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Cadmium and Chromium Removal Capacity of Pandan Leaves (*Pandanus amaryllifolius* Roxb. Ex Lindl.) and Texas Mud Baby [*Echinodosus cordifolius* (L.) Griseb.]

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ABSTRACT

Background: This study aimed to determine removal capacity and bioaccumulation levels of the cadmium and chromium contaminate from water samples using *Pandanus amaryllifolius* Roxb. ex Lindl. and *Echinodosus cordifolius* (L.) Griseb, compared with the control groups.

Methods: Technically, the concentrations of Cd and Cr in water and plants were measured by inductively coupled plasma optical emission spectrometry.

Result: In our study, the concentrations of Cd and Cr in water after removal duration 7 days, different between the control and the experimental groups was statistically significant at $p<0.05$. Interestingly, removal capacity experiment, *P. amaryllifolius* demonstrated the highest removal capacity for Cd and Cr, achieving 92.87% and 51.07% removal, respectively. Combined use of *P. amaryllifolius* and *E. cordifolius* showed slightly lower capacity, while *E. cordifolius* alone achieved the lowest removal capacity. The bioaccumulations of Cd and Cr in the *E. cordifolius* and *P. amaryllifolius* were tested. After 7 days of absorption, in the experiment accumulated the highest amount of Cd and Cr in the root more than the stem and leaf, respectively. The outcome of this study provides low cost, providing good efficiency in getting rid of HMs and being environmentally friendly.

Key words: Bioaccumulation, Heavy metals, Pandan leaves, Removal capacity, Texas mud baby.

INTRODUCTION

Currently, Thailand has more environmental problems. Particularly, there are problems with water pollution or sewage sources that are not managed and the people are not aware of the importance of the problem (Buddee *et al.,* 2021). Environmental systems, including soil, water and air, are exposed to toxic heavy metals due to human activities (Abd-Elaal *et al.,* 2020) because the increasing population and industrial activities release uncontrolled pollutants into water systems. When it comes to environmental protection, an increasing of hazardous materials and wastes have been discharged into the environment and come into contact with aquatic ecosystems (Mitra *et al.,* 2022; Ansari *et al.,* 2024).

Metal contaminations in the environment is a widespread phenomenon. Heavy metals (HMs), a main group of aquatic pollutants, can bioaccumulate in organism, biomagnify in the food chain and are resistant to biodegradation (Morahdy *et al.,* 2021). Wastewater and effluent discharges from these sources contribute to HMs pollution in rivers and lakes (Cruz-Esquivel *et al.,* 2023). Natural and human-caused processes discharge their excessive heavy metal pollution into aquatic environments, raising worries for global health (Rohilla *et al.,* 2021; Taslima *et al.,* 2022). Cadmium is a noxious heavy metal (Yomso and Siddique, 2024). Long-term exposure to Cd pollution leads many fish tissues to absorb and accumulate Cd, which changing the structure and function of the liver and gills (Zhang *et al.,* 2023). Chronic toxicities of chromium (Cr) are accumulated for a long time in fish; the occurrence of Cr varies in fish depending upon their age, development and other physiological variables. It also produced a detrimental impact on behavior and cytotoxicity (Garai *et al.,* 2021). HMs removal from wastewater is required before its reuse in an industry, agriculture and aquaculture (Abd-Elaal *et al.,* 2020). The expense of removing HMs using conventional treatment techniques such coagulation-flocculation, precipitation and other sophisticated oxidation processes is high (Razzak *et al.,* 2022). Therefore, in order to eliminate these HMs and raise effluent regulations, it is now essential to implement an affordable green technology (Ukhurebor *et al.,* 2021).

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Because plant macrophytes are inexpensive to construction, operation and maintain, using them to treat wastewater is an economical method (Cristescu *et al.,* 2018). Several plant species are used in the well-known technique of phytoremediation to eliminate pollutants from water and wastewater (Bhat *et al.,* 2022).

To address these challenges, this study investigated the potential of two plant species, *Pandanus amaryllifolius* and *Echinodosus cordifolius*, in removing Cd and Cr from water contaminate sample. For increase the alternative of removing HMs, low cost, providing good efficiency in getting rid of HMs and being environmentally friendly.

MATERIALS AND METHODS

Studied plant species and preparation

This experiment was studied in March 2024 to June 2024 at Department of Fisheries Laboratory, Faculty of Agricultural, Khon Kaen University, Thailand. Plant samples in the experiment were *Pandanus amaryllifolius* Roxb. ex Lindl. and *Echinodosus cordifolius* (L.) Griseb.

Each plants species select that are nearby in age, size and shape and equal amount. Healthy *P. amaryllifolius* plants were selected with no flowers, a complete root system and heights ranging from 40-50 cm. The older leaves were trimmed, leaving 12-15 healthy leaves on each plant. *E. cordifolius* plants with a complete root system were selected, with heights between 20-30 cm. The older leaves were trimmed, leaving 12-15 healthy leaves on each plant. For seven days in a lab setting, plants of each species were acclimated in a circular fiberglass container with 100 L of dechlorinated tap water and aeration (Fig 1). Following acclimatization, the chosen plants were carefully cleaned with new water before being assigned to each experimental group.

Experimental chemicals preparation

The analytical cadmium (II) nitrate ($Cd(NO_3)_2$) and potassium dichromate ($K_2Cr_2O_7$) were obtained from Loba Chemie Pvt. Ltd. (Mumbai, Maharashtra, India). The stock solution (10,000 mg/L of Cd and Cr) was prepared by dissolving 27.4430 and 28.2896 g of $Cd(NO_3)_2$ and $K_2Cr_2O_7$, respectively, in 1,000 milliliters of distilled water. This method was modified from Palanippan and Karthikeyan (2009).

Experimental design

Random design experiments were conûgured at the same environmental conditions and carried out with samples or phases obtained during similar in the Department of Fisheries Laboratory, Khon Kaen University, Thailand. The study removal capacity of Cd and Cr used *E. cordifolius* and *P. amaryllifolius*.

The test solutions were prepared by diluting the stock solution with 20 L dechlorinated tap water in a glass tank ($48\times23\times28$ cm^3) as a diluent, it combines of Cd and Cr per a glass tank. The reason for combining them was the objective to test for potential interaction effects and is this simply the realistic scenario being modeled of wastewater treatment system.

Four treatments of the experimental groups as shown in Fig 2 were executed: The first treatment, no plant was used as an experimental control. The second treatment consisted of *E. cordifolius*, which could be fixed in the future board frame, of 8 plants per rectangle 10 centimeter of water surface. The third treatment consisted of *P. amaryllifolius* plants, which were kept at 8 plants per rectangle 10 centimeter. The fourth treatment included of combined 4 plants of *E. cordifolius* + 4 plants of *P. amaryllifolius*. Sufficient aeration was provided during the experiment, with three replications. The hydraulic retention time is 7 days. The concentration Cd and Cr were 5.1713 mg/L (Khamlerd *et al.,* 2024) and 72.4429 mg/L (Khamlerd, unpublished), respectively.

Water samples were collected before and after each treatment with 50 mL in a bottle of plastic. For plant samples, collect before and after each treatment, separating the different parts of a plant: Roots, stems and leaf. Preparation of plant tissues: each root, stem and leaf of plants was oven-dried at 80°C overnight and it is the pulp of plants.

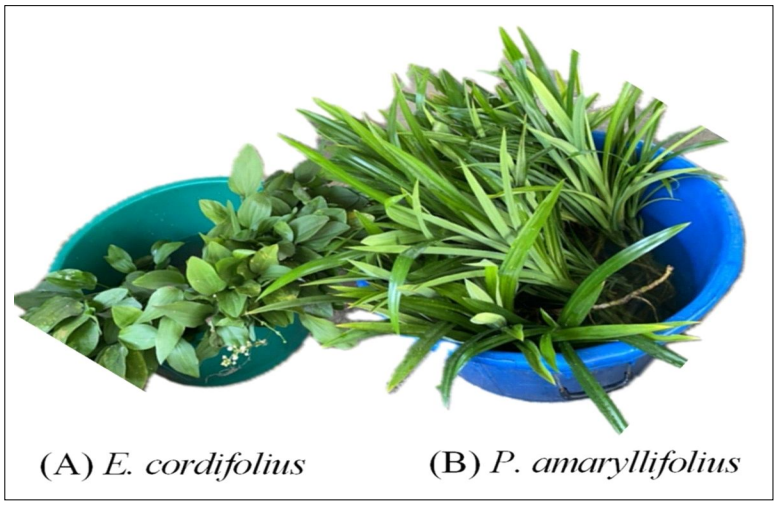


Fig 1: (A) Pandan leaves (*Pandanus amaryllifolius* Roxb.) and (B) Texas mud baby [*Echinodosus cordifolius* (L.) Griseb] on acclimatization.

Cadmium and chromium concentrations analyses in water sample and plant tissues

The water samples (20 mL) were digested with HNO_3 (7 mL) and H_2O_2 (3 mL). The samples were then microwave digestion (Titan MPS, PerkinElmer, Inc., USA) at 160-200°C for 40 minutes (USEPA, 1992). In the plants (root, stem and leaf) after which the samples were homogenized into a fine powder for further analysis. A mixture of concentrated HNO_3 (8 mL) and H_2O_2 (2 mL) were added to plant samples (0.5 g dry weight). The samples were then microwave digestion at 160-190°C, for 1 hour and 15 minutes. Distilled water was added to dilute the sample final volume (50 mL) and filtered by GF/A paper. Sample blank (distilled water) was also subjected to the same microwave procedure. The water and plant samples were analyzed for Cd and Cr content with ICP-OES (ICP-OES, AVIO 220 Max, PerkinElmer, Inc., USA). The method was chosen, as it can detect trace amounts of HMs with high precision. The Cd and Cr concentrations in the water and plant samples were then calculated into the unit of mg/L and mg/kg (dry weight), respectively (Yang *et al.,* 2013). Wavelength and limits of detection (LOD) in the ICP-OES analyses of Cd and Cr were 226.5020 and 267.7190 nm (wavelength); 0.1 and 0.2 mg/L (LOD), respectively (Roehrich, 2016).

The calculation of HMs removal capacity percentage was using the following equation:

$$\%\text{Removal capacity} = \frac{(Ci\text{-}Cf)}{Ci} \times 100 \qquad ...(1)$$

Where

Ci and Cf = Initial and final of HMs concentration, respectively.

Statistical analysis

Analysis the different amounts of cadmium and chromium concentrations in water and plant were analyzed using one-way ANOVA, by Duncan's new multiple range test (DMRT) were performed to determine if there were significant changes between different treatment groups (Duncan, 1955). All the statistical tests were conducted at $p<0.05$, a 95% confidence level.

RESULTS AND DISCUSSION

Cadmium and chromium concentrations in the water samples and % removal capacity

Table 1 presents concentrations of Cd and Cr in water. The average concentrations of Cd and Cr in the control were Cd, 5.12±0.19 and Cr, 70.42±1.02 mg/L (before). After removal 7 days, the results showed that *P. amaryllifolius* had the best lower to remove Cd and Cr; the values were 0.37±0.07 and 34.45±0.52 mg/L, respectively. When compared between the control and the experimental groups, the average of Cd and Cr concentrations in water after removal was difference statistically significant ($p<0.05$).

Removal capacity of Cd and Cr from natural processes like degradation and precipitation was assessed in the experimental and control groups. The results are displayed in Table 1, which unequivocally demonstrates the HMs removal through the natural precipitation process. *Echinodosus cordifolius* and *Pandanus amaryllifolius* were employed to test the elimination capacity of HMs, using this finding as a guide. When both plants were planted separately, the elimination of Cd and Cr was much higher than the values of the control experimental group. Interestingly, results of removal capacity showed *P. amaryllifolius* had the best ability to remove Cd and Cr; the values were 92.87% and 51.07%, respectively. While, the combination of *E. cordifolius* and *P. amaryllifolius*; the values were 91.17% and 49.66%, respectively and *E. cordifolius*;

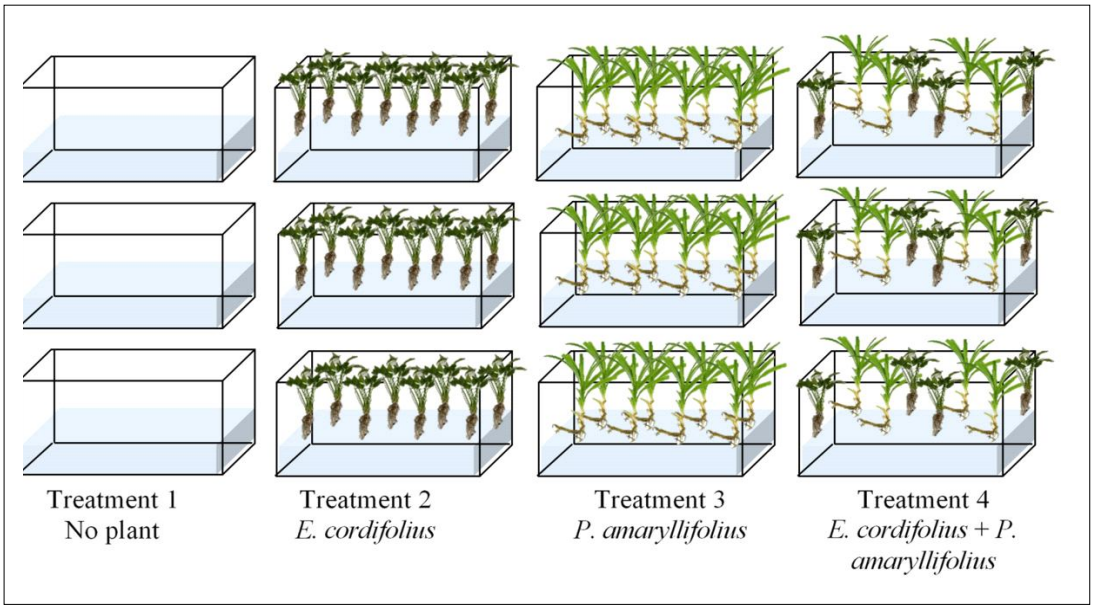


Fig 2: Photograph show the experimental groups.

the values were 87.54% and 47.92%, respectively. These aquatic plants' consumption of metals is one of the potential processes involved in the elimination of HMs. Since the rhizosphere is the immediate area around the root, alterations in its composition and physical characteristics can readily impact the uptake of heavy metals by the plants (Abd-Elaal *et al.,* 2020). The process of bioremediation, which includes bioaccumulation, biosorption and phytoremediation, uses naturally occurring organisms to convert toxic compounds into less toxic or non-toxic ones. A natural method of using green plants to absorb contaminants through their roots and move them to the upper portion of the plant is called phytoremediation (Yadav *et al.,* 2021). Organic and/or inorganic pollutants can be removed from contaminated water, wastewater and sediments. The bioavailability and water characteristics all affect the treatment process's mechanism and effectiveness (Cristescu *et al.,* 2018). Potentially native plant species with rapid growth rates, broad root systems, adaptability to a variety of settings, high tolerance and the capacity to deposit toxins in their aboveground portions are ideal for use in phytoremediation wastewater treatment. All plant species consume essential nutrients from their soil, sediment and water conditions like heavy metals (Mohan *et al.,* 2023). Also, temperature, pH and water salinity are a few environmental variables that might affect plant development and phytoremediation capacity (Rezania, *et al.,* 2016). Kaewmanee and Muleng (2016) reported the efficiency of wastewater treatment from dyes showed that *T. angustifolia* is the best in terms of Pb and Cr removal, but the combining system is better in terms of removal time. *C. alternifolius* L. is the best for Cd removal. The separated system gives better Cd removal efficiency compared to the combined system using only 9 days of hydraulic retention time. The best absorb Cd is *Hydrilla verticillate*. The Cd maximum values were 86.64% at a Cd concentration of 4 mg/L (Sombutsiri and Sillapapiromsuk, 2019).

Table 1: The concentrations of cadmium and chromium in water samples and % removal capacity.

The experimental groups	Cd and Cr concentrations in water (mg/L)		% Removal capacity
	Before (0 day)	After (7 days)	
Cd concentrations			
T1- No plant (control)	5.12±0.19	4.58±0.02^{a}	10.62
T2- *E. cordifolius*	5.12±0.19	0.64±0.47^{b}	87.54
T3- *P. amaryllifolius*	5.12±0.19	0.37±0.07^{b}	92.87
T4- *E. cordifolius* + *P. amaryllifolius*	5.12±0.19	0.45±0.04^{b}	91.17
Cr concentration			
T1- No plant (control)	70.42±1.02	68.69±0.81^{a}	2.44
T2- *E. cordifolius*	70.42±1.02	36.67±2.19^{b}	47.92
T3- *P. amaryllifolius*	70.42±1.02	34.45±0.52^{b}	51.07
T4- *E. cordifolius* + *P. amaryllifolius*	70.42±1.02	35.45±0.62^{b}	49.66

The values that do not share the same superscript (a, b) are significant different from the control group (p<0.05).

Table 2: The concentrations of cadmium and chromium in root, stem and leaf of *E. cordifolius* and *P. amaryllifolius.*

The experimental groups	Cd and Cr concentrations (mg/kg dry weight)		
	Root	Stem	Leaf
Cd concentrations			
E. cordifolius (control)	18.93±1.37^{c}	3.89±0.76^{c}	0.87±0.06^{c}
T2 *E. cordifolius* (7 days)	3,683.14±39.21^{a}	85.79±3.49^{a}	20.06±1.08^{b}
P. amaryllifolius (control)	2.36±0.36^{C}	2.48±0.25^{C}	0.59±0.42^{C}
T3 *P. amaryllifolius* (7 days)	993.43±3.62^{B}	225.88±10.33^{B}	53.00±2.2898^{B}
T4 *E. cordifolius* (7 days)	1,635.60±55.21^{b}	49.25±5.47^{b}	24.73±2.79^{a}
T4 *P. amaryllifolius* (7 days)	2,147.68±7.41^{A}	289.13±7.01^{A}	88.11±1.87^{A}
Cr concentrations			
E. cordifolius (control)	3.38±1.03^{c}	5.24±0.40^{c}	0.63±0.08^{c}
T2 *E. cordifolius* (7 days)	9,981.62±20.04^{a}	1,164.80±20.19^{a}	559.52±30.87^{b}
P. amaryllifolius (control)	2.27±0.19^{C}	7.71±0.19^{C}	0.55±0.24^{C}
T3 *P. amaryllifolius* (7 days)	6,048.57±30.87^{B}	1,596.28±74.29^{A}	382.56±2.91^{B}
T4 *E. cordifolius* (7 days)	5,408.97±68.59^{b}	648.37±29.23^{b}	700.12±6.75^{a}
T4 *P. amaryllifolius* (7 days)	7,921.99±60.04^{A}	869.67±23.90^{B}	509.36±9.28^{A}

The values that do not share the same superscript (a, b, c for *E. cordifolius* and A, B, C for *P. amaryllifolius*) are significant different from the control group (p<0.05).

Cadmium and chromium concentrations in the root, stem and leaf of *E. cordifolius* and *P. amaryllifolius*

The Cd and Cr concentrations in the root, stem and leaf of *E. cordifolius* and *P. amaryllifolius* are shown in Table 2. The average concentrations of Cd and Cr accumulated the highest amount in the root of *E. cordifolius* (T2) were 3,683.14±39.21 and 9,981.62±20.04 mg/kg, respectively. In the stem, the high accumulation of Cd in *P. amaryllifolius* (T4) and Cr in *P. amaryllifolius* (T3), the values were 289.13±7.01 and 1,596.28±74.29 mg/kg, respectively. While, the highest of Cd accumulated of the leaf in *P. amaryllifolius* (T4) is 88.11±1.87 mg/kg, but Cr accumulated in *E. cordifolius* (T4) is 700.12±6.75 mg/kg. After 7 days of absorption, all of the experiments accumulated the highest amount of Cd and Cr in the root>stem>leaf. When compared between the control and the experimental groups, the average of Cd and Cr concentrations in water after removal was difference statistically significant (p<0.05).

Natural sources include water pollution and industrial wastewater can release heavy metals (HMs) into the environment (Al-Naggar *et al.,* 2018). According to Xing *et al.* (2013), aquatic plants and/or plants are also known to accumulate heavy metals (HMs) in the aquatic environment. The temperature, pH, aeration, electrical conductivity, plant species, size, root system, leaf type, growth, moisture content and the kind of heavy metals in the water itself are some of the many variables that affect how well plants absorb HMs (Muliyadi *et al.,* 2023). In the present study, after 7 days of absorption, the experiments accumulated the highest amount of Cd and Cr in the root>stem>leaf. Similarity, Wongthanate *et al.* (2014) reported *E. cordifolius* (L.) Griseb. had the highest capacity of Pb accumulation in the root. Based on research results, several plants are known to be able to absorb HMs, include *Colocasia esculenta* and *Typha latifolia* (Muliyadi *et al.,* 2023). Because HMs bind to plant cells and produce a gradient across the membrane, there is an increase in HMs in plant parts (Muliyadi *et al.,* 2023). As the quantities of HMs in tissues rose over time, causing saturation, a subsequent decline in uptake was clearly seen. Oxidative stress, which can be brought on by As, Cd, Cr and Pb and the harmful effects of heavy metals (HMs) can also cause this (Ashok and Harini, 2024). Cd, Cr and other metals are mostly collected in the roots of the majority of terrestrial and aquatic plant species (Wu *et al.,* 2015).

CONCLUSION

The concentrations of Cd and Cr in water after for 7 days removal was different statistically significant at p<0.05, between the control and the experimental groups. The removal capacity showed *P. amaryllifolius* had the best ability to remove Cd and Cr; the values of the removal efficiency were 92.87% and 51.07%, respectively. Secondly, order of removal efficiency, Cd and Cr, is the combination of *E. cordifolius* and *P. amaryllifolius*; the values were 91.17% and 49.66%, respectively. Thirdly, removal efficiency is *E. cordifolius*; the values were 87.54% and 47.92%, respectively. The bioaccumulation of Cd and Cr in *E. cordifolius* and *P. amaryllifolius* were tested. After 7 days, in the experiment accumulated the highest amount of Cd and Cr in root>stem>leaf.

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Conflict of interest

The authors declare that there are have no conflict of interest regarding the publication of this article.

REFERENCES

Abd-Elaal, A.-E.M., Aboelkassem, A., Gad, A.A.M., Ahmed, S.A.S. (2020). Removal of heavy metals from wastewater by natural growing plants on River Nile banks in Egypt. *Water Practice and Technology.* **15(4):** 947-959.

Al Naggar, Y., Khalil, M.S., Ghorab, M.A. (2018). Environmental pollution by heavy metals in the aquatic ecosystems of Egypt. *Open Access Journal of Toxicology.* **3(1):** 001-009.

Ansari, M.K.A., Iqbal, M., Ahmad, M., Munir, M., Gaffar, S.A., Chaachouay, N. (2024). Heavy metal stress and cellular antioxidant systems of plants: A review. *Agricultural Reviews.* **45(3):** 400-409. doi: 10.18805/ag.RF-321.

Ashok, D., Harini, B.P. (2024). Spatial Evaluation of the heavy metal iron in soil, pond water and its mobility into the muscles of Zebrafish using ICP-OES. *Agricultural Science Digest.* **44(2):** 382-387. doi: 10.18805/ag.D-5869.

Bhat, S.A., Bashir, O., Haq, S.A.U., Amin, T., Rafiq, A., Ali, M., Americo-Pinheiro, J.H.P., Sher, F. (2022). Phytoremediation of heavy metals in soil and water: An eco-friendly, sustainable and multidisciplinary approach. Chemosphere. 303(Part 1): 134788.

Buddee, S., Rattanaburi, P., Chaithada, P., Rotduang, P. and Malawet, T. (2021). Adsorption of metal ions by using Vetiver grass and Cattai. The 4th National and International Research Conference, Buriram Rajabhat University. pp 1111-1117.

Cristescu, A.C., Covaliu, C., Popa, L., Dumitru, D., Anghelet, A. (2018). Study on use of *Typha angustifolia* L. wastewater treatment: Promising method in removal of copper ions present in aquatic solution. Engineering for Rural Development. *Jelgava.* **23:** 714-719.

Cruz-Esquivel, Á., Díez, S., Marrugo-Negrete, J.L. (2023). Genotoxicity effects in freshwater fish species associated with gold mining activities in tropical aquatic ecosystems. Ecotoxicology and Environmental Safety. **253:** 114670.

Duncan, D.B. (1995). Multiple range and multiple F tests. *Biometrics.* **11:** 1-42.

Garai, P., Banerjee, P., Mondal, P., Saha, N.C. (2021). Effect of heavy metals on fishes: Toxicity and bioaccumulation. *Journal of Clinical Toxicology.* **11(S18):** 1-10.

Kaewmanee, J., Muleng, C. (2016). Efficiency comparison of wastewater treatment from dyes using *Cyperus alternifolius* L. and *Typha angustifolia*. The 15th National Environmental Conference, Environmental Engineering Association of Thailand. 11R2-02: 1-8.

Khamlerd, C., Wongmaneeprateep, S., Prisingkorn, W., Doan, H.V., Doolgindachbaporn, S. (2024). Acute toxicity of cadmium on silver barb, *Barbonymus gonionotus* (Bleeker, 1850), nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) and climbing perch, *Anabas testudineus* (Bloch, 1792). *Environment Asia.* **17(1):** 169-181.

Mitra, S., Chakraborty, A.J., Tareq, A.M., Emran, T.B., Nainu, F., Khusro, A., Idris, A.M., Khandaker, M.U., Osman, H., Alhumaydhi, F.A., Gandara, J.S. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University-Science.* **34(3):** 101865.

Mohan, J., Pandey, A., Singh, V. (2023). Application of aquatic plant *Ceratophyllum demersum* (L.) in phytoremediation of wastewater. *Agricultural Science Digest.* **43(5):** 655-660. doi: 10.18805/ag.D-5443.

Morahdy, A.E.M.A., Darwish, W.S., Hussein, M.A.M., Mohamed, M.A.A., Hussein, M.M.A. (2021). Lead and cadmium content in Nile tilapia (*Oreochromis niloticus*) from Egypt: A study for their molecular biomarkers. *Scientific African.* **12:** e00794.

Muliyadi, M., Purwanto, P., Sumiyati, S., Mussadun, M. (2023). Bioaccumulation of heavy metals using aquatic plant in wastewater. *International Journal of Public Health Science.* **12(2):** 690-698. http://doi.org/10.11591/ijphs.v12i2.22742.

Palanippan, P.L.R.M., Karthikeyan, S. (2009). Bioaccumulation and depuration of chromium in the selected organs and whole-body tissues of freshwater fish *Cirrhinus mrigala* individually and in binary solutions with nickel. *Journal of Environmental Sciences-China.* **21(2):** 229-236.

Razzak, S.A., Faruque, M.O., Alsheikh, Z., Alsheikhmohamad, L. Alkuroud, D., Alfayez, A., Hossain, S.M.Z., Hossain, M.M. (2022). A comprehensive review on conventional and biological-driven heavy metals removal from industrial wastewater. *Environmental Advances.* **7:** 100168. https://doi.org/10.1016/j.envadv.2022.100168.

Rezania, S., Taib, S.M., Md Din, M.F., Dahalan, F.A., Kamyab, H. (2016). Comprehensive review on phytotechnology: Heavy metals removal by diverse aquatic plants species from wastewater. *Journal of Hazardous Materials.* **318:** 587-599.

Roehrich, A.M. (2016). ICP guide: ICP-OES detection limits. Retrieved June 19, 2024, from www.perkinelmer.com/atomicspectroscopy.

Rohilla, V., Kathait, G.S., Biswas, D., Thapliyal, P., Ruhela, B. (2021). Estimation of heavy metals in some Indian Black Tea leaves by inductively coupled plasma mass spectrometer (ICP-MS) and associated health risks. *Indian Journal of Agricultural Research.* **55(2):** 181-186. doi: 10.18805/IJARe.A-5429.

Sombutsiri, P., Sillapapiromsuk, S. (2019). Efficiency comparison of Cd absorption in water using *Typha angustifolia* and *Hydrilla verticillate*. Faculty of Science Journal Research. Lampang Rajabhat University. **1(4):** 1-12.

Taslima, K., Al-Emran, Md., Rahman, M.S., Hasan, J., Ferdous, Z., Rohani, M.F., Shahjahan, M. (2022). Impacts of heavy metals on early development, growth and reproduction of fish-a review. *Toxicology Reports.* **9:** 858-868.

Ukhurebor, K.E., Nwankwo, W., Adetunji, C.O., Makinde, A.S. (2021). Artificial intelligence and internet of things in instrumentation and control in waste biodegradation plants: Recent developments. *Microbial Rejuvenation of Polluted Environment.* **3:** 265-279.

United States Environmental Protection Agency [U.S. EPA]. (1992). Method 3005A: Acid digestion of waters for total recoverable or dissolved metals for analysis by FLAA or ICP spectroscopy. Revision 1. Washington, District of Columbia: United States Environmental Protection Agency, Office of Science and Technology, Office of Water.

Wongthanate, J., Anusasnee, N., Prapagdee, B., Kumsopa, A. (2014). Removal of lead from synthetic wastewater using aquatic plants. *The Journal of Industrial Technology.* **10(3):** 16-30.

Wu, Z.C., Zhao, X.H., Sun, X.C., Tan, Q.L., Tang, Y.F., Nie, Z.J., Hu, C. (2015). Xylem transport and gene expression play decisive roles in cadmium accumulation in shoots of two oilseed rape cultivars (*Brassica napus*). *Chemosphere*. **119:** 1217-1223.

Xing, W., Wu, H., Hao, W., Huang, W., Liu, G. (2013). Bioaccumulation of heavy metals by submerged macrophytes: Looking for hyperaccumulators in Eutrophic Lakes. *Environmental Science and Technology.* **47(9):** 4695-4703.

Yadav, M., Singh, G., Jadeja, R.N. (2021). 6 Phytoremediation for heavy metal removal. Pollutions and Water Management: Resources, Strategies and Scarcity. 1st ed. 128-150.

Yang, L., Li, Y., XJ, G., Ma, X., Yan, G. (2013). Comparison of dry ashing, wet ashing and microwave digestion for determination of trace elements in Periostracum serpentis and Periostracum cicadae by ICP-AES. *Journal of the Chilean Chemical Society.* **58(3):** 1876-1879.

Yomso, J., Siddique, A. (2024). Phytotoxic effect of cadmium induced stress on LAI, CGR and yield of rice plant (*Oryza sativa* L.). *Agricultural Science Digest.* **44(1):** 63-67. doi: 10.18805/ag.D-5587.

Zhang, C., Lin, C., Li, L., Mohsen, M., Wang, T., Wang, X., Zhang, L., Huang, W. (2023). Single and combined effects of microplastics and cadmium on the sea cucumber *Apostichopus japonicus*. *Marine Environmental Research.* **186:** 105927.