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Phytoremediation of Aluminum and Iron from Industrial Wastewater Using *Ipomoea aquatica* and *Centella asiatica*

Marlia Mohd Hanafiah ^{1,2,*}, Muhamad F. Zainuddin ¹, Nurul Umairah Mohd Nizam ¹, Azhar Abdul Halim ¹ and Akhtar Rasool ^{3,4}

¹ Department of Earth Sciences and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, UKM Bangi 43600, Selangor Darul Ehsan, Malaysia; marlia.mhanafiah@gmail.com (M.F.Z.); umairahnizam@yahoo.com (N.U.M.N.); azharhalim@ukm.edu.my (A.A.H.)

² Centre for Tropical Climate Change System, Institute of Climate Change, Universiti Kebangsaan Malaysia, UKM Bangi 43600, Selangor Darul Ehsan, Malaysia

³ Toxicology Unit, Pharmacology and Toxicology Division, CSIR-Indian Institute of Chemical Technology, Hyderabad 500007, India; Akhtarrasool01@gmail.com

⁴ Department of Environmental Sciences, Osmania University, Hyderabad 500007, India

* Correspondence: mhmarlia@ukm.edu.my; Tel.: +603-89215865

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Abstract: Heavy metals accumulation from industrial wastewater even at low concentrations can cause long term cumulative health effects. To overcome this problem, phytoremediation is an alternative method to treat industrial wastewater. In this study, *Ipomoea aquatica* and *Centella asiatica* were used as phytoremediation plants for removing aluminum (Al) and iron (Fe) from industrial wastewater. The results showed that the regression value (R^2) for all metal concentrations (mg/L) over treatment day is positive and similar to $R^2 = 1$. This result indicated that the metal concentration exhibits a good relationship for reflecting the decrease in the metal concentration with the proportion of treatment day. It was found that *I. aquatica* accumulates higher Al and Fe contents than *C. asiatica*. The translocation factor of both plants was found to be greater than 1, implying that both plants can accumulate and extract heavy metals from industrial wastewater.

Keywords: phytoremediation; industrial wastewater; *Ipomoea aquatica*; *Centella asiatica*; Malaysia

1. Introduction

The rapid increase in industrial activities and the increase in the human population have resulted in the increase in water, air, and soil pollution [1,2]. Hence, some efforts to conserve and preserve the environment are required. Untreated effluents resulting from industrial activities, which contain a high content of heavy metals, can pollute water sources [3,4]. Morais et al. [5] and Shuhaimi et al. [6] have independently reported that heavy metals are the main environmental pollutants, and refining, smelting, and plating intermediate industries represent one of the contributors.

In general, industrial wastewater is often treated by a combination of physical, chemical, and biological treatment methods. Such a combined treatment can guarantee the maximum elimination of various pollutants, such as organic and inorganic pollutants. However, the treatment methods are expensive, which is not feasible in the industrial sector. A number of treatment methods have been developed to remove heavy metals from wastewater [7–10]. Phytoremediation is an alternative technique that can be employed to treat industrial wastewater for reducing water pollution [11].

As a more cost-effective, environmentally friendly technology, phytoremediation is a nature-based treatment, particularly employed for treating contaminated soil, groundwater, and surface water [12].

Phytoremediation refers to technologies that use various plants to stabilize, remove, or destroy environmental contaminants. Basically, phytoremediation functions via the ability of plants to translocate, accumulate, and restore or degrade pollutants [13,14]. Ahmadpour et al. [15] and Favas et al. [16] have independently reported that phytoremediation is defined as green-plant engineering that can destroy, restore, and reduce heavy metals and trace elements from the environment.

Although several studies on phytoremediation have been performed in Malaysia, further study is still required to enhance the understanding of this alternative technology. Research on the variety of plants, type of medium, pollutant specification, and analysis costs needs to be conducted before implementation to ensure the maximum outcomes. Souza et al. [17] reported that heavy-metal extraction is affected by the ability of plants to accumulate heavy metals, soil concentration and physicochemical characteristics, and the strength of the metallic bond in soil.

In Malaysia, Environmental Quality (Sewage and Industrial Effluents) Regulation and Drinking Water Quality Standards have been adopted by water regulatory bodies. Wastewater and effluent discharge must satisfy the prescribed criteria before its release to water sources. Therefore, phytoremediation for wastewater treatment is crucial as it can accumulate heavy metals from contaminated water [18,19]. Rahman et al. [20] and Karami and Shamsuddin [21] have independently reported that phytoremediation plants can accumulate heavy metals from contaminated soils. Chai et al. [7] reported that several plant species are suitable for use as pollutant removal agents. Yap et al. [14] have used *Centella asiatica* for the removal of heavy metals from soil samples, while Majid et al. [22] have examined the ability of *Acacia mangium* for the removal of heavy metals from sewage sludge. *Hibiscus cannabinus* has been used to remove Pb from contaminated soil [23], while *Amaranthus paniculatus* and *Brassica juncea* have been used by Rahman et al. [20] to treat Pb- and Cu-contaminated soil.

Choo et al. [24] have used *Nymphaea spontanea* to remove Cu from plating industrial effluents. Besides, Syuhaida et al. [25] have used *N. oleracea* and *E. crassipes* to treat wastewater contaminated with Pb, Cd, and Cu. Their results revealed that *N. oleracea* is more efficient than *E. crassipes* for accumulating the selected heavy metals. *Pistia stratiotes* and *E. crassipes* have been used to treat aquaculture wastewater from a fish pond in Semanggol, Perak [26]. Lim et al. [27] have used *Chlorella vulgaris* to treat wastewater released from the textile industry. Ashraf et al. [28] have used several plant species such as *Phragmites australis*, *Imperata cylindrica*, *Cyperus rotundus*, *Nelumbo nucifera*, and *Pteris vittata* to remove heavy metals from tin ore remnants in Bestari Jaya, Selangor.

In this study, the effectiveness of *Ipomoea aquatica* and *C. asiatica* for the extraction of aluminum (Al) and iron (Fe) from pulp and paper industrial effluents was investigated, and the translocation factors (TFs) of Al and Fe by *I. aquatica* and *C. asiatica* were compared. *I. aquatica* and *C. asiatica* were selected as phytoremediation plants due to their rapid growth rates and low management costs [29,30]. This was consistent with the phytoremediation concept, which affords a more cost-effective wastewater treatment technology. Hence, this phytoremediation biotechnology method can be applied for wastewater treatment to reduce water pollution, and such efforts can certainly contribute significantly towards sustainable development.

2. Materials and Methods

The samples used herein were industrial wastewater from a paper mill that was collected at Cheng Industrial, Malacca, with coordinates of 2°14'48.7"U 102°13'50.4"T.

2.1. Preparation of Phytoremediation Plants

This study was conducted in a hydroponic system, where the hydroponic method was suitable for aquatic and semi-aquatic plants. Besides, this system was a cost-effective system, with space savings, and required minimal supervision, in addition, the plants grew more rapidly as they did not have to work hard to obtain nutrients. The nitrogen, phosphorus, and potassium (N:P:K) (7:7:7) solutions were used to replace the Hoagland solution to provide nutrient essentials for plant growth, as has been

reported by Syuhaida et al. [25]. Seedlings were collected from a selected waterbody at Universiti Kebangsaan Malaysia (UKM), Bangi, Selangor. The seedlings were washed and soaked in distilled water, followed by sowing on cotton wool. Cotton wool was used as a platform to float plants in the tank, and this method also was applied for wastewater treatment in a synthetic reservoir. Figure 1 shows two reservoirs with a dimension of 1 m × 0.5 m × 0.30 m, which were used to grow *I. aquatica* and *C. asiatica*. Thirty-gram samples of each plant were placed in the reservoir filled with 6 L of wastewater for the simulated extraction of heavy metals.

Figure 1. Schematic of the aquatic plant germination in a reservoir.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

The growth of seedlings took about 20 days in an open environment to ensure optimum growth. The samples were subsequently transferred into a secondary reservoir filled with wastewater. Next, the samples were subjected to the selected treatment at 24 °C for 10 days, as has been reported by Ton et al. [31]. At this stage, the water quality and plant conditions were monitored and recorded. A total of 48 samples for heavy metal extraction were obtained, including 12 samples of water for the determination of the heavy metal content in water after the treatment. The plants were harvested, and the water was analyzed at time intervals of 0, 2, 4, 6, 8, 10 days after exposure for 10 days, as has been reported by Ladislav et al. [32].

2.2. Harvesting and Sample Preparation

In this study, the plants in each reservoir were harvested according to the specified time. Then, the plants were rinsed with tap water, followed by distilled water, to wash any remaining dirt and heavy metal residue from the shoots and roots, followed by drying on a filter paper. Figure 2 shows the harvested and separated plants. The wet sample weight was determined on a digital weighing scale, and the reading was recorded. The plants were cut into three parts: stems, roots, and leaves. Then, the samples were dried in an oven at 70–85 °C until a constant dry sample weight was obtained. The samples were dried for 2 days to achieve constant weight, and the reading was recorded. The samples were crushed and ground into a fine paste according to the roots, stems, and leaves by using a mortar and pestle. The samples were subjected to hot plate acid digestion.

2.3. Hot Plate Acid Digestion and Atomic Absorption Spectrometry

First, 1 g of sample was added into a porcelain dish and dried in a furnace at 80 °C. After cooling, the samples were digested in 5 mL of a 10% hydrochloric acid (HCl) solution. Next, the porcelain dish was placed on the hot plate, and samples were heated to obtain a clear solution. Then, 10 mL of 20% nitric acid (HNO₃) was added, and the samples were heated at 100 °C for 1 h. Then, the digested solution was cooled to room temperature and filtered by using a 0.45-μm cellulose filter

paper. The filtered samples were purified with Millipore water to obtain a concentrated solution of 50 mL. The samples were then analyzed by atomic absorption spectrometry (AAS, AA-6800 Shimadzu, Japan). AAS was employed to determine the heavy-metal concentration of both plants as follows (Equation (1)):

$$\text{Heavy-metal concentration} \left(\frac{\text{mg}}{\text{kg}} \right) = \frac{\left[A_m \left(\frac{\text{mg}}{\text{L}} \right) \times B_e (\text{L}) \right]}{C_a (\text{kg})} \quad (1)$$

A_m = The total heavy-metal concentration of Fe and Al in plant (mg/L)

B_e = Volume of extraction (L)

C_a = The plant mass (kg)

Figure 2. Harvesting process of (a) *Ipomoea aquatica* and (b) *Centella asiatica*, and the separation of; (c) leaves, (d) stems, and (e) roots of *Ipomoea aquatica* and *Centella asiatica*.

The extracted heavy metals were analyzed by AAS by the manual injection method. The accuracy of AAS measurements was verified by using a prepared solution and blank according to each heavy metal group. Validation was performed by calibration using a blank. A calibration curve was obtained, reflecting the standards of the heavy metal solution group.

2.4. Translocation Factor and Accumulated Heavy Metal Amount

TF is a ratio of the ability of plants to translocate heavy metals from roots through shoots [33]. $TF < 1$ indicates that heavy metals are accumulated in the roots and vice versa. TF is expressed as follows (Equation (2)):

$$TF = \frac{\text{Heavy-metal concentration of stems (mg/kg)}}{\text{Heavy-metal concentration of roots (mg/kg)}} \quad (2)$$

The amount of heavy metals accumulated in plants was determined from the changes in shoots, stems, and roots, which was measured according to the biomass that can be harvested under controlled conditions [32].

3. Statistical Analysis

Data were collected and sorted by using IBM SPSS Statistics version 22 software. ANOVA test was conducted to measure the difference in the amount of the heavy metals accumulated in the leaves, stems, and roots from day 0 until day 10 of treatment. Analysis was also conducted to compare changes in the heavy metal accumulation of the leaves, stems, and roots and the effect of the selected plant species on the heavy metal content of water.

4. Quality Control

All of the apparatuses used in this study were soaked overnight in a 5% HNO₃ solution, followed by rinsing with distilled water and drying before use. For each measurement, the reading was measured three times to obtain an average value. For the heavy-metal concentration analysis, 15 mL of each sample solution was added into a vial for flame atomic absorption spectroscopy analysis. The amount of the absorbed plants was analyzed on an AAS (AA-6800 Shimadzu, Japan). The HNO₃ solution was used as a blank for the plant sample, which was digested without additional plant materials. The samples were measured in triplicate for each injection by AAS, and the analysis was conducted for every 2–3 samples.

5. Results and Discussion

5.1. Initial Characteristics of Wastewater

Wastewater was collected from the paper mill at the effluent channel, which is the final channel before being discharged into the waterbody. The in-situ parameters were recorded by using a YSI multiprobe, whereas other physico-chemical analyses were determined in the laboratory. Then, 1 L of the wastewater sample was collected and analyzed by inductively coupled plasma mass spectrometry for the determination of the heavy metal content. Results indicated that the heavy metal content is in compliance with the industrial effluent discharge standards as stated in the Environmental Quality (Sewage and Industrial Effluents) Regulation. Table 1 summarizes the results obtained from the analysis of the physico-chemical and heavy metal contents. According to the results obtained herein, Al and Fe were selected for the simulation of wastewater remediation to examine the ability of the selected aquatic plants to extract heavy metals. Then, wastewater was treated by using 30 g of *I. aquatica* and *C. asiatica* in a 6-L reservoir in the open air for 10 days.

5.2. Wastewater Treatment

5.2.1. *Ipomoea Aquatica*

Figure 3 shows readings for the Al content accumulated by *I. aquatica* for 10 days of treatment. Readings recorded on day 0, 2, 4, 6, 8, and 10 were ~0.30, 0.13, 0.12, 0.10, 0.08, and 0.04 mg/L, respectively. On the final day of the treatment, the heavy-metal concentration of the wastewater decreased up to 87%. A significant drop was recorded on the second day of treatment, with ~57%. Figure 3 also shows readings for the Fe content for 10 days of treatment. Readings recorded on day 0, 2, 4, 6, 8, and 10 were ~1.09, 0.87, 0.86, 0.8, 0.81, and 0.68 mg/L respectively. The heavy-metal concentration decreased by ~38% on the final day of treatment. A significant drop was recorded on the second day of treatment, which was ~20%.

Table 1. Analysis of the heavy metal content from industrial wastewater.

Parameter	Industrial Wastewater	Department of Environment (DOE) (2009)	
		Standard A	Standard B
pH	7.86	6.0–9.0	5.5–9.0
Temperature (°C)	31.0	40	40
Turbidity (NTU)	20.07	-	-
Total Dissolved Solid (mg/L)	1132	-	-
Conductivity (µs)	1613	-	-
Fluoride (F ⁻)	0.8	2.0	5.0
Nitrate (mg/L)	41.52	-	-
Chemical Oxygen Demand (mg/L)	40	-	-
Biological Oxygen Demand (mg/L)	5.6	-	-
Hardness (mg/L)	829	-	-

Element	Heavy Metals Concentration (mg/L)	Department of Environment (DOE) (2009) (mg/L)	
Aluminum	0.30	10	15
Barium	0.12	1.0	2.0
Calcium	136.84	-	-
Iron	1.09	1.0	5.0
Potassium	12.58	-	-
Lithium	0.02	-	-
Magnesium	11.02	-	-
Manganese	0.07	0.20	1.0
Nickel	0.01	0.20	1.0
Rubidium	0.03	-	-
Strontium	0.35	-	-
Zinc	0.07	2.0	2.0

* not detected, elements: Arsenic, Beryllium, Bismuth, Cadmium, Cobalt, Chromium, Caesium, Copper, Gallium, Lead, Selenium, silver.

Figure 3. Reduction of: (a) Al concentration by *Ipomoea aquatica*; (b) Al concentration by *Centella asiatica*; (c) Fe concentration by *Ipomoea aquatica*; and (d) Fe concentration by *Centella asiatica*.

5.2.2. *Centella asiatica*

Figure 3 also shows readings for the Al content accumulated by *C. asiatica* for 10 days of treatment. Readings recorded on day 0, 2, 4, 6, 8, and 10 were ~0.30, 0.20, 0.13, 0.0, 0.10, and 0.05 mg/L, respectively.

On the final day of treatment, the heavy-metal concentration decreased by 83%. A significant drop was recorded on the second day of treatment, which was ~33%. Figure 3 also shows readings for the Fe content for 10 days of treatment. Readings recorded on day 0, 2, 4, 6, 8, and 10 were ~1.09, 0.90, 0.83, 0.78, 0.79, and 0.60 mg/L, respectively. The heavy-metal concentration decreased by 45% on the final day of treatment. A significant drop was recorded on the second day of treatment, which was ~17%.

The present study found evidence of the ability of *C. asiatica* and *I. aquatica* as phytoremediation plants for removing Al and Fe. These results were in good agreement with those reported previously, indicative of the ability of *C. asiatica* and *I. aquatica* for removing various pollutants. *C. asiatica* and *I. aquatica* were assessed in previous studies for its ability to remove various pollutants and water quality parameters, e.g., chemical oxygen demand (COD), biochemical oxygen demand (BOD), and ammoniacal nitrogen (NH₃-N) [34], cadmium [35], lead [36], nitrate [37], total suspended solid (TSS) [38,39], copper [40], phosphate [41,42], nitrogen and phosphorus [43], and chromium (VI) [44]. Based on the previous studies, *C. asiatica* was found to be more efficient to remove most of the pollutants compared to *I. aquatica*. By comparing the efficiency rate of *C. asiatica* and *I. aquatica* obtained from the present study, a similar pattern of results was found in Ismail et al. [3] that have identified *S. grossus* as a hyperaccumulator in the phytoremediation of Al and Fe. It should be noted that, however, the removal percentage rate of pollutants varies depending on the type of wastewater, duration of treatment, concentration of pollutant, etc.

5.2.3. Amount of Heavy Metals in Leaves, Stems, and Roots

Figure 4 presents the amount of heavy metals according to the treatment period for the leaf, stem, and root sections. The average Al content accumulated by *I. aquatica* was ~1054 mg/kg per day, while the average Fe content was 972 mg/kg per day. The average contents of Al and Fe of *C. asiatica* were less than those (~767 mg/kg per day and ~47 mg/kg per day, respectively) of *I. aquatica*.

Figure 4. Accumulation of Al and Fe in the: (a) leaf; (b) stem, and (c) root sections by *Ipomoea aquatica* and *Centella asiatica*.

(a) *Ipomoea aquatica*

Figure 4 shows the contents of Al in the leaf, stem, and root sections for day 2 to 10 of treatment by *I. aquatica*. Readings recorded for the leaf section were 973, 332, 261, 27, and –15 mg/kg. Overall, ~1577 mg/kg of heavy metals was accumulated at 10 days of treatment, with an average of 157 mg/kg per day. The highest amount of heavy metals was recorded on the second day of treatment, which was ~62%. On the final day of treatment, the percentage of heavy metals in leaves was the lowest, which was 0.01% of the total amount of heavy metals.

The contents of heavy metals recorded for the stem section were 3055, 1157, 130, 88, and 18 mg/kg. In total, ~4447 mg/kg of heavy metals was recorded for day 2 to 10 of treatment, with an average content of 448 mg/kg per day. The highest amount of heavy metals was recorded on the second day, which was ~69% of the total amount of heavy metals, while the percentage of heavy metals was the lowest on the final day, which was 0.01%. The contents of heavy metals in the root section were 2859, 614, 556, 321, and 175 mg/kg. About 4524 mg/kg of heavy metals was recorded for 10 days of treatment, with an average amount of ~452 mg/kg per day. The highest heavy metal content was recorded on the second day, which was ~49%. On the final day of treatment, the percentage of heavy metals in leaves was the lowest, which was 0.08% of the total amount of heavy metals.

Figure 4 also shows the contents of Fe in the leaf, stem, and root sections for day 2 to 10 of treatment. The contents of heavy metals accumulated in leaves were 113, 190, 499, –56, and 75 mg/kg. Overall, ~821 mg/kg of heavy metals was accumulated at 10 days of treatment, with an average of 82 mg/kg per day. The highest content of heavy metals was recorded on the sixth day, which was ~61% of the total amount of heavy metals, while the percentage of heavy metals was the lowest on the eighth day, which was 0.07%. The contents of the heavy metals accumulated in the stem section were 1606, 197, 55, –9, and –83 mg/kg. About 1767 mg/kg of heavy metals was recorded for 10 days of treatment, with an average amount of ~177 mg/kg per day. The highest content of heavy metals was recorded on the second day, which was ~91%. On the final day of treatment, the percentage of heavy metals in leaves was the lowest, which was 0.05% of the total amount of heavy metals. Readings recorded for the root section were 2198, 1089, 824, 621, and 352 mg/kg. Overall, ~5084 mg/kg of heavy metals was accumulated at 10 days of treatment, with an average of 508 mg/kg per day. The highest content of heavy metals was recorded on the second day, which was ~43%. On the final day of treatment, the percentage of heavy metals in leaves was the lowest, which was 0.07% of the total amount of heavy metals.

(b) *Centella asiatica*

Figure 4 shows the contents of Al in the leaf, stem, and root sections for day 2 to 10 of treatment by *C. asiatica*. Readings recorded for the leaf section were 3205, 690, 125, 111, and 72 mg/kg. In total, ~4202 mg/kg of heavy metals was accumulated at 10 days of treatment, with an average of 420 mg/kg per day. The highest content of heavy metals was recorded on the second day, which was ~76%. On day 10, the percentage of heavy metals in leaves was the lowest, which was 0.02% of the total amount of heavy metals.

The contents of heavy metals recorded for the stem section were 2661, 1364, 303, 122, and 138 mg/kg. About 4588 mg/kg of heavy metals was recorded for 10 days of treatment, with an average amount of 459 mg/kg per day. The highest content of heavy metals was recorded on the second day, which was ~58% of the total amount of heavy metals, while the percentage of heavy metals was the lowest on the eighth day, which was 0.03%. The contents of heavy metals in the root section were 1497, 210, 2, –338, and –440 mg/kg. About 931 mg/kg of heavy metals was recorded for 10 days of treatment, with an average amount of 93 mg/kg per day. The highest content of heavy metals was recorded on the second day, which was >160%. On the final day of treatment, the percentage of heavy metals in leaves was the lowest, which was 47% of the total amount of heavy metals.

Figure 4 also shows the contents of Fe in the leaf, stem, and roots sections for day 2 to 10 of treatment. The contents of heavy metals accumulated in leaves were 667, 242, 169, 177, and 217 mg/kg.

About 1472 mg/kg of heavy metals was accumulated at 10 days of treatment, with an average of 147 mg/kg per day. The highest amount of heavy metals was recorded on the second day of treatment, which was 45% of the total amount of heavy metals, while the percentage of heavy metals was the lowest on the sixth day, which was 11%. The contents of heavy metals accumulated in the stem section were 268, 357, 55, 65, and 204 mg/kg. At 10 days of treatment, 948 mg/kg of heavy metals was recorded, with an average amount of ~95 mg/kg per day. The highest amount of heavy metals was recorded on the fourth day, which was 38%. On the sixth day of treatment, the percentage of heavy metals in leaves was the lowest, which was 0.06% of the total amount of heavy metals. Readings recorded for the root section were –214, –245, –451, –484, and –557 mg/kg. Overall, ~1950 mg/kg of heavy metals was accumulated at 10 days of treatment, with an average of 195 mg/kg per day. The highest amount of heavy metals was recorded on the 10th day, which was ~29%, while on the second day of treatment, the percentage of heavy metals in leaves was the lowest, which was 11% of the total amount of heavy metals.

5.2.4. Translocation Factor of Heavy Metals

Table 2 shows the TF of aluminum and iron, reflecting the ability of *I. aquatica* to extract heavy metals from roots to shoots. Results revealed that $TF < 1$ for *I. aquatica*, indicating that heavy metals are accumulated in the roots. For Al accumulation, the highest TF was observed on the fourth day of treatment, which was 0.54, and the lowest TF was observed on the final day of treatment, which was 0.09. For Fe accumulation, the highest TF of 0.61 was observed on the sixth day of treatment, and the lowest TF of 0.09 was observed on the eighth day.

Table 2. Translocation factor for *Ipomoea aquatica* and *Centella asiatica* from root to leave (R/L).

Translocation Factor/Day (TF)						
<i>Ipomoea aquatica</i>						
Day	2	4	6	8	10	MIN
Aluminum	0.34	0.54	0.47	0.08	(0.09)	0.27
Iron	0.05	0.17	0.61	0.09	0.21	0.19
<i>Centella asiatica</i>						
Day	2	4	6	8	10	MIN
Aluminum	2.14	3.28	54.94	0.33	0.16	11.97
Iron	3.11	0.99	0.38	0.37	0.39	1.05

Table 2 also shows the TF of aluminum and iron, reflecting the ability of *C. asiatica* to extract heavy metals from roots to shoots. Results indicated for Al, $TF > 1$, and the highest TF of 55 is observed on the sixth day of treatment. The lowest TF of 0.16 was observed on the 10th day of treatment. For Fe accumulation, $TF < 1$ was observed for *C. asiatica*, implying that heavy metals are accumulated in the roots or other parts of the plant. The highest TF of 3.11 was observed on the second day of treatment, and the lowest TF of 0.37 was observed on the eighth day.

The results showed that there were significant differences in iron translocation factors in the stems by *Ipomoea aquatica* compared to leaves. For *Centella asiatica*, a significant value was obtained for the amount of iron in the leaves and stems. For aluminum, *Ipomoea aquatica* recorded a significant value for metal translocation from roots to leaves and from roots to stems. However, no significant value was recorded for the aluminum by *Centella asiatica*.

Basically, most of the heavy metals accumulate in plant roots because the surface area of root hairs is greater than those of stems and leaves for the absorption of heavy metals [14]. Besides, roots are the first part of a plant that absorb heavy metals from soil or a waterbody before their distribution to the other parts. In addition, compared to stems and leaves, roots are the only covered part, and they are in contact with the growth medium. Hence, roots demonstrate more potential to absorb nutrients and pollutants due to their plant physiology.

Ismail et al. [3] found that the *Scirpus grossus* accumulated Al and Fe from mining wastewater, implying the potential of *Scirpus grossus* as a hyperaccumulator in the phytoremediation of Al and Fe. Syabani et al. [44] have reported bioconcentration factor (BCF) < 1 for *C. asiatica*. However, TF > 1 was observed for the accumulation of Pb, Cu, and Zn, indicating that even though *C. asiatica* is not a potential hyper accumulator or a phytostabilization agent, this species is tolerant to Pb, Cu, and Zn. A BCF range from 0.01 to 0.10 for Zn and Pb revealed that *C. asiatica* is a weak accumulator for these metals. Based on the study conducted by Yoon et al. [45], the highest ratio of lead (Pb) concentration reflects the accumulation from roots to stems, while the lowest ratio reflects accumulation from roots to leaves. The study determined the concentrations of Pb and Cd accumulated in *I. aquatica* at Laguna de Bay Filipina. Results indicated that the Pb concentration of the plant section follows the order of roots $\geq$ vertical stems $\geq$ horizontal stems $\geq$ leaves. The ratio is 0.82 stems/roots and 0.36 leaves/roots.

A graph of the heavy-metal concentration (mg/L) over treatment days revealed that the regression (R²) value is positive and close to R² of 1: R² for Al is 0.7607, and R² for Fe is 0.8239 for *I. aquatica*, and R² for Al is 0.8182 and R² for Fe is 0.8862 for *C. asiatica*. This result indicated that the heavy-metal concentration exhibits a good relationship for reflecting the decrease in the heavy-metal concentration over the treatment day. If the regression was similar to R² = 1, it verified the relationship between the variables and vice versa, if R² < 1.

In addition, the TF of roots to stems was calculated to determine the location of heavy metal accumulation as an alternative for the accumulation of heavy metals from roots to leaves. Table 3 summarizes the TF of aluminum and iron, reflecting the ability of *I. aquatica* to extract heavy metals from roots to stems. The results indicated that TF < 1 for *I. aquatica*, indicating that most of the heavy metals are still accumulated in the roots. For Al accumulation, the highest TF was observed on the second day of treatment, which was 1.89, while the lowest TF was observed on the final day, which was 0.10. For Fe accumulation, the highest TF was observed on the second day of treatment, which was 0.73, and the lowest TF was observed on the eighth day, which was 0.01.

Table 3. Translocation factor for *Ipomoea aquatica* and *Centella asiatica* from root to stem (R/S).

Translocation Factor/Day (TF)						
<i>Ipomoea aquatica</i>						
Day	2	4	6	8	10	MIN
Aluminum	1.07	1.89	0.23	0.27	0.10	0.71
Iron	0.73	0.18	0.07	−0.01	−0.23	0.15
<i>Centella asiatica</i>						
Day	2	4	6	8	10	MIN
Aluminum	1.78	6.48	133.20	(0.36)	(0.31)	28.16
Iron	(1.25)	(1.46)	(0.12)	(0.13)	(0.37)	(0.67)

Table 3 also shows the TF of aluminum and iron, reflecting the ability of *C. asiatica* to extract heavy metals from roots to stems. Results indicated that TF > 1 for Al accumulation, and the highest TF is observed on the sixth day of treatment, which is 133. The lowest TF was obtained on the final day, which was 0.31. For Fe accumulation, TF < 1, and it is negative, indicating that most of the heavy metals are not accumulated in the roots due to the amount of heavy metals in the roots was negative.

Results obtained for the TF of heavy metals via their accumulation in leaves and stems by *I. aquatica* revealed that a significant TF variation is observed for the stem section compared to the leaf section. For Al accumulation, *I. aquatica* exhibited significant TF of heavy metals from roots to leaves (R/L) and from roots to stems (R/S), while for *C. asiatica*, a significant value was obtained for the amount of Fe in leaves and stems. No significant value for Al accumulation was observed, even though TF for stems (TF = 132) and leaves (TF = 54) was different.

6. Conclusions

In this study, *Ipomoea aquatica* and *Centella asiatica* were selected as phytoremediation plants based on their rapid growth rate and lower maintenance costs. Results revealed that *I. aquatica* exhibits higher Al content than *C. asiatica*. It was also found that the average content of Fe accumulated by *I. aquatica* was greater than that accumulated by *C. asiatica*. Besides, with respect to the wastewater treatment by *I. aquatica*, a significant variation between the TF of Fe in the stem compared to the leaf section was observed, indicating that most of the Fe accumulate in stems. For *C. asiatica*, $TF < 1$ for Fe in leaves and stems, and it was negative, indicating that heavy metals are not accumulated in roots because the amount of heavy metals in the roots was negative. $TF > 1$ for Al accumulated in leaves and stems of both plant species, indicating that both plants can accumulate and extract heavy metals from wastewater.

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