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ANALYZING THE EFFICACY OF *Salvinia molesta* AND *Pistia stratiotes* AS PHYTOREMEDIATION AGENT FOR HEAVY METALS

H.W.L. Fonseka[1], S.K. Gunatilake[1], J.M.C.K. Jayawardana[1], and S.S.R.M.D.H.R. Wijesekara[1]

Department of Natural Resources, Faculty of Applied Sciences, Sabaragamuwa University of Sri Lanka[1]

ABSTRACT

To rejuvenate our declining ecosystems, it is imperative to promptly face the issue of heavy metal contamination, which serves as the underlying cause for pollution globally. Phytoremediation, which is the ability of certain plants to accumulate, break down, or neutralize pollutants in water, soil, or air, offers a promising solution. The current investigation aimed to assess the efficacy of Salvinia molesta and Pistia stratiotes in removing heavy metals from apparel industrial wastewater. In a controlled indoor environment, the wastewater underwent treatment using these plants, while control tanks of the same size without any plants were maintained for comparison. This setup included three replicates for each treatment. Over 18 days, samples of the wastewater were collected and analyzed for the presence of Cadmium (Cd), Copper (Cu), and Zinc (Zn) using an Atomic Absorption Spectrophotometer (AAS) every three days. An initial analysis of the untreated wastewater was conducted. Statistical analysis employed one-way ANOVA to compare the average concentrations in the effluent and the removal percentages across various treatment conditions. Pistia stratiotes exhibited a higher Cd reduction rate (29.97%) compared to Salvinia molesta (18.13%). Tanks containing Salvinia molesta showed a more substantial Cu removal rate (52.47%), while Pistia stratiotes demonstrated a lower Cu reduction (42.37%). As for Zinc (Zn), it decreased by 22.89% and 17.87% in tanks where Salvinia molesta and Pistia stratiotes were used, respectively. This study, conducted over an 18-day trial period, underscores the effectiveness of both plant types in removing Cd, Cu, and Zn from the wastewater. The preferential absorption was observed for Cu over the other two metals. For Salvinia molesta, the removal efficiency followed the sequence: Cu>Zn>Cd, whereas for Pistia stratiotes, it was Cu>Cd>Zn. These findings demonstrate that both plant species can thrive while accumulating these heavy metals in apparel industrial wastewater.

KEYWORDS: *Atomic Absorption Spectrophotometer, Hydrophytes, Metals, Phytoremediation, Wastewater*

Corresponding Author: H.W.L. Fonseka, Email: *wasanalfonseka@gmail.com*

https://orcid.org/0009-0007-8683-4362

1. INTRODUCTION

Despite regional variations in pollution intensity and levels, heavy metal contamination is a worldwide problem. At least 20 metals are categorized as hazardous, and a half of them are released into the environment at levels that are very dangerous to human health (Akpor and Muchie, 2010; Ajayi and Ogunbayio, 2012; Roy *et al*., 2018). Strong metals and metalloid contamination has been caused by rapid population increase, deforestation, urbanization, industry development, exploration, and exploitation of the environment (Ajayi and Ogunbayio, 2012; Balamoorthy *et al.*, 2022; Ullah *et al*., 2022). Both people and other living things can become unhealthy after being exposed to heavy metals. Additionally, this category of pollutants has the potential to increase fatalities and the prevalence of severe, fatal diseases (Balamoorthy *et al.*, 2022). Acute poisoning in people can result in serious failure of the liver, brain, kidneys, reproductive system, and nervous system (Moktar and Mohd Tajuddin, 2019).

Toxic heavy elements like Cadmium (Cd), Zinc (Zn), Chromium (Cr), Lead (Pb), and Copper (Cu) serve as instances of harmful heavy metals that are well-known for their detrimental impact on the environment (Balamoorthy *et al.*, 2022). Because of their persistence, biomagnification, and accumulation in the food chain, the disposal of heavy metals without effective treatment creates a serious risk to public health (Ekanayake and Manage, 2017; Roy *et al*., 2018; Balamoorthy *et al.*, 2022). Cancer, organ damage, nervous system impairment, and restricted growth and development are just a few of the serious consequences (Ajayi and Ogunbayio, 2012; Akpor and Muchie, 2010; Roy *et al*., 2018). The contamination by these metallic elements has adverse effects on the ecosystem and contributes to the issue of global warming (Balamoorthy *et al.*, 2022). Therefore, it necessitates the implementation of measures to mitigate metal pollution.

For the purpose of removing heavy metals from leachate, a variety of techniques have been developed, including chemical precipitation, chemical oxidation or reduction, electrochemical treatment, ultrafiltration, reverse osmosis, electro-dialysis, the use of membrane technology, solvent extraction, evaporation recovery, and ion exchange process (Ajayi and Ogunbayio, 2012; Victor *et al*., 2016; Sadi *et al*., 2018; Ekanayake and Pathmalal, 2020; Singh *et al*., 2021; Balamoorthy *et al*., 2022). Although the technologies indicated above have been shown to remove contaminants, they are very expensive, may produce a huge amount of waste, and are therefore not economically viable (Moktar and Mohd Tajuddin, 2019). Strategies are being examined and improved to address this environmental concern system (Moktar and Mohd Tajuddin, 2019). The most popular treatments fall into the recycling, filtration, biological, and chemical categories, although phytoremediation and the employment of plants in the purification process have drawn interest as a potential solution (Singh *et al.*, 2021; Ting *at. el.*, 2020).

Using a cutting-edge technique called phytoremediation, pollutants can be removed from soils, air, groundwater, and surface water (Moktar *et al*., 2018; Moktar and Tajuddin, 2019; Ekanayake *et al.*, 2021; Singh *et al.*, 2021; Ting *at. el.*, 2020). In the wastewater treatment industry, phytoremediation has gained attention as a new emerging green technology because of a variety of advantages, most notably low operating costs and environmental friendliness (Jayaweera and Kasturiarachchi, 2018; Ting *et al*., 2020; Ekanayake *et al.*, 2021). Phytoremediation encompasses a series of techniques, including rhizosphere biodegradation, phytostabilization, phytoextraction, rhizofiltration, phytovolatilization, phytodegradation, and hydraulic control (Balamoorthy *et al*., 2022). This technique makes use of the organic and inorganic pollutants that macrophytes and the microbial rhizosphere flora of their roots naturally break down and sequester (Seguil *et al*., 2022).

Phytoremediation technology involves the direct use of different plant species to absorb, gather, detoxify, and neutralize contaminants in soils, sediments, wastewater, surface water, or groundwater, employing physical, chemical, and biological processes (Roy *et al*., 2018; Seguil *et al.*, 2022). This approach not only helps protect the environment but also does so in a cost-effective manner, as noted by Lakshmi et al. in 2017. Many plants previously recognized for their remarkable ability to absorb and store diverse toxic metals are currently under assessment for their involvement in the process of phytoremediation, which aims to purify soils and water contaminated with trace elements (Balamoorthy *et al.*, 2022). Plant roots absorb pollutants, which accumulate in bodily tissues before gradually decomposing into less harmful forms (Seguil *et al*., 2022).

Terrestrial plants play a vital role in purifying both contaminated soil and water by accumulating heavy metals in their tissues, as demonstrated by Balamoorthy *et al.*, 2022. In the case of aquatic phytoremediation plants, which are components of aquatic treatment systems, their primary goal is to eliminate pollutants from wastewater by utilizing naturally or artificially moist soils (Seguil *et al*., 2022). These aquatic plants effectively remove pollutants like heavy metals, organic and inorganic contaminants, and pharmaceutical residues from various sources of wastewater, including industrial, domestic, and agricultural sources (Mustafa and Hayder, 2021).

Research suggests that aquatic macrophytes efficient at wastewater treatment in comparison to terrestrial plants due to their rapid growth, increased biomass production, greater capacity for absorbing pollutants, and their ability to enhance purification when in direct contact with contaminated water, as observed in the study by Wickramasinghe and Jayawardana, 2018. These aquatic plants are essential components of freshwater ecosystems as they provide food, shelter, structure, and coverage for a variety of terrestrial and aquatic animal species (Seguil *et al*., 2022). In the context of phytoremediation, free-floating aquatic plants are considered more suitable due to their ready availability, high productivity, and their capacity to store and harvest pollutants (Mustafa and Hayder, 2021).

Numerous researchers have examined and assessed the effectiveness of aquatic macrophytes in wastewater treatment (Ekperusi *et al*., 2019; Kaflea *et al*., 2022; Mustafa *et al.*, 2022). Various types of aquatic plants, both free-floating and submerged, such as *P. stratiotes*, *S. molesta*, *Lemna* spp., *Azolla pinnata*, *Landoltia punctata*, *Marsilea mutica*, *Eichhornia crassipes*, *Spirodela polyrhiza*, and *Riccia fluit*, as well as emergent plants like *Hygrophilla corymbosa*, *Ruppia maritima*, *Najas marina*, *Hydrilla verticillata*, *Egeria densa*, *Vallisneria americana*, and *Myriophyllum aquaticum*, were utilized for wastewater treatment. Additionally, other plant species, including *Cyperus* spp., *Iris virginica*, *Nuphar lutea*, *Imperata cylindrical*, *Justicia americana*, and *Diodia virgin*, were employed (Ekperusi *et al*., 2019).

Because of the adverse impact of its secondary effluent on the environment, the techniques could potentially become costly and economically impractical. Hence, it remains imperative to establish a cost-effective wastewater treatment method. Heavy metal removal efficiencies can vary widely depending on the plant species used for the phytoremediation. According to the literature, *Salvinia molesta* and *Pistia stratiotes* have not been extensively researched to comparative treatment of apparel industrial wastewater from the apparel industry in Sri Lanka. Therefore, the goal of the present study is to evaluate the potential of *Salvinia molesta* and *Pistia stratiotes* phytoremediation capabilities for biologically removing heavy metals from low-concentrated wastewater generated from an apparel industry in Sri Lanka.

2. METHODOLOGY

After selecting suitable aquatic plants for the experiment, same sized, small and healthy plants were kept in tap water for seven days to acclimatize. Raw wastewater from an apparel company in Sri Lanka was collected and diluted appropriately (Raw wastewater 1: Tap water 4). Then, sampling was conducted every three days for 18 days of the experiment. Thereafter, wastewater samples were analysed for heavy metals over time.

At the end of the experiment, percentage reductions of heavy metals were determined for each plant species. The data was subjected to one-way analysis of variance (ANOVA), and findings were deemed statistically significant if the p-value was less than 0.05.

A. Selection and collection of plants

The ideal plant species for phytoremediation should have a wide distribution in nature, be easy to cultivate, yield a lot of biomass, be immune to the harms caused by metals and pollutants, and have a high absorption (Ekanayake *et al.*, 2021; herbivores; Kafle *et al.*, 2022; Ullah *et al.*, 2022.). Due to their availability and to assess how these plants respond to low concentrated industrial effluent from the textile industry, *Salvinia molesta* and *Pistia stratiotes* were chosen for the present investigation. *Salvinia molesta* and *Pistia stratiotes* plants were gathered in a plastic container in a nonpolluted environment. Then, they were kept until they were carried to the location for stabilization. Both plant species were small, healthy, and of the same size.

B. Stabilization of selected aquatic plants

Young and healthy aquatic plants of the same size were collected from their sources. Then, their bodies and roots were completely cleaned to remove dirt, any trapped material, and any macrophyte debris. Before the experiment, plants were thoroughly cleansed and cleaned with tap water (Victor *et al.*, 2016; Wickramasinghe and Jayawardana, 2018; Mustafa and Hayder, 2020). Two large plastic bowls filled with tap water were used to maintain the plants (Nizam *et al.*, 2020).

Healthy young plants were chosen for the experiment, and dead leaves were taken out (Kumar and Deswal, 2020). For seven days, collected plants were stabilized in tap water for stabilization (Wickramasinghe and Jayawardana, 2018; Moktar and Tajuddin, 2019; Singh *et al.*, 2021).

C. Collection of wastewater

Grab sampling technique was used to collect raw wastewater from the inlet of the sewage treatment plant of an apparel industry into a container. Heavy metals including Cu, Cd, and Zn in the collected raw wastewater were assessed using an Atomic Absorption Spectrophotometer (Varian AA240FS).

D. Experimental setup

An indoor setup was created so that the plants would cooperate with natural processes and receive enough aeration and sunlight (Moktar *et al.*, 2018; Kafle *et al.*, 2022). Before the experiment, the undiluted raw wastewater was adequately diluted (Raw Wastewater 1: Tap water 4).

Three treatment groups comprising three replicates from each treatment group and the control were set up in tanks with nine circular plastic tanks of the same size in each tank setup. These tanks were cleaned with diluted (Raw wastewater 1: Tap water 4) apparel industrial wastewater (Nizam *et al.*, 2020; Ullah *et al.*, 2022). Diluted wastewater in plastic tanks with a 10 L capacity was divided into three treatment groups, each of which had three replicas, keeping the control tanks of wastewater free of plants.

E. Transferring and storing aquatic plants to the prepared tanks

25 g of plants from each species were utilized to treat a 10 L sample of diluted wastewater from each tank. Three replicates of each of the acclimatized plants were transplanted to the tanks. Three replicates of each species were made to get an average reading to guarantee a predictable trend of pollution reduction. No additional effluent was added to the tanks at any stage during the experiment (Nizam *et al.*, 2020). The set-up was created so that the plants were allowed to cooperate with natural processes and receive enough aeration and sunlight (Moktar *et al.*, 2018; Kafle *et al.*, 2022). To observe the development of the plant's effects on the wastewater, information and observations from each day were collected (Moktar, *et al.*, 2018).

F. Sampling of wastewater

Initial sampling

On the day the experimental setup was assembled, wastewater samples from each tank were collected using 250 mL sample bottles as the initial sampling. Sample bottles and caps were rinsed with sample water. Following sampling, the bottle cap was taped shut and labelled. Triplicate analyses of each parameter were performed. Heavy metals were determined in each tank after wastewater samples were collected using the grab sampling technique and 250 mL sample bottles every three days for 18 days.

Before being used for testing, samples were stored at a cold (4 °C) temperature (Wickramasinghe and Jayawardana, 2018).

A Varian AA240FS Atomic Absorption Spectrometer was used to determine heavy metals in the samples. Before analysis, 50 mL of wastewater samples were filtered through 25 mm Syringe Filters (Nylon membrane, 0.22 m) and digested with 5 mL of concentrated Nitric acid (HNO_3) (APHA, 2005-Section 3030E). The acidified and filtered materials were analyzed to determine heavy metals including Cd, Cu, and Zn in the Varian model AA240FS Flame Atomic Absorption Spectrophotometer user manual.

Sampling of wastewater over time

Investigations of the development of the plant's effects on the wastewater were conducted using observations from each day (Moktar, *et al*., 2018). After transferring the plants, wastewater samples were collected in sample bottles and analyzed for heavy metals every three days for the 18 days of the experiment.

G. Determination of percentage reductions of heavy metals

Following 18 days, the effluent heavy metals concentration percentage reductions were calculated using the equation 1;

$$\textbf{Percentage Reductions} = \frac{I0 - I1}{I0} \textbf{ x 100 …. (1)}$$

I_o – Initial concentration,

I_1 – Concentration at the end of the experiment

H. Data and statistical analysis

Descriptive statistics were used to illustrate how the wastewater quality fluctuated over time in the treatment and control tanks.

The mean effluent concentrations and reduction percentages for the various treatments and control groups were compared after 18 days using one-way ANOVA. The software packages Minitab ®17 and MS Excel 2016 were used to examine the data.

3. RESULTS AND DISCUSSION

A. Reduction efficiencies of Cd

Initial Cd content of the wastewater was 0.78±0.0058 mg/L. Figure 1 shows the average Cd levels after an 18-day period in tanks treated with plants. At the end of the experiment, Cd concentrations were recorded in tanks treated with *S. molesta, P. stratiotes* and control tanks as 0.63±0.0038 mg/L, 0.55±0.0382 mg/L, and 0.81±0.0414 mg/L respectively. Table 1 shows the Cd variation (mg/ L) during the experiment.

Table 1: Cd variation (mg/ L) during the experiment

Day	*S. molesta*	*P. stratiotes*	Control
Initial day	0.77±0.0085	0.78±0.0035	0.78±0.0167
Day 3	0.76±0.0084	0.77±0.0067	0.81±0.0650
Day 6	0.73±0.0056	0.74±0.0050	0.81±0.0081
Day 9	0.75±0.0066	0.72±0.0191	0.88±0.0618
Day 12	0.72±0.0046	0.67±0.0344	0.88±0.0289
Day 15	0.67±0.0140	0.66±0.0131	0.79±0.0682
Day 18	0.63±0.0038	0.55±0.0382	0.81±0.0414

(Values in the table are mean ± SD of 3 replicates)

At the end of the experiment, a reduction of Cd was not recorded in control tanks. After 18 days, there was a substantial ($p < 0.05$) reduction in the average Cd values measured in the control tanks and the plant-filled tanks. Compared to other days, 0.66±0.0131 mg/L of Cd concentration in wastewater recorded on the 15th day was reduced to 0.55±0.0382 mg/L at the end of the 18th day by the tanks treated with *P. stratiotes*. The *P. stratiotes* tank showed the highest Cd reduction efficiency of the investigated plant species (29.97%), whereas *S. molesta* showed a reduction efficiency of 18.13%. According to the findings from this study, *P. stratiotes* exhibited greater Cd reduction when exposed to wastewater from the apparel industry.

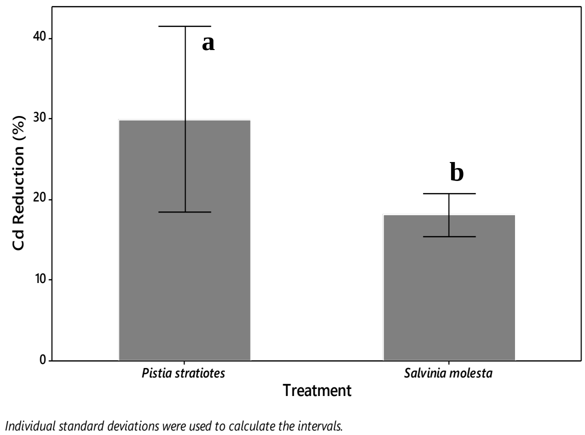

Figure 1: Average percentage reductions of Cd after 18 days

Because it is very poisonous and easily absorbed from the environment by organisms, Cd is a non-essential element that can enter the food chain through wastewater (Balamoorthy *et al.*, 2022). As the availability of this metal is highly dependent on the pH, the retention of Cd in contaminated water bodies requires special care (Mulligan *et al.* 2001). In the research conducted by Wickramasinghe and Jayawardana (2018), the tank treated with *P. stratiotes* showed the maximum Cd reduction (47.4%), whereas *S. molesta* showed a reduction efficiency of 36.8%. The present study also indicated a higher Cd percentage reduction in the tank treated with *P. stratiotes* in comparison to *S. molesta*. According to Donatus (2016), before treatment Cd concentration was 0.251 mg/L while it was 0.018 mg/L after treatment with *Salvinia molesta* on industrial wastewater. In the pH range of 0 to 9, Cd^{2+} is soluble; however, above this point, Cd is present in the form of oxides, which are either little or no soluble at all (Schwantes *et al.,* 2015).

B. Reduction efficiencies of Cu

Cu was initially present in industrial wastewater at a concentration of 0.56±0.0153 mg/L. At the end of the experiment, Cu concentrations were recorded in tanks treated with *S. molesta*, *P. stratiotes* and control tanks as 0.27±0.0159 mg/L, 0.32±0.0320 mg/L, and 0.75±0.1716 mg/L respectively. At the end of the experiment, a Cu reduction was not recorded in control tanks. Cu level of the tanks treated with *S. molesta* was 0.51±0.0245 mg/L on the 3rd day and 0.27±0.0159 mg/L at the end of the experiment (day 18th).

Table 2 shows the Cu variation (mg/ L) during the experiment.

Table 2: Cu variation (mg/ L) during the experiment

Day	*S. molesta*	*P. stratiotes*	Control
Initial day	0.57±0.0081	0.56±0.0218	0.59±0.0125
Day 3	0.51±0.0245	0.53±0.0119	0.55±0.0290
Day 6	0.49±0.0225	0.49±0.0191	0.57±0.0470
Day 9	0.43±0.0159	0.44±0.0196	0.59±0.0497
Day 12	0.38±0.0603	0.43±0.0393	0.68±0.0341
Day 15	0.32±0.0250	0.34±0.0079	0.64±0.0457
Day 18	0.27±0.0159	0.32±0.0320	0.75±0.1716

(Values in the table are mean ± SD of 3 replicates)

Compared to the 3rd day during the experiment, 0.53±0.0119 mg/L of Cu concentration in wastewater was decreased to 0.32±0.0320 mg/L at the end of the 18th day by the tanks treated with *P. stratiotes*. The efficacy of *S. molesta* in the removal of Cu from wastewater was improved by 52.47 % while it was 42.37 % for *P. stratiotes.* Therefore, according to the obtained results, as represented in Figure 2, higher Cu reduction efficiency was recorded by *S. molesta* in comparison to *P. stratiotes.*

According to the study by Miretzky, Saralegui and Cirelli (2004), Cu removal percentages were 97.3 %, 72.2 % and 73.5 % for *P. stratiotes* when adding Cu concentration was 1, 2 and 4 mg/ L. In the study Manjunath and Kousar (2016), tanks treated with *P. stratiotes* and *S. molesta* recorded 100% reduction of Cu in 25% and 50% concentration of the effluent percentage. In that study, before the phytoremediation, the Cu concentration in effluent was negligible and it was zero after the treatment with *P. stratiotes* and *S. molesta.*

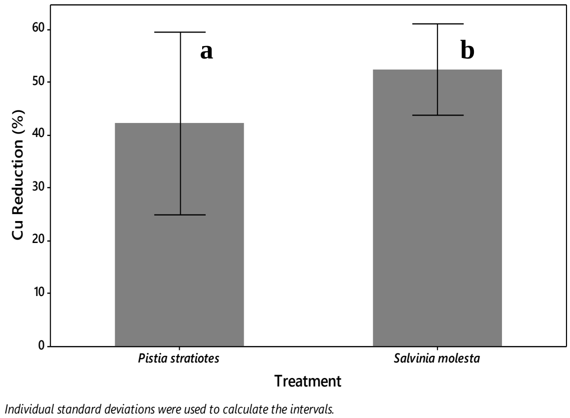

Figure 2: Average percentage reductions of Cu after 18 days

According to Donatus (2016), before treatment Cu concentration was 1.092 mg/L while it was 2.035 mg/L after treatment with *Salvinia molesta* on industrial wastewater.

The findings of Fia *et al.* (2015) study indicated, total suspended particle removal is linked to the primary mechanism of Cu removal, which they claim can vary with pH. They observed a removal of Cu from 91% to 98% in their study. Cu have been diluted and redistributed to new plants after the development of the plants. Additionally, it is permitted for the plant to introduce the element into the system, which can result in the creation of poorly soluble Cu complexes in alkaline pH conditions (Schwantes *et al.,* 2015).

C. Reduction efficiencies of Zn

The wastewater's initial Zn concentration was 0.43± 0.0058 mg/L. At the end of the experiment, Zn concentrations were recorded in tanks treated with *S. molesta, P. stratiotes* and control tanks as 0.34±0.0010 mg/L, 0.36±0.0062 mg/L, and 0.40±0.0037 mg/L respectively. There was no Zn reduction was recorded in control tanks at the end of the experiment, therefore, figure 3 shows the average Zn percentage reductions following an 18-day trial in tanks treated with plants. At the end of the experiment, 22.89 % Zn removal efficiency was recorded by *S. molesta* while it was 17.87 % for *P. stratiotes.*

Table 3 sho**ws** the Zn variation (mg/ L) during the experiment.

Table 3: Zn variation (mg/ L) during the experiment

Day	*S. molesta*	*P. stratiotes*	Control
Initial day	0.44±0.0004	0.43±0.0052	0.43±0.0024
Day 3	0.41±0.0014	0.38±0.0024	0.42±0.0093
Day 6	0.40±0.0120	0.37±0.0007	0.40±0.0013
Day 9	0.37±0.0066	0.36±0.0086	0.46±0.0060
Day 12	0.44±0.0008	0.32±0.0044	0.39±0.0056
Day 15	0.42±0.0023	0.44±0.0070	0.40±0.0025
Day 18	0.34±0.0010	0.36±0.0062	0.40±0.0037

(Values in the table are mean ± SD of 3 replicates)

After 18 days, as Figure 3, there was no noticeable difference between the average Zn values measured in the control tanks and the tanks containing plants ($p > 0.05$). Based on the obtained results of the present study, higher absorption of Zn was recorded by *S. molesta* from apparel industrial wastewater.

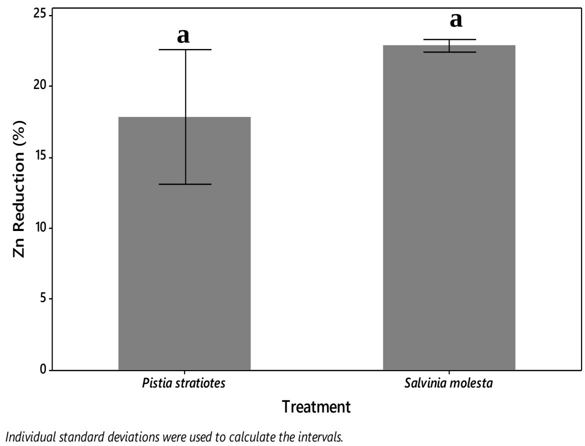

Figure 3: Average percentage reductions of Zn after 18 days

Zinc is necessary for the growth of plants and the stimulation of enzymes involved in photosynthesis (Moktar and Tajuddin, 2019). According to Fia *et al.* 2015, Zn removal ranges from 51% to 99% depending on the total suspended solids' direct removal ratio. This metal also tends to be less soluble when the pH is close to neutrality. In 2012, according to the study conducted by Matos *et al.,* (2012) achieved 88% Zn removal efficiency. Zn was removed by 70% and 55%, respectively, when Módenes, *et al.,* (2009) examined the removal of Zn at various temperatures (30 ºC and 50 ºC). Zn precipitation according to pH fluctuation was confirmed by Módenes *et al.,* (2009), who also confirmed that the precipitation process starts when the pH rises over 5.50. According to the study by Schwantes *et al.*, 2015, aquatic plants' senescence may have caused Zn to be released into the environment. Zn may have precipitated such as $ZnOH^+$, ZnO, and $Zn(OH)_2$, though, as *P. stratiotes* discharged the metal into the media. There was no reduction of heavy metals recorded in control tanks during the experiment.

The findings of the current study showed that two plant species are efficient in removing heavy metals (Cd, Zn, and Cu) from apparel industrial wastewater media throughout an 18-day trial period. Among these, absorption of Cu was higher than that of the other two metals. The efficiency of removal was in this order Cu>Zn>Cd for *S. molesta* while it was Cu>Cd>Zn for *P. stratiotes*.

Rhizofiltration, phytostabilization, phytodegradation, phytoextraction, and phytovolatilization are a few of the techniques that plants utilize to clean up contaminated soil and water that are included in phytoremediation (Fletcher *et al*., 2020; Balamoorthy *et al.*, 2022; Kafle *et al*., 2022). Rhizofiltration, which refers to the removal of contaminants from aqueous medium by a plant's root system, can be used to indicate how the chosen plant kinds remove metals from wastewater (Lakshmi *et al.*, 2017; Wani *et al*., 2017; Wickramasinghe and Jayawardana, 2018; Fletcher *et al.*, 2020; Kafle *et al*., 2022).

The accumulation and distribution of heavy metals in plants is influenced by variety of factors including plant species, root region, environmental factors, root composition and component species, and soil physio-chemical and biological characteristics (Lakshmi *et al.*, 2017). Balamoorthy *et al.*, (2022) stated that heavy metals are absorbed and excreted by plants via translocation and absorption processes. The presence of plants and their uptake during in the photosynthetic process for plant growth during the experimental period are related to the reduction of heavy metals (Moktar and Tajuddin, 2019). Balamoorthy *et al.*, (2022) stated that, due to the fact that the initial contact of plants with the toxins occurred on its own, the rhizomes of the plant are considerable to the phytoremediation process. According to studies, Nizam *at el.*, (2020) and Sa'at and Zaman (2017), the leaves and roots of *S. molesta* are very effective at capturing and removing pollutants, particularly heavy metals. Findings of Roy, Jahan and Rahman (2018), indicated that the heavy metals were being biomagnified by *Eichhornia, Spirodela,* and *Pistia stratiotes* by collecting them in their bodies and root systems.

The present study showed that these plants take up contaminants and store them as biomass, showing a high tolerance for contaminants like heavy metals and an ability to absorb large amounts of them. The overall results demonstrate that *S. molesta* and *P.stratiotes* can be used as effective and efficient phytoremediation agents to remove heavy metals in low-concentration apparel industrial wastewater for 18 days.

4. CONCLUSION

The results of this investigation suggest that *S. molesta* and *P. stratiotes* are effective at eliminating heavy metals from wastewater used in the apparel industry. Several conventional methods are being used to remediate the contaminants in the apparel wastewater. They consist of reverse osmosis solvent extraction, electrolysis, chemical oxidation, ion exchange, coagulation, chemical precipitation, and ultra-filtration (Ekanayake and Manage, 2020). However, a lot of these techniques are pricey, and some of them result in a lot of sludge. In this present study, heavy metals and other toxins from apparel effluent were removed using a phytoremediation approach that included floating aquatic plants. *S. molesta* was more effective than *P.*

stratiotes at removing Cu, Cd, and Zn, with removal efficiencies of 52.47%, 18.13%, and 22.89%, respectively. *S. molesta* was shown to be a better accumulator of Cu and Zn than Cd, according to the study's findings. As compared to Zn, it was found that *P. stratiotes* was a superior accumulator of Cu and Cd. After going through the phytoremediation process, the treated plant material can be safely burned away, and the accumulated metals can be recovered for use in industry. The current analysis is consistent with the numerous phytoremediation studies conducted on *Salvinia molesta* and *Pistia stratiotes* demonstrating that those plants are effective heavy metal accumulators and can be employed in apparel industrial wastewater phytoremediation.

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