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Review

Advancements in Phytoremediation Techniques for Purification of Industrial Wastewater: A review

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Abstract
Phytoremediation is considered as an economical and ecologically beneficial approach that has demonstrated efficacy in cleaning up contaminated water and soils. Particularly, phytoremediation is the only approach used for various types of wetlands when applied on a large scale to purify industrial effluent. Nonetheless, most research on the phytoremediation of contaminated water in wetland-type reactors has been done as a black box. The pollutant removal efficiency is the sole criterion used to assess performance, and data available regarding the processes and mechanisms involved in pollutant removal in these systems. Therefore, this chapter aims to provide a quick overview of the fundamental procedures of phytoremediation including characteristics, mechanisms, and microbial and plant Interactions in Rhizoremedation Processes. Furthermore, this chapter covered the difficulties and approaches associated with applying phytoremediation on a large scale, as well as the methods used by aquatic plants to eliminate both organic and inorganic pollutants from water and some examples of its industrial applications.

Keywords: Phytoremediation, Aquatic Plants, Industrial Wastewater, Pollutant removal Constructed Wetlands

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1. Introduction
The elimination of water pollutants could not be achieved with conventional wastewater treatment. The wastewater effluent still contains traces of harmful contaminants. Therefore, an alternative technology is required to minimize pollutant concentration down to an acceptable level; various technologies for treating wastewater are presented. Nevertheless, the bulk of these techniques are expected to include substantial maintenance costs, carbon emissions would be high, excessive sludge output, and substantial energy requirements [1-3].

Eco-friendly and inexpensive remediation techniques are necessary for the sustainable management of aquatic environments. However, both inorganic and organic pollutants may be eliminated by aquatic plants. The phytoremediation is used to remediate wastewater and absorb nutrients from the wastewater through their roots [4-6]

Several plant species can accumulate specific contaminants. It has been demonstrated that phytoremediation is more successful, economical, and ecologically benign than traditional treatments like *Thelypteris palustris*, *Brassica juncea*, and *Typha latifolia*, have a high capacity for phytoremediation, which involves the use of the bioaccumulation process to remove heavy metals like Cu and Zn [7]. *Pistia stratiotes* and *Salvinia mo- lesta* are also commonly employed for the treatment of wastewater from domestic, industrial, and agriculture [8].

Plant species are not the only essential component of an effective phytoremediation process; the contribution of rhizosphere-associated microbes is significant in the phytoremediation process [9]. Microorganisms contribute to the improvement of the phytoremediation process through bioaugmentation and biosorption [10]. It has been found that several organisms can improve the phytoremediation process, including *Rhodococcus, Pseudomonas, Bacillus 95 mycobacterium, Acidovo- rax, Alcaligenes, Paenibacillus* [11].

There is extremely limited evidence regarding the dynamics and mechanisms that govern pollutant removal in these systems and the performance is solely determined by the efficiency of the removal of pollutants. This chapter provides a brief overview of the fundamental procedures, parameters, and interactions between microbe-plant and rhizo-remediation in phytoremediation. It also discusses the difficulties and strategies of phytoremediation, including how aquatic plants may remove both organic and inorganic toxins from water, as well as some examples of its usage in various industries.

Phytoremediation Principles

It is important to distinguish between the concepts of phytoremediation and bioremediation. Heterotrophic bacteria are the ones that aid in the bioremediation process by breaking down organic pollutants, mineralizing them, accumulating metals and other components, and oxidizing inorganic substances [12].

The phytoremediation technique relies on the ability of photoautotroph microorganisms to deal with pollutants through processes such as:

- Releasing organic materials as byproducts of their metabolism during maintenance and growth, increases the population of heterotrophic bacteria.
- Increase the number of facultative, anaerobic and aerobic organisms in the rhizosphere during root dieback by pumping oxygen into the root zone of the plant and releasing secondary metabolites. This will help these organisms break down or accumulate pollutants.
- Pollutants are transported into active microbial zones through evapotranspiration, flow obstruction, and other mechanisms [13,14]

More specifically, as Table 1 illustrates, phytoremediation techniques can be classified into numerous categories, including phytostabilization, phytovolatilization, phytodegradation, phytofiltration, and phytoextraction.

Table 1. Varieties of phytoremediation methods, influencing factors, and applications.

Type of phytoremediation	Mechanisms	Influential factors	Applications	Reference
Phytodegradation/ phyto-oxidation	Terrestrial and aquatic plants absorb, store, and break down organic compounds to produce harmless byproducts. This process is known as phytodegradation. Enzymes are involved in development and senescence. Also, engaged in the detoxification and metabolism of plants.	Soil conditions, plant species, and pollutant concentration and composition.	soil, sludges made of silt, surface and groundwater, wastewate r, compound-contaminated air and wetlands,	[15] [16]
Phytofiltration	Contaminants accumulating in the rhizosphere	The plant needs to be highly metal-resistant, very adsorption-surface-tolerant, and highly hypoxic-tolerant. The kind and depth of contaminants affect long-term maintenance, which is very species-specific and inhibits plant growth.	landfill leachates, phosphate, Wetlands, radioactive waste, organic compounds, nitrate and metals-contaminated groundwater, ammonium, wastewater and pathogens	[17]
Phytovolatilization	Change from toxic to less toxic compound. leaves' volatilization	The potential for precipitation to cause pollutants to be redeposited into ecosystems	groundwaterup, Soils, sludge, sediments, and wetlands	[18]
Phytoextraction	Hyperaccumulation transfers contaminants to plant tissues that can be harvested.	Potential for contaminants to seep into groundwater	Soil	[19]
Phytostabilization	Reforestation to stop soil erosion and the transportation of absorbed pollutants	Plants regulate the redox, pH, and soil gases that lead to sorption, precipitation, and speciation, which create stable mineral deposits.	Soil, wetlands, leachate pond sediments, mining tailings, certain pesticides, anilines, and phenols	[20]

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Microbial and Plant Interaction in Rhizoremedation Processes

The most crucial region for phytoremediation is the rhizosphere. The area where contaminants and the treatment agent (plant) come into touch is known as the rhizosphere [21]. Al-Ajalin et al. [22] found that the roots of plants significantly aided the removal of pollutants from wastewater. In addition to the root, rhizobacteria—a type of microbe—strongly assist in the pollutant's breakdown within the rhizosphere [23]. Interactions between microbes and plant roots cause pollutants in the polluted media to be removed, as shown in Figure 1 [24].

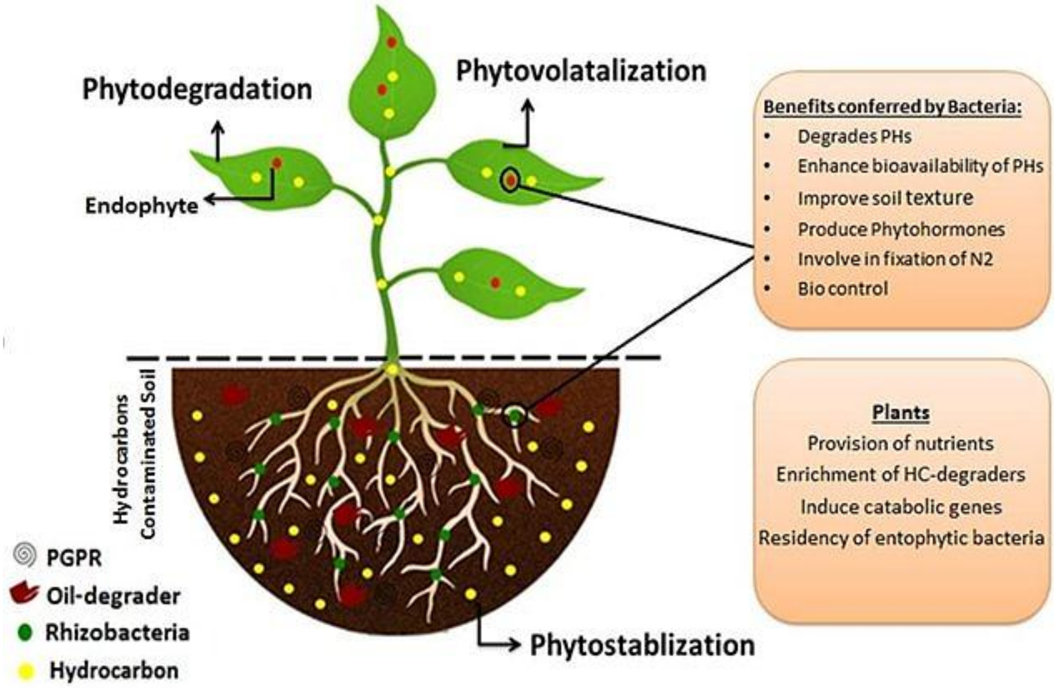

Fig.1. Interaction between microbes and plants during phytoremediation

The phytoremediation of contaminants from wastewater involves four main rhizosphere interactions: phytostabilization, phytostimulation biodegradation, and rhizofiltration [25] A process termed phytostimulation allows plants to exude their fluids into the rhizosphere. The exudates that are generated close to the root area create an ideal growing environment for rhizobacteria. Exudates encourage the formation of rhizobacteria, which engage in symbiotic relationships. Rhizodegradation and phytostimulation are inextricably linked processes. Rhizodegradation is the process by which contaminants in the rhizosphere are broken down by rhizobacteria [26].

There will be greater breakdown of contaminants as the more rhizobacteria proliferate. Rhizodegradation typically happens when wastewater with a high content of organic compounds is being treated. Rhizobacteria may function as a stabilizing agent in heavy metal-containing wastewater, converting the metals' ionic state into a stable state [27,28]. Additionally, rhizobacteria are capable of bioaccumulation, which stabilizes heavy metal levels inside of cells. However, plant exudates also contain complex compounds that can either directly bind with

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metals to generate metal exudates that are subsequently stabilized in the rhizosphere (a process known as phytostabilization) or increase the solubility of metals (so that they can be treated further by rhizobacteria) [29]. However, plant roots physically remediate wastewater by filtering out larger chemicals within their roots. This technique was mostly used in the treatment of contaminants with species of fibrous roots. Following the completion of multiple processes in the rhizosphere, a plant proceeds with phytoextraction, whereby it utilizes transfer mechanisms to assimilate contaminants and then concentrates them within its cells [30]. Both the pollutant and its intermediary compounds after they have been broken down by rhizobacteria can be the subject of phytoextraction. Using a sub-surface or free-surface constructed wetland to treat wastewater does not significantly differ in its methods [31].

Innovative Approaches in Plant-Microbe Collaboration

Even though applying phytoremediation to remediate industrial wastewater has several benefits, this technique still has some difficulties. Table 2 summarizes some of the phytoremediation implementation issues along with potential solutions.

Table 2: Challenges and strategies for applying phytoremediation technique

Challenges	Strategies
In the rhizosphere, there is little contact with pollutants	Development of an effective wetland system
Area requirement	Provide an ideal growing environment
Environmental circumstances	Controlled environment under ideal circumstances
Plant's ability to tolerate pollutants	Phytotoxicity test and range finding
Time requirement	Integrated treatment technology
Biomass management	Biomass conversion into useful products

For phytoremediation to be effective, several factors must be met, such as temperature, humidity, sunlight, and specific nutrients needed for the growth of plants. Thus, all of these requirements must be satisfied during application to yield the best removal efficiency [32]. Because tropical regions have year-round sunshine and the ideal temperature and humidity for plant growth, phytoremediation is thought to be highly appropriate for usage there; unlike sub-tropical regions, a controlled environment is necessary. To keep the ideal climatic conditions for plants to cure contaminants, greenhouse treatment is advised [33]. Plants can sustain their performance year-round in a regulated setting, which could result in the appropriate removal efficiency. Since the rhizosphere is where contaminants and treatment agents come into contact, it is the most crucial area for phytoremediation. When plant roots do not make good touch with contaminants, this could become problematic [34]. To address this problem, the design of a suitable artificial wetland must be completed

When creating a suitable artificial wetland, there are many critical factors to take into account such as the kind of plants, features of the pollutants, depth of the constructed wetland, how the pollutants are disposed of, the kind of wetland that will be utilized, and the plant growth medium [35]. By employing the biological approach, studies must be aware that specific pollutant concentrations can interfere with phytoremediation's ability to work. Only specific plants that can withstand significant pollutant loading may be more effective at elimination during treatment. Before applying phytoremediation, it is necessary to select the right species and execute range finding and phytotoxicity tests in order to prevent plant mortality, which could lower removal performance [36].

Plants can serve as the primary treatment option if they can tolerate a pollution concentration of 100%. However, the second or third option for treatment should be selected if the plant can tolerate only lower concentrations of contaminants. These challenges are closely associated with the rate at which plants degrade contaminants while receiving treatment [37]. Chemical treatment has a different reaction than Biological treatment. Stoichiometry of reaction is based on the products and equilibrium of reactants to regulate the degradation of pollutants in chemical treatment. Given that biological treatments entail complicated systems involving multiple components occurring during treatment, plants' capabilities cannot be simply calculated as products equilibrium and reactants [38]. The majority of studies recommend using phytoremediation as a secondary or tertiary treatment to address these problems and clean wastewater before releasing it into bodies of water.

The primary course of treatment is chemical treatment, which could decrease the pollutant load during the phytoremediation stage and before the application.

result in a higher removal rate, hence cutting down on the amount of time and surface area needed for treatment [39]. Plant biomass is generated as the plant grows throughout the treatment and can be regarded as extensive in quantity. If harmful compounds were treated by phytoremediation, the generated plant biomass must be managed in accordance with the accepted practices for managing toxic compounds [40]

Numerous studies on exploiting biomass have been effectively implemented to transform biomass into various products such as animal feed, fertilizer, charcoal, adsorbent, and biofuel. By applying these conversion alternatives, phytoremediation-based wastewater treatment may result in a cleaner production strategy through treatment by products [41-43].

Selection of Aquatic plants for effective Phytoremediation

Phytoremediation requires aquatic plants in order to degrade and remove contaminants from aquatic environments such as ferns, freshwater-adapted angiosperms and pteridophytes. For the treatment of wastewater, aquatic plants are mostly favored over terrestrial ones because of their higher biomass production, quicker growth rate, and superior capacity to remove contaminants from wastewater due to direct contact [44]. Diverse pollutants have different harmful effects on aquatic plants. A few detrimental reactions of aquatic plants to pollutants in the water include chlorosis, decreased growth, withering, a decrease in the length or volume of roots and shoots, a decrease in chlorophyll, plant death, and a decrease in photosynthetic activity [45]. De Campos et al. (2019) conducted a study wherein *Pistia stratiotes* exposed to a high concentration of arsenite indicated that while this species could sustain their biomass, there

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was notable chlorosis in the leaves, a decrease in the root volume, and cell membrane destruction [46].

Different aquatic plants have different capacities to absorb pollutants. Consequently, it is important to consider the traits of the chosen plants in order to lessen the adverse impacts on the growth of the plants in a phytoremediation method. tolerance to the intended heavy metals' harmful effects, high growth rates, widely dispersed, highly branched root system, capacity to break down pollutants, control chemical speciation, handle high concentrations of the heavy metals, shifting heavy metal accumulation from the roots to the shoots, high bioaccumulation potential increased above-ground biomass production [47,48].

Wastewater is a blend of several heavy metals, chemicals and pure water from commercial, industrial, agricultural, and household sources. Pesticides (deltamethrin, hexachlorocyclohexane, glyphosate, fenhexamid), personal care products and pharmaceuticals (i.e., pain relief medication, hormones, and antibiotics) and persistent organic pollutants constitute the main organic pollutants. In contrast, the most common inorganic pollutants include nutrients (P, K, and N) and metalloid elements (Cu, Fe, Pb Al, Cd and Ni). Given that, these different contaminants have various detrimental consequences on the ecosystem; their presence warrants considerable consideration [49,50] According to Fletch et al. (51), such toxins have the potential to have the following negative consequences on chronic toxicity, eutrophication, antibiotic resistance and endodontic disruption and environment

Types of aquatic plants

Aquatic plants have received a lot of attention because of their capacity to purify contaminated water bodies. These plants are the greatest choice for breaking down pollutants in a phytoremediation system because of their extensive root systems. Aquatic plants can be divided into three categories based on the way they grow: free-floating, emergent and submerged plants [52].

Aquatic plants that have submerged roots and floating leaves are known as free-floating plants. Numerous free-floating aquatic plants have undergone in-depth research and have been given the go-ahead to be used in various phytoremediation systems such as water hyacinths (*Eichhornia*), water lettuce (*Pistia*), Duckweeds (*Wolffia and Lemna Spirodela*) and water ferns (*Salvinia*, *Azolla*). These plants are well-known for their capacity to remove a broad range of heavy metals, organic and inorganic pollutants, nutrients, and pesticides, from many different sources, including sewage, runoff from farms, and domestic and industrial wastewater. Furthermore, those plants can flourish in contaminated areas with extreme variations in pH, temperature, and nutrition levels [45, 53]. The term "submerged aquatic plants" refers to mud-rooted plants that typically thrive underwater. The primary component that absorbs pollutants is their leaves including water mint (*Mentha aquatic*), hornwort (*Ceratophyllum demersum*), Esthwaite waterweed (*Hydrilla*), watermilfoil (*Myriophyllum*) and pondweed (*Potamogeton*). The majority of these plants are typically found in lakes, ponds, and streams with slow currents. Furthermore, several variables, including temperature, pH, and the types and concentrations of contaminants, affect how well these plants remove pollutants [54,55].

These plants maintain their roots below the water's surface while growing their branches and leaves above it. The common emergent aquatic plants that are useful for phytoremediation include foxtail flats edge (*Cyperus alopecuroides*), bulrush (*Scirpus*), reed canary grass (*Phalaris arundinacea*), cattails (*Typha*) and common reed (*Phragmites australis*). Due to their relative ease of

harvesting, these plant species have drawn a lot of interest in the field of nutrient phytoremediation and are frequently used in constructed wetland construction [45,53].
Additionally, transgenic plants are another kind of plant that has sparked attention in phytoremediation. In order to improve the detoxification of organic contaminants and enable higher metabolism, transgenic plants were modified to carry out certain gene functions, hence facilitating more efficient phytoremediation. Using this method, organic contaminants in the rhizosphere zone are broken down by enzymes secreted by integrated genes. *Tailored Nicotiana tabaccum* and *Arabidopsis thaliana* are two examples of transgenic plants that effectively eliminate mercury, cadmium, and heavy metals [56].
Numerous aquatic plant species have been extensively researched for their potential in phytoremediation, with some significant achievements. Several typical aquatic plants that have been used in phytoremediation experiments recently are shown in Table 3. It should be highlighted, nonetheless, that the efficiency of a pollutant's degradation depends on several interrelated parameters, such as the physicochemical features of the pollutant plant, length of exposure, the characteristics of the surrounding environment, and the concentration of the pollutant [57].

Table 3: Current research on phytoremediation employing some famous aquatic plants

Plant species	Life form	Target contaminant	Removal effectiveness	Reference
Pistiastratiotes	Free-floating	phosphates, Ammonium-Nitrogen, Chemical oxygen demand, nitrates	73.72-92.89% for phosphates, 76.78–98.79% for Ammonium-Nitrogen, 47.82–88.00% for chemical oxygen demand and 16.92-97.14% for nitrates	[58]
Scirpus validus	Emerged	Decabromodiphenyl ether	72.22-92.84%	[59]
Myriophyllum aquaticum	Submerged	Total phosphorus	78.2–89.8%	[60]
Lemnaminuta	Free-floating	Phenol and Hexavalent chromium	phenol 100% and 75–85% for Hexavalent chromium	[61]
		Lead	82.23-93.19%	[62]
Typha latifolia	Emerged	As, Hg Pb, Zn and Cu	>80% for all metals, with Pb at 64%.	[63]
		Nickel, lead, and Cadmium	84% for Nickel, 95% for lead,and 93% for Cadmium	[64]
		Chromium	96.70%	[65]
Lemna minor	Free-floating	Methylene Blue Dye (MBD)	80.56%	[27]
Spirodela polyrhiza	Free-floating	Ofloxacin	93.73–98.36%	[66]

		Antibiotic		
Scirpusgrossus	Emerged	SS, color and COD	87.2% for SS 55.8% forcolor and 66.1% for COD	[67]
		Clomazone - Herbicides	90%	[68]
Hydrilla verticillate	Submerged	Suspended Solid, COD and BOD	55.55% for Suspended Solid, 77.78% for COD and 66.72% for BOD	[69]
		Caesium and Cobalt	60% for Caesium and 90% for Cobalt	[70]
Eichhornia crassipes	Free-floating	dissolved organic nitrogen and Ammonium nitrogen	>99% for dissolved organic nitrogen and Ammonium nitrogen	[71]
		BOD, COD and TSS	93% for BOD 88% for COD and 98% for TSS	[72]
		Phenol	90-99%	[73]
Phragmites australis	Emerged	Paroxetine and bezafibrate Pharmaceuticals	65-95% for paroxetine and 47-75% for bezafibrate	[74]
Scirpus mucronatus	Emerged	Total Petroleum Hydrocarbon (TPH)	74.9-82.1%	[75]
Myriophyllum spicatum	Submerged	Zinc oxide	29.5-70.3%	[76]

Constructed wetlands for effective industrial wastewater treatment

The most popular phytoremediation model, which adheres to the fundamentals of phytoremediation, is the constructed wetland. Sub-surface flow built wetlands (SSFCW) and free water surface flow constructed wetlands (FWSCW) are the two main categories of constructed wetlands (CW). Subsurface flow can be divided into several categories: vertical flow (VF) CW, horizontal flow (HF) CW, free vertical flow (FVF) CW, and hybrid-type CW [77]. A constructed wetland can eliminate a large amount of organic contaminants, particularly nutrients like phosphorus and nitrogen. To improve the effluent's quality, a constructed wetland could be added to an integrated wastewater treatment plant's system following biological secondary treatment [78,79]. Table 4 summarizes the extensive use of constructed wetlands in several industries.

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Table 4: Constructed wetland treatment of industrial wastewater.

Industry	Wastewater	Plant	Removal (%)	Year	Country
Tannery Industry	-	*Typha latifolia* and *Phragmites australis,*	COD: 92 BOD_5: 88	2005-2006	Portugal
Sugar industry	Molasses after Anaerobic	*Thalia dealbata ,Typha augustifolia* and *Cyperus involucratus*	BOD_5: 88–89 N-NH4+: 77- 82%, SS: 90–93 Total phosphorus: 70–76 COD: 67 Molasses pigment: 72–77	2007	Thailand
Glass industry	Wastewater from the factory's machinery and the washing of glass sheets.	Pampas grass	TSS: 99 COD: 90 TP: 96 BOD_5: 90 TN: 95	2018	Iran
Tannery Industry	-	*I. pseudacorus* *Canna indica, Stenotaphrum secundatum,* *P. australis,* and *T. latifolia*	BOD_5: 41–58 COD: 41–73	-	Portugal
Winery industry	-	*Nymphaea rustica, Elodea Canadensis, demersum, Ceratophyllum, Phragmites australis, Typha latifolia* and *Nymphaea alba*	COD: 87-98 Total nitrogen: 50-90 BOD_5: 92-98 Total phosphorus: 20-60 TSS: 70-90	2001	Italy
Winery industry	winery, sewage	*, Iris pseudacorus L,* *Scirpus lacustris L., Canna indica L.,* *Cyperus Papyrus var. Siculus,* *Nymphaea alba L., Phragmites australis L* and *Scirpus lacustris L.*	Removal 81% for BOD_5, 78% for COD and 69% for TSS	2014-2018	Italy
Dairy industry	Dewatering aerobic sludge.	*Phragmites australis*	N-NH +:4 89.2–85.7%, TKN: 82.4–76.5%, TP: 30.2–40.6% BOD_5: 88.1– 90.5%,	2012	Poland

Olive mill industry	Extraction process Effluents	*Phragmites australis*	Removals 75%, 70%,87% and 70%, for TKN, COD, ortho-phosphate and phenols	2010	Greece
Metallurgic industry	combined sewage and manufacturing effluents	*E. crassipes*, **P. cordata** and *T. domingensis*	Cr: 86 Nitrate: 70 Nitrite: 60 Fe: 95 Ni: 67	2002-2004	Argentina
Oil well	generated water from oil fields	*Scirpus californicus, Typha latifolia*	CW lowers water-soluble hazardous components that are appropriate for irrigation.	2000	US, South Carolina
Mining industry(Gold mining)	mining wastewater that has been tampered with using HgNO3	*Limnocharis flava*	Hg: 90	2016	Colombia
Industrial estate	(Chemicals, plastic textile, marble, steel, ghee, soap, detergent, and cooking oil).	*A. plantago-aquatica*, *P. australis*, *T. latifolia*, *C. aquatilis*, and *P. stratiotes*	Cu: 48.3 Pb: 50 Fe: 74.1 Cd: 91.9 Cr: 89 Ni: 40.9	2003–2004.	Pakistan

Conclusion

One of the first methods for eliminating contaminants from the environment, especially in soil and water, is phytoremediation. The utilization of the interaction between plant roots and root microbes is the fundamental idea behind phytoremediation. In order to develop a more reliable, successful, and efficient model, an in-depth understanding of the mechanisms behind the interactions between microbes and root plants is necessary. The preferred model for phytoremediation is the constructed wetland. This model's versatility and robustness give it many possibilities going forward. Recently, constructed wetland systems can incorporate several developed technologies, including Microbial Fuel Cells. It is important to investigate the possibilities of integrating phytoremediation with another cutting-edge technology in order to lower costs and improve effluent quality.

References

1. Park, J. K., & Oh, K. (2023). Advancements in phytoremediation research for soil and water resources: Harnessing plant power for environmental cleanup. Sustainability, 15(18), 13901.
2. Kathi, S., & Mahmoud, A. E. D. (2024). Trends in Effective Removal of Emerging Contaminants from Wastewater: A Comprehensive Review. Desalination and Water Treatment, 100258.
3. Liu X, Li S, Chen W, Yuan H, Ma Y, Siddiqui MA, Iqbal A. Assessing Greenhouse Gas Emissions and Energy Efficiency of Four Treatment Methods for Sustainable Food Waste Management. Recycling. 2023 Aug 27;8(5):66.
4. Kafle, A., Timilsina, A., Gautam, A., Adhikari, K., Bhattarai, A., & Aryal, N. (2022). Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents. Environmental Advances, 8, 100203.
5. Ahmed, A. M., & Kareem, S. L. (2024). Evaluation of the effectiveness of phytoremediation technologies utilizing Lemna minor in constructed wetlands for

wastewater treatment. Biomass Conversion and Biorefinery, 1-13.
6. Shahi Khalaf Ansar, B., Kavusi, E., Dehghanian, Z., Pandey, J., Asgari Lajayer, B., Price, G. W., & Astatkie, T. (2023). Removal of organic and inorganic contaminants from the air, soil, and water by algae. Environmental Science and Pollution Research, 30(55), 116538-116566.
7. Hejna, M., Moscatelli, A., Stroppa, N., Onelli, E., Pilu, S., Baldi, A., & Rossi, L. (2020). Bioaccumulation of heavy metals from wastewater through a Typha latifolia and Thelypteris palustris phytoremediation system. Chemosphere, 241, 125018.
8. Mustafa, H. M., & Hayder, G. (2021). Recent studies on applications of aquatic weed plants in phytoremediation of wastewater: A review article. Ain Shams Engineering Journal, 12(1), 355-365.
9. Xiao, Y., Chen, L., Li, C., Ma, J., Chen, R., Yang, B., ... & Fang, J. (2023). Role of the rhizosphere bacterial community in assisting phytoremediation in a lead-zinc area. Frontiers in Plant Science, 13, 1106985.
10. Ayilara, M. S., & Babalola, O. O. (2023). Bioremediation of environmental wastes: the role of microorganisms. Front Agron 5: 1183691.
11. Sharma, P., Tripathi, S., Chaturvedi, P., Chaurasia, D., & Chandra, R. (2021). Newly isolated Bacillus sp. PS-6 assisted phytoremediation of heavy metals using Phragmites communis: Potential application in wastewater treatment. Bioresource technology, 320, 124353.
12. Saha, L., Tiwari, J., Bauddh, K., & Ma, Y. (2021). Recent developments in microbe–plant-based bioremediation for tackling heavy metal-polluted soils. Front Microbiol 12: 731723.
13. Tiodar, E. D., Văcar, C. L., & Podar, D. (2021). Phytoremediation and microorganisms-assisted phytoremediation of mercury-contaminated soils: challenges and perspectives. International Journal of Environmental Research and Public Health, 18(5), 2435.
14. Zhao L, Lyu C, Li Y. Analysis of factors influencing plant–microbe combined remediation of soil contaminated by polycyclic aromatic hydrocarbons. Sustainability. 2021 Sep 26;13(19):10695.
15. Kagalkar, A. N., Jadhav, M. U., Bapat, V. A., & Govindwar, S. P. (2011). Phytodegradation of the triphenylmethane dye Malachite Green mediated by cell suspension cultures of Blumea malcolmii Hook. Bioresource technology, 102(22), 10312-10318.
16. Park, S., Kim, K. S., Kim, J. T., Kang, D., & Sung, K. (2011). Effects of humic acid on phytodegradation of petroleum hydrocarbons in soil simultaneously contaminated with heavy metals. Journal of environmental sciences, 23(12), 2034-2041.
17. Sandhi, A., Landberg, T., & Greger, M. (2018). Phytofiltration of arsenic by aquatic moss (Warnstorfia fluitans). Environmental Pollution, 237, 1098-1105.
18. Zayed, A., Pilon-Smits, E., deSouza, M., Lin, Z. Q., & Terry, N. (2020). Remediation of selenium-polluted soils and waters by phytovolatilization. In Phytoremediation of contaminated soil and water (pp. 61-83). CRC press.
19. Yu, G., Jiang, P., Fu, X., Liu, J., Sunahara, G. I., Chen, Z., ... & Wang, X. (2020). Phytoextraction of cadmium-contaminated soil by Celosia argentea Linn.: A long-term field study. Environmental Pollution, 266, 115408.
20. Arliyani, I., Tangahu, B. V., Mangkoedihardjo, S., Zulaika, E., & Kurniawan, S. B. (2023). Enhanced leachate phytodetoxification test combined with plants and rhizobacteria bioaugmentation. Heliyon, 9(1).
21. Wang, J., & Delavar, M. A. (2023). Techno-economic analysis of phytoremediation: A strategic rethinking. Science of The Total Environment, 165949.
22. Al-Ajalin, F. A. H., Idris, M., Abdullah, S. R. S., Kurniawan, S. B., & Imron, M. F. (2020). Evaluation of short-term pilot reed bed performance for real domestic

wastewater treatment. Environmental Technology & Innovation, 20, 101110.

23. Jehawi, O. H., Abdullah, S. R. S., Kurniawan, S. B., Ismail, N. I., Idris, M., Al Sbani, N. H., ... & Hasan, H. A. (2020). Performance of pilot Hybrid Reed Bed constructed wetland with aeration system on nutrient removal for domestic wastewater treatment. Environmental Technology & Innovation, 19, 100891.
24. Figure Fatima K, Imran A, Naveed M, Afzal M. Plant-bacteria synergism: An innovative approach for the remediation of crude oil-contaminated soils. Soil Environ. 2017 Nov 28;36(2):93-113.
25. Khan AU, Khan AN, Waris A, Ilyas M, Zamel D. Phytoremediation of pollutants from wastewater: A concise review. Open Life Sciences. 2022 May 13;17(1):488-96.
26. Chojnacka, K., Moustakas, K., & Mikulewicz, M. (2023). The combined rhizoremediation by a triad: plant-microorganism-functional materials. Environmental Science and Pollution Research, 30(39), 90500-90521.
27. Imron, M. F., Kurniawan, S. B., Ismail, N. I., & Abdullah, S. R. S. (2020). Future challenges in diesel biodegradation by bacteria isolates: a review. Journal of Cleaner Production, 251, 119716.
28. Vocciante, M., Grifoni, M., Fusini, D., Petruzzelli, G., & Franchi, E. (2022). The role of plant growth-promoting rhizobacteria (PGPR) in mitigating plant's environmental stresses. Applied Sciences, 12(3), 1231.
29. Yan, A., Wang, Y., Tan, S. N., Mohd Yusof, M. L., Ghosh, S., & Chen, Z. (2020). Phytoremediation: a promising approach for revegetation of heavy metal-polluted land. Frontiers in plant science, 11, 359.
30. Purwanti, I. F., Obenu, A., Tangahu, B. V., Kurniawan, S. B., Imron, M. F., & Abdullah, S. R. S. (2020). Bioaugmentation of Vibrio alginolyticus in phytoremediation of aluminium-contaminated soil using Scirpus grossus and Thypa angustifolia. Heliyon, 6(9).
31. Rahman, M. E., Bin Halmi, M. I. E., Bin Abd Samad, M. Y., Uddin, M. K., Mahmud, K., Abd Shukor, M. Y., ... & Shamsuzzaman, S. M. (2020). Design, operation and optimization of constructed wetland for removal of pollutant. International Journal of Environmental Research and Public Health, 17(22), 8339.
32. Mocek-Płóciniak, A., Mencel, J., Zakrzewski, W., & Roszkowski, S. (2023). Phytoremediation as an effective remedy for removing trace elements from ecosystems. Plants, 12(8), 1653.
33. Bolan, S., Padhye, L. P., Jasemizad, T., Govarthanan, M., Karmegam, N., Wijesekara, H., ... & Bolan, N. (2023). Impacts of climate change on the fate of contaminants through extreme weather events. Science of The Total Environment, 168388.
34. Hassan, I., Chowdhury, S. R., Prihartato, P. K., & Razzak, S. A. (2021). Wastewater treatment using constructed wetland: Current trends and future potential. Processes, 9(11), 1917.
35. Almuktar, S. A., Abed, S. N., & Scholz, M. (2018). Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review. Environmental Science and Pollution Research, 25, 23595-23623.
36. Abdullah, S. R. S., Al-Baldawi, I. A., Almansoory, A. F., Purwanti, I. F., Al-Sbani, N. H., & Sharuddin, S. S. N. (2020). Plant-assisted remediation of hydrocarbons in water and soil: Application, mechanisms, challenges and opportunities. Chemosphere, 247, 125932.
37. Priya, A. K., Muruganandam, M., Ali, S. S., & Kornaros, M. (2023). Clean-up of heavy metals from contaminated soil by phytoremediation: A multidisciplinary and eco-friendly approach. Toxics, 11(5), 422.
38. Kwoczynski, Z., & Čmelík, J. (2021). Characterization of biomass wastes and its possibility of agriculture utilization due to biochar production by torrefaction process. Journal of Cleaner Production, 280, 124302.
39. Islam, M. M., Saxena, N., & Sharma, D. (2024). Phytoremediation as a green and

sustainable prospective method for heavy metal contamination: a review. RSC Sustainability.

40. Edgar, V. N., Fabián, F. L., Mario, P. C. J., & Ileana, V. R. (2021). Coupling plant biomass derived from phytoremediation of potential toxic-metal-polluted soils to bioenergy production and high-value by-products—A review. Applied Sciences, 11(7), 2982.
41. Abd Kadir, A., Abdullah, S. R. S., Othman, B. A., Hasan, H. A., Othman, A. R., Imron, M. F., ... & Kurniawan, S. B. (2020). Dual function of Lemna minor and Azolla pinnata as phytoremediator for Palm Oil Mill Effluent and as feedstock. Chemosphere, 259, 127468.
42. Das, S. K., Ghosh, G. K., & Avasthe, R. (2021). Applications of biomass derived biochar in modern science and technology. Environmental Technology & Innovation, 21, 101306.
43. Rezania, S., Oryani, B., Cho, J., Sabbagh, F., Rupani, P. F., Talaiekhozani, A., ... & Lotfi Ghahroud, M. (2020). Technical aspects of biofuel production from different sources in Malaysia—a review. Processes, 8(8), 993.
44. Sood, A., Uniyal, P. L., Prasanna, R., & Ahluwalia, A. S. (2012). Phytoremediation potential of aquatic macrophyte, Azolla. Ambio, 41, 122-137.
45. Ansari, A. A., Naeem, M., Gill, S. S., & AlZuaibr, F. M. (2020). Phytoremediation of contaminated waters: An eco-friendly technology based on aquatic macrophytes application. The Egyptian Journal of Aquatic Research, 46(4), 371-376
46. Correa, D. F., Beyer, H. L., Fargione, J. E., Hill, J. D., Possingham, H. P., Thomas-Hall, S. R., & Schenk, P. M. (2019). Towards the implementation of sustainable biofuel production systems. Renewable and Sustainable Energy Reviews, 107, 250-263.
47. Uddin, M. M., Zakeel, M. C. M., Zavahir, J. S., Marikar, F. M., & Jahan, I. (2021). Heavy metal accumulation in rice and aquatic plants used as human food: A general review. Toxics, 9(12), 360.
48. Zhakypbek, Y., Kossalbayev, B. D., Belkozhayev, A. M., Murat, T., Tursbekov, S., Abdalimov, E., ... & Allakhverdiev, S. I. (2024). Reducing Heavy Metal Contamination in Soil and Water Using Phytoremediation. Plants, 13(11), 1534.
49. Boulkhessaim, S., Gacem, A., Khan, S. H., Amari, A., Yadav, V. K., Harharah, H. N., ... & Jeon, B. H. (2022). Emerging trends in the remediation of persistent organic pollutants using nanomaterials and related processes: A review. Nanomaterials, 12(13), 2148.
50. Rajput, P., Singh, A., Agrawal, S., Ghazaryan, K., Rajput, V. D., Movsesyan, H., ... & Alexiou, A. (2024). Effects of environmental metal and metalloid pollutants on plants and human health: exploring nano-remediation approach. Stress Biology, 4(1), 1-25.
51. Fletcher, J. (2022). Optimising multi-pollutant phytoremediation strategies to sustainably improve raw water quality.
52. Falahi, O. A. A., Abdullah, S. R. S., Hasan, H. A., Othman, A. R., Ewadh, H. M., Kurniawan, S. B., & Imron, M. F. (2022). Occurrence of pharmaceuticals and personal care products in domestic wastewater, available treatment technologies, and potential treatment using constructed wetland: a review. Process Safety and Environmental Protection, 168, 1067-1088.
53. Ali, S., Abbas, Z., Rizwan, M., Zaheer, I. E., Yavaş, İ., Ünay, A., ... & Kalderis, D. (2020). Application of floating aquatic plants in phytoremediation of heavy metals polluted water: A review. Sustainability, 12(5), 1927.
54. Dhir, B., & Dhir, B. (2013). Aquatic plant species and removal of contaminants. Phytoremediation: role of aquatic plants in environmental clean-up, 21-50.
55. Javed, M. T., Tanwir, K., Akram, M. S., Shahid, M., Niazi, N. K., & Lindberg, S. (2019). Phytoremediation of cadmium-polluted water/sediment by aquatic macrophytes: role of plant-induced pH changes. In Cadmium toxicity and

tolerance in plants (pp. 495-529). Academic Press.

56. Tiwari, S., & Sarangi, B. K. (2019). Transgenics for arsenic and chromium phytoremediation. Transgenic plant technology for remediation of toxic metals and metalloids, 167-185.
57. Anand, R., & Philip, L. (2024). Catalytic pulsed plasma treatment for organic micropollutants: unveiling the synergistic role of photocatalysts in radical generation and degradation mechanisms. Environmental Science: Water Research & Technology.
58. Olguín, E. J., García-López, D. A., González-Portela, R. E., & Sánchez-Galván, G. (2017). Year-round phytofiltration lagoon assessment using Pistia stratiotes within a pilot-plant scale biorefinery. Science of the Total Environment, 592, 326-333.
59. Zhao, L., Jiang, J., Chen, C., Zhan, S., Yang, J., & Yang, S. (2017). Efficiency and mechanism of the phytoremediation of decabromodiphenyl ether-contaminated sediments by aquatic macrophyte Scirpus validus. Environmental Science and Pollution Research, 24, 12949-12962.
60. Liu, F., Zhang, S., Luo, P., Zhuang, X., Chen, X., & Wu, J. (2018). Purification and reuse of non-point source wastewater via Myriophyllum-based integrative biotechnology: a review. Bioresource technology, 248, 3-11.
61. Paisio, C. E., Fernandez, M., González, P. S., Talano, M. A., Medina, M. I., & Agostini, E. (2018). Simultaneous phytoremediation of chromium and phenol by L emna minuta Kunth: a promising biotechnological tool. International journal of environmental science and technology, 15, 37-48.
62. Bind, A., Goswami, L., & Prakash, V. (2018). Comparative analysis of floating and submerged macrophytes for heavy metal (copper, chromium, arsenic and lead) removal: sorbent preparation, characterization, regeneration and cost estimation. Geology, Ecology, and Landscapes, 2(2), 61-72.
63. Anning, A. K., & Akoto, R. (2018). Assisted phytoremediation of heavy metal contaminated soil from a mined site with Typha latifolia and Chrysopogon zizanioides. Ecotoxicology and environmental safety, 148, 97-104.
64. Bello, A. O., Tawabini, B. S., Khalil, A. B., Boland, C. R., & Saleh, T. A. (2018). Phytoremediation of cadmium-, lead-and nickel-contaminated water by Phragmites australis in hydroponic systems. Ecological engineering, 120, 126-133.
65. Gemeda, S., Gabbiye, N., & Alemu, A. (2019). Phytoremediation Potential of Free Floating Plant Species for Chromium Wastewater: The Case of Duckweed, Water Hyacinth, and Water Lilies. In Advances of Science and Technology: 6th EAI International Conference, ICAST 2018, Bahir Dar, Ethiopia, October 5-7, 2018, Proceedings 6 (pp. 519-535). Springer International Publishing.
66. Singh, V., Pandey, B., & Suthar, S. (2019). Phytotoxicity and degradation of antibiotic ofloxacin in duckweed (Spirodela polyrhiza) system. Ecotoxicology and Environmental Safety, 179, 88-95.
67. Yusoff, M. F. M., Rozaimah, S. A. S., Hassimi, A. H., Hawati, J., & Habibah, A. (2019). Performance of continuous pilot subsurface constructed wetland using Scirpus grossus for removal of COD, colour and suspended solid in recycled pulp and paper effluent. Environmental Technology & Innovation, 13, 346-352.
68. Escoto, D. F., Gayer, M. C., Bianchini, M. C., da Cruz Pereira, G., Roehrs, R., & Denardin, E. L. (2019). Use of Pistia stratiotes for phytoremediation of water resources contaminated by clomazone. Chemosphere, 227, 299-304.
69. Jamil, M. H., Ishak, F. A., Syukor, A. A., Sulaiman, S., Siddique, M. N. I., & Zainuddin, S. Z. (2019). Man-made Lake of Taman Pertanian, Kuantan: the valuation of water quality and nutrient removal by using Hydrilla verticillata sp. and Myriophyllum aquaticum sp. as submerged plant species. Materials Today: Proceedings, 19, 1552-1561.

70. Saleh, H. M., Moussa, H. R., El-Saied, F. A., Dawoud, M., El Said, A. N., & Wahed, R. S. A. (2020). Adsorption of cesium and cobalt onto dried Myriophyllum spicatum L. from radio-contaminated water: Experimental and theoretical study. Progress in Nuclear Energy, 125, 103393.
71. Qin, H., Diao, M., Zhang, Z., Visser, P. M., Zhang, Y., Wang, Y., & Yan, S. (2020). Responses of phytoremediation in urban wastewater with water hyacinths to extreme precipitation. Journal of Environmental Management, 271, 110948.
72. Nash, D. A. H., Abdullah, S. R. S., Hasan, H. A., Idris, M., Othman, A. R., Al-Baldawi, I. A., & Ismail, N. I. (2020). Utilisation of an aquatic plant (Scirpus grossus) for phytoremediation of real sago mill effluent. Environmental Technology & Innovation, 19, 101033.
73. Chang, G., Yue, B., Gao, T., Yan, W., & Pan, G. (2020). Phytoremediation of phenol by Hydrilla verticillata (Lf) Royle and associated effects on physiological parameters. Journal of hazardous materials, 388, 121569.
74. Dias, S., Correia, B., Fraga-Santiago, P., Silva, C., Baptista, P. C., Gomes, C. R., & Almeida, C. M. R. (2021). Potential of an estuarine salt marsh plant (Phragmites australis (Cav.) Trin. Ex Steud 10751) for phytoremediation of bezafibrate and paroxetine. Hydrobiologia, 848, 3291-3304.
75. Almansoory, A. F., Idris, M., Abdullah, S. R. S., Anuar, N., & Kurniawan, S. B. (2021). Response and capability of Scirpus mucronatus (L.) in phytotreating petrol-contaminated soil. Chemosphere, 269, 128760.
76. Ergönül, M. B., Nassouhi, D., Çelik, M., & Atasağun, S. (2021). A comparison of the removal efficiencies of Myriophyllum spicatum L. for zinc oxide nanoparticles (ZnO NP) in different media: a microcosm approach. Environmental Science and Pollution Research, 28, 8556-8568.
77. Marín-Muñiz, J. L., Zitácuaro-Contreras, I., Ortega-Pineda, G., López-Roldán, A., Vidal-Álvarez, M., Martínez-Aguilar, K. E., ... & Zamora-Castro, S. (2024). Phytoremediation Performance with Ornamental Plants in Monocultures and Polycultures Conditions Using Constructed Wetlands Technology. Plants, 13(7), 1051.
78. Parde, D., Patwa, A., Shukla, A., Vijay, R., Killedar, D. J., & Kumar, R. (2021). A review of constructed wetland on type, treatment and technology of wastewater. Environmental Technology & Innovation, 21, 101261.
79. Thakur, T. K., Barya, M. P., Dutta, J., Mukherjee, P., Thakur, A., Swamy, S. L., & Anderson, J. T. (2023). Integrated phytobial remediation of dissolved pollutants from domestic wastewater through constructed wetlands: An interactive macrophyte-microbe-based green and low-cost decontamination technology with prospective resource recovery. Water, 15(22), 3877.

Here are the provided references converted into APA style:

1. Park, J. K., & Oh, K. (2023). Advancements in phytoremediation research for soil and water resources: Harnessing plant power for environmental cleanup. *Sustainability, 15*(18), 13901. https://doi.org/10.3390/su151813901
2. Kathi, S., & Mahmoud, A. E. D. (2024). Trends in effective removal of emerging contaminants from wastewater: A comprehensive review. *Desalination and Water Treatment, 100258.* https://doi.org/10.1080/19443994.2024.100258
3. Liu, X., Li, S., Chen, W., Yuan, H., Ma, Y., Siddiqui, M. A., & Iqbal, A. (2023). Assessing greenhouse gas emissions and energy efficiency of four treatment methods for sustainable food waste management. *Recycling, 8*(5), 66. https://doi.org/10.3390/recycling8050066
4. Kafle, A., Timilsina, A., Gautam, A., Adhikari, K., Bhattarai, A., & Aryal, N. (2022). Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents. *Environmental*

Advances, *8*, 100203. https://doi.org/10.1016/j.envadv.2022.100203

5. Ahmed, A. M., & Kareem, S. L. (2024). Evaluation of the effectiveness of phytoremediation technologies utilizing *Lemna minor* in constructed wetlands for wastewater treatment. *Biomass Conversion and Biorefinery,* 1-13. https://doi.org/10.1007/s13399-024-03069-0
6. Shahi Khalaf Ansar, B., Kavusi, E., Dehghanian, Z., Pandey, J., Asgari Lajayer, B., Price, G. W., & Astatkie, T. (2023). Removal of organic and inorganic contaminants from the air, soil, and water by algae. *Environmental Science and Pollution Research, 30*(55), 116538–116566. https://doi.org/10.1007/s11356-023-27046-6
7. Hejna, M., Moscatelli, A., Stroppa, N., Onelli, E., Pilu, S., Baldi, A., & Rossi, L. (2020). Bioaccumulation of heavy metals from wastewater through a *Typha latifolia* and *Thelypteris palustris* phytoremediation system. *Chemosphere, 241,* 125018. https://doi.org/10.1016/j.chemosphere.2019.125018
8. Mustafa, H. M., & Hayder, G. (2021). Recent studies on applications of aquatic weed plants in phytoremediation of wastewater: A review article. *Ain Shams Engineering Journal*, *12*(1), 355–365. https://doi.org/10.1016/j.asej.2020.09.002
9. Xiao, Y., Chen, L., Li, C., Ma, J., Chen, R., Yang, B., ... & Fang, J. (2023). Role of the rhizosphere bacterial community in assisting phytoremediation in a lead-zinc area. *Frontiers in Plant Science, 13,* 1106985. https://doi.org/10.3389/fpls.2023.1106985
10. Ayilara, M. S., & Babalola, O. O. (2023). Bioremediation of environmental wastes: The role of microorganisms. *Frontiers in Agronomy, 5,* 1183691. https://doi.org/10.3389/fagro.2023.1183691
11. Sharma, P., Tripathi, S., Chaturvedi, P., Chaurasia, D., & Chandra, R. (2021). Newly isolated *Bacillus* sp. PS-6 assisted phytoremediation of heavy metals using *Phragmites communis*: Potential application in wastewater treatment. *Bioresource Technology, 320,* 124353. https://doi.org/10.1016/j.biortech.2020.124353
12. Saha, L., Tiwari, J., Bauddh, K., & Ma, Y. (2021). Recent developments in microbe–plant-based bioremediation for tackling heavy metal-polluted soils. *Frontiers in Microbiology, 12,* 731723. https ://doi.org/10.3389/fmicb.2021.731723
13. Tiodar, E. D., Văcar, C. L., & Podar, D. (2021). Phytoremediation and microorganisms-assisted phytoremediation of mercury-contaminated soils: Challenges and perspectives. *International Journal of Environmental Research and Public Health, 18*(5), 2435. https://doi.org/10.3390/ijerph18052435
14. Zhao, L., Lyu, C., & Li, Y. (2021). Analysis of factors influencing plant–microbe combined remediation of soil contaminated by polycyclic aromatic hydrocarbons. *Sustainability, 13*(19), 10695. https://doi.org/10.3390/su131910695
15. Kagalkar, A. N., Jadhav, M. U., Bapat, V. A., & Govindwar, S. P. (2011). Phytodegradation of the triphenylmethane dye Malachite Green mediated by cell suspension cultures of *Blumea malcolmii* Hook. *Bioresource Technology, 102*(22), 10312–10318. https://doi.org/10.1016/j.biortech.2011.08.018
16. Park, S., Kim, K. S., Kim, J. T., Kang, D., & Sung, K. (2011). Effects of humic acid on phytodegradation of petroleum hydrocarbons in soil simultaneously contaminated with heavy metals. *Journal of Environmental Sciences*, *23*(12), 2034–2041. https://doi.org/10.1016/S1001-0742(11)60836-5
17. Sandhi, A., Landberg, T., & Greger, M. (2018). Phytofiltration of arsenic by aquatic moss (*Warnstorfia fluitans*). *Environmental Pollution, 237,* 1098–1105.

https://doi.org/10.1016/j.envpol.2017.11.059

18. Zayed, A., Pilon-Smits, E., deSouza, M., Lin, Z. Q., & Terry, N. (2020). Remediation of selenium-polluted soils and waters by phytovolatilization. In *Phytoremediation of Contaminated Soil and Water* (pp. 61-83). CRC Press. https://doi.org/10.1201/9780429430740-5
19. Yu, G., Jiang, P., Fu, X., Liu, J., Sunahara, G. I., Chen, Z., ... & Wang, X. (2020). Phytoextraction of cadmium-contaminated soil by *Celosia argentea* Linn.: A long-term field study. *Environmental Pollution, 266*, 115408. https://doi.org/10.1016/j.envpol.2020.115408
20. Arliyani, I., Tangahu, B. V., Mangkoedihardjo, S., Zulaika, E., & Kurniawan, S. B. (2023). Enhanced leachate phytodetoxification test combined with plants and rhizobacteria bioaugmentation. *Heliyon, 9*(1). https://doi.org/10.1016/j.heliyon.2023.e12600
21. Wang, J., & Delavar, M. A. (2023). Techno-economic analysis of phytoremediation: A strategic rethinking. *Science of The Total Environment, 165949.* https://doi.org/10.1016/j.scitotenv.2023.165949
22. Al-Ajalin, F. A. H., Idris, M., Abdullah, S. R. S., Kurniawan, S. B., & Imron, M. F. (2020). Evaluation of short-term pilot reed bed performance for real domestic wastewater treatment. *Environmental Technology & Innovation, 20,* 101110. https://doi.org/10.1016/j.eti.2020.101110
23. Jehawi, O. H., Abdullah, S. R. S., Kurniawan, S. B., Ismail, N. I., Idris, M., Al Sbani, N. H., ... & Hasan, H. A. (2020). Performance of pilot hybrid reed bed constructed wetland with aeration system on nutrient removal for domestic wastewater treatment. *Environmental Technology & Innovation, 19,* 100891. https://doi.org/10.1016/j.eti. 2020.100891
24. Fatima, K., Imran, A., Naveed, M., & Afzal, M. (2017). Plant-bacteria synergism: An innovative approach for the remediation of crude oil-contaminated soils. *Soil Environment, 36*(2), 93–113. https://doi.org/10.1016/j.soilen.2017.11.001
25. Khan, A. U., Khan, A. N., Waris, A., Ilyas, M., & Zamel, D. (2022). Phytoremediation of pollutants from wastewater: A concise review. *Open Life Sciences, 17*(1), 488–496. https://doi.org/10.1515/biol-2022-0050
26. Chojnacka, K., Moustakas, K., & Mikulewicz, M. (2023). The combined rhizoremediation by a triad: plant-microorganism-functional materials. *Environmental Science and Pollution Research, 30*(39), 90500–90521. https://doi.org/10.1007/s11356-023-27046-6
27. Imron, M. F., Kurniawan, S. B., Ismail, N. I., & Abdullah, S. R. S. (2020). Future challenges in diesel biodegradation by bacteria isolates: A review. *Journal of Cleaner Production, 251,* 119716. https://doi.org/10.1016/j.jclepro.2019.119716
28. Vocciante, M., Grifoni, M., Fusini, D., Petruzzelli, G., & Franchi, E. (2022). The role of plant growth-promoting rhizobacteria (PGPR) in mitigating plant's environmental stresses. *Applied Sciences, 12*(3), 1231. https://doi.org/10.3390/app12031231
29. Yan, A., Wang, Y., Tan, S. N., Mohd Yusof, M. L., Ghosh, S., & Chen, Z. (2020). Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. *Frontiers in Plant Science, 11*, 359. https://doi.org/10.3389/fpls.2020.00359
30. Purwanti, I. F., Obenu, A., Tangahu, B. V., Kurniawan, S. B., Imron, M. F., & Abdullah, S. R. S. (2020). Bioaugmentation of *Vibrio alginolyticus* in phytoremediation of aluminium-contaminated soil using *Scirpus grossus* and *Thypa angustifolia*. *Heliyon, 6*(9). https://doi.org/10.1016/j.heliyon.2020.e05000

31. Rahman, M. E., Bin Halmi, M. I. E., Bin Abd Samad, M. Y., Uddin, M. K., Mahmud, K., Abd Shukor, M. Y., ... & Shamsuzzaman, S. M. (2020). Design, operation and optimization of constructed wetland for removal of pollutant. *International Journal of Environmental Research and Public Health, 17*(22), 8339. https://doi.org/10.3390/ijerph17228339
32. Mocek-Płóciniak, A., Mencel, J., Zakrzewski, W., & Roszkowski, S. (2023). Phytoremediation as an effective remedy for removing trace elements from ecosystems. *Plants, 12*(8), 1653. https://doi.org/10.3390/plants12081653
33. Bolan, S., Padhye, L. P., Jasemizad, T., Govarthanan, M., Karmegam, N., Wijesekara, H., ... & Bolan, N. (2023). Impacts of climate change on the fate of contaminants through extreme weather events. *Science of The Total Environment, 168388.* https://doi.org/10.1016/j.scitotenv. 2023.168388
34. Hassan, I., Chowdhury, S. R., Prihartato, P. K., & Razzak, S. A. (2021). Wastewater treatment using constructed wetland: Current trends and future potential. *Processes, 9*(11), 1917. https://doi.org/10. 3390/pr9111917
35. Almuktar, S. A., Abed, S. N., & Scholz, M. (2018). Wetlands for wastewater treatment and subsequent recycling of treated effluent: A review. *Environmental Science and Pollution Research, 25,* 23595–23623. https://doi.org/10.1007/s11356-018-1995-0
36. Abdullah, S. R. S., Al-Baldawi, I. A., Almansoory, A. F., Purwanti, I. F., Al-Sbani, N. H., & Sharuddin, S. S. N. (2020). Plant-assisted remediation of hydrocarbons in water and soil: Application, mechanisms, challenges and opportunities. *Chemosphere, 247,* 125932. https://doi.org/10.1016/j.chemosphere.2020 .125932
37. Priya, A. K., Muruganandam, M., Ali, S. S., & Kornaros, M. (2023). Clean-up of heavy metals from contaminated soil by phytoremediation: A multidisciplinary and eco-friendly approach. *Toxics, 11*(5), 422. https://doi.org/10.3390/toxics11050422
38. Kwoczynski, Z., & Čmelík, J. (2021). Characterization of biomass wastes and its possibility of agriculture utilization due to biochar production by torrefaction process. *Journal of Cleaner Production, 280,* 124302. https://doi.org/10.1016/j.jclepro.2020.1243 02
39. Islam, M. M., Saxena, N., & Sharma, D. (2024). Phytoremediation as a green and sustainable prospective method for heavy metal contamination: A review. *RSC Sustainability.* https://doi.org/10.1039/d3su 00123a
40. Edgar, V. N., Fabián, F. L., Mario, P. C. J., & Ileana, V. R. (2021). Coupling plant biomass derived from phytoremediation of potential toxic-metal-polluted soils to bioenergy production and high-value by-products—A review. *Applied Sciences, 11*(7), 2982. https://doi.org/10.3390/app11072982
41. Abd Kadir, A., Abdullah, S. R. S., Othman, B. A., Hasan, H. A., Othman, A. R., Imron, M. F., ... & Kurniawan, S. B. (2020). Dual function of *Lemna minor* and *Azolla pinnata* as phytoremediator for palm oil mill effluent and as feedstock. *Chemosphere, 259,* 127468. https://doi.org/10.1016/j.chemosphere.2020 .127468
42. Das, S. K., Ghosh, G. K., & Avasthe, R. (2021). Applications of biomass derived biochar in modern science and technology. *Environmental Technology & Innovation, 21,* 101306. https://doi.org/10.1016/j.eti.2020.101306
43. Rezania, S., Oryani, B., Cho, J., Sabbagh, F., Rupani, P. F., Talaiekhozani, A., ... & Lotfi Ghahroud, M. (2020). Technical aspects of biofuel production from different sources in Malaysia—a review. *Processes, 8*(8), 993. https://doi.org/10.3390/pr8080993
44. Sood, A., Uniyal, P. L., Prasanna, R., & Ahluwalia, A. S. (2012). Phytoremediation potential of aquatic

macrophyte, *Azolla*. *Ambio*, *41*, 122–137. https://doi.org/10.1007/s13280-011-0220-5

45. Ansari, A. A., Naeem, M., Gill, S. S., & AlZuaibr, F. M. (2020). Phytoremediation of contaminated waters: An eco-friendly technology based on aquatic macrophytes application. *The Egyptian Journal of Aquatic Research*, *46*(4), 371–376. https://doi.org/10.1016/j.ejar.2020.10.001
46. Correa, D. F., Beyer, H. L., Fargione, J. E., Hill, J. D., Possingham , H. P., Thomas-Hall, S. R., & Schenk, P. M. (2019). Towards the implementation of sustainable biofuel production systems. *Renewable and Sustainable Energy Reviews*, *107*, 250–263. https://doi.org/10.1016/j.rser.2019.03.022
47. Uddin, M. M., Zakeel, M. C. M., Zavahir, J. S., Marikar, F. M., & Jahan, I. (2021). Heavy metal accumulation in rice and aquatic plants used as human food: A general review. *Toxics*, *9*(12), 360. https://doi.org/10.3390/toxics9120360
48. Zhakypbek, Y., Kossalbayev, B. D., Belkozhayev, A. M., Murat, T., Tursbekov, S., Abdalimov, E., ... & Allakhverdiev, S. I. (2024). Reducing heavy metal contamination in soil and water using phytoremediation. *Plants*, *13*(11), 1534. https://doi.org/10.3390/plants13111534
49. Boulkhessaim, S., Gacem, A., Khan, S. H., Amari, A., Yadav, V. K., Harharah, H. N., ... & Jeon, B. H. (2022). Emerging trends in the remediation of persistent organic pollutants using nanomaterials and related processes: A review. *Nanomaterials*, *12*(13), 2148. https://doi.org/10.3390/nano12132148
50. Rajput, P., Singh, A., Agrawal, S., Ghazaryan, K., Rajput, V. D., Movsesyan, H., ... & Alexiou, A. (2024). Effects of environmental metal and metalloid pollutants on plants and human health: Exploring nano-remediation approach. *Stress Biology*, *4*(1), 1–25. https://doi.org/10.1007/s44199-024-00001-0
51. Fletcher, J. (2022). Optimising multi-pollutant phytoremediation strategies to sustainably improve raw water quality. *Journal of Environmental Management*. https://doi.org/10.1016/j.jenvman.2022.114123
52. Falahi, O. A. A., Abdullah, S. R. S., Hasan, H. A., Othman, A. R., Ewadh, H. M., Kurniawan, S. B., & Imron, M. F. (2022). Occurrence of pharmaceuticals and personal care products in domestic wastewater, available treatment technologies, and potential treatment using constructed wetland: A review. *Process Safety and Environmental Protection*, *168*, 1067–1088. https://doi.org/10.1016/j.psep.2022.06.018
53. Ali, S., Abbas, Z., Rizwan, M., Zaheer, I. E., Yavaş, İ., Ünay, A., ... & Kalderis, D. (2020). Application of floating aquatic plants in phytoremediation of heavy metals polluted water: A review. *Sustainability*, *12*(5), 1927. https://doi.org/10.3390/su12051927
54. Dhir, B., & Dhir, B. (2013). Aquatic plant species and removal of contaminants. In *Phytoremediation: Role of Aquatic Plants in Environmental Clean-up* (pp. 21-50). Springer. https://doi.org/10.1007/978-3-319-00180-0_2
55. Javed, M. T., Tanwir, K., Akram, M. S., Shahid, M., Niazi, N. K., & Lindberg, S. (2019). Phytoremediation of cadmium-polluted water/sediment by aquatic macrophytes: Role of plant-induced pH changes. In *Cadmium Toxicity and Tolerance in Plants* (pp. 495-529). Academic Press. https://doi.org/10.1016/B978-0-12-814868-0.00024-4
56. Tiwari, S., & Sarangi, B. K. (2019). Transgenics for arsenic and chromium phytoremediation. In *Transgenic Plant Technology for Remediation of Toxic Metals and Metalloids* (pp. 167-185). Springer . https://doi.org/10.1007/978-3-030-15777-5_10
57. Anand, R., & Philip, L. (2024). Catalytic pulsed plasma treatment for organic micropollutants: Unveiling the synergistic role of photocatalysts in radical generation and degradation mechanisms. *Environmental Science: Water Research &*

Technology. https://doi.org/10.1039/D3EW00712A

58. Olguín, E. J., García-López, D. A., González-Portela, R. E., & Sánchez-Galván, G. (2017). Year-round phytofiltration lagoon assessment using *Pistia stratiotes* within a pilot-plant scale biorefinery. *Science of the Total Environment*, *592*, 326–333. https://doi.org/10.1016/j.scitotenv.2017.03.086
59. Zhao, L., Jiang, J., Chen, C., Zhan, S., Yang, J., & Yang, S. (2017). Efficiency and mechanism of the phytoremediation of decabromodiphenyl ether-contaminated sediments by aquatic macrophyte *Scirpus validus*. *Environmental Science and Pollution Research*, *24*, 12949–12962. https://doi.org/10.1007/s11356-017-0241-0
60. Liu, F., Zhang, S., Luo, P., Zhuang, X., Chen, X., & Wu, J. (2018). Purification and reuse of non-point source wastewater via *Myriophyllum*-based integrative biotechnology: A review. *Bioresource Technology*, *248*, 3–11. https://doi.org/10.1016/j.biortech.2017.06.021
61. Paisio, C. E., Fernandez, M., González, P. S., Talano, M. A., Medina, M. I., & Agostini, E. (2018). Simultaneous phytoremediation of chromium and phenol by *Lemna minuta* Kunth: A promising biotechnological tool. *International Journal of Environmental Science and Technology*, *15*, 37–48. https://doi.org/10.1007/s13762-017-1390-5
62. Bind, A., Goswami, L., & Prakash, V. (2018). Comparative analysis of floating and submerged macrophytes for heavy metal (copper, chromium, arsenic and lead) removal: Sorbent preparation, characterization, regeneration and cost estimation. *Geology, Ecology, and Landscapes*, *2*(2), 61–72. https://doi.org/10.1080/24749508.2018.1430800
63. Anning, A. K., & Akoto, R. (2018). Assisted phytoremediation of heavy metal contaminated soil from a mined site with *Typha latifolia* and *Chrysopogon zizanioides*. *Ecotoxicology and Environmental Safety*, *148*, 97–104. https://doi.org/10.1016/j.ecoenv.2017.10.022
64. Bello, A. O., Tawabini, B. S., Khalil, A. B., Boland, C. R., & Saleh, T. A. (2018). Phytoremediation of cadmium-, lead- and nickel-contaminated water by *Phragmites australis* in hydroponic systems. *Ecological Engineering*, *120*, 126–133. https://doi.org/10.1016/j.ecoleng.2018.07.014
65. Gemeda, S., Gabbiye, N., & Alemu, A. (2019). Phytoremediation potential of free floating plant species for chromium wastewater: The case of duckweed, water hyacinth, and water lilies. In *Advances of Science and Technology: 6th EAI International Conference, ICAST 2018, Bahir Dar, Ethiopia, October 5-7, 2018, Proceedings 6* (pp. 519–535). Springer International Publishing. https://doi.org/10.1007/978-3-030-19573-0_43
66. Singh, V., Pandey, B., & Suthar, S. (2019). Phytotoxicity and degradation of antibiotic ofloxacin in duckweed (*Spirodela polyrhiza*) system. *Ecotoxicology and Environmental Safety*, *179*, 88–95. https://doi.org/10.1016/j .jes.2019.04.014
67. Yusoff, M. F. M., Rozaimah, S. A. S., Hassimi, A. H., Hawati, J., & Habibah, A. (2019). Performance of continuous pilot subsurface constructed wetland using *Scirpus grossus* for removal of COD, colour and suspended solid in recycled pulp and paper effluent. *Environmental Technology & Innovation*, *13*, 346–352. https://doi.org/10.1016/j.eti.2018.11.002
68. Escoto, D. F., Gayer, M. C., Bianchini, M. C., da Cruz Pereira, G., Roehrs, R., & Denardin, E. L. (2019). Use of *Pistia stratiotes* for phytoremediation of water resources contaminated by clomazone. *Chemosphere*, *227*, 299–304. https://doi.org/10.1016/j.chemosphere.2019.04.086
69. Jamil, M. H., Ishak, F. A., Syukor, A. A., Sulaiman, S., Siddique, M. N. I., & Zainuddin, S. Z. (2019). Man-made Lake

of Taman Pertanian, Kuantan: The valuation of water quality and nutrient removal by using *Hydrilla verticillata* sp. and *Myriophyllum aquaticum* sp. as submerged plant species. *Materials Today: Proceedings*, *19*, 1552–1561. https://doi.org/10.1016/j.matpr.2019.06.020

70. Saleh, H. M., Moussa, H. R., El-Saied, F. A., Dawoud, M., El Said, A. N., & Wahed, R. S. A. (2020). Adsorption of cesium and cobalt onto dried *Myriophyllum spicatum* L. from radio-contaminated water: Experimental and theoretical study. *Progress in Nuclear Energy*, *125*, 103393. https://doi.org/10.1016/j.pnucene.2020.103393
71. Qin, H., Diao, M., Zhang, Z., Visser, P. M., Zhang, Y., Wang, Y., & Yan, S. (2020). Responses of phytoremediation in urban wastewater with water hyacinths to extreme precipitation. *Journal of Environmental Management*, *271*, 110948. https://doi.org/10.1016/j.jenvman.2020.110948
72. Nash, D. A. H., Abdullah, S. R. S., Hasan, H. A., Idris, M., Othman, A. R., Al-Baldawi, I. A., & Ismail, N. I. (2020). Utilisation of an aquatic plant (*Scirpus grossus*) for phytoremediation of real sago mill effluent. *Environmental Technology & Innovation*, *19*, 101033. https://doi.org/10.1016/j.eti.2020.101033
73. Chang, G., Yue, B., Gao, T., Yan, W., & Pan, G. (2020). Phytoremediation of phenol by *Hydrilla verticillata* (Lf) Royle and associated effects on physiological parameters. *Journal of Hazardous Materials*, *388*, 121569. https://doi.org/10.1016/j.jhazmat.2020.121569
74. Dias, S., Correia, B., Fraga-Santiago, P., Silva, C., Baptista, P. C., Gomes, C. R., & Almeida, C. M. R. (2021). Potential of an estuarine salt marsh plant (*Phragmites australis* (Cav.) Trin. Ex Steud 10751) for phytoremediation of bezafibrate and paroxetine. *Hydrobiologia*, *848*, 3291–3304. https://doi.org/10.1007/s10750-021-04663-0
75. Almansoory, A. F., Idris, M., Abdullah, S. R. S., Anuar, N., & Kurniawan, S. B. (2021). Response and capability of *Scirpus mucronatus* (L.) in phytotreating petrol-contaminated soil. *Chemosphere*, *269*, 128760. https://doi.org/10.1016/j.chemosphere.2020.128760
76. Ergönül, M. B., Nassouhi, D., Çelik, M., & Atasağun, S. (2021). A comparison of the removal efficiencies of *Myriophyllum spicatum* L. for zinc oxide nanoparticles (ZnO NP) in different media: A microcosm approach. *Environmental Science and Pollution Research*, *28*, 8556–8568. https://doi.org/10.1007/s11356-020-11663-5
77. Marín-Muñiz, J. L., Zitácuaro-Contreras, I., Ortega-Pineda, G., López-Roldán, A., Vidal-Álvarez, M., Martínez-Aguilar, K. E., ... & Zamora-Castro, S. (2024). Phytoremediation performance with ornamental plants in monocultures and polycultures conditions using constructed wetlands technology. *Plants*, *13*(7), 1051. https://doi.org/10.3390/plants13071051
78. Parde, D., Patwa, A., Shukla, A., Vijay, R., Killedar, D. J., & Kumar, R. (2021). A review of constructed wetland on type, treatment and technology of wastewater. *Environmental Technology & Innovation*, *21*, 101261. https://doi.org/10.1016/j.eti.2020.101261
79. Thakur, T. K., Barya, M. P., Dutta, J., Mukherjee, P., Thakur, A., Swamy, S. L., & Anderson, J. T. (2023). Integrated phytobial remediation of dissolved pollutants from domestic wastewater through constructed wetlands: An interactive macrophyte-microbe-based green and low-cost decontamination technology with prospective resource recovery. *Water*, *15*(22), 3877. https://doi.org/10.3390/w15223877