelter and Refinery, Iran. Water (Switzerland), 14(22)

Soenardjo, N. and Mentari, R.J. 2023. Akumulasi Logam Pb dan Cu pada Akar, Daun dan Serasah Mangrove di Perairan Pekalongan. Buletin Oseanografi Marina, 12(3), 456–464.

Soheti, P., Sumarlin, L.O. and Marisi, D.P. 2020. Fitoremediasi Limbah Radioaktif Cair Menggunakan Kayu Apu (Pistia stratiotes) Untuk Menurunkan Kadar Torium. Eksplorium, 41(2), 139.

Sumardiono, S., Matin, H.H.A., Sulistianingtias, I., Nugroho, T.Y. and Budiyono, B. 2023. Effect of physical and biological pretreatment on sugarcane bagasse waste-based biogas production. Materials Today: Proceedings, 87, 41-44.

Syafrudin, Nugraha, W.D., Agnesia, S.S., Matin, H.H.A. and Budiyono. 2018. Enhancement of Biogas Production from Rice Husk by NaOH and Enzyme Pretreatment. E3S Web of Conferences, 31, 02002.

Syafrudin S., Nugraha W.D., Matin H.H.A., Saputri E.S. and Budiyono B. 2020. The Effectiveness of Biogas Method from Rice Husks Waste: Liquid Anaerobic Digestion and Solid-State Anaerobic Digestion. IOP Conference Series: Earth and Environmental Science, 448, 012007.

Tampubolon, O.F.R., Ismanto, A., Suryoputro, A.A.D., Muslim, M. and Indrayanti, E. 2021. Simulasi Pola Sebaran Logam Berat Tembaga (Cu) di Perairan Kota Pekalongan. Indonesian Journal of Oceanography, 3(2), 174–188.

Tan, H.W., Pang, Y.L., Lim, S. and Chong, W.C. 2023. A state-of-the-art of phytoremediation approach for sustainable management of heavy metals recovery. Environmental Technology and Innovation, 30, 103043.

Taufikurahman, T., Suryati, A., Kadar, M.R. and Wulansari, N.A. 2017. Phytoremediation of Chromium Polluted Water Using Water Hyacinth (Eichhornia crassipes (Mart.) Solms), Water Lettuce (Pistia stratiotes L.), and Water Hyssop (Bacopa monnieri L.) in a Simulated Constructed Wetland. Proceeding of The 7th Annual Basic Science International Conference – 2017, 7(9), 147–152.

Violita, L., Apriani, I. and Sulastri, A. 2020. Kemampuan Tanaman Kangkung Air Dalam Menurunkan Krom Heksavalen (Cr6+) Pada Limbah Cair Sablon. Jurnal Rekayasa Lingkungan, 13(1), 37–44.

Wahyuno, D., Sari, M.P. and Florina, D. 2020. Temuan Penyakit Baru Uromyces acori (Uredinales) Penyebab Nekrosis pada Daun Tanaman Jeringau (Acorus calamus) di Indonesia Uromyces acori (Uredinales) A Causal Agent of Rust Disease of Sweet Flag (Acorus calamus) in Indonesia. Jurnal Fitopatologi Indonesia, 16(3), 81–86.

Wajong, R.S., Polii, B. and Rotinsulu, W.C. 2022. Pengaruh Penyerapan Eceng Gondok (Eichornia crassipes) Dan Apu Apu (Pistia stratiotes) Terhadap Konsentrasi Cu Dan Zn Pada Air Limbah Pertambangan PT J Resources Bolaang Mongondow. Agri-Sosioekonomi, 18(3), 765–774.

Wibowo, Y.G., Anwar, D., Rinovian, A., Jarwinda, Sudibyo, Maryani, A.T., Syarifuddin, H., Yuliansyah, A.T. and Petrus, H.T.B.M. 2025. Bioresource Technology Reports Integrated adsorption-phytoremediation as facile and low-cost method for recovery of valuable minerals from mining waste. Bioresource Technology Reports, 29(March), 102093.

Widodo, S., Safitri, D., Asmiani, N. and Bechtel, A. 2018. Treatment of Cr6+ using phytoremediation method in Rante Pond of PT. Vale Indonesia Tbk. International Journal of Engineering and Science Applications, 5(2), 93–100.

Yustiningsih, M., Naisumu, Y.G. and Berek, A. 2019. Deep Flow Technique (Dft) Hidroponik Menggunakan Media Nutrisi Limbah Cair Tahu dan Kayu Apu (Pistia Stratiotes L) Untuk Peningkatan Produktivitas Tanaman. Mangifera Edu, 4(1), 40–51.

Zahari, N.Z., Fong, N.S., Cleophas, F.N. and Rahim, S.A. 2021. The Potential of Pistia stratiotes in the Phytoremediation of Selected Heavy Metals from Simulated Wastewater. International Journal of Technology, 12(3), 613–624.

Zain, A.S. and Sitogasa, P.S.A. 2025. Potensi Fitoremediasi Salvinia molesta terhadap Logam Berat dalam Limbah Cair: Pendekatan melalui Analisis Biokonsentrasi Faktor dan Faktor Translokasi. X(3), 14113–14120.

Zakaria, M.H., Ramaiya, S.D., Bidin, N., Syed, N.N.F. and Bujang, J.S. 2023. Nutritional values of wild edible freshwater macrophytes. PeerJ, 11.