PHYTOREMEDIATION ECOLOGICAL TECHNOLOGY: A REVIEW ON HEAVY METALS (AS, CD, PB, CU AND ZN) UPTAKE BY AQUATIC PLANTS

Huynh The An[(1)]

(1) Thu Dau Mot University
Corresponding author: anht@tdmu.edu.vn

DOI: 10.37550/tdmu.EJS/2024.02.553

Article Info

Volume: 6
Issue: 02
June 2024
Received: April 13th, 2024
Accepted: May 5th, 2024
Page No: 259-267

Abstract

Phytoremediation is an ecofriendly that has shown promising results for the contaminants like heavy metals. Because of its advantages as a cost-effective, efficient, environment- and eco-friendly technology based on the use of metal-accumulating plants. This paper aims to compile some information about heavy metals of arsenic, cadmium, lead, copper and zinc (As, Cd, Pb, Cu and Zn) sources, effects and their treatment. It also reviews deeply about phytoremediation technology, including the heavy metal uptake mechanisms and several research studies associated about heavy metals (As, Cd, Pb, Cu and Zn) and aquatic plants are used to process these heavy metals.

Keywords: aquatic plants, heavy metals, phytoremediation, uptake

1. Introduction

Heavy metals are among the contaminants in the environment. In addition to the effects of nature, practically every human activity has the potential to produce heavy metals as byproducts. Among the things that contribute to the contamination of ecosystems are the migration of these contaminants into regions that are not impacted by them as dust or leachates via the soil and the spread of sewage sludge containing heavy metals (Gaur et al., 2004). This increase of heavy metal (As, Cd, Pb, Cu and Zn) concentration is a major concern to both humans and ecosystem (Kabata-Pendias, 2000), because of their non-biodegradable nature. Instant and necessary measures are required to remediate such polluted systems. Of all the remediation technologies, phytoremediation has been preferred because of its cost-effectiveness, ecofriendly nature and simple maintenance (Kamran et al., 2014).

Phytoremediation is one of bioremediation techniques can be used as an alternative solution for heavy metal remediation proscess. The phytoremediation of metals is a cost-effective, efficient, environment- and eco-friendly 'green' technology based on the use of metal-accumulating plants to remove toxic metals, including radionuclides as well as organic pollutants from contaminated soils and water (Raskin et al., 1997; Ali et al., 2013).

Aquatic plants are of special interest, because they are capable of bio-accumulating toxic metals and nutrients in large quantities in comparison to terrestrial plants (Pratas et al., 2012). Studies have found that during the pollutant stress these plants produce metal-binding cysteine-rich peptides (phytochelatins), which detoxify heavy metals by forming complexes with them (Kinnersley, 1993). Plants are capable of removing the metal contamination from water as well as from soil. Aquatic plants of all types whether free floating, submerged or emergent's all are known for removing heavy metals.

The objectives of this review is to discuss the potential of phytoremediation technique to treat heavy metal contaminated sites, to give the general information about phytoremediation and use of plants for phytoremediation processes of heavy metals from the environment and also to provide a brief list of aquatic plants efficient for remediation of various metals.

2. Toxic effects of heavy metals on human health and plants

Elements with metallic characteristics and an atomic number >20 are typically referred to as heavy metals. Cd, As, Pb, Zn, and Cu are the heavy metal pollutants that are most frequently found (Lasat, 1999). Some of these metals, like Zn and Cu, are micronutrients required for plant growth, whereas others, like Cd and Pb, have unidentified biological functions (Gaur & Adholeya, 2004).

Heavy metals in the environment come from anthropogenic (human intervention) and natural sources. The primary anthropogenic sources are electroplating, mining, smelting, use of pesticides and fertilizers, use of biosolids in agriculture, sludge dumping, industrial discharge, atmospheric deposition, and volcanic activity. The most significant natural sources are mineral weathering, erosion, and volcanic activity (Ali et al., 2013; Dixit et al., 2015).

2.1. Toxic effects of heavy metals on human health

Metallic elements are an intrinsic component of the environment. Their presence is con-sidered unique in the sense that it is difficult to remove them completely from the environment once they enter in it. With the increasing use of a wide variety of metals in industry and in our daily life, problem arise from toxic metal pollution of the environment have assumed serious dimensions (Environment, 2024).

Metal containing industrial effluents constitute a major source of metallic pollution of hydrosphere. Another means of dispersal is the movement of drainage water from catchment areas which have been contaminated by waste from mining and smelting units. The sources of chief toxic metals and their harmful effects on human health are given in Table 1.

TABLE 1. Sources and human health effects of some heavy metals

Heavy metals	Sources (Ali et al., 2013; Sharma & Agrawal, 2005)	Effect on human health (Dixit et al., 2015)
Cd	Paints and pigments, plastic stabilizers, phosphate fertilizer, cadmium-containing plastics electroplated, ore outcrops, coal combustion, sewage sludge, and garbage.	Calcium control in biological systems is impacted by carcinogenic, mutagenic,endocrine-disrupting, lung-damaging, and fragile-bones substances.
As	Pesticides and wood preservatives	ATP (Adenosine triphosphate) generation and other vital physiological activities, such as oxidative phosphorylation, are affected.
Pb	Aerial emission from combustion of lead petrol, battery manufacture, herbicides and insecticides, ore outcrops, metal smelters, waste, sewage sludge.	Children that receive too much exposure suffer from stunted growth, diminished intellect, loss of short-term memory, learning and coordination issues, and an increased risk of cardiovascular disease.
Zn	Ore outcrops, metal smelters, blast furnaces, metal emission from tires, waste, sewage sludge, high tension lines, food additives.	Dizziness, fatigue etc, fumes of zinc oxide is strongly carcinogenic cause respiratory trouble.
Cu	Pesticides, fertilizers, waste, sewage sludge, high tension lines, food additives, ore outcrops, metal smelters.	Damage to the brain and kidneys, liver cirrhosis and persistent anemia from high levels, gastrointestinal discomfort.

Cadmium (Cd): The primary sources of cadmium in air and water resources are industries involved in the extraction, electroplating, refinement, and welding of cadmium-containing products. Cadmium was also released by phosphate and pesticide manufacturing companies. It mostly emits vapor, which reacts fast to produce oxide and chloride compounds. It is known to build up in the human liver and kidney and is known to be carcinogenic at extremely low concentrations. Toxic exposure to cadmium causes hypertension, renal damage, respiratory issues, and heart disease (Rahimzadeh et al., 2017).

Arsenic (As): Arsenic is produced as a byproduct of the metal refining process. In industrial areas, its concentrations may reach nearly 25-100ng/m^3. Inorganic arsenic is known to be particularly hazardous in both acute and chronic forms. It first enters the body of a person by way of eating, inhalation, or skin absorption. As soon as it enters the body, it is transported across a variety of organs, including the skin, kidney, liver, and lungs (Saha et al., 1999). It has been proven to cause cancer. Red blood cell destruction, renal damage, and jaundice are all effects of arsenic toxicity in humans.

Lead (Pb): From medical and biochemical problems at levels of about 10µg /dL to coma and death at levels of more than 100µg/dL, lead toxicity correlates with blood lead concentration. Lower than 70µg/dL of blood lead concentrations can harm the hematological system, kidneys, and central nervous system. For every10µg/dL increase in blood lead levels, intelligence test scores can drop by two to three points as a result of lead exposure. Additionally, elevated blood lead levels are linked to neurodevelopmental problems like as behavioral issues, learning difficulties, attention deficit disorders, and deficiencies in fine and gross motor skills (Flora et al., 2006).

Zinc (Zn): Around zinc smelters and refineries, there is zinc in the air. Open hearth furnaces refine scrap galvanized iron by emitting 20-30 grams of zinc each hour. The majority of the zinc in the air is present as fumes of zinc oxide, which is extremely hazardous to humans and causes allergy and respiratory issues. It is one of the health issues that affect numerous organs if it is exposed through the ingestion of tainted food and water or by inhaling zinc fumes. Long-term exposure to zinc compounds from various sources, including food, water, and the air, has harmful effects on the body's nervous, respiratory, and digestive systems, and it also promotes cancer (Rahimzadeh et al., 2020).

Copper (Cu): Acute copper toxicity can cause a variety of diseases, including death in extreme circumstances. Chronic copper toxicity can cause serious brain abnormalities and liver damage (Uriu-Adams & Keen, 2005). In humans, acute copper poisoning is uncommon. Patients with Wilson disease and cases of infantile cirrhosis linked to high copper intakes provide the majority of the evidence for persistent toxicity (Olivares & Uauy, 1996).

2.2. Toxic effects of heavy metals on plants

Plants are adversely affected by heavy metals. They cause higher aquatic plants to produce less, develop more slowly, lose chlorophyll (chlorosis) and contain less protein. These metals are permanently integrated into plants, where they are then transferred to animals and people. The aquatic plants and animals are a good source of bio-purification processes going on naturally in rivers, ponds and lakes.

These metals can be taken up by plants. Heavy metals including copper, lead, mercury, and zinc are readily absorbed by plants, according to experimental evidence. Through their leaves, plants directly absorb toxins from the air, while their roots directly absorb toxins from the soil or water (Alengebawy et al., 2021).

The usual pathway is through the leaves with gaseous pollutants. Studies on aquatic plants have demonstrated that a phase of fast and passive absorption to the cell wall typically initiates the uptake of both harmful heavy metals and organo-halogens. Foliar deposition of metals is more important route of contamination than is root absorption.

In higher aquatic plants as *Elodea canadensis* and *Eichornia*, the uptake of water-borne toxicants by the stems and leaves is more significant than the absorption from sediments by the roots. It is also known to us those plants can generate atmospheric particulate matter in the form of metallic ions.

The absorbed heavy metals (Cu, Hg and Zn) can be discharged from leaf surfaces to the atmosphere. Experiments on *Pisum sativum* (Pea), *Vicia fabae* (Bakla) and seedling of *Pinus sylvestris* (chir) have clearly shown that heavy metals are easily absorbed by their roots and they travel all through the plants, and ultimately some of them passed out from the leaf surface.

The industrial wastes containing heavy metal pollute the water and this water is used for irrigation purposes. The land becomes mineralized and some of these harmful minerals are absorbed by the plants from the roots. These are released from plant surfaces in a particulate form and vitiate the atmosphere (Singh & Kalamdhad, 2011).

3. Phytoremediation ecological technology

3.1. Definition of Phytoremediation ecological technology

Ecological technology is relatively unfamiliar; For the "second generation" of water resource issues, ecological technology offers a relatively unproven but cost-effective solution. It can be summed up as the planning, development, maintenance, and management of landscape and aquatic structures, as well as the accompanying plant and animal species, for the benefit of both people and the environment. In order to introduce it, case studies with cost and performance statistics that contrast it with "traditional" engineering are used. Better performance, lower costs, numerous benefits, and greater acceptance by the public and regulators are just a few of the significant potential benefits that ecological engineering may provide. Structures that are sturdy and self-maintaining but not always as finely engineered can be less expensive. Costs for operation and maintenance are reduced by using natural energy sources and self-regulating systems. The auxiliary advantages may be environmental, recreational, or financial (Barrett, 1999).

Many books and articles have provided concise descriptions of phytoremediation approaches. The word "phytoremediation" is a general term made up of the Latin root remedium and the Greek prefix phyto (plant) (to correct or remove an evil) (Tangahu et al., 2011). Table 2 lists a few definitions of phytoremediation that have been provided by various academics.

TABLE 2. "Phytoremediation" definition

Number	"Phytoremediation" definition
1	Using plants to restore deteriorated environments (Moreno et al., 2008)
2	Remediation of harmful compounds found in polluted soil, groundwater, sludge, sediment, wastewater, and surface water using plants (Rodriguez et al., 2005)
3	The process of removing, destroying, or sequestering dangerous pollutants from media including air, water, and soil using plants, especially trees and grasses (Vara Prasad & de Oliveira Freitas, 2003)
4	The use of vascular plants to eliminate or neutralize environmental contaminants (Bhattacharya, 2006)
5	A new approach for cleaning up the environment that uses specifically chosen and engineered metal-accumulating plants (Liu et al., 2000)
6	The deliberate use of green plant material to eliminate, contain, or render harmless environmental pollutants such as heavy metals, trace elements, organic compounds, and radioactive materials found in soil or water. This concept covers all plant-influenced biological, chemical, and physical processes that help plants and the free-living creatures that make up the plant rhizosphere absorb, sequester, degrade, and metabolically digest pollutants (Negri et al., 1996)
7	The term "phytoremediation" refers to a group of technologies that use various plants as a containment, eradication, or extraction method. A developing technique called phytoremediation employs a variety of plants to remove, extract, contain, or immobilize pollutants from soil and water (National Risk Management Research Laboratory, 2000)
8	In general, phytoremediation refers to the utilization of plants and the accompanying microbes to eliminate, degrade, or stabilize pollutants (Van Ginneken et al., 2007)

According to the experts mentioned above, phytoremediation is generally defined as a new method that uses particular plants to purge a contaminated area of dangerous chemicals in order to improve the quality of the environment.

3.2. Groups of aquatic plants

Aquatic plants primarily flourish in water. Their types vary widely; some are extremely similar to ordinary terrestrial plants, while others are very dissimilar. Aquatic plants can be divided into four main classes: algae, emergent, floating, and submerged plants. The placement of their roots and leaves is used to classify them (Sciencing, 2024).

The oldest and most prevalent class of aquatic plants is algae. They have no roots, stems, or leaves and are mostly found in the water. Despite their tiny size, algae form the foundation of the ocean food chain. Algae species include muskgrass and *lyngbya*.

Emerged plants, often referred to as emersed plants, are rooted to the water's surface but have the majority of their foliage above it. These plants require continuous sunshine exposure. Plants that have just emerged include redroot and knotweed.

Submerged Plants: Submerged or submersed plants are rooted to the bottom of the water, and the majority of their foliage is submerged. These plants have tiny, slender leaves. Bog moss and hydrilla are two examples of submerged plants.

Floating-Leaved Plants: Floating plants have roots that take in water, but they are not anchored to the surface of the water. In freshwater or saltwater, floating plants can be discovered. These plants have flat, sturdy leaves that stay flat so they can absorb more sunlight. Lilies of many kinds, including water lilies and banana lilies, as well as water hyacinths are frequent examples of floating plants.

3.3. The role of aquatic plants

The pollutant removal efficiency of some aquatic plant species has been verified under experimental conditions and shows that they have potential in wastewater treatment (Tripathi & Shukla, 1991). The ability of aquatic plants to transport oxygen from the air into the water is known by their roots, allowing the formation of aerobic groups around the plant roots. Aerobic microorganisms are suitable for the biodegradation of complex organic compounds into simple substances. The products of this decomposition process will be used by plants for growth and development. The ability to remove inorganic, organic, and heavy metal contaminants from water has been shown to be symbiotic between aquatic plants and the microorganisms living in and around their roots. Plants and microorganisms can achieve high treatment efficiency when they work together in a balanced ecosystem. The stems and leaves of semi-submerged plants and the roots of plants floating on the surface of the water reduce the flow rate, cause changes in infiltration and sedimentation of particles (sediment, organic debris), and are the place where survival of many species of algae and microorganisms. Oxygen is transferred from the stem and leaves to the roots and released to the root zone, creating favorable conditions for nitrification reactions. Therefore, aquatic plants play a major role in reducing the concentrations of NH_4^+, NO_2^-, NO_3^-, PO_4^{3-} as well as TSS and COD. Besides, some aquatic plants are also highly effective in reducing the concentration of heavy metals by their exchange mechanism (Tripathi & Shukla, 1991).

The type of metallic elements, their ionic form, the season, the state of the substrate, and the type of plant species all affect the removal of heavy metals by phytoremediation. The abundance of aquatic plants significantly improved the effectiveness of wastewater treatment (Ali et al., 2020). Aquatic plants actively and passively circulate vital components, which precisely and significantly contribute to sustaining the wetlands' biology (Březinová & Vymazal, 2015). The following order is often followed by a decrease in the content of heavy metals in aquatic macrophytes found in wetlands: roots are more important than leaves and stems (Bonanno, 2011). Moreover, the high level of heavy metals does not provide enough proof that heavy metals are absorbed by aquatic plants in wetlands. The biomass of the specific aquatic plant has a significant impact on the uptake of heavy metals in wetlands (Bhattacharya, 2006).

3.4. Other advantages of aquatic plants

Aquatic macrophytes outperform other plants in the cleanup of heavy metals, according to research on phytoremediation (Ali et al., 2020). They are the most suitable, readily available phytoremediation plants because of their vast distribution, rapid rate of growth, substantial biomass, low cost, and adaptability to harmful contaminants. Due to their ability to assemble and remove persistent organic contaminants from water bodies, these aquatic plants are being used in purification systems that are receiving increased attention from around the world (Leguizamo et al., 2017; Daud et al., 2018).

Heavy metals and nutrition from water sources must be consumed and removed, the proper phytoremediation technology requires periodic harvesting of the plant biomass. The key feature favoring this method for the treatment of pollutants is the conversion of biomass into unique material. According to numerous research, the biomass of aquatic plants can later be utilized as animal feed, helpful in the generation of biogas, and compost (Shahid et al., 2018). The Lemna minor biomass's bio-sorption and bioaccumulation were observed, indicating a potential usage as animal feed (Daud et al., 2018). Starch, cellulose, and hemicelluloses are all forms of sugar found in aquatic plants. Lactic acid, ethanol, and other significant products are created as a result of this fermentable sugar's carbohydrate breakdown. As a result, the sugar that aquatic plants contain is a novel, promising characteristic that supports their contribution to an eco-sustainable environment. In the course of their enzymatic hydrolysis, aquatic plants like pistia stratiotes have been found to create sugar (Mishima et al., 2006). Water birds can feed on free-floating aquatic plants such as *Spirodela sp.*, *Wolffia spp.*, *Azolla spp.*, and duckweeds. Additionally, they provide a haven for tiny mollusks and insect larvae. Additionally, fish hide in their shadow, these plants' mattresses spread and multiply. Aquatic plants can be effectively employed to enhance fishpond aquaculture. For the use of aquatic plants like *Canna generalis L.* and *Typha angustifolia*. in aquaculture, the elimination of nitrogenous waste is another advantage. *Cyperus involucratus* and *Echinodoruscordifolius* effectively eliminated ammonia, nitrate, and nitrite. (Nakphet et al., 2017).

4. Application of aquatic plants in pollution treatment

Many technologies to treat heavy metal pollution by aquatic plants have been successfully formed, developed, and applied in practice. In Asian countries, where the flora is extremely diverse, information on heavy metal tolerant plants is very limited. However, for the past ten years or so, scientists in Asian countries have focused their research on this group of aquatic plants because of their scientific and practical importance. The group of plants with high tolerance to one or more heavy metals are objects of science and of great practical value. Due to their adaptability. Some studies on the apply of aquatic plants in wastewater treatment in the world are summarized and showed in Table 3

TABLE 3. Some studies on using aquatic plants in wastewater treatment in the world

No.	Treatment object	Experimental aquatic plants	Nation	References
1	Industrial wastewater	Zannichellia palustris, Ruppia maritima, Potamogeton pectinatus, Zostera japonica, and Z. marina.	Japan	Kondo et al., 2003
2	Domestic wastewater	Nelumbo nucifera; Hydrilla verticillata	Thailand	Kanabkaew & Puetpaiboon, 2004
3	Industrial wastewater	*Potamogeton pectinatus* L. and *Potamogeton malaianus* Miq.	China	Peng et al.,2008
4	Seafood wastewater	*Thalia deabata J., Cyperus involucratus, Canna siamensis, Heliconia spp., Hymenocallis littoralis,* and *Typha augustifolia*	Thailand	Sohsalam et al., 2008
5	Aquaculture wastewater	*Eichhornia crassipes*; *Pistia stratiotes*	Malaysia	Akinbile & Yusoff, 2012
6	Textile wastewater	Algae	Bangladesh	Roy et al., 2018
7	Cu and Pb in aqueous Medium	*Enydra Fluctuans*	India	Parven et al.,2022
8	Nitrogen and phosphorus in Simulated wastewater	*Iris ensata Thunb*. and *Potamogeton malaianus* Miq	China	Xu et al., 2021
9	Mining and municipal wastewaters	*Typeha latifolia, Bolboscholnus ascbersus, Xanthium, Pragmites sp.,* and *Lythnium salicaria*	Turkey	Sasmaz et al., 2021
10	Industrial wastewater	*Azolla* and *Salvania molesta*	Bangladesh	Arefin et al., 2021

In wealthy nations like the United States, France, Japan, Germany, and Korea, etc., wastewater treatment technology using aquatic plants has been developed very successfully. Since the 1980s, many wastewater treatment facilities in the US states have developed and applied pollution treatment technology with the use of floating plants and stable lake systems. The method of treating organic and inorganic pollution in the rhizosphere of some aquatic plants - also known as “Rhizosphere method", has been researched and implemented effectively by German scientists in many places. Japanese scientists have designed polluted water purification systems using aquatic plant ecosystems in the form of Bio-parks to reduce the pollution of large lakes (Yamagata et al., 2010).

In the past ten years, Vietnamese scientists have focused on studying and researching on heavy metal pollution. Many studies focus on assessing the level of heavy metal pollution in rivers that directly receive or are affected by wastes from factories, or industrial zones and the effects of them to plants (Hung, 2016). Nguyen et al. (2005) studied the treatment of domestic wastewater (after septic tanks) by an underground filter planted with vertical flow plants with experimental plants: *Phragmites communis*, *Cyberus involucratus*, *Typha orientalis*, and *Dracaena fragrans*. The water treatment efficiency of the system is quite good and stable. The author believes that this technology is suitable for household, household group, tourist destination, service, farm, industry etc…in Vietnam. Tran et al. (2008) used *Phragmites australis* and *Vetiveria zizanioides* in treating wastewater containing chromium and nickel by the root zone method at the pilot scale (73 liters/day), with a 7-day retention period for the treatment efficiency is over 70% with Ni and over 90% with Cr^{+6} and Cr^{+3}.

In order to treat domestic and industrial wastewater, aquatic plants have been widely used as part of water pollution treatment technologies around the world. In recent years, this technology is used as an effective and socially accepted method because of its low cost and simple operation.

5. Conclusion

Phytoremediation can be an alternative solution as a green technology to treat heavy metal contaminated areas. Plants used in this technique adopted a variety of mechanisms to deal with heavy metals. Heavy metals form one of largest category of contaminants that are efficiently removed by aquatic plants. According to previous studies, several plants have a high potential as heavy metals bioaccumulator and can be used for phytoremediation process of heavy metals.

References

Akinbile, C. O., & Yusoff, M. S. (2012). Assessing water hyacinth (*Eichhornia crassopes*) and lettuce (*Pistia stratiotes*) effectiveness in aquaculture wastewater treatment. *International Journal of phytoremediation*, *14*(3), 201-211.

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M. Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. *Toxics*, *9*(3), 42.

Ali, H., Khan, E., & Sajad, M. A. (2013). Phytoremediation of heavy metals—concepts and applications. *Chemosphere, 91*(7), 869-881.

Ali, S., Abbas, Z., Rizwan, M., Zaheer, I. E., Yavaş, İ., Ünay, A., Daim, M. M. A., Jumah, M. B., Hasanuzzaman, M. & Kalderis, D. (2020). Application of floating aquatic plants in phytoremediation of heavy metals polluted water: a review. *Sustainability, 12*(5), 1927.

Arefin, M. A., Rashid, F., & Islam, A. (2021). A review of biofuel production from floating aquatic plants: an emerging source of bio-renewable energy. *Biofuels, Bioproducts and Biorefining, 15*(2), 574-591.

Barrett, K. R. (1999). Ecological engineering in water resources: The benefits of collaborating with nature. *Water international, 24*(3), 182-188.

Bhattacharya, T., Banerjee, D. K., & Gopal, B. (2006). Heavy metal uptake by Scirpus littoralis schrad. from fly ash dosed and metal spiked soils. *Environmental monitoring and assessment, 121*(1), 363-380.

Bonanno, G. (2011). Trace element accumulation and distribution in the organs of *Phragmites australis* (common reed) and biomonitoring applications. *Ecotoxicology and Environmental Safety, 74*(4), 1057-1064.

Březinová, T. & Vymazal, J. (2015). Evaluation of heavy metals seasonal accumulation in Phalaris arundinacea in a constructed treatment wetland. *Ecological Engineering*, 79, 94-99.

Daud, M. K., Ali, S., Abbas, Z., Zaheer, I. E., Riaz, M. A., Malik, A., Hussain, A., Rizwan, M., Rehman, M. Z. & Zhu, S. J. (2018). Potential of duckweed (Lemna minor) for the phytoremediation of landfill leachate. *Journal of chemistry*.

Dixit, R., Malaviya, D., Pandiyan, K., Singh, U. B., Sahu, A., Shukla, R., Singh, B. P., Rai, J. P., Sharma, P. K., Lade, H., & Paul, D. (2015). Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes. *Sustainability, 7*(2), 2189-2212.

Flora, S. J., Flora, G., & Saxena, G. (2006). *Environmental occurrence, health effects and management of lead poisoning*. In Lead (pp. 158-228). Elsevier Science BV.

Gaur, A., & Adholeya, A. (2004). Prospects of arbuscular mycorrhizal fungi in phytoremediation of heavy metal contaminated soils. *Current Science*, 528-534.

Hung, N. T. (2016). Solanum nigrum L., Plants that have the ability to treat cadmium contaminated soil. *Vietnam J. Agri. Sci.,14*(8), 1231-1237. (*in Vietnamese*)

Jan, A. T., Azam, M., Siddiqui, K., Ali, A., Choi, I., & Haq, Q. M. R. (2015). Heavy metals and human health: mechanistic insight into toxicity and counter defense system of antioxidants. International journal of molecular sciences, 16(12), 29592-29630.Sharma, R. K., & Agrawal, M. (2005). Biological effects of heavy metals: an overview. *Journal of environmental Biology*, *26*(2), 301-313.

Kabata-Pendias, A. (2000). *Trace elements in soils and plants*. CRC press. Taylor & Francis Group.

Kamran, M. A., Amna, Mufti, R., Mubariz, N., Syed, J. H., Bano, A., & Chaudhary, H. J. (2014). The potential of the flora from different regions of Pakistan in phytoremediation: a review. *Environmental Science and Pollution Research*, 21, 801-812.

Kanabkaew, T., & Puetpaiboon, U. (2004). Aquatic plants for domestic wastewater treatment: Lotus (Nelumbo nucifera) and Hydrilla (Hydrilla verticillata) systems. *Aquatic*, *26*(5), 750.

Kinnersley, A. M. (1993). The role of phytochelates in plant growth and productivity. *Plant growth regulation,* 12, 207-218.

Kondo, K., Kawabata, H., Ueda, S., Hasegawa, H., Inaba, J., Mitamura, O., Seike, Y. & Ohmomo, Y. (2003). Distribution of aquatic plants and absorption of radionuclides by plants through the leaf surface in brackish Lake Obuchi, Japan, bordered by nuclear fuel cycle facilities. *Journal of Radioanalytical and Nuclear Chemistry, 257*(2), 305-312.

Lasat, M. M. (1999). Phytoextraction of metals from contaminated soil: a review of plant/soil/metal interaction and assessment of pertinent agronomic issues. *Journal of Hazardous Substance Research, 2*(1), 5.

Leguizamo, M. A. O., Gómez, W. D. F., & Sarmiento, M. C. G. (2017). Native herbaceous plant species with potential use in phytoremediation of heavy metals, spotlight on wetlands—a review. *Chemosphere*, 168, 1230-1247.

Liu, D., Jiang, W., Liu, C., Xin, C., & Hou, W. (2000). Uptake and accumulation of lead by roots, hypocotyls and shoots of Indian mustard [Brassica juncea (L.)]. *Bioresource Technology, 71*(3), 273-277.

Mishima, D., Tateda, M., Ike, M., & Fujita, M. (2006). Comparative study on chemical pretreatments to accelerate enzymatic hydrolysis of aquatic macrophyte biomass used in water purification processes. *Bioresource technology, 97*(16), 2166-2172.

Moreno, F. N., Anderson, C. W., Stewart, R. B., & Robinson, B. H. (2008). Phytofiltration of mercury-contaminated water: volatilisation and plant-accumulation aspects. Environmental and Experimental *Botany, 62*(1), 78-85.

National Risk Management Research Laboratory. (2000). *Introduction to phytoremediation*. National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency.

Negri, M. C., Hinchman, R. R., & Gatliff, E. G. (1996). *Phytoremediation: using green plants to clean up contaminate soil, groundwater, and wastewater (No. ANL/ES/CP-89941; CONF-960804-38)*. Argonne National Lab. (ANL), Argonne, IL.

Nguyen, V. A., Pham, T. N., Le, H. T., Karin, T., & Andrzej, T. (2005). *Wastewater treatment by vertical-flow tree plantations in Vietnamese conditions*. Collection of scientific reports, National Environmental Conference 2005, Ministry of Natural Resources and Environment, 877-881. Vietnamese

Olivares, M. & Uauy, R. (1996). Limits of metabolic tolerance to copper and biological basis for present recommendations and regulations. *The American journal of clinical nutrition, 63*(5), 846S-852S.

Parven, S., De, A., & Gupta, A. (2022). Cu and Pb accumulation and removal from aqueous medium by Enydra fluctuans Lour.(Asteraceae)—a medicinal plant with potential for phytoremediation. Environmental *Science and Pollution Research*, 1-11.

Peng, K., Luo, C., Lou, L., Li, X., & Shen, Z. (2008). Bioaccumulation of heavy metals by the aquatic plants Potamogeton pectinatus L. and Potamogeton malaianus Miq. and their potential use for contamination indicators and in wastewater treatment. *Science of the total environment, 392*(1), 22-29.

Pettit, N. E., Ward, D. P., Adame, M. F., Valdez, D., & Bunn, S. E. (2016). Influence of aquatic plant architecture on epiphyte biomass on a tropical river floodplain. *Aquatic botany*, 129, 35-43.

Pratas, J., Favas, P. J., Paulo, C., Rodrigues, N., & Prasad, M. N. V. (2012). Uranium accumulation by aquatic plants from uranium-contaminated water in Central Portugal. *International Journal of phytoremediation, 14*(3), 221-234.

Rahimzadeh, M. R., Rahimzadeh, M. R., Kazemi, S., & Moghadamnia, A. A. (2017). Cadmium toxicity and treatment: An update. *Caspian journal of internal medicine, 8*(3), 135.

Rahimzadeh, M. R., Rahimzadeh, M. R., Kazemi, S., & Moghadamnia, A. A. (2020). Zinc Poisoning-Symptoms, Causes, Treatments. *Mini-reviews in medicinal chemistry, 20*(15), 1489-1498.

Raskin, I., Smith, R. D., & Salt, D. E. (1997). Phytoremediation of metals: using plants to remove pollutants from the environment. *Current opinion in biotechnology, 8*(2), 221-226.

Rodriguez, L., Lopez-Bellido, F. J., Carnicer, A., Recreo, F., Tallos, A., & Monteagudo, J. M. (2005). *Mercury recovery from soils by phytoremediation. In Environmental Chemistry*, 197-204. Springer, Berlin, Heidelberg.

Roy, C., Jahan, M., & Rahman, S. (2018). Characterization and treatment of textile wastewater by aquatic plants (macrophytes) and algae. *Eur J Sustain Dev Res, 2*(3), 29.

Saha, J. C., Dikshit, A. K., Bandyopadhyay, M., & Saha, K. C. (1999). A review of arsenic poisoning and its effects on human health. *Critical reviews in environmental science and technology, 29*(3), 281-313.

Sasmaz, M., Uslu Senel, G., & Obek, E. (2021). Strontium accumulation by the terrestrial and aquatic plants affected by mining and municipal wastewaters (Elazig, Turkey). *Environmental Geochemistry and Health, 43*(6), 2257-2270.

Shahid, M. J., Arslan, M., Ali, S., Siddique, M., & Afzal, M. (2018). Floating wetlands: a sustainable tool for wastewater treatment. *Clean–Soil, Air, Water, 46*(10), 1800120.

Singh, J. & Kalamdhad, A. S. (2011). Effects of heavy metals on soil, plants, human health and aquatic life. *Int J Res Chem Environ, 1*(2), 15-21.

Sohsalam, P., Englande, A. J., & Sirianuntapiboon, S. (2008). Seafood wastewater treatment in constructed wetland: Tropical case. *Bioresource Technology, 99*(5), 1218-1224.

Tangahu, B. V., Sheikh Abdullah, S. R., Basri, H., Idris, M., Anuar, N., & Mukhlisin, M. (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. *International Journal of Chemical Engineering*.

Tran, V. T., Nguyen, D. T., Do, T. A., Nguyen, T. K., & Dang, D. K. (2008). Using Phragmites Australis and Vetiveria zizanioides in treatment of chromium and Nickel-containing wastewater by rhizosphere method. *Journal of Science and Technology, 46* (3), 5-23. Vietnamese

Tripathi, B. D., & Shukla, S. C. (1991). Biological treatment of wastewater by selected aquatic plants. *Environmental Pollution, 69*(1), 69-78.

Van Ginneken, L., Meers, E., Guisson, R., Ruttens, A., Elst, K., Tack, F. M., Vangronsveld, J., Diels, L. & Dejonghe, W. (2007). Phytoremediation for heavy metal-contaminated soils combined with bioenergy production. *Journal of Environmental Engineering and Landscape Management, 15*(4), 227-236.

Vara Prasad, M. N., & de Oliveira Freitas, H. M. (2003). Metal hyperaccumulation in plants: biodiversity prospecting for phytoremediation technology. *Electronic journal of biotechnology, 6*(3), 285-321.

Xu, J., Liu, J., Hu, J., Wang, H., Sheng, L., Dong, X., & Jiang, X. (2021). Nitrogen and phosphorus removal in simulated wastewater by two aquatic plants. *Environmental Science and Pollution Research, 28*(44), 63237-63249.

Yamagata, H., Yoshizawa, M., & Minamiyama, M. (2010). Assessment of current status of zinc in wastewater treatment plants to set effluent standards for protecting aquatic organisms in Japan. *Environmental monitoring and assessment*, *169*(1), 67-73.