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Phytoremediation Using a Diversity of Plant Species: A Literature Review

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ABSTRACT

Phytoremediation has received growing recognition as an environmentally friendly and sustainable approach for mitigating heavy metal contamination in both terrestrial and aquatic ecosystems. The approach utilizes the inherent capacity of certain plant species to uptake, accumulate, and immobilize hazardous metals such as cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), and chromium (Cr) either within plant tissues or in the rhizosphere. This review synthesizes findings from 35 academic studies to evaluate the effectiveness of various plant species in phytoremediation. The mechanisms examined include phytoaccumulation, phytostabilization, and phytovolatilization, all of which are shaped by plant physiological traits, site conditions, and the nature of contaminants.

Among the reviewed species, *Brassica juncea*, *Vetiveria zizanioides*, *Azolla pinnata*, and *Lemna minor* were consistently identified as high-performing candidates. *Azolla pinnata*, for example, demonstrated removal efficiencies exceeding 95% for Fe and 98% for Mn within a seven-day period, while *Lemna minor* showed up to 99.5% Mn and 98.8% Cu removal, highlighting their rapid uptake capacity and environmental adaptability. The results indicate that successful phytoremediation requires careful selection of plant species, taking into account the properties of the pollutants, the ecological conditions of the location, and the defined remediation objectives.

According to the review, the performance of phytoremediation is determined primarily by the species growth dynamics, their tolerance thresholds to heavy metals, and their efficiency in translocating and storing pollutants in aboveground biomass. Aquatic macrophytes like *Eichhornia crassipes* and *Lemna spp*. Provide extra benefits such as rapid growth, low land requirements, and compatibility with constructed wetland systems. Overall, this study underscores the strategic value of plant biodiversity in designing effective phytoremediation frameworks and supports the integration of species-specific strategies for post-mining and industrial site rehabilitation.

INTRODUCTION

From a biotechnological perspective, phytoremediation involves harnessing plants and their related microorganisms to facilitate the decomposition, stabilization, or eradication of organic pollutants across various environmental media, including terrestrial, aquatic, and atmospheric compartments. Over the past few decades, this method has gained significant scientific interest due to its relatively low expense, capacity to rehabilitate contaminated ecosystems naturally, and wide social acceptance. Phytoremediation, compared to traditional techniques such as soil excavation or chemical treatments, provides an ecosystem-based solution that is less damaging and more sustainable.

Globally, contamination by heavy metals including Cd, Pb, As, Hg, and Cr has developed into a pressing environmental concern, largely due to their long-term stability in ecosystems and their harmful ecological effects. The increased levels of these hazardous elements are primarily linked to human activities such as mining, intensive agriculture, and industrial discharges. To address this issue, phytoremediation has emerged as a sustainable method that utilizes the natural abilities of specific plants to uptake, store, and immobilize pollutants within their biomass.

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Each plant species has its own set of mechanisms for dealing with environmental contaminants. Plants known as hyperaccumulators, like *Pteris vittata* for arsenic and *Thlaspi caerulescens* for zinc and cadmium, can move significant quantities of metals to their aerial parts. In contrast, certain species may be more efficient in phytostabilization or phytovolatilization processes. As a result, comprehending the variety of plant species used in phytoremediation is critical for selecting the most appropriate species for unique site conditions and contaminant.

An analysis of 35 peer-reviewed publications reveals the utilization of phytoremediation strategies involving a broad spectrum of plant species. The findings emphasize the pollutant-specific remediation potential of individual plants and provide comparative evaluations of their efficiency under distinct ecological settings. It also explores complementary techniques, such as utilizing rhizospheric microbes and making genetic changes. The goal is to give a thorough examination of phytoremediation techniques and application potential based on plant species diversity.

METHODOLOGY

Figure 1 illustrates the research phases. This investigation is a review of various academic articles. A literature review entails a thorough analysis and assessment of similar previous studies (Snyder, 2019). This investigation aims to compile and assess the phytoremediation capabilities of different plants. The phases of research carried out are outlined as follows:

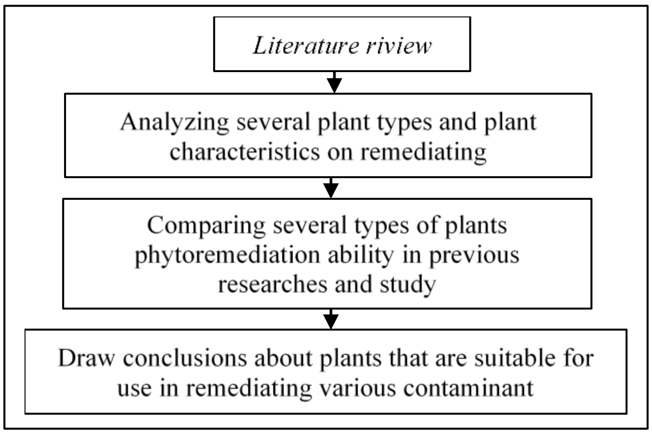

FIGURE 1. Flow Chart of Research Stages

RESULTS DAN DISCUSSIONS

Phytoremediation, classified as a biotechnological intervention, takes advantage of the inherent abilities of certain plant species to counteract environmental degradation, especially within ecosystems contaminated by heavy metals. Its growing popularity is attributed to both its relatively low cost and its ecological compatibility when contrasted with traditional physical or chemical remediation practices. (Ali et al., 2013; Pulford & Watson, 2003). It is consistent with sustainable environmental management practices to utilize living organisms specifically green plants that can thrive in contaminated places while detoxifying the pollutants (PilonSmits, 2005).

Plants engaged in phytoremediation operate via a variety of physiological and biochemical processes. They can absorb harmful metals and pollutants via their root systems, translocating them to their aerial parts for storage, transformation, or volatilization (Yadav, 2010). In certain situations, these plants can transform toxic compounds into less hazardous or more stable chemical forms. This process is frequently improved by the presence of microbes, particularly those connected with the rhizosphere, which help increase contaminant bioavailability and promote plant health (Ma et al., 2011).

Phytoremediation techniques are generally divided into three main mechanisms: phytoaccumulation, phytostabilization, and phytovolatilization. Phytoaccumulation, often referred to as phytoextraction, is the process by which plants take up contaminants from soil or water and concentrate them within their tissues. In phytostabilization, pollutants are confined to the root zone, thereby reducing their mobility and bioavailability. Phytovolatilization, on the other hand, involves the absorption of pollutants that are subsequently converted into volatile compounds and released into the atmosphere in a less harmful form (Salt et al., 1998; Marques et al., 2009).

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Extensive research has identified a variety of plant species capable of effectively participating in phytoremediation of different contaminants. Aquatic macrophytes such as *Eichhornia crassipes* and *Lemna minor* have exhibited high efficiency in removing heavy metals like Pb, Cd, and Cu from polluted water systems (Rezania et al., 2016). In contrast, terrestrial species including *Brassica juncea* and *Helianthus annuus* have been the focus of considerable investigation due to their capacity to extract toxic elements from soil environments (Kumar et al., 1995; Ebbs & Kochian, 1998). The overall performance of phytoremediation, however, is strongly influenced by the metal-uptake ability and environmental resilience of the species involved.

Phytoremediation is a flexible and site-adaptable approach due to the diversity of plant species and variation in contaminant kinds. However, its success is heavily dependent on parameters such as hydrogen potential (pH), contaminant solubility, and plant-microbe interactions. To increase efficiency, phytoremediation is frequently combined with complementary techniques such as chelating agents (such as Ethylenediaminetetraacetic Acid (EDTA), a chemical compound that binds metal ions and increases their bioavailability), the use of beneficial endophytic bacteria, or plant genetic modification to enhance uptake and tolerance (Rascio & Navari-Izzo, 2011; Doty, 2008). Phytoremediation thus shows strong potential as a sustainable and holistic solution for cleaning ecosystems polluted with hazardous chemicals. The following plants have been recognized in prior studies as successful in lowering metal contaminant levels in contaminated surroundings:

Table 1. Various Research Result of Plant Use for Phytoremediation

Research Author	Year	Research Title	Result
Study by Yunus, R. and N. S. Prihatini	2018	Remediation of Acid Mine Drainage Contaminated with Iron (Fe) and Manganese (Mn) at PT. JBG, South Kalimantan Using *Eichhornia crassipes* and *Eleocharis dulcis* as Phytoremediators	Integrating *Eichhornia crassipes* and *Eleocharis dulcis* in phytoremediation offers a viable and sustainable solution for the long-term mitigation of iron (Fe) and manganese (Mn) pollutants in acid mine drainage (AMD).
Sri Pertiwi Estuningsih, Bambang Y., Yonanda	2018	In PT. Bukit Asam Tanjung Enim, South Sumatra, Acid Water from Coal Mining is Treated Using Phytoremediation.	*Eichornia crassipes*, *Neptunia oleracea*, and *Limnocharis flava* are effective in remediating AMD-derived manganese (Mn).
Ashton Lee Suelee, Syarifah Nur M. S.H. Faradiella, et al.	2017	The Role of *Vetiveria zizanioides* (Vetiver Grass) in Phytoremediation: A Sustainable Approach to Treating Water Contaminated by Heavy Metals	Vetiver grass (*Vetiveria zizanioides*) has been confirmed as an efficient phytoremediator capable of lowering the levels of copper (Cu), iron (Fe), manganese (Mn), lead (Pb), and zinc (Zn) in acid mine drainage (AMD).
Mardalena, M. Faizal, A. Napoleon	2018	Use of *Eichhornia crassipes*, *Salvinia natans*, and *Pistia stratiotes* in Phytoremediation to Eliminate Fe and Mn from Coal Mine Wastewater	The mitigation of iron (Fe) and manganese (Mn) contamination in acid mine drainage was successfully achieved using all three macrophytes: *Salvinia natans*, *Pistia stratiotes*, and *Eichhornia crassipes*.
Herniwanti, Priatmadi, Yanuwiadi, and Soemarno	2013	Utilization of Vegetation in Passive Phytoremediation Strategies for Acid Mine Drainage Remediation	The application of *Hydrilla verticillata*, *Ipomoea aquatica*, *Pistia stratiotes*, *Cyperus odoratus*, and *Eleocharis dulcis* has proven effective in mitigating Fe and Mn contamination in AMD, alongside exhibiting a positive influence on pH neutralization.
Rika A.N, Singgih T.W, Nina T. et al.	2020	The Use of Water Mimosa (*Neptunia oleracea*) to Phytoremediate Coal Acid Mine Drainage	*Neptunia oleracea* (water mimosa) has demonstrated effectiveness in lowering concentrations of total suspended solids (TSS), Fe, Mn, and SO_4 in acid mine drainage (AMD), while simultaneously improving pH levels.

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According to Qadri, Uqab, Javeed, and colleague	2022	Phytoremediation Potential of *Ceratophyllum demersum* as a Biological Accretion Tool for Heavy Metal Cleanup	Research suggests that the aquatic plant known as *Ceratophyllum demersum* may have the ability to eliminate cadmium (Cd) and manganese (Mn) from contamination.
C.O. Akinbile, A.T. Ogunrinde, C.M. Hasfalina, et al.	2015	Using *Azolla pinnata* in Free Water Surface Wetlands to Remediate Household Wastewater	In phytoremediation experiments on household wastewater, *Azolla pinnata* is efficient at removing Fe and Zn.
A. Marwa	2023	Tanzania's Wetland Plant Treatment Potentials for Acid Mine Drainage are Assessed.	*Cyperus imbricates, Pennisetum purpureum, Typha latifolia,* and *Phragmites* Mauritius have all been demonstrated to be effective in the treatment of AMD removal and stabilization of sulfate, nickel, manganese, iron, zinc, and copper in contaminated aquatic environments
P.K. Rai	2021	Evaluating the Phytoremediation Capacity of Non-Native Wetland Species *Phragmites karka* and *Arundo donax* for Arsenic and Heavy Metal Removal: Implications for Water, Energy, and Food (WEF) Sustainability	A group of trace metals including chromium (Cr), zinc (Zn), nickel (Ni), arsenic (As), and copper (Cu) known for their persistence and bioaccumulative potential in contaminated ecosystems were successfully removed from contaminated water by *Arundo donax* and *Phragmites karka.*
A study by J. Xin and co-authors	2020	*Pontederia cordata* is a Promising Aquatic Plant Species with Considerable Potential for Remediating Wetland Environments Polluted by Heavy Metals	*Pontederia cordata* has proven effective for cadmium (Cd) removal.
The study conducted by Moreno, Anderson, and Stewart	2008	Phytofiltration of Water Contaminated with Mercury: Aspects of Volatilization and Accumulation by Plants	*Brassica juncea* has shown to be successful in cleaning up mercury from polluted water.
S. Biswas, S. Jayaram, I. Philip	2024	Assessing the Functional Role of *Bacillus amyloliquefaciens* Endophyte Derived from *Alternanthera philoxeroides* in Heavy Metal Remediation, Diesel Degradation, and Biosurfactant Synthesis	*Alternanthera philoxeroides* is very effective at eliminating chromium (Cr) and lead (Pb) from polluted water.
Dajiang Yan, Shan Xue, Zhibin Zhang	2023	In Phytoremediation, Air Nanobubble Water Improves Plants Absorption and Resistance Cadmium (Cd)	*Alternanthera philoxeroides* has proven effective for remediating cadmium (Cd).
Research conducted by Faisal, Taha, and Hassan	2023	Subsurface Flow Created Wetlands for Processing Simulated Wastewater Containing Cadmium (Cd) Ions with *Canna indica* and *Typha domingensis* Included	The combination of *Typha domingensis* and *Canna indica* in phytoremediation proved effective in reducing the quantity of cadmium (Cd) in wastewater.
V. Mgobozi, A.J Afolayan, G.A. Otunola	2016	Potential of *Egeria densa* (Plach.) Casp. to Uptake Heavy Metal	It has been demonstrated that *Egeria densa* can absorb zinc (Zn) and manganese (Mn).

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Research by Harguinteguy, Pignata, and Fernandez-Cirelli	2015	Phytoremediation of Ni, Pb, and Zn through Bioaccumulation in Aquatic Plants *Myriophyllum aquaticum* and *Egeria densa*	Compared to *Egeria densa*, *Myriophyllum aquaticum* demonstrates greater efficiency in eliminating heavy metals like nickel, lead, and zinc from contaminated water systems.
S. Singh, J. Kar wadiya,S. Srivas tava	2022	The Promise of Indigenous Plant Varieties for Cleaning Up Soil and Water Polluted with Arsenic (As)	Among various plant species, *Marsilea quadrifolia* and *Eichhornia crassipes* exhibit the highest potential for arsenic (As) removal through phytoremediation.
The investigation by Bello, Tawabini, and Khalil	2018	Hydroponic Systems Utilizing *Phragmites australis* to Phytoremediation Water Polluted with Cadmium (Cd), Lead (Pb), and Nickel (Ni)	A hydroponic method that utilizes *Phragmites australis* can be used to get rid of lead (Pb), nickel (Ni), and cadmium (Cd) from contaminated water.
Research conducted by Ismail, Abdullah, and Idris	2019	At the same time, iron and aluminum are absorbed and translocated by *Scirpus grossus* from mining wastewater	Due to its strong metal uptake ability, *Scirpus grossus* is considered a viable candidate for hyperaccumulative treatment of iron and aluminum in polluted aquatic systems.
In their study, Xia, Hua, and Xue	2021	Phytoremediation Potential of *Myriophyllum elatinoides* for Treating Boron (B)-Contaminated Water at Low Concentrations	The phytoremediation of water contaminated with boron (B) may be promising with *Myriophyllum elatinoides.*
The study conducted by Mosoarca and Vancea	2018	Evaluation of Adsorption, Bioaccumulation, and Kinetic Characteristics in the Phytoremediation of Cobalt from Wastewater by *Elodea canadensis*	Cobalt (Co) can be a phytoremediation from wastewater using *Elodea canadensis.*
According to the research conducted by Bingol, Ozmal, and Akın	2017	Phytoremediation Potential of *Lythrum salicaria L.* for the Removal and Uptake of Nickel from Aqueous Solutions	It was discovered that *Lythrum salicaria l.* with the addition of Hoagland solution was effective for removing nickel (Ni) from aqueous solutions.
R. Kurniawan, H. Hamim	2022	Tailings Area as A Source of Possible Phytoaccumulator Plants as A Phytomining Agent for Gold (Au)	Based on the results, *Typha angustifolia* and *Cyperus haspan* are identified as highly promising species for gold (Au) accumulation via phytoaccumulation mechanisms.
S. Mukhtar, H.N Bhatti, M. Khalid	2010	The Promise of Sunflower (*Helianthus annuus l.*) in Cleaning Water Polluted with Nickel (Ni) and Lead (Pb)	According to the findings, with the introduction of synthetic chelator, *Helianthus annuus l.* successfully absorbed nickel (Ni) and lead (Pb).
The findings of Souza, Borges, and Braga	2019	Optimization Study on the Phytoremediation Potential of *Lemna valdiviana* for Arsenic (As)-Contaminated Water	According to studies, *Lemna valdiviana* is an efficient macrophyte for bioaccumulation.
A.C. Remigio, M. Edraki, A.J.M. Baker	2021	The Aquatic Plant *Crassula helmsii* is a True Hyperaccumulator of Copper (Cu)	It was discovered that *Crassula helmsii* is a successful plant for removing copper from wastewater.
J. Augustynowicz M. Grosicki	2010	Chromium (VI) Removal using the Water Plant *Callitriche cophocarpa* Sendtn.	Research has shown that *Callitriche cophocarpa* is beneficial. Aim of fixing the situation.

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Research by Axtell and Sternberg	2003	Lead (Pb) and Nickel (Ni) Extraction with *Microspora* and *Lemna minor*	The removal of nickel (Ni) and lead (Pb) is effective using microspore biomass of *Lemna minor.*
The analysis conducted by R. Bennicelli and co-authors	2004	Utilization of *Azolla caroliniana* for Detoxification of Municipal Wastewater Contaminated with Hg (II), Cr (III), and Cr (VI)	According to the findings, *Azolla caroliniana* can accumulate significant amounts of chromium (Cr) and mercury (Hg).
W. Guayjarernpanishk, P. Sampanpanish	2024	Water Hyacinth is Utilized for Cleaning Up Pollution from Acid Mine Drainage Caused by Arsenic (As), Manganese (Mn), and Copper (Cu) Through the Application of Sodium Phytate.	Sodium Phytate (SP)-added *Eichhornia crassipes* proved to be successful in remediating arsenic (As), manganese (Mn), and coppper (Cu).
Research by Gomes and colleagues	2014	Role of *Typha domingensis* in Constructed Wetlands for the Treatment of Mercury-Polluted Aquatic Systems	The effectiveness of *Typha domingensis* at removing mercury (Hg) from wastewater was determined to be significant.
The collaborative work of Al-Baldawi, Yasin, and Jasim	2022	Phytoremediation Capability, Adsorption Rates and Isotherm Models for Copper Elimination by *Lemna minor* and *Azolla filiculoides*	*Lemna minor* and *Azolla filiculoides* were discovered to be efficient at removing Copper (Cu) from wastewater.
S. Subpiramaniyan, S.C. Hong, P. Yi	2023	Evaluation of *Azolla imbricata* (Roxb.) Nakai for Phytoremediation and Its Biochemical Adaptations to Metal Cutting Fluid Waste and Abiotic Stress from Temperature and Humidity	*Azolla imbricata* has shown potential as a low-cost remediation agent for eliminating zinc, cadmium, and lead from industrial waste cutting fluids.
S. Bharti, T. Kumar Banerjee	2012	Phytoremediation of The Coalmine Effluent	Phytoremediation of Fe, Mn, Cu, Zn, Ni, Pb, Cr, and Cd from coal mining wastewater was successfully carried out by *Lemna minor* and *Azolla pinnata* with high efficiency.

Table 2. Plant Species used for Phytoremediation

Research Author	Plant Species	Observation Time	Remediation Parameter	Result
Study by Yunus, R. and N. S. Prihatini	Combined used of *Eichornia crassipes* and *Eleocharis dulcis*	25 days	Fe Mn	• Fe = (87.11−95.28) % • Mn = (70.08−79.84) %
Sri Pertiwi Estuningsih, Bambang Y., Yonanda	*Eichornia crassipes*	30 days	Mn	• Mn = (21.30−23.17) %
	Neptunia oleracea			• Mn = (12.20−22.81) %
	Limnocharis flava			• Mn = (91.46−94.31) %

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Ashton Lee Suelee, Syarifah Nur M. S.H. Faradiella, et al.	*Vetiveria zizanioides*	10 days	Element Cu, transition metal Fe, Mn, Pb and Zinc (Zn)	• Cu = 1,568 ppm • Fe = 20,746 ppm • Mn = 835 pm • Pb = 4,449 ppm • Zn = 983 ppm
Mardalena, M. Faizal, A. Napoleon	*Salvinia natans*	30 days	Fe Mn	• Fe = 56.923 % • Mn = 69.437 %
	Pistia stratiotes			• Fe = 44.872 % • Mn = 39.262 %
	Eichornia crassipes			• Fe = 73.077 % • Mn = 30.803 %
Herniwanti, Priatmadi, Yanuwiadi, and Soemarno	Aquatic plant species include: *Eleocharis dulcis*	29 days	pH Fe Mn	• pH = 28% • Fe = 70% • Mn = 38%
	Cyperus odoratus			• pH = 44% • Fe = 18% • Mn = 6%
	Hydrilla vercilata			• pH = 42% • Fe = 24% • Mn = 9%
	Ipomea aquatic and			• pH = 53% • Fe = 13% • Mn = 12%
	Pistia stratatiotes			• pH = 41% • Fe = 65% • Mn = 55%
Rika A.N, Singgih T.W, Nina T. et al.	*Neptunia oleracea*	7 Days	pH Fe Mn Sulfate	Findings revealed that pH levels increased by 0.0322 per day, whereas concentrations of Fe, Mn, and sulfate declined by 0.4760, 0.4809, and 0.818 mg/L per day, respectively.
H. Qadri, B. Uqab, O. Javeed, et al.	*Ceratophyllum demersum*	28 days	Cd Mn	• Cd = 47 % • Mn = 42 %
C.O. Akinbile, A.T. Ogunrinde, Hasfalina C.M, et al.	*Azolla pinnata*	28 days	Fe (mg/l) Zn (mg/l)	Dry Season: • Fe = 0.01±0 • Zn = 4±0.03 Wet Season: • Fe = 2.09±1.41 • Zn = 4.11±0.39
A. Marwa	*Cyperus imbricatus*	63 days	The study measured SO_4 (sulfate), Cu (copper), Fe (iron), Mn	• SO_4 = 28 ± 646 • Cu = 0.01 ± 0.2 • Fe = 0.03± 0.6 • Mn = 0.2± 12 • Ni = 0.01 ± 0.5 • Zn = 3.2 ± 0.8

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	Pennisetum purpureum		(manganese Ni (nickel), and Zn (zinc) concentrations in units of mg/L	• SO_4 = 126 ± 66 • Cu = 0.03 ± 0.1 • Fe = 0.04 ± 0.7 • Mn = 0.1± 9 • Ni = 0.01 ± 0.8 • Zn = 2.2± 1.6
	Typha latifolia			• SO_4 = 502 ± 56 • Cu = 0.02 ± 0.2 • Fe = 0.05 ± 0.5 • Mn = 3.5 ± 14 • Ni = 0.005 ± 0.8 • Zn = 4.3 ± 0.4
	Phragmites mauritianus			• SO_4 = 393± 625 • Cu = 0.01 ± 0.1 • Fe = 0.01 ± 0.6 • Mn = 0.2± 11 • Ni = 0.04 ± 0.8 • Zn = 3 ± 1.2
P. K. Rai	*Phragmites karka* and *Arundo donax*	21 days	As Cr Cu Ni Zn	• As = 31 %, • Cr = 73.3% • Cu = 64.2% • Ni = 62.6% • Zn = 69.2%
J. Xin, S. Ma, Y. Li	*Pontederia cordata*	15 days	Cd	The treatment achieved 76.9% efficiency for Cd removal.
The study conducted by Moreno, Anderson, and Stewart	*Brassica juncea*	14 days	Hg	Hg removal effectiveness reached 95%.
S. Biswas, S. Jayaram, I. Philip	*Alternanthera philoxeroides*	6 weeks	Cr (VI) Pb	• Cr (VI) = 25,5% • Pb = 92,3%
D. Yan, S. Xue, Z. Zhang	*Alternanthera philoxeroides*	30 days	Cd	The results show that 280.81 ± 14.04 mg Cd/kg^{-1}, without air nanobubble, boosted up to a 17.39% uptake increase with the addition of 25% of air nanobubble.
B. Sharma, S. Ram, S. Vyas	Combined use of *Canna indica* and *Typha domingensis*	5 days	Cd	The treatment showed 84% efficiency in Cd removal.
V. Mgobozi, A.J. Afolayan, G.A. Otunola	*Egeria densa*	14 days	Mn Zn	The treatment process achieved high removal efficiencies, with (Mn) reduced by 97.52% and (Zn) by 98.44%.

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Research by Harguinteguy, Pignata, and Fernandez-Cirelli	*Myriophyllum aquaticum*	7 days	Ni Zn Pb	Threshold values for Ni, Zn, and Pb were set at 10, 20, and 15 mg/L, respectively.
	Egeria densa			The acceptable limits for heavy metals were established as follows: nickel (Ni) at 10 mg L^{-1}, zinc (Zn) at 15 mg L^{-1}, and lead (Pb) at 15 mg L^{-1}.
S. Singh, J. Karwadiya, S. Srivastava	*Eicchornia crassipes*	7 days	As	Bioconcentration factor (BCF) of (As) in plant uptake was 3.47.
	Marsilea quadrifolia			BCF for this parameter reached 3.36.
The investigation by Bello, Tawabini, and Khalil	*Phragmites australis*	6 weeks	Cd Pb Ni	The treatment process achieved removal efficiencies of 93% for cadmium (Cd), 95% for lead (Pb), and 16% for nickel (Ni).
Research conducted by Ismail, Abdullah, and Idris	*Scirpus grossus*	102 days	Fe Al	Iron (Fe) was detected at 50.277 mg kg^{-1} and aluminum (Al) at 7.744 mg kg^{-1} in the sample.
J. Xia, T. Hua, Y. Xue	*Myriophyllum elatinoides*	56 days	B	Shoot concentration reached 1296.5 mg/kg and root concentration reached 350.7 mg/kg at 40 mg/L (B).
G. Mosoarca, C. Vancea	*Elodea canadensis*	14 days	Co	Effectiveness of Co removal reached 93.34%.
N.A. Bingol, F. Ozmal, B. Akın	*Lythrum salicaria l.*	7 days	Ni	10 mg Ni/l maximum.
R. Kurniawan, H. Hamim	*Typha angustifolia*	–	Au	Evaluation indicated *Typha angustifolia* absorbed the largest amount of Au, capacity at (2.863 g ha^{-1} dry weight), with *C. haspan* showing similar value of 2.856 g ha^{-1}.
	Cyperus haspan			
S. Mukhtar, H.N Bhatti, M. Khalid	*Helianthus annuus l.*	30 days	Ni Pb	Among the analyzed metals, the highest concentrations were observed for Pb at 72.28 mg/kg and Ni at 55.82 mg/kg.
The findings of Souza, Borges, and Braga	*Lemna Valdiviana*	7 days	As	1190 mg kg^{-1} As (dry weight), up to 82 % As reductions.

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A.C. Remigio, M. Edraki, A.J.M. Baker	*Crassula helmsii*	7 days	Cu	Plants exposed to 5 mg/L Cu showed bioaccumulation levels of 5870 µg Cu g^{-1}.
J. Augustynowicz M. Grosicki	*Callitriche cophocarpa*	21 days	Cr (VI)	Accumulation levels rose steadily from 470 mg kg^{-1} (dry weight) to a maximum of 1000 mg kg^{-1} within three weeks.
Research by Axtell and Sternberg	*Lemna minor*	10 days	Pb Ni	• Pb = 76 % • Ni = 82 %
The analysis conducted by R. Bennicelli and co authors	*Azolla caroliniana*	12 days	Hg^{2+}, Cr^{3+}, and Cr^{6+}	Removal efficiencies reached 71% for Hg (II) at 0.1 mg/dm^3, 74% for Cr (III) at 1.0 mg/dm^3, and 100% for Cr (VI) at 0.1 mg/dm^3.
W. Guayjarernpanishk, P. Sampanpanish	*Eichhornia crassipes*	30 days	As Mn Cu	• As = 282.38 ± 26.23 mg/kg of 1.0 mg/L • Mn = 9764.19 ± 357.36 mg/kg of 20 mg/L • Cu = 121.74 ± 9.43 of 2 mg/L)
M.D. Basallote, V. Zarco	*Typha domingensis*	27 days	Hg	The treatment achieved a 99.6 ± 0.4% reduction in Hg content of wastewater.
I. A. Baldawi, et al.	*Azolla filiculoides*	7 days	Cu	Complete removal 100% of copper was achieved from water containing 1.00 mg/L Cu.
	Lemna minor			Treatment of 1.00 mg/L Cu-contaminated water resulted 74% reduction.
S. Subpiramaniyan, S.C. Hong, P. Yi	*Azolla imbricata (Roxb.) Nakai.*	10 days	Zn Cd Pb	Elemental analysis revealed considerable variations, with zinc (Zn) at 1110 mg kg^{-1}, cadmium (Cd) at 282 mg kg^{-1}, and lead (Pb) highest accumulation at 2494 mg kg^{-1}.
S. Bharti, T. Kumar Banerjee	*Azolla pinnata*	7 days	The metals analyzed this study included Fe (iron), Mn (manganese), Cu (copper), Zn (zinc), Ni (nickel), Pb	• Fe = 95.4 % • Mn = 98 % • Cu = 93 % • Zn = 95 % • Ni = 662% • Pb = 86.9 % • Cr = 77,7 % • Cd = 85.3 %

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Lemna minor	(lead), Cr (chromium), and Cd (cadmium)	• Fe = 93.1 % • Mn = 99.5 % • Cu = 98,8% • Zn = 96.7% • Ni = 94.5% • Pb = 84 % • Cr = 76 % • Cd = 86.7 %

Over 35 plant species from diverse taxonomic families, including Brassicaceae (*Brassica juncea*), Poaceae (*Vetiveria zizanioides*), Fabaceae (*Neptunia oleracea*), and Asteraceae (*Helianthus annuus*) have been comprehensively evaluated for their phytoremediation capacities. The ability of these plant families to efficiently absorb and redistribute heavy metals is largely attributed to their adaptable physiology, high endurance under extreme environmental stress, and well-developed root systems. (Ali et al., 2013; Rascio & Navari-Izzo, 2011). An outstanding case is *Brassica juncea*, widely acknowledged for its hyperaccumulating capacity to mobilize and store considerable levels of Cd, Pb, and Zn within its above-ground organs, playing a crucial ecological function in remediating heavy-metal contaminated ecosystems (Ebbs & Kochian, 1998). Similarly, *Vetiveria zizanioides* has demonstrated exceptional metal accumulation potential, with recorded uptakes reaching 20,746 ppm of iron (Fe), 4,449 ppm of lead (Pb), 1,568 ppm of copper (Cu), 835 ppm of manganese (Mn), and 983 ppm of zinc (Zn) (Suelee et al., 2017), making it suitable for heavy metal environments.

Among leguminous plants, *Neptunia oleracea* has demonstrated considerable effectiveness in remediating polluted water bodies, not only by reducing concentrations of iron (Fe) and manganese (Mn) but also by significantly improving water pH and lowering sulfate and Total Suspended Solids (TSS) levels (Rika et al., 2020). The diversity of physiological traits among these species underscores the importance of site-specific plant selection, highlighting that the success of phytoremediation relies on aligning plant characteristics with contaminant profiles and environmental conditions.

Literature surveys indicate that nearly 60% of remediation studies have concentrated on heavy metals, with particular focus on Pb, Cd, Cr, and As, underscoring global concerns regarding their persistence in the environment and inherent toxicity (Mahar et al., 2016; Sharma & Agrawal, 2005). Principal anthropogenic sources include mining activities, metallurgical processing, leather tanning, and pesticide leachates. As non-biodegradable elements capable of bioaccumulation, these metals pose significant and long-lasting threats to both ecosystems and human health (Yadav, 2010). Hence, the effectiveness of phytoremediation strategies critically depends on selecting plant species with the capacity to tolerate and efficiently accumulate such pollutants.

Due to its dense root system, *Vetiveria zizanioides* is effective in stabilizing soils while simultaneously absorbing large amounts of Pb, Zn, and Cu (Danh et al., 2009). *Brassica juncea* is valued for its fast growth, high biomass yield, and strong capacity for metal translocation, making it suitable for large-scale use and recovery of pollutants after harvest (Kumar et al., 1995). In contrast, *Pteris vittata* serves as a unique hyperaccumulator of arsenic, often storing levels in its fronds that exceed those in the soil (Ma et al., 2001). These plants have been investigated under both laboratory and field conditions, confirming their practical utility in phytoremediation.

Improved phytoremediation outcomes can be achieved by managing soil conditions and biological inputs. Adjusting pH, adding organic matter, and maintaining moisture enhance metal availability for uptake (Ma et al., 2011), while beneficial microbes such as rhizobacteria and mycorrhizae strengthen plant health and contaminant removal (Glick, 2010; Chen et al., 2005). Additionally, genetic modification strategies such as the overexpression of metal transporter genes or stress-responsive proteins have been explored to create transgenic plants with superior detoxification capabilities (Doty, 2008; Rascio & Navari-Izzo, 2011).

Particular attention has been paid to aquatic macrophytes because of their fast growth, little land need, and large surface area for metal absorption. *Eichhornia crassipes* has shown to be highly effective in reducing manganese (Mn) by 9,764.19 mg/kg and arsenic (As) by 282.38 mg/kg in water (Guayjarernpanishk & Sampanpanish, 2024), while *Lemna minor* achieved 99.5% manganese (Mn) and 96.7% zinc (Zn) removal (Bharti & Banerjee, 2012). Their applicability in constructed wetlands and industrial effluent systems makes them ideal for decentralized, low-cost treatment strategies. Moreover, their biomass can be repurposed into biofuels or fertilizers, contributing to circular bioeconomy models (Rezania et al., 2016; Rai, 2008).

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Among the species assessed, *Azolla pinnata* and *Lemna minor* consistently demonstrated outstanding performance as versatile phytoremediators in both terrestrial and aquatic environments. *Azolla pinnata* removed up to 98% Mn, 95.4% Fe, 93% Cu, and 86.9% Pb in just seven days, while also accumulating Cd, Cr, Ni, and Zn (Bharti & Banerjee, 2012). Similarly, *Lemna minor* reached removal rates of 99.5% Mn, 98.8% Cu, and 96.7% Zn in aquatic systems, underscoring its hyperaccumulative strength. With fast biomass growth, adaptability, and easy harvest, both species are ideal for treating industrial effluents and rehabilitating mining-impacted sites (Rezania et al., 2016).

CONCLUSION

Based on the results of the analysis, phytoremediation emerges as a sustainable remediation strategy that utilizes the natural capabilities of plants to cleanse contaminated ecosystems, presenting a promising solution for mitigating heavy metal pollution in regions influenced by industrial discharge and mining practices. Its overall success is closely tied to the physiological traits of selected species, particularly their efficiency in absorbing, immobilizing, or accumulating metals such as lead, cadmium, chromium, arsenic, and mercury. The analysis revealed the following:

a. From 35 scientific studies reviewed, *Azolla pinnata* and *Lemna minor* stood out as the most efficient phytoremediators, demonstrating high removal rates of various heavy metals within relatively short timeframes.
b. Terrestrial species such as *Brassica juncea* and *Vetiveria zizanioides* also showed remarkable potential in soil remediation due to their extensive root systems and strong metal accumulation capacity.
c. The diversity of plant types involved, from aquatic macrophytes to deep-rooted terrestrial plants, indicates that phytoremediation strategies must be tailored to the specific site conditions and types of contaminants.

With appropriate species selection and site alignment, phytoremediation offers not only a cost-effective remediation solution but also a scalable and ecologically restorative approach for rehabilitating heavy metal-contaminated lands. Moreover, this strategy contributes to long-term environmental sustainability by enhancing soil health, supporting biodiversity, and reducing the ecological footprint of conventional remediation methods. When integrated into broader environmental management practices, phytoremediation has the potential to transform degraded sites into productive and resilient ecosystems.

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REFERENCES

1. Akanil, B., Ozmal, F., & Akin, B. (2017). Phytoremediation and Biosorption Potential of *Lythrum salicaria L*. for Nickel Removal from Aqueous Solutions. Polish Journal of Environmental Studies, Vol. 26. http://dx.doi.org/10.15244/pjoes/70628
2. Akeem, B., Bassam, S.T., Amjad, B. K., Christopher, R.B., Tawfik, A.S. (2018). Phytoremediation of Cadmium Lead) and Nickel Contaminated Water by *Phragmites australis* in Hydroponic Systems. Ecological Engineering, Vol. 120, p. 126−133. https://doi.org/10.1016/j.ecoleng.2018.05.035
3. Akinbile, C., Ogunrinde, A., Che Man, H., Hamidi, H., & Aziz, H. (2015). Phytoremediation of Domestic Wastewaters in Free Water Surface Constructed Wetlands Using *Azolla pinnata*. International Journal of Phytoremediation, Vol. 17, No. 10, p. 979–985. https://doi.org/10.1080/15226514.2015.1058330
4. Ali, H., Khan, E., & Sajad, M. A. (2013). Phytoremediation of Heavy Metals Concepts and Applications. Chemosphere, Vol. 91, No. 7, p. 869–881. https://doi.org/10.1016/j.chemosphere.2013.01.075

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5. Ariyani, D., Syam, R., Utami, U. B. L., & Nirtha, R. I. (2014). Study of Fe and Mn Metal Absorption by Rat Purun Plants (*Eleocharis dulcis*) in Mine Acid Water by Phytoremediation. Journal of Scientific and Applied Chemistry, Vol. 8, No. 2, p. 87–93. https://doi.org/10.56064/jps.v20i2.507
6. Ayad, A.H.F., Duaa, S.T., Waqed, H. H., Sandeep, K.L., Sabah, A., & Samjhana, P. (2023). Subsurface Flow Constructed Wetlands for Treating of Simulated Cadmium Ions Wastewater with Presence of *Canna indica* and *Typha domingensis*. Chemosphere, Vol. 338. https://doi.org/10.1016/j.chemosphere.2023.139469
7. Basallote, M. D., Zarco, V., Macias, F., Canovas, C. R., & Hidalgo, P. J. (2023). Metal Bioaccumulation in Spontaneously Grown Aquatic Macrophytes in Fe Rich Substrates of a Passive Treatment Plant for Acid Mine Drainage. Journal of Environmental Management, Vol. 345. https://doi.org/10.1016/j.jenvman.2023.118495
8. Bennicelli, R., Stępniewska, Z., Banach, A., Szajnocha, K., & Ostrowski, J. (2004). The Ability of *Azolla caroliniana* to Remove Heavy Metals (Hg (II), Cr (III), Cr (VI)) from Municipal Waste Water. Chemosphere, Vol. 55, No. 1, p. 141‒146. https://doi.org/10.1016/j.chemosphere.2003.11.015
9. Bharti, S., & Banerjee, T.K. (2012). Phytoremediation of the Coalmine Effluent, Ecotoxicology and Environmental Safety, Vol. 81, p. 36‒42. https://doi.org/10.1016/j.ecoenv.2012.04.009
10. Biswas, S., Jayaram, S., Philip, I., Balasubramanian, B., Pappuswamy, M., Barcelo, D., Chelliapan, S., Kamyab, H., Sarojini, S., & Vasseghian, Y. (2024). Appraisal of The Potential of Endophytic Bacterium *Bacillus amyloliquefaciens* from *Alternanthera philoxeroides*: A Triple Approach to Heavy Metal Bioremediation, Diesel Biodegradation, and Biosurfactant Production. Journal of Environmental Chemical Engineering, Vol. 12, No. 5. https://doi.org/10.1016/j.jece.2024.113454
11. Carlos A. H., Pignata, M.L., & Cirelli, A.F. (2015). Nickel, Lead and Zinc Accumulation and Performance in Relation to Their Use in Phytoremediation of Macrophytes *Myriophyllum aquaticum* and *Egeria densa*. Ecological Engineering, Vol. 82, p. 512‒516. http://dx.doi.org/10.1016/j.ecoleng.2015.05.039
12. Chen, B. D., Zhu, Y. G., Duan, J., Xiao, X. Y., & Smith, S. E. (2005). Effects of Arbuscular Mycorrhizal Inoculation on Plant Growth and Metal Uptake by Plants Grown in a Soil Contaminated with Heavy Metals. Environmental Pollution, Vol. 138, No. 2, p. 298–308. https://doi.org/10.1016/j.envpol.2005.03.005
13. Corzo, R.A., & Edraki, M., Baker, A.J.M, & Antony, V.E. (2021). Is the Aquatic Macrophyte *Crassula helmsii* a Genuine Copper Hyperaccumulator. Plant and Soil. Vol. 464. https://link.springer.com/article/10.1007/s11104-021-04955-4
14. Dajiang, Y., Shan, X., Zhibin, Z., Guodong, X., Yanhao, Z., Jianan, G., & Wen, Z. (2023). Air Nanobubble Water Improves Plant Uptake and Tolerance Toward Cadmium in Phytoremediation. Environmental Pollution, Vol. 337. https://doi.org/10.1016/j.envpol.2023.122577
15. Danh, L. T., Truong, P., Mammucari, R., Tran, T., & Foster, N. (2009). *Vetiver grass*, *Vetiveria zizanioides*: A Choice Plant for Phytoremediation of Heavy Metals and Organic Wastes. International Journal of Phytoremediation, Vol. 11, No. 8, p. 664–691. https://doi.org/10.1080/15226510902787302
16. Doty, S. L. (2008). Enhancing Phytoremediation through the Use of Transgenics and Endophytes. New Phytologist, Vol. 179, No. 2, p. 318–333. https://doi.org/10.1111/j.1469-8137.2008.02446.x
17. Ebbs, S. D., & Kochian, L. V. (1998). Phytoextraction of Zinc by Oat (*Avena sativa*), Barley (*Hordeum vulgare*), and Indian Mustard (*Brassica juncea*). Environmental Science & Technology, Vol. 32, No. 6, p. 802–806. https://doi.org/10.1021/es970603m
18. Fabio N. M., Anderson, C.W.N., Stewart, R.B., & Robinson, B.H. (2008). Phytofiltration of Mercury Contaminated Water: Volatilisation and Plant Accumulation Aspects. Environmental and Experimental Botany, Vol. 62, p. 78‒85. http://dx.doi.org/10.1016/j.envexpbot.2007.07.007
19. Giannin, M., Vancea, C., Popa, S., & Boran, S. (2018). Bioaccumulation and Kinetics Parameters of the Phytoremediation of Cobalt from Wastewater Using *Elodea Canadensis.* Bulletin of Environmental Contamination & Toxicology, Vol. 100, p. 733–739. https://doi.org/10.1007/s00128-018-2327-3
20. Glick, B. R. (2010). Using Soil Bacteria to Facilitate Phytoremediation. Biotechnology Advances, Vol. 28, No. 3, p. 367–374. https://doi.org/10.1016/j.biotechadv.2010.02.001
21. Guayjarernpanishk, W., & Sampanpanish, P. (2024). Efficiency of Sodium Phytate in The Remediation of As, Mn, and Cu Contamination in Acid Mine Drainage Using Water Hyacinth. Heliyon. Vol. 10, No. 4. https://doi.org/10.1016/j.heliyon.2024.e26590
22. Herniwanti. (2013). Water Plants Characteristic for Phytoremediation of Acid Mine Drainage Passive Treatment. Journal of Environmental Science, Vol. 10, No. 2, p. 45–52.
23. Ismail, I., Mangesa, R., & Irsan, I. (2020). Bioaccumulation of Heavy Metal Mercury (Hg) in Mangroves of *Rhizophora mucronata* in Kayeli Bay, Buru Regency. BIOSEL (Biology Science and Education): Journal of Science and Education Research, Vol. 9, No. 2, p. 139–153. https://doi.org/10.33477/bs.v9i2.1637

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24. Israa, A.A, Yasin, S.R., Jasim, S.S., Abdullah, S.R.S., Almansoory, A.F., & Ismail, N.I. (2022). Removal of Copper by *Azolla filiculoides a*nd *Lemna minor*: Phytoremediation Potential, Adsorption Kinetics and Isotherms, Heliyon, Vol.8, No. 1. http://dx.doi.org/10.1016/j.heliyon.2022.e11456
25. Izmail, N.I., Abdullah, S.R.S., Idris, M., Hasan, H.A., Halmi, M.E., Sbani, N.H., & Jehawi, O.H. (2019). Simultaneous Bioaccumulation and Translocation of Iron and Aluminium from Mining Wastewater by *Scirpus grossus*. Desalination and Water Treatment, Vol. 163, p. 133−142. https://doi.org/10.5004/dwt.2019.24201
26. Jianpan, X., Ma, S., Li, Y., Zhao, C., & Tian, R. (2020). *Pontederia cordata*, an Ornamental Aquatic Macrophyte With Great Potential in Phytoremediation of Heavy Metal Contaminated Wetlands. Ecotoxicology and Environmental Safety, Vol. 203. https://doi.org/10.1016/j.ecoenv.2020.111024
27. Jingye, X., Hua, T., Xue, Y., Zhao, L., Sun, H., & Liu, C. (2021). *Myriophyllum elatinoides*: A potential Candidate for The Phytoremediation of Water with Low Level Boron Contamination. Journal of Hazardous Materials, Vol. 401. http://dx.doi.org/10.1016/j.jhazmat.2020.123333
28. Joann, A., Grosicki, M., Fajerska, E.H., Lekka, M., Waloszek, A., & Koloczek. H. (2010). Cr (VI) Bioremediation by Aquatic Macrophyte *Callitriche cophocarpa sendtn*. Chemosphere, Vol. 79, p. 1077−1083. http://dx.doi.org/10.1016/j.chemosphere.2010.03.019
29. Kumar, P. B. A. N., Dushenkov, V., Motto, H., & Raskin, I. (1995). Phytoextraction: The Use of Plants To Remove Heavy Metals From Soils. Environmental Science & Technology, Vol. 29, No. 5, p. 1232–1238. https://doi.org/10.1021/es00005a014
30. Kurniawan, R., Hamim, H., Henny, C., & Satya, A. (2022). Identification of Potential Phytoaccumulator Plants from Tailings Area as a Gold Phytomining Agent. Journal of Ecological Engineering, Vol. 23, No. 1, p. 169−181. https://doi.org/10.12911/22998993/143978
31. Ma, L. Q., Komar, K. M., Tu, C., Zhang, W., Cai, Y., & Kennelley, E. D. (2001). A Fern That Hyperaccumulates Arsenic. Nature, Vol. 409, No. 6820, p. 579. https://doi.org/10.1038/35054664
32. Ma, Y., Rajkumar, M., & Freitas, H. (2011). Inoculation of Plant Growth Promoting Bacterium Achromobacter Xylosoxidans Strain for Improved Phytoremediation of Zn Contaminated Soil. Journal of Hazardous Materials, Vol. 189, No. 1–2, p. 363–370. https://doi.org/10.1016/j.jhazmat.2011.02.054
33. Mahar, A., Wang, P., Li, R., Zhang, Z., & Wang, Q. (2016). Immobilization of Lead and Cadmium in Contaminated Soil Using Amendments: A review. Environmental Pollution, Vol. 218, p. 1130–1141. https://doi.org/10.1016/j.envpol.2016.08.051
34. Marcos, V.T.G., Souza, R.R., Teles, V.S., & Mendes, E.A. (2014). Phytoremediation of Water Contaminated with Mercury Using *Typha Domingensis* in Constructed Wetland. Chemosphere, Vol. 103, p. 228−233. http://dx.doi.org/10.1016/j.chemosphere.2013.11.071
35. Mardalena, M., Faizal, M., & Adipati, N. (2018). Metal of Iron (Fe) and Manganese (Mn) from Wastewater Coal Mining with Phytoremediation Techniques Using Floating Fern (*Salvinia natans*), Water Lettuce (*Pistia stratiotes*), and Water Hyacinth (*Eichhornia crassipes*). BIOVALENTIA: Biological Research Journal, Vol. 4, No.1, p. 45–52. https://doi.org/10.24233/BIOV.4.1.2018.107
36. Marques, A. P., Rangel, A. O., & Castro, P. M. (2009). Remediation of Heavy Metal Contaminated Soils: Phytoremediation as A Potentially Promising Clean Up Technology. Critical Reviews in Environmental Science and Technology, Vol. 39, No. 8, p. 622–654. https://doi.org/10.1080/10643380701798272
37. Marwa, A. (2024). Evaluation of Wetland Plants Treatment Potentials for Acid Mine Drainage in Tanzania. Nigerian Journal of Technology, Vol. 43, No. 2, p. 381–390. https://doi.org/10.4314/njt.v43i2.21
38. Morin, J. V., & Santi, D. (2020). Phytoremediation Study of Lead (Pb) and Cadmium (Cd) Metals by Kayambang Plant (*Salvinia molesta*). Natural Journal, Vol. 16, No. 2, p. 85–95. http://dx.doi.org/10.30862/jn.v16i2.112
39. Mukhtar, S., Bhatti, H.N., Khalid, M., & Anwar, M. (2010). Potential of Sunflower (*Helianthus annuus l.)* for Phytoremediation of Nickel (Ni) and Lead (Pb) Contaminated Water. Pakistan Journal of Botany, Vol. 42, No.6.
40. Nasution, R., Wardana, S., Tanzerina, N., Estuningsih, S., & Juswardi. (2020). Potential of *Neptunia oleracea* Lour. on Phytoremediation Coal Acid Mine Drainage. Sriwijaya Bioscientia, Vol. 1, No. 2, p. 35–38. https://doi.org/10.24233/sribios.1.2.2020.190
41. Nicholas, R.A., Sternberg, S.K., & Claussen, K. (2003). Lead and Nickel Removal Using Microspora and *Lemna minor*. Bioresource Technology, Vol. 89, No. 1, p. 41−48. http://dx.doi.org/10.1016/S0960-8524(03)00034-8
42. Qadri, H., Baba, U., Javaid, O., Hamid Dar, G., & Bhat, R. (2021). *Ceratophyllum demersum*: An accretion biotool for heavy metal remediation. *Science of The Total Environment*, 806, 150548. https://doi.org/10.1016/j.scitotenv.2021.150548
43. Pertiwi, S., Juswardi, J., Yudono, B., & Nita, F. A. (2013). Phytoremediation Ability of *Salvinia molesta* at Several Concentrations of Petroleum Liquid Waste. Journal of Science Research, Vol. 16, No. 1.

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44. Smits, P.E. (2005). Phytoremediation. Annual Review of Plant Biology, Vol. 56, p. 15–39. https://doi.org/10.1146/annurev.arplant.56.032604.144214
45. Pulford, I. D., & Watson, C. (2003). Phytoremediation of Heavy Metal Contaminated Land by Trees: A review. Environment International, Vol. 29, No. 4, p. 529–540. https://doi.org/10.1016/S0160-4120(02)00152-6
46. Rai, P. (2021). Heavy Metals and Arsenic Phytoremediation Potential of Invasive Alien Wetland Plants *Phragmites karka* and *Arundo donax*: Water Energy Food (WEF) Nexus linked sustainability implications. Bioresource Technology Reports, Vol. 15. https://doi.org/10.1016/j.biteb.2021.100741
47. Rai, P. K. (2008). Heavy Metal Pollution in Aquatic Ecosystems and Its Phytoremediation Using Wetland Plants: an Ecosustainable Approach. International Journal of Phytoremediation, Vol. 10, No. 2, p. 133–160. https://doi.org/10.1080/15226510801913918
48. Rascio, N., & Izzo, N.F. (2011). Heavy Metal Hyperaccumulating Plants: How and Why do it? and What Makes Them So Interesting. Plant Science, Vol. 180, No. 2, p. 169–181. https://doi.org/10.1016/j.plantsci.2010.08.016
49. Rezania, S., Taib, S. M., Din, M. F. M., Dahalan, F. A., & Kamyab, H. (2016). Comprehensive Review on Phytotechnology: Heavy Metals Removal by Diverse Aquatic Plant Species from Wastewater. Journal of Hazardous Materials, Vol. 318, p. 587–599. https://doi.org/10.1016/j.jhazmat.2016.07.053
50. Rugh, C. L., Senecoff, J. F., Meagher, R. B., & Merkle, S. A. (1998). Development of Transgenic Yellow Poplar for Mercury Phytoremediation. Nature Biotechnology, Vol. 16, No. 10, p. 925–928. https://doi.org/10.1038/nbt1098-925
51. Salt, D. E., Smith, R. D., & Raskin, I. (1998). Phytoremediation. Annual Review of Plant Physiology and Plant Molecular Biology, Vol. 49, No. 1, p. 643–668. https://doi.org/10.1146/annurev.arplant.49.1.643
52. Sharma, P., & Agrawal, M. (2005). Biological Effects of Heavy Metals: An Overview. Journal of Environmental Biology, Vol. 26, No. 2, p. 301–313.
53. Singh, S., Karwadiya, J., Srivastava, S., Patra, P.K., & Venugopalan, V.P. (2022). Potential of Indigenous Plant Species for Phytoremediation of Arsenic Contaminated Water and Soil. Ecological Engineering, Vol. 175, 2022. http://dx.doi.org/10.1016/j.ecoleng.2021.106476
54. Sivakumar, S., Hong, S.C., Yi, P.I., Jang, S.H., Suh, J.M., Jung, E.S., Park, J.S., Palanivel, V., Song, Y.C., Cho, L.H., Park, Y.H., & Kim, J.K. (2023). Biochemical Responses and Phytoremediation Potential of *Azolla imbricata (Roxb.) Nakai* in Water and Nutrient Media Exposed to Waste Metal Cutting Fluid along with Temperature and Humidity Stress. Journal of Hazardous Materials, Vol. 451. https://doi.org/10.1016/j.jhazmat.2023.131101
55. Snyder, H. (2019). Literature Review as A Research Methodology: An Overview and Guidelines. Journal of Business Research. Vol. 104, p. 333‒339. https://doi.org/10.1016/j.jbusres.2019.07.039
56. Souza, T.D., Borges, A.C., Braga, A.F., Veloso, R.W., & Matos, A.T. (2019). Phytoremediation of Arsenic Contaminated Water by *Lemna Valdiviana*: An Optimization Study. Chemosphere, Vol. 234, p. 402‒408. http://dx.doi.org/10.1016/j.chemosphere.2019.06.004
57. Suelee, A.L., Hasan, S.N.M.S., Kusin, F.M., Yusuff, F.M., & Ibrahim, Z.Z.. (2017). Phytoremediation Potential of Vetiver Grass (*Vetiveria zizanioides*) for Treatment of Metal-Contaminated Water. Water, Air, & Soil Pollution. Vol. 228, No. 158. https://link.springer.com/article/10.1007/s11270-017-3349-x
58. Yadav, S. K. (2010). Heavy Metals Toxicity in Plants: An Overview on The Role of Glutathione and Phytochelatins in Heavy Metal Stress Tolerance of Plants. South African Journal of Botany, Vol. 76, No. 2, p. 167–179. https://doi.org/10.1016/j.sajb.2009.10.007
59. Yunus, R., & Prihatini, N. S. (2018). Phytoremediation of Fe and Mn of Coal Mine Acid Water with Water Hyacinth (*Eichornia crassipes*) and Rat Purun (*Eleocharis dulcis*) in the LBB System at PT. JBG South Kalimantan. Journal of Scientific, Vol. 7, No. 1, p. 73‒85. https://doi.org/10.35580/sainsmat7164812018
60. Zhou, Q. X., & Song, Y. F. (2007). Remediation of contaminated soils: Principles and methods. Beijing: Science Press.

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