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Innovation in Utilisation of Apu-Apu (*Pistia stratiotes*) for Phytoremediation of Heavy Metal Contaminants in Industrial Wastewater – A Case Study on Local Biodiversity

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ABSTRACT

Environmental pollution due to heavy metals in industrial wastewater is a serious problem for human health and ecosystems. This study aims to evaluate the effectiveness of *Pistia stratiotes* in absorbing heavy metals such as Pb, Cd, Hg, Ni, Cu, and Zn from wastewater. The method used was a quantitative experiment with observations for 3 weeks. Industrial wastewater was analysed before and after treatment using a spectrophotometer to measure heavy metal concentrations. The results showed that *Pistia stratiotes* was able to significantly reduce heavy metal concentrations, especially Pb with a reduction of up to 79.6% from the initial concentration of 2.50 mg/L to 0.51 mg/L. The reduction effectiveness for Cd reached 79.2%, Hg 78%, and Ni 77.2%. However, Cu and Zn reductions were lower, at 70% and 69.3%, respectively. This study concludes that *Pistia stratiotes* has great potential as an effective phytoremediation agent to reduce heavy metal concentrations in industrial wastewater.

Keywords: phytoremediation, apu-apu*(Pistia stratiotes*), heavy metals, wastewater.

INTRODUCTION

Environmental pollution due to industrial activities has become one of the most pressing global problems. In many countries, the rapid rise of the industrial sector, particularly the manufacturing and mining sectors, has led to increased levels of harmful contaminants, such as heavy metals, in aquatic ecosystems. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), copper (Cu) and zinc (Zn) can accumulate in industrial wastewater and pose a serious threat to human health and the environment. Previous studies confirm that heavy metal contamination has toxic effects on aquatic organisms, affects the food chain, and potentially causes bioaccumulation in humans (Sheng et al., 2020). These heavy metals are also often difficult to break down naturally, so they remain in the environment for long periods of time and cause lasting damage. Industrial effluents contaminated with heavy metals, if not managed properly, can contaminate water sources used for daily activities such as drinking, bathing and irrigation (Kristanti and Hadibarata, 2023; Rojali et al., 2023). Water pollution by heavy metals impacts water quality and human health, increasing the risk of chronic diseases such as cancer, organ dysfunction, and nervous system damage (Wu et al., 2020). This issue is particularly relevant in developing countries that have limited effluent treatment technologies, as well as weak environmental regulatory oversight.

In recent decades, many technologies have been developed to reduce heavy metal content in industrial wastewater. Conventional methods, such as chemical precipitation, filtration, adsorption, and ion exchange, are often used to remove heavy metals (Feng et al., 2000; Peng and Guo, 2020; Yadav et al., 2021). However, these methods are usually costly, complex to operate, and often produce secondary waste that requires further treatment (Fu and Wang, 2011). Therefore, there is a need to find more environmentally friendly, cost-effective and sustainable methods to deal with this problem. Phytoremediation is one technology that is increasingly being recognised in the effort to address heavy metal pollution issues. Phytoremediation is the process of utilising plants to remove contaminants from the environment, be it from soil, water or air. Certain plants have the ability to absorb, accumulate, and metabolise heavy metals in their tissues, thereby reducing the concentration of heavy metals in the surrounding environment (Ali et al., 2013). This technology is considered environmentally friendly because it does not require additional chemicals and uses natural processes inspired by the ability of plants to interact with their environment.

One of the plants being investigated for phytoremediation is apu-apu (*Pistia stratiotes*). Apu-apu is known as an aquatic plant that has a high ability to absorb heavy metals from water, as well as grow quickly and easily adapt to contaminated environments (Li et al., 2015; Nasir et al., 2023). Several previous studies have shown that apu-apu can adsorb various heavy metals such as Pb, Cd, Hg, and Ni from wastewater, with varying effectiveness depending on environmental conditions and the type of metals present (Huynh et al., 2021; Okunowo and Ogunkanmi, 2010).

Although phytoremediation technology has been recognised as a potential solution to heavy metal pollution problems, a major challenge in its application is the limitation in the sorption and accumulation capacity of plants. Aquatic plants such as apu-apu, despite having significant sorption capacity, often take a long time to reach maximum effectiveness in the phytoremediation process (As' ari et al., 2022; Purnama et al., 2018). In addition, there are other factors that affect the success of phytoremediation, such as pH conditions, temperature, and the initial concentration of heavy metals in the water (Barbhuiya et al., 2024; Pang et al., 2023; Sabreena et al., 2022).

Although various studies have been conducted to explore the potential of apu-apu in heavy metal phytoremediation, most of the studies are still focused on laboratory scale and controlled conditions. These studies usually do not account for complex environmental variability, such as naturally occurring fluctuations in pH, temperature and heavy metal concentrations in open environments. This raises the question of how effective this apu-apu-based phytoremediation technology would be if applied under field conditions or in more diverse natural environments. In addition, most of the existing studies only focus on one or two specific types of heavy metals. For example, research by (Amboga, 2011) examined the ability of apu-apu to absorb Pb and Zn, while other studies by Nallakukkala et al. (2022) only assessed the reduction of Cd and Hg in industrial wastewater. Studies exploring the ability of apu-apu to sequester multiple heavy metals in one system are limited. This suggests a knowledge gap that needs to be addressed, especially in a more holistic study that includes different types of heavy metals commonly found in industrial wastewater.

Furthermore, local biodiversity factors have often been neglected in previous phytoremediation studies. In fact, local biodiversity can play an important role in determining the success and sustainability of phytoremediation efforts in a region. Plants native to the region are more likely to adapt to local environmental conditions and have better interactions with local microbes that also play an important role in the phytoremediation process (Futughe et al., 2020).

This research aims to address these gaps by evaluating the potential of apu-apu as a phytoremediation agent under real environmental conditions, and assessing its effectiveness in absorbing various heavy metals simultaneously. In addition, this research will also consider local biodiversity factors in the phytoremediation process, so as to produce a more sustainable solution that is suitable for local environmental conditions.

METHODS

Research design

This study used an experimental design with a quantitative approach. The study was conducted at the Ecology and Environment Laboratory in the Department of Environmental Health, Poltekkes Kemenkes Surabaya, East Java, over a 3-week period. This research design allowed us to monitor changes in heavy metal concentrations in wastewater over time and assess the impact of apu-apu in the phytoremediation process. This study was conducted to evaluate the ability of apu-apu (*Pistia stratiotes*) in phytoremediating heavy metals in industrial wastewater effluents, using a pre and post research design without control. This method was chosen to focus measurements on changes in wastewater quality before and after the application of phytoremediation, so that the effectiveness of *Pistia stratiotes* can be analysed directly. The study was conducted in a 100-litre container filled with industrial wastewater that had been analysed for its initial heavy metal content. The container was then planted with Pistia stratiotes, with environmental conditions controlled to ensure the feasibility of the phytoremediation process. During the research process, the pH of the effluent in the containers was maintained at a range of 6.5 to 7.5 using a buffer solution, as this pH range is considered optimal for Pistia stratiotes growth as well as heavy metal binding activity. The temperature was set at 25 °C ± 2 °C, considering the temperature conditions of the natural environment of *Pistia stratiotes*. The lighting used was natural sunlight simulated with full spectrum fluorescent lamps for 12 hours per day to support the photosynthesis process of the plants.

Materials and tools

The main materials used in this study were apu-apu (*Pistia stratiotes*) plants, which were obtained from the natural habitat around Jagir River, Surabaya. In addition, industrial wastewater contaminated with heavy metals was collected from industries in Surabaya and tested to determine the initial concentration of heavy metals. Tools used included a 100-litre container for planting, a spectrophotometer for heavy metal analysis, a pH meter for water pH measurement, and temperature and humidity gauges.

Wastewater preparation

Before conducting experiments, we took wastewater samples and analysed them to determine the initial concentrations of heavy metals, including Pb, Cd, Hg, Ni, Cu, and Zn. The results of this preliminary analysis provided basic information on the level of pollution present in the wastewater to be used in the study.

Plant preparation

The apu-apu plants were planted in containers containing prepared wastewater. Each container was filled with 10–15 apu-apu plants to ensure optimal growth conditions. Prior to treatment, the plants were given one week to adapt. During this adaptation period, we monitored the initial growth of the plants and ensured that the environmental conditions inside the containers were stable.

Repetition and treatment

Repetition is done by dividing the sample into three groups (R1, R2, R3), each with three containers. Each group will be evaluated at different times at week 1, 2, and 3. During the treatment period, we recorded plant growth, including the number of leaves, wet weight and root length of the plants, and took wastewater samples weekly for heavy metal concentration analysis. This study focused on the efficient duration of observing changes in heavy metal concentrations, so 3 weeks was considered a representative time to obtain valid results without overextending the study period. In addition, observations over a longer period of time may run the risk of causing damage or degradation to the plants due to the accumulation of heavy metals in the plant tissues, which would affect the accuracy of the results (Ali et al., 2020; Kristanti and Hadibarata, 2023).

Data analysis

After treatment, wastewater samples were analysed using a spectrophotometer to measure heavy metal concentrations. Calculation of the effectiveness of heavy metal reduction was carried out based on changes in concentration over time. Calculation of the effectiveness of heavy metal reduction using formula 1.

$$\text{Reduction effectiveness (\%)} = \frac{IC - FC}{IC} \times 100 \quad (1)$$

where: IC – initial concentration, FC – final concentration

RESULTS

Table 1 illustrates the growth of apu-apu (*Pistia stratiotes*) plants during the phytoremediation process. On day 0, the plants had 5 leaves, a wet weight of 50 grams, and a root length of 10 cm. Over time, there was a significant increase in all three parameters. On day 7, the number of leaves increased to 7, wet weight rose to 57 grams, and root length reached 14 cm. The growth trend continued until day 21, where the number of leaves became 12, wet weight increased predominantly to 78 grams, and root length reached 17 cm. This data indicates a stable and optimal growth of the apu-apu plants during phytoremediation.

Table 1. Growth of apu-apu (*Pistia stratiotes*) during phytoremidiation

Days	Number of leaves	Wet weight (g)	Root length (cm)
0	5	50	10
7	7	57	14
14	10	61	16
21	12	78	17

Table 2 shows the decrease in concentration of various heavy metals in industrial wastewater after the phytoremediation process using apu-apu. From the table, heavy metal Pb had an initial concentration of 2.50 mg/L. After phytoremediation, the average final concentration of Pb metal dropped to 0.51 mg/L, which showed a significant reduction with the reduction effectiveness reaching about 79.6%. For Cd metal, the initial concentration was 1.20 mg/L, which after the phytoremediation process was reduced to an average of 0.25 mg/L, giving a similarly high reduction effectiveness of 79.2%. Meanwhile, heavy metal Hg, which had an initial concentration of 0.50 mg/L, decreased to an average of 0.11 mg/L, resulting in a reduction effectiveness of 78%. Furthermore, Ni metal which had an initial concentration of 1.80 mg/L decreased to an average of 0.41 mg/L, with a reduction effectiveness of 77.2%. For Cu metal, the initial concentration was 2.00 mg/L and decreased to an average of 0.60 mg/L, with a lower reduction rate than the other metals at 70%. Zn metal had the largest initial concentration of 3.00 mg/L and after phytoremediation was reduced to an average of 0.92 mg/L, giving a reduction effectiveness of 69.3%. Overall, the apu-apu plant was shown to be effective in reducing heavy metal concentrations in industrial wastewater, with the most significant reduction rates occurring for Pb and Cd metals, both of which showed reduction effectiveness rates above 79%.

DISCUSSION

The use of apu-apu showed significant results in reducing heavy metal concentrations from industrial wastewater. Table 2 shows that the average concentrations of heavy metals such as Pb, Cd, Hg, Ni, Cu, and Zn were effectively reduced after the phytoremediation process. This concentration reduction varied, with Pb metal experiencing a 77% reduction, from an initial concentration of 2.50 mg/L to an average of 0.51 mg/L. High concentration reductions were also recorded for Cd with a 79% reduction, Hg by 80%, and Ni by 75%.

This success indicates that *Pistia stratiotes* is able to absorb and accumulate heavy metals in its body tissues. The phytoremediation ability of this plant is influenced by several factors, including its extensive root structure, metal-binding capacity of plant tissues, and environmental conditions such as pH and water temperature. Research by (Barbhuiya et al., 2024; Pang et al., 2023) confirmed that pH and temperature affect the efficiency of heavy metal uptake by aquatic plants. This study is in line with our results, where stable environmental conditions during the experiment provided optimal results in heavy metal uptake.

From the results of plant growth during phytoremediation, it can be seen that the number of leaves, wet weight, and root length of *Pistia stratiotes* increased significantly. This shows that these plants are not only able to survive in contaminated water conditions, but also grow well.

Table 2. Average heavy metal concentration before and after phytoremediation (*Pistia stratiotes*)

Heavy metal	Pre concentration (mg/L)	Post concentration (mg/L) (R1)	Post concentration (mg/L) (R2)	Post concentration (mg/L) (R3)	Mean post concentration (mg/L)	Reduction effectiveness (%)
Pb	2.50	0.55	0.53	0.46	0.51	79.6
Cd	1.20	0.28	0.26	0.22	0.25	79.2
Hg	0.50	0.12	0.10	0.10	0.11	78.0
Ni	1.80	0.45	0.43	0.35	0.41	77.2
Cu	2.00	0.65	0.59	0.55	0.60	70.0
Zn	3.00	1.00	0.92	0.84	0.92	69.3

This is in accordance with a study by Karmakar et al. (2018), which indicates that *Pistia stratiotes* can adapt to contaminated environmental conditions and still grow well, as long as environmental parameters such as temperature and pH remain within the appropriate range for plant growth.

The efficiency of *Pistia stratiotes* in reducing heavy metal concentrations can be seen from the observation of metal concentrations in wastewater after treatment. Pb metal, as one of the most common heavy metals in industrial wastewater, showed a significant decrease in this study. Another study by Zahari et al. (2021) also reported similar results, where *Pistia stratiotes* was effective in absorbing Pb with a reduction of up to 99.31% within 4 weeks. This high efficiency is likely due to the high affinity of Pb to the plant cell wall, which allows this metal to be rapidly accumulated.

For other heavy metals such as Cd, Hg, and Ni, the concentration reduction was also very significant. For example, the 79% reduction in Cd was consistent with the results reported by (Amboga, 2011), which found that *Pistia stratiotes* has a high Cd absorption capacity under various wastewater conditions. The study showed that this plant can accumulate Cd in root and leaf tissues, reducing the concentration of this metal significantly in water. However, there was a slight difference in the absorption efficiency of Cu and Zn metals, where the decrease in concentration was not as great as the other metals. The decrease in Cu and Zn concentrations were 67.5% and 66.7%, respectively. Nonetheless, these results remain significant and in line with other studies. For example, research by Wang et al. (2018) showed that Cu and Zn have lower affinity to plant tissues compared to heavy metals such as Pb and Cd, so the rate of uptake by aquatic plants tends to be slower.

This study is consistent with various international studies that have been conducted in the past decade on the phytoremediation potential of *Pistia stratiotes* for heavy metal removal from wastewater. For example, Li et al. (2022) showed that *Pistia stratiotes* has an effective phytoremediation ability in removing heavy metals such as Pb, Cd, and Zn from wastewater, both on a laboratory scale and in natural environments.

Furthermore, research by (Fu and Wang, 2011) highlighted that one of the main advantages of phytoremediation over conventional methods such as adsorption or filtration is its lower cost as well as its ability to treat multiple types of contaminants simultaneously. In this study, *Pistia stratiotes* was able to handle six types of heavy metals simultaneously, which reflects the potential of this plant to be used in real environmental scenarios, where wastewater is often contaminated by various heavy metals. However, the results from this study also showed some limitations. The efficiency of metal uptake by aquatic plants is highly dependent on environmental parameters such as pH, temperature, and initial concentration of heavy metals. For example, research by (Irhamni et al., 2017) showed that heavy metal uptake by aquatic plants can be significantly decreased if the pH of the water is too low or too high, or if the ambient temperature is inappropriate. This can be a challenge in the application of phytoremediation technology under dynamic environmental conditions. Research by Thijs et al. (2016) dan Delgado-González et al. (2021) also emphasised that besides plants, microorganisms around the roots of aquatic plants also play an important role in the phytoremediation process. Soil and water microbes can interact with heavy metals, helping to convert them into forms that are more easily absorbed by plants. In this context, further understanding of local microbial diversity and their interactions with *Pistia stratiotes* could be key to improving phytoremediation efficiency.

Although the results of this study indicate that *Pistia stratiotes* has great potential to be used in industrial wastewater phytoremediation, there are several challenges that need to be considered. One of them is the limited capacity of the plant to absorb heavy metals. Although these plants can significantly reduce heavy metal concentrations, their effectiveness decreases as the initial concentration of metals in water increases. Research by (Muthusaravanan et al., 2018) suggested that in wastewater conditions with very high heavy metal concentrations, it is necessary to pre-treat or use a combination of several water treatment techniques prior to phytoremediation to achieve optimal results. In addition, the application of phytoremediation in the field also requires consideration regarding the management of plant waste after the process is completed. Plants that have accumulated large amounts of heavy metals must be managed properly to prevent the release of heavy metals back into the environment. Research by (Ali et al., 2013) suggests that plant biomass that has been used in phytoremediation can be further utilised, for example through conversion into bioenergy or safe biocompost, so that the phytoremediation process can become more sustainable. This research also paves the way for further exploration of local biodiversity and its potential in phytoremediation. Aquatic plants such as *Pistia stratiotes* growing in a particular region may have adapted to the local environmental conditions, which may increase their effectiveness in absorbing heavy metals in the region. In addition, interactions with local microbial species may enhance the plants' ability to absorb and metabolise heavy metals.t (Futughe et al., 2020).

CONCLUSIONS

Based on the results of this study, it can be concluded that *Pistia stratiotes* is an effective phytoremediation agent in reducing the concentration of various heavy metals from industrial wastewater. Its efficiency in absorbing metals such as Pb, Cd, and Hg is very significant, while the absorption of metals such as Cu and Zn requires a longer time. This study also reinforces previous findings on the potential of aquatic plants in phytoremediation and emphasises the importance of considering environmental factors as well as local biodiversity in the application of this technology in the field. In the future, further research is needed to explore the use of *Pistia stratiotes* on a larger scale, as well as understanding the interaction with local microbes and the effects of environmental parameters on phytoremediation efficiency.

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