

Article

A Small-Scale Study on Removal of Heavy Metals from Contaminated Water Using Water Hyacinth

An The Huynh ^{1,2}, Yi-Ching Chen ^{1,*}  and Bich Ngoc Thi Tran ³ ¹ Department of Environmental Engineering, Da-Yeh University, Changhua 51591, Taiwan; anht@tdmu.edu.vn² Department of Management Sciences, Thu Dau Mot University, Binh Duong 590000, Vietnam³ Institute of Environmental Sciences and Technology, Tra Vinh University, Tra Vinh 940000, Vietnam; ngocbich@tvu.edu.vn

* Correspondence: yiching@mail.dyu.edu.tw; Tel.: +88-69-3910-7419

Abstract: The aim of this research was to determine whether water hyacinth can be used to remove heavy metals, such as cadmium, arsenic, lead, zinc, and copper, from industrial wastewater. Investigations of the pollution removal or prevention potential of aquatic macrophytes, such as heavy metal bio-indicators in aquatic habitats, can prove to be advanced field studies. Water hyacinth is one of the aquatic plant species that has been effectively utilized for the treatment of wastewater. It is extremely effective in removing stains, suspended solids, BOD, organic matter, and heavy metals. This research focused on the use of water hyacinth to treat wastewater from heavy metals. Water hyacinths can grow in sewage, absorbing and digesting contaminants and transforming sewage effluents into comparatively clean water in the process. As a result, the plants have the potential to be used as natural water purification systems at a fraction of the cost of a standard sewage treatment facility. The experiment was performed using healthy, young, and acclimatized water hyacinths. Containment water with a cadmium concentration of 0.5 mg/L, arsenic concentration of 0.5 mg/L, lead concentration of 2 mg/L, zinc concentration of 5 mg/L, and copper concentration of 5 mg/L was added to five different polyethylene pots with 100 g of water hyacinth in each pot. After 30 days, the removal efficiency for heavy metals (Cd, As, Pb, Zn, and Cu) reached 59–92%, and the results were within the permitted limits according to the National Technical Regulation on Industrial Wastewater in Vietnam. Based on this information, it is possible to deduce that water hyacinth can be utilized to remove cadmium, arsenic, lead, zinc, and copper from industrial wastewater effluents efficiently.

Keywords: heavy metals; water hyacinth; cadmium; arsenic; lead; zinc; copper

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1. Introduction

Water pollution is a burning problem for developing countries. As societies grow, the amount of domestic and industrial waste also increases exponentially. Amounts of waste are increasing but the centralized treatment systems are not enough to deal with them along with unconcentrated discharge habits, which have caused extremely serious water pollution. In particular, heavy metal pollution involving cadmium (Cd), arsenic (As), lead (Pb), zinc (Zn), and copper (Cu) is a serious problem due to the particularly dangerous toxicity of these elements affecting human health, organisms, and the environment [1].

Traditional methods, including physical and chemical processes used to treat heavy metals, are being applied, most of which have complex processes, are quite expensive in terms of economics, and have high technical requirements [2]. A study on removing arsenic contamination in soil by phytoremediation has been published [3]. Additionally, wastewater treatment using aquatic plants has been applied in many parts of the world, which has the advantages of low costs, easy operation, and high pollution treatment level [4–6]. This is a technology for the treatment of wastewater in natural and environmentally friendly conditions while increasing biodiversity and improving the landscape, environment, and local ecosystems [7].

The popular application of water hyacinth (*Eichhornia crassipes*) for wastewater treatment has gained worldwide acclaim [8]. Several metals have extraordinarily high attraction and accretion capacities for water hyacinths [9,10]. A typical marshland colonized by water hyacinth can act, in a way, as “nature’s kidney” for proper wastewater treatment, preserving the earth’s valuable water resources [8]. Water hyacinth has gained much attention for its capacity to be cultivated in extremely polluted water, in addition to its tendency to accumulate metal ions [11]. Water scarcity is becoming more prevalent around the biosphere and in numerous countries it might be unavoidable by the end of the year. With the realization that surface water contamination is a worldwide problem, the situation becomes much more alarming. Several methods for sustainable water resource utilization have been developed to solve this problem, with wastewater recovery and reuse currently being one of the most important targets. The two most common anthropogenic sources of metal in aquatic ecosystems, according to research, are domestic and industrial waste [12]. Heavy metals in water can be dangerous even in small quantities. Since the beginning of the industrial revolution, hazardous metal contamination in the biosphere has increased drastically. Water hyacinth is an aquatic plant that can effectively remove a variety of pollutants from water, making it important in wastewater treatment [4,5].

Water hyacinth is a major material in the handicrafts industry in Vietnam. It is cheap and commonly planted. Furthermore, water hyacinth can be a good tool for the removal of heavy metal contamination through phytoremediation technology. For economic reasons, the use of water hyacinth in wastewater treatment should be promoted in Vietnam. In addition, water hyacinth is also used in Vietnam as fodder for livestock, compost for mushrooms, and manure. Dried water hyacinth can be processed for use in braided ropes, weaving mats, crafts, or furniture. Therefore, this study was conducted to evaluate the ability of water hyacinth to absorb heavy metals (Pb, Cd, Zn, Cu, As) from wastewater. The results indicated good performance in the reduction of concentrations of heavy metals. The removal efficiency for heavy metals (Cd, As, Pb, Zn, and Cu) reached 59–92% after 30 days, notably for Pb, which was reduced by 92.4%.

2. Characteristics of Water Hyacinth

2.1. Water Hyacinth

Water hyacinth is a rapidly growing, floating aquatic plant from the South American Amazon Bay [13]. It is well-known for its propensity to multiply, with the plant’s population being able to double in just 12 days. Its propensity to flourish in severely contaminated waters is also well-known. As an aquatic plant capable of improving oxidation pond effluent quality and a key factor for single, integrated, and advanced treatment systems for urban, agricultural, and industrial waste streams, water hyacinth has been intensively explored. Beside wastewater treatment, water hyacinth can also be used in valuable products like biogas, bioethanol, biohydrogen, biofertilizers, and fish feed [14].

2.2. Ecological Factors

The ability of ecological technology to recover and reuse resources is an environmentally friendly feature. In aquatic ecosystems, for example, nutrients from phosphorous and nitrogenous wastewater components are recycled into usable biomass via ecological food chains. Warm, nutrient-rich water is ideal for water hyacinth growth. The ideal H⁺ ion potential for this aquatic plant’s growth is neutral; however, it can potentially withstand hydrogen values ranging from 4 to 10. Water hyacinth can be used to treat a variety of types of wastewater thanks to this key feature. The ideal water temperature for growth is between 28 °C and 30 °C. Temperatures exceeding 33 °C stifle further development. The ideal air temperature is between 21 °C and 30 °C. Water hyacinth can also thrive in both nutrient-rich and nutrient-poor water, as well as in water that has been heavily contaminated with diverse biological and inorganic industrialized effluents containing metal ions [15–17]. Water hyacinth is a common and prolific plant that is free-floating, highly tolerant of harsh settings, and capable of rapid vegetative reproduction and survival in a variety of environ-

ments. The maximum reproductive rate is 54.4 g dry weight/m²/day [15,16]. Plants grow more quickly in the summer, covering 15% more surface area every day.

2.3. Socio-Economic Potential of Water Hyacinth in Vietnam

Water hyacinths were introduced into Vietnam around 1905 and developed throughout the Southern Rivers on inland canals, affecting agricultural production, waterway traffic, and drainage [18]. Water hyacinths also hinder fishing and seriously affect water supply. They grow rapidly in the rainy season, and they are the residences of mosquitoes and disease-causing insects. Water hyacinth seems useless but it is considered a valuable and precious raw material for handicrafts and a “new discovery of the 21st century” because it has been exploited and used since the flood season in 2000. Recently, people in the area of the Mekong Delta have been interested in handicraft products made from this plant. Furthermore, according to the statistics of the General Department of Vietnam Customs (GDVNC), these products are also exported to foreign countries to meet the needs of fastidious markets such as those of the US, China, Japan, Europe, and South Korea, [19].

Thanks to this handicraft industry, many localities have solved unemployment problems and helped farmers increase their incomes, contributing to the eradication of hunger and poverty reduction. Since 2000, water hyacinth knitting has developed strongly in the Mekong Delta, especially in the provinces of Dong Thap, Long An, An Giang, and Vinh Long, and the development of this profession has created more jobs and increased income for farming households. Therefore, water hyacinth is also heavily exploited to provide raw materials for production.

2.4. Mechanism of Wastewater Treatment Using Water Hyacinth

Contaminants and stockpiles can be found in water hyacinth biomass. As they store pollutants in their tissues, these plants are known as bioaccumulators. They have a high tolerance for pollutants such as heavy metals and may absorb significant quantities of them. Phytoextraction is a technique for the removal of heavy metals from contaminated water sources [20]. The routes for pollutant uptake are described below.

Root absorption: The roots absorb contaminants in the aquatic environment. A large cation change throughout the cell membrane is caused by the presence of carboxyl groups in the root system. This acts as a mechanism for heavy metal transport within the root system, where active absorption takes place. Aerobic bacteria develop well in the water systems due to the root structures of water hyacinths (as well as other aquatic floras). Aerobic bacteria acquire nutrients and harvest inorganic compounds, which plants consume as nourishment. The plants improve rapidly and can be collected as rich and profitable fertilizer.

Foliar absorption: In addition to root absorption, foliar absorption can provide plants with small amounts of some pollutants. They are absorbed passively by stoma cells and cuticle fissures.

In this type of absorption, fibrous or feathery roots are trapped in floating particles and germs as bacterial and fungal growth attachment points. Pollutants on the root surface are absorbed by the bacteria that live on it. An ionic imbalance throughout the cell membrane also occurs.

3. Methods

3.1. Instruments

The instruments used in the study included a micropipette (Eppendorf, Hamburg, Germany), flask, test tube, electric stove, and an analytical balance from Adam (UK) with an accuracy of 0.0001 mg.

ICP-MS equipment (Perkin Elmer, Waltham, MA, USA, ELAN 9000) was used to analyze samples with the following parameters: RF power: 1000 (W); sample injector (Perkin Elmer, Waltham, MA, USA): 26 (rpm); auxiliary gas (Perkin Elmer, Waltham, MA, USA): 2 (L/min); plasma gas (Perkin Elmer, Waltham, MA, USA): 0.85 (L/min); nebulizer gas (Perkin Elmer, Waltham, MA, USA): 2.4 (L/min).

3.2. Chemicals

Standard solutions of cadmium, arsenic, lead, copper, and zinc were prepared in a standard solution of 100 µg/mL.

The chemicals used were all pure chemicals manufactured by Merck Chemical (Darmstadt, Germany). The solutions were prepared with double-distilled water.

3.3. Analysis Sample

The sample collection and processing period started on 20 May 2021. After being planted, the sample was monitored and the heavy metal content in the water was analyzed three times, after 10, 20, and 30 days, to observe the metal content in water treated with water hyacinth over time. The heavy metals (Cd, As, Pb, Zn, and Cu) in the plants were determined using inductively coupled plasma-mass spectrometry.

3.4. Experimental Setup

The experiments lasted 30 days and 100 g of water hyacinth was used in the pot. For planting, 30-L foam containers were used, which were washed of dust and soil with distilled water beforehand. The plants were fixed with stones (inexpensive, poorly absorbing substrates). Concentration selection experiments were undertaken based on the permitted threshold levels for Cd, As, Pb, Zn, and Cu in water environments according to the QCVN 40:2011/BTNMT National Technical Regulation on Industrial Wastewater in Vietnam. The experimental concentration was three to five times higher than the allowable threshold. Water hyacinth was grown in irrigation water containing the heavy metals Cd, As, Pb, Zn, and Cu according to selected concentrations:

1. Plant water containing 0.5 mg/L of Cd (II);
2. Plant water containing 0.5 mg/L of As (III);
3. Plant water containing 2 mg/L of Pb (II);
4. Plant water containing 5 mg/L of Zn (II);
5. Plant water containing 5 mg/L of Cu (II).

As a matching plant control sample, plants were planted in distilled water with stone media.

The analytical parameters were Cd, As, Pb, Zn, and Cu in water.

3.5. Water Properties

When simplifying the natural environment, the possibility of the accumulation of heavy metals in the plants had to be taken into consideration whilst at the same time ensuring the accuracy of the experiment. The water composition helped us to identify the nutrient content and determine whether additional nutrients had to be added to the plants [21]. Further, the metal content in the water was also an aspect that we were interested in. Identifying the presence of metal ions and the amount of accumulation helped us to assess whether there was competition for these metal ions in the accumulation in the plants and to identify the research plant that could handle Cd, As, Pb, Zn, and Cu metal ions [2]. The water samples were collected in Phu Giao district, Binh Duong, Vietnam, and the levels of water quality are listed in Table 1.

Based on the results of the water quality analysis shown in Table 1 and the Vietnam National Technical Regulation QCVN 08-MT:2015/BTNMT (Column B1), the parameters for water quality and other heavy metals content were within the allowable thresholds of the national standards. The appropriate quantities of nutrients and mineral ions required for proper plant development were used and there were no metal elements that could obstruct the accumulating process. As a result, the uptake of the tested elements should have been faster.

Table 1. Results of water quality analysis.

No.	Parameters	Unit	Content	QCVN 08-MT:2015/BTNMT (Column B1)
1	Temperature	°C	25.1	-
2	pH	-	6.7	5.5–9
3	EC	µS/cm	58	-
4	DO	mg/L	8.77	≥4
5	TDS	mg/L	27	-
6	BOD ₅	mg/L	12.2	15
7	COD	mg/L	23.3	30
8	TSS	mg/L	7.3	50
9	As	mg/L	<0.005	0.05
10	Cd	mg/L	<0.0005	0.01
11	Pb	mg/L	<0.005	0.05
12	Cr	mg/L	<0.005	0.04
13	Hg	mg/L	<0.0005	0.001
14	Zn	mg/L	0.051	1.5
15	Mn	mg/L	0.158	0.5
16	Fe	mg/L	0.772	1.5
17	Total nitrogen	mg/L	2.92	-
18	N-NO ₃ ⁻	mg/L	0.97	10
19	N-NO ₂ ⁻	mg/L	<0.005	0.05
20	N-NH ₄ ⁺ /NH ₃	mg/L	<0.006	0.9
21	Total phosphorus	mg/L	<0.05	-
22	P-PO ₄ ³⁻	mg/L	<0.05	0.3
23	S ²⁻	mg/L	<0.04	-
24	CN ⁻	mg/L	-	0.05
25	Coliform	MPN/100mL	1600	7500

3.6. Data Analysis

The analyzed data were assessed and compared with the current QCVN 40:2011/BTNMT Vietnamese standards. The data were processed using Excel and Statgraphics software.

4. Results and Discussions

4.1. The Height Growth of Water Hyacinth after 30 Days

By definition, plant growth is associated with the process of increasing the mass, height, and size of cells or cell organelles. Growth can also represent the development and reproduction of a plant [22]. Height is one of the important indicators for assessing the growth of plants containing different environmental heavy metals (Cd, As, Pb, Zn, and Cu). In addition to the dependence of height on the genetic characteristics of a variety, it also depends on external conditions such as climate, temperature, oxygen, mineral nutrition, fertilizer, water, etc. [23]. The growth of plants in polluted water is important for the absorption and accumulation of heavy metals in plants. The height results for the water hyacinths are presented in Table 2. There was a significant difference in height growth for these samples with $p < 0.05$, which could validly explain their differences in plant growth.

Table 2. Effects of heavy metal concentrations on the height growth of water hyacinths after 30 days.

Element	Original Height(cm)	Height after 30 Days (cm)
Cd	43	44.0 ^a ± 0.5
As	43	44.3 ^{ab} ± 0.5
Pb	43	45.7 ^{bc} ± 0.8
Zn	43	46.3 ^c ± 1.5
Cu	43	46.7 ^c ± 0.6

$p = 0.0105^*$

(1) a, b, and c represent statistically different values. (2) * means significant with $p < 0.05$.

The results in Table 2 show that the height growth rate of the water hyacinths depended on the absorption capacity of the plants. The decreasing height corresponded to the heavy metals contained in the water in the order Cu > Zn > Pb > As > Cd. The growth condition can be described as follows:

- Plant growth in water environment with 0.5 mg/L Cd and As content. Water hyacinth showed good growth signs, strong and green stems and leaves. The height did not change much;
- Plant growth in a water environment contaminated with Pb continued after 30 days; however, the stems and leaves had yellowed, and some stems and leaves were wilted;
- The plants in water with a Zn concentration of 5 mg/L grew well, increasing in height and standing strong, but in the last days of the cycle, some leaves were wilted and yellowed;
- The plants in water with 5 mg/L of Cu showed good growth: there was an increase in height in some of the canopies and the appearance of extra branches in young trees, lush green stems, and leaves.

The height of the water hyacinth in each pot was considered as height growth. As water hyacinth is a wild plant, it grows very well under natural conditions [24]. However, the height growth of the water hyacinths differed depending on the different metals; some plants even withered, died, and did not develop young plants. The biomass of the pot was then significantly reduced.

4.2. The Ability of Water Hyacinth to Accumulate Heavy Metals

Phytoremediation refers to the use of plants to partially or substantially remediate selected contaminants in contaminated soil, sludge, sediment, groundwater, surface water, and wastewater [25]. Phytoremediation is popular because of its cost-effectiveness, aesthetic advantages, and long-term applicability [26].

The objective of utilizing water hyacinth in phytoremediation technique testing was to assess its efficiency for heavy metal treatment. Therefore, after being planted, the sample was monitored and the heavy metal content in the water was analyzed three times, after 10, 20, and 30 days, to observe the metal content in water treated with water hyacinth over time. The results are presented in Table 3.

Table 3. The concentrations of heavy metals in water treated with water hyacinth over time.

Days	Cadmium (Cd) Concentration			Arsenic (As) Concentration			Lead (Pb) Concentration			Zinc (Zn) Concentration			Copper (Cu) Concentration		
	Cd (mg/L)	CV (%)	H (%)	As (mg/L)	CV (%)	H (%)	Pb (mg/L)	CV (%)	H (%)	Zn (mg/L)	CV (%)	H (%)	Cu (mg/L)	CV (%)	H (%)
0	0.5			0.5			2			5			5		
10	0.406 ± 0.0006	0.14	18.8	0.394 ± 0.0006	0.15	21.2	1.498 ± 0.001	0.07	25.1	3.891 ± 0.002	0.05	22.2	3.859 ± 0.002	0.05	22.8
20	0.301 ± 0.002	0.51	39.8	0.285 ± 0.001	0.35	43.0	0.618 ± 0.002	0.32	69.1	2.686 ± 0.001	0.04	46.3	2.527 ± 0.003	0.12	49.5
30	0.203 ± 0.002	0.75	59.4	0.196 ± 0.002	1.02	60.8	0.153 ± 0.005	3.27	92.4	1.989 ± 0.004	0.18	60.2	1.963 ± 0.0006	0.03	60.7
QCVN 40:2011/BTNMT (Column B)	0.1			0.1			0.5			3			2		

H (%): removal efficiency percentage, CV (%): coefficient of variation.

The results show that the ability of water hyacinth to accumulate heavy metals gradually decreased with the remaining heavy metal content in the water in the order Cd < Zn < Cu < As < Pb. In addition, Table 3 also shows that, with regard to the experimental conditions of the sample pots, the concentrations of Cd, As, Pb, Zn, and Cu in the water decreased gradually with increasing time of treatment with water hyacinth. Specifically, the Cd, As, Pb, Zn, and Cu in the water had initial concentrations of 0.5 mg/L, 0.5 mg/L, 2 mg/L, 5 mg/L, and 5 mg/L, respectively. Ten days after planting the water hyacinths, the concentrations of Cd, As, Pb, Zn, and Cu in the water were 0.406 mg/L, 0.394 mg/L, 1.498 mg/L, 3.891 mg/L, and 3.859 mg/L, respectively. By day 30 of the experiment, the remaining Pb content in the solution reached the lowest level (0.153 mg/L) compared to the

other elements, and it was within the permitted limits according to Column B of the QCVN 40:2011/BTNMT National Technical Regulation on Industrial Wastewater in Vietnam.

The experiments on growing water hyacinths in water containing heavy metals (Cd, As, Pb, Zn, and Cu) showed that this plant can still grow and develop at a certain level of pollution. The analysis results for the heavy metal content (Cd, As, Pb, Zn, and Cu) in the water showed a trend of decreasing concentration over time. Thus, water hyacinth has the ability to clean water contaminated with heavy metals (Cd, As, Pb, Zn, and Cu) very well.

4.3. Removal Efficiency Percentage and Remaining Percentages of Heavy Metals in Water

The removal efficiency percentage for the plants' ability to absorb heavy metals (Cd, As, Pb, Zn, and Cu) in the water over time is shown in Table 3.

The treatment efficiencies of water hyacinth for Cd, As, Pb, Zn, and Cu over the 30 days of the experiment were 59.4%, 60.8%, 92.4%, 60.2%, and 60.7% respectively, corresponding to the initial concentrations of 0.5 mg/L, 0.5 mg/L, 2 mg/L, 5 mg/L, and 5 mg/L. By the end of the 30-day survey period, the cleaning rates of the water hyacinths for all heavy metals (Cd, As, Pb, Zn, and Cu) were mostly high (59–92%).

The results show that the remaining heavy metal content in the water treated with water hyacinths decreased significantly after 30 days compared to the original concentrations. The remaining percentage of Pb especially was only 7.65%, corresponding to an original concentration of 2 mg/L.

The findings of the pot trials reveal that this plant has the potential to absorb heavy elements such as cadmium, arsenic, lead, zinc, and copper from wastewater. When the plants were added to the pots, the cadmium, arsenic, lead, zinc, and copper concentrations in the pots with the plants were significantly reduced. As a result, we can conclude that evaporation and settlement caused very little loss. The results show that water hyacinth is an effective plant capable of removing heavy metals from wastewater.

Previous bench-scale tests [27] using water hyacinth treatment for polluted river water and synthetic solutions demonstrated up to 63% removal of Al, 62% Zn, 47% Cd, 22% Mn, and 23% As in just seven hours of exposure to the plant. The results demonstrated very good removal efficiency in a very short time compared with this study, which only achieved removals of 18.8% Cd and 21.2% As in 10 days. Nevertheless, the initial metal concentrations were very low (0.00623 mg/L Cd and 0.00211 mg/L As) in the bench-scale tests compared to the much higher initial metal concentrations (0.5 mg/L Cd and 0.5 mg/L As) used in this study. Additionally, a study of water hyacinth as a biosorbent has been undertaken by using dry water hyacinth biomass [28]. This study involved a test that achieved 93% As(III) removal efficiency with 120 min shaking time and initial metal concentrations of 0.2 mg/L in solution. However, it is hard to make an objective comparison since the treatment mechanism was different to this study.

5. Conclusions

The efficiency of wastewater treatment for the removal of Cd, As, Pb, Zn, and Cu was assessed according to the concentrations of heavy metals in water. The elimination of contaminants from the water was quite effective when the plants were grown together. According to the results of the experiments, water hyacinth was able to reduce Cd concentration by 59.4%, As concentration by 60.8%, Pb concentration by 92.4%, Zn concentration by 60.22%, and Cu concentration by 60.74%. The total heavy metal concentration was reduced by 66.7%. This treatment system proved cost-effective because of the low installation and maintenance costs. The system could be used alone or in conjunction with other wastewater treatment systems. In conclusion, the current study revealed the viability of employing the aquatic plant *Eichhornia* to treat wastewater in a "sustainable" and environmentally benign manner. As this was merely a laboratory-size baseline study, more research on a larger scale is needed in the future, with a focus on phytoremediation and resource utilization.

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