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Bioremediation of heavy metals in contaminated water bodies

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Abstract

Heavy metals are naturally occurring elements of the environment, but their geochemical cycles and biochemical balance have been disrupted by human use. Heavy metals including cadmium, copper, lead and others are consequently released in excess into natural resources like soil and aquatic ecosystems. Long-term exposure to and increased buildup of these heavy metals can have detrimental impacts on aquatic biota and human health. In order to get rid of these toxic contaminants one of the most environmentally friendly, economical, safer, and cleanest technologies for decontaminating places contaminated with a variety of contaminants is bioremediation. The technique of employing biological agents to remove harmful waste from the environment is referred to as "bioremediation". The hazardous waste that greatly harms the environment is heavy metals in wastewater. This review article provides a comprehensive analysis of bioremediation, including its types, effects of heavy metals on human health, bioremediation of heavy metals in polluted water, microbe-mediated bioremediation of heavy metals. There are also reports on a few possible species of plants and microbes that are frequently employed to remove heavy metals. The phytoremediation of heavy metals, phytoremediation methods, difficulties in microbial-mediated bioremediation, and recommendations for further bioremediation research are also examined in this article.

Keywords: Heavy metal; Decontaminating; Contaminants; Bioremediation; Phytoremediation

1. INTRODUCTION

Water is one of the vital natural resources which is necessary to sustain our lives on earth. Water pollution occurs when harmful substances, such as chemicals or microbes, enter a body of water, reducing its quality and posing risks to humans and environment. Though large amount of water is present on earth but a very little fraction is fresh that can be used and this issue needs to be resolved for sustainable development of economy, society and stability of nation. The main reason behind scarcity of water for human use is that freshwater is not available because of anthropogenic activity like urbanisation, industrialisation, population growth, disposal of untreated waste which has put strain of water quality in general. In recent years there is increase in magnitude of contaminants which include organic compounds in water bodies like pesticides, personal care items, pharmaceutical products, detergents, food additives and preservatives, surfactants and heavy metals etc (Huser, 2016). A significant portion of the globe's fresh water supplies are used for farming and cattle production, making the agricultural industry not only the largest consumer of freshwater resources worldwide, but also a major source of water pollution. Water pollution is primarily caused by agriculture worldwide. Additionally, it plays a significant role in groundwater and estuary contamination. Fertilizers, insecticides, and animal waste from farms and livestock activities contaminate waterways with nutrients and diseases such as bacteria and viruses during rainy seasons. The biggest threat to water quality globally is nutrient pollution, which is brought on by too much nitrogen and phosphorus in the air or water. This can result in algal blooms, which are poisonous blooms of blue-green algae that can be dangerous to both humans and wildlife. The impact of natural pollution, sometimes referred to as non-point source pollution, is greater than that of manmade or point source pollution. It affects subterranean and surface waters, among other water sources, and it may occur accidentally or irregularly.

2. HEAVY METAL CONTAMINATION OF WATER

Heavy metals are metals with relatively high densities (more than 5gm/cm3), atomic weights (more than 50), and atomic numbers (Ahmad, 2021). Since the 1940s, the exponential rise of industrial activities in newly independent countries, primarily in Asia, has significantly increased the environmental presence of several heavy metals. Industrialization, which is still in its primitive form in many parts of the world, uses various heavy metals in wholly unregulated ways that harm the environment via water, air, and soil. Heavy metals' ability to survive changes in weather, moisture content, and long-distance movement exposes the biosphere to these contaminants on a continuous basis. Heavy metals are highly persistent in the open environment, adaptable to long-distance movement, poisonous, nonbiodegradable, and capable of bioaccumulation (Mirzabeygi et al., 2017). Heavy metal contamination in the environment is mostly caused by anthropogenic activities such as mining, pesticide-based agriculture, and various industrial activities, as well as natural phenomena such as volcanic eruptions and weathering of metal-bearing rocks. Heavy metal levels in water are determined by the aquifer's local geology, hydrogeology, and geochemical features. Weathering of sedimentary rocks such as limestone, dolomite, or shale contaminates or pollutes the water. When water interacts with rock elements, these elements are added into the water, resulting in pollution (Sharma, 2022). The primary causes of water pollution include domestic sewage, solid waste burning, coal and oil combustion, pyrometallurgical activities, and mining. aquatic, whether in the form of snow or rain, transports Hg-contaminated soil to nearby aquatic bodies (Gupta et al., 2022). Heavy metals found in polluted environments, such as Pb (II), Hg (II), Cd (II), and As (III), pose serious risks to ecosystems and human health. Because lead-acid battery recycling, industrial emissions, and the use of leaded gasoline all generate heavy metal pollutants like Pb (II), these pollutants are extensively distributed. Its accumulation in sediments, water, and the ground has a negative impact on both aquatic and terrestrial ecosystems. Human exposure to lead has been connected to neurotoxicity, delayed cognitive development in children, and a number of adult health issues, such as disorders of the heart and kidneys (Hjelm et al., 2012). Heavy metals, when released into water and soil, can lead to health issues, including cancer, organ damage, and skin problems (Singh et al., 2023). In addition to Pb (II), Hg (II), Cd (II), and As (III), other heavy metals commonly found in polluted environments include chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), and selenium (Se). Industrial processes including electroplating, tanning leather, and making stainless steel are often the source of chromium contamination. Hexavalent Cr is known to be a mutagen and carcinogen in both humans and other species. It has been connected to the emergence of respiratory conditions, skin irritations, and increased susceptibility to lung cancer (Lin et al., 2022 and Singh et al., 2022). Heavy metals can accumulate in sediments and aquatic organisms, disrupting aquatic ecosystems and biodiversity. They may impair the growth, reproduction, and survival of aquatic plants and animals, leading to shifts in community structure and ecological imbalances. Heavy metals are toxic to humans even at low concentrations and can bioaccumulate in the food chain. Chronic exposure to heavy metals through contaminated water or seafood consumption can lead to a range of health problems, including neurological disorders, kidney damage, cardiovascular diseases, and cancer. The environment and human health are seriously threatened by these heavy metals because of their toxicity, persistent nature, and tendency to bioaccumulate. To lessen the negative effects of heavy metal pollution on ecosystems and safeguard public health, effective monitoring, remediation, and prevention measures are essential (Jeyakumar et al., 2022 and Sreedevi et al., 2022). Some common sources of heavy metal contamination in water include; Industrial Activities such as mining, metal smelting, manufacturing, and electroplating release heavy metals such as lead, cadmium, mercury, and chromium into water bodies through wastewater discharges and runoff. Agricultural Practices includes use of fertilizers, pesticides, and animal manure in agriculture can lead to the accumulation of heavy metals such as arsenic, copper, and zinc in water bodies through surface runoff and leaching. Urban areas generate runoff containing heavy metals from sources such as vehicle emissions, construction activities, road salts, and stormwater drainage systems, which can contaminate nearby water bodies. Heavy metals can also enter water bodies through atmospheric deposition, where they are carried by wind and precipitation from industrial emissions, anthropogenic sources, combustion processes, and volcanic activity.

Table 1: Hazardous effects of Heavy Metals on Human health

Heavy Metal	**Related hazardous effects**	**References**
As	Inorganic As is carcinogenic and can cause cancer of the skin, lungs, liver and bladder. It also causes perforation of Nasal Septum and Peripheral Neuropathy.	Mahurpawar (2015)
Cd	Low levels of Cd exposure can cause impairment to the cardiovascular system, skeletal system, kidneys, liver, and eyesight and hearing. Cadmium has significant teratogenic and mutagenic effects, but it also has negative effects on human male and female reproductive at low concentrations and alters the course of pregnancy	(Kumar et al., 2019)
Cr	It is widely recognized that Cr (VI) can have extremely dangerous toxic effects that can be	Mishra and Bharagava (2016)

	fatal, including cancer mutations and genotoxic problems in both humans and animals.	
Cu	It harms the brain and kidneys, high level causes liver cirrhosis, persistent anemia, and irritation of the stomach and intestines	(Yadav et al., 2017)
Hg	Depression, autoimmune illness, sleepiness, exhaustion, hair loss, sleeplessness, memory loss, restlessness, blurred vision, tremors, irrational outbursts, brain damage, lung and renal failure	(Yadav et al., 2017)
Ni	Large amount of Ni causes prostate, lung, nasal, and throat cancers; feeling ill and lightheaded after being around nickel gas. respiratory malfunction, pulmonary embolism, birth abnormalities, Chronic bronchitis and asthma, skin rashes and other allergic reactions.	Mahurpawar (2015)
Pb	All organs are negatively impacted by lead, but the kidneys are most severely affected. Fanconi-like syndrome is brought on by proximal tubular dysfunction, which is brought on by acute lead nephropathy. The symptoms of chronic lead nephropathy include glomerulonephritis, renal failure, atrophy of the tubules, and hyperplasia.	(Mitra et al., 2022)
Zn	Overdosing of Zn causes dizziness and exhaustion.	(Yadav et al., 2017)

Se	Overconsumption can result in selenosis, which can cause neurological symptoms, gastrointestinal problems, and hair loss.	Rayman and Margaret (2012)

3. BIOREMEDIATION

The branch of biotechnology known as **"bioremediation"** is used to reduce and treat polluted water that uses live organisms—such as bacteria and microbes—to remove poisons, pollutants, and contaminants from soil, water, and other environments. It is one of most promising technique to treat polluted water bodies and has economic benefits and no adverse environment impact. The process of bioremediation involves promoting the growth of specific microorganisms that use pollutants such as oil, solvents, and pesticides as food and energy sources. These microorganisms break down pollutants into innocuous gases like carbon dioxide and little amounts of water. The ideal balance of foods, nutrients, and temperature is needed for bioremediation. If certain components are missing, the removal of pollutants could take longer. The atmosphere can be made more conducive to bioremediation by introducing "amendments" such molasses, vegetable oil, or plain air. Microorganisms consume sustenance from their surroundings, such as dirt or water. Contaminants might provide additional nourishment for microorganisms. The contaminant performs two functions for the microorganisms. First, the pollutant offers the carbon required for growth. Second, microorganisms get energy by breaking chemical bonds and moving electrons away from the pollutant. This is known as an oxidation/reduction reaction. The contaminant that loses electrons is oxidized, and the chemical that accepts electrons (electron acceptor) is reduced. The energy received from electron transfer is combined with carbon and some electrons to create new cells. Microbes mostly use oxygen as an electron acceptor, but also employ nitrate, sulphate, iron, and CO_2. The energy from electron transfer, together with carbon and some electrons, is used to create new cells. Microbes mostly use oxygen as an electron acceptor, but also employ nitrate, sulphate, iron, and CO_2. Most bioremediation systems are conducted under aerobic circumstances; however, running a system under anaerobic conditions may permit microbial organisms to digest ordinarily resistant compounds (Kulshrestra, 2014).

4. TYPES OF BIOREMEDIATIONS

4.1 Bio stimulation

The bacteria are triggered to start the process, as the name implies. First, the polluted soil is combined with unique nutrients and other essential elements in liquid or gaseous form. It promotes the proliferation of microorganisms, which enables them and other bacteria to quickly and effectively remove pollutants from the environment. Bio stimulation is the process of changing the bioenvironment in order to reactivate existing microorganisms and efficiently complete the specified bioprocesses. This can be accomplished by supplying a variety of micronutrients and electron acceptors, including phosphorus, nitrogen, oxygen, and carbon. Bio stimulation is the addition of certain nutrients to waste, either with the naturally occurring microbes accessible in acceptable volumes and types, or by adding the appropriate microorganisms to degrade the waste effectively. In general, a biosystem can be supported by a specifically constructed equipment called a bioreactor, which treats waste using the appropriate microorganisms. The bioreactor's primary function is to produce an appropriate bioenvironment for microorganism growth and activity, allowing the bio stimulation process to take place (Abatenh et al., 2017).

4.2 Bioaugmentation

Sometimes, in order to remove the pollutants, specific locations call for the use of microorganisms. Take municipal wastewater as an example. The bioaugmentation method is employed in these unique circumstances. There is just one significant flaw in this procedure. Controlling the proliferation of microorganisms throughout the process of eliminating a specific contamination becomes nearly difficult. Bioaugmentation (the process of adding selected strains/mixed cultures to wastewater reactors to improve the catabolism of specific compounds, such as refractory organics or overall COD) is a promising technique for solving practical problems in WWTPs and increasing removal efficiency. Bioaugmentation is classified into two basic strategies: bioaugmentation by enrichment with indigenous microorganisms and bioaugmentation by enrichment with nonindigenous microorganisms. Bioaugmentation employs more microbes to "reinforce" biological waste treatment populations, allowing them to successfully reduce pollutant load by converting it into less hazardous molecules (Herrero and Stuckey, 2015). The most popular technique to use bioaugmentation technology is to add microorganisms with specific degrading capabilities to the target pollutants. This requires obtaining one or more high-efficiency microbial strains that use target pollutants as their principal carbon and energy source. The additional microbes may be adhered to the carrier, forming a highly effective biofilm, or they may reside freely.

Although many pure microorganisms have an excellent degrading effect on certain target contaminants in wastewater treatment (Abatenh et al., 2017).

4.3 Intrinsic Bioremediation

It is also known as passive bioremediation or natural attenuation, is a natural degradation process that relies solely on the metabolism of native microorganisms to remove harmful toxins, with no artificial stages to promote biodegradation activity. This approach is the most cost-effective in-situ bioremediation technique due to the lack of external variables. However, regular monitoring is required for bioremediation to be ongoing and sustained.

The following are the essential requirements that must be followed in order for intrinsic bioremediation to be effective:

1. A suitable population of biodegrading microorganisms in the polluted site.
2. Optimal environmental conditions (temperature, pH, moisture level, and oxygen content).
3. Carbon and nitrogen supplies that can support microbial activity and growth.
4. Enough time for microorganisms to transform contaminants into less toxic compounds (Silva et al., 2020).

This method for biological remediation of blocked groundwater is based on a stimulation-optimization strategy powered by machine learning and particle swarm optimization (ELM-PSO). This leads in less expensive pumping technology and lower capital requirements for the entire operation. Intrinsic remediation has also been investigated for the removal of Cr (VI) from shallow unsaturated soil. Microorganisms may survive in high concentrations of Cr (VI) in the soil, and their subcellular machinery is used to interact with heavy metals. Microbial inoculants can be used to remediate heavy metals in situ. Cr (VI) interacts with Fe (II) ions via redox processes, and the release of iron in soluble forms stimulates the reduction reaction (Bala et al., 2022).

5. BIOREMEDIATION OF HEAVY METALS IN POLLUTED WATER

Aside from the fact that heavy metals kill microorganisms during the biological treatment of wastewater, which delays the process of water purification, their presence in aquatic environments is known to seriously harm aquatic life. The majority of heavy metal salts dissolve in water and create aqueous solutions, they cannot be separated using standard physical methods. For the removal of heavy metal ions, biological techniques like biosorption and bioaccumulation may offer a compelling substitute to physio-chemical techniques (Yadav et al., 2017).

Recent studies have shown that a wide variety of bacteria can collect high concentrations of metals. Therefore, the application of microbial cells in heavy metal remediation presents a viable substitute for current heavy metal decontamination techniques. Research has been done on the utilization of algae, fungus, and bacteria that accumulate heavy metals; these materials are more useful when employed in biological processes that remove heavy metals from wastewater. Biosorption, bioaccumulation, bio reduction, bioprecipitation, bio volatilization, bioleaching, composting, land farming, bioreactors, bio piles, and bio sparging are some of the methods used to accomplish the bioremediation of heavy metals (Jasrotia et al., 2017). The other two mechanisms that can be demonstrated in a phytoremediation case are Phyto stimulation and rhizo filtration. Biosorption and bioaccumulation are two distinct mechanisms that are widely present in a wide range of organisms, including plants. The complex process of biosorption involves the interaction and adsorption of metal ions from the surrounding environment by biosorbents. Many natural resources are used as a biosorbent, including biomass from plants, animals, fungi, algae, and bacteria as well as industrial byproducts and agricultural wastes. Usually, dead biomass or cells are utilized for biosorption, a highly effective method of removing heavy metal contaminants at incredibly low concentrations, as low as parts per billion. In certain cases, live cellular biomass is actively used in the process of biosorption to eliminate heavy metals. Surface adsorption resulting from physical, chemical, complexation, diffusion, or precipitation interactions are the mechanisms involved. The heavy metals are drawn to the cellular surface because it typically has a negative charge (Vega-Páez et al., 2019). However, in certain cases, the cellular surface may include a mucus layer to adsorb metal. The reduction and detoxification of heavy metals are made possible by the ionic interactions they have. Complexation is the term for the aggregation of two or more metal species and functional groups on the cell surface. The two types of complexes that are primarily found in biosorption are monodentate and polydentate complexes (Kanamarlapudi et al., 2018). In monodentate complexes, the metal ion forms covalent bonds with the ligands at the center, while in polydentate complexes, multiple metal ions bind to the ligands at multiple sites. Due to the possibility of toxic metal accumulation in cells that obstruct metabolic function and cause cell death, using living biomass for sorption may not be feasible. Bioaccumulation refers to the absorption of pollutants by living biomass/cells, which includes the active intake of heavy metals through metabolism. The efficiency with which heavy metals are removed from the environment is determined by metabolism-dependent trafficking processes such as passive diffusion, ion pumps, protein channels, and carrier mediated transport. Heavy metals move across phospholipid bilayers in live cells in two steps. Heavy metals cling to the cell surface independent of metabolism, followed by internalization via the cell membrane in the second stage. This process is similar to cellular uptake of important ions like Na2+, K+, and Ca2+.The metal cations with equal charge and ionic radius hijack the essential ion channels and enters the intracellular phase (Jeyakumar et al., 2023).

Many bacteria have evolved defense against toxic metal ions in order to survive in heavy metal-polluted environments, and the majority of microorganisms are known to possess certain genes that confer resistance against metal ions. The resistance genes usually reside on chromosomes or plasmids (Yadav et al., 2017). Because of their tiny size, widespread distribution, capacity to grow in controlled environments, and resistance to a variety of environmental stresses, bacteria were employed as biosorbents. They can use bioaccumulation, precipitation, or biosorption to remove heavy metals from contaminated locations. (Gadd, 2010).

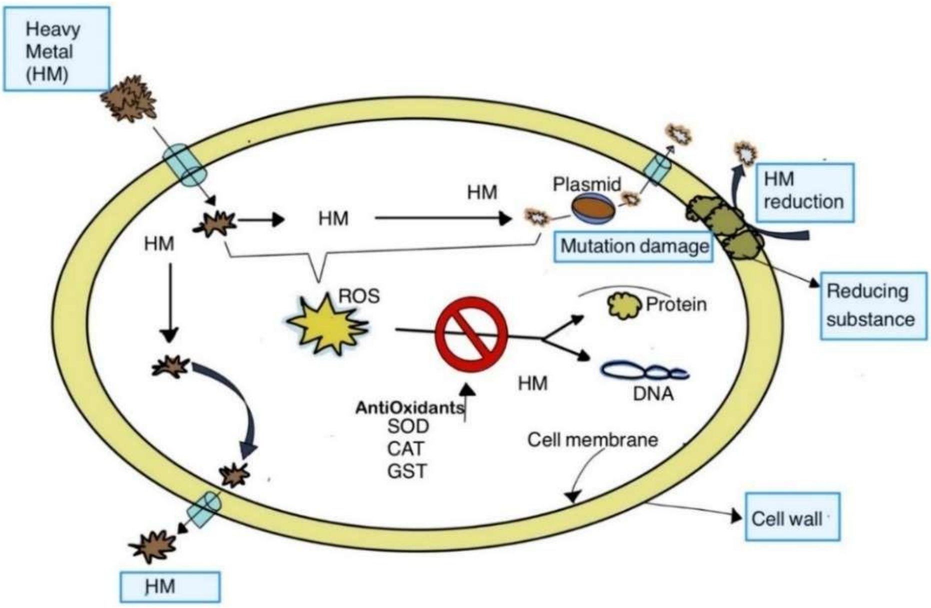

Figure 1: Bioremediation of Heavy Metals

Table 2: Various Bacterial species and heavy metals removed by them

Potential Bacteria	**Heavy metal**	**References**
Shewanella putrefaciens	Cd	(Wang et al., 2019)
Ochrobactrum MT180101	Cu	Torres (2020)
Bacillus thuringiensis	Hg	(Saranya et al., 2019)
Enterobacter cloacae	Hg (II)	(Chen et al., 2018)
Bacillus cereus	Cr	(Nayak et al., 2018)
Cellulosimicrobium Sp. *(KX710177)*	Pb	Bharagava and Mishra (2018)
Sporosarcinasaromensis (M52)	Cr	(Zhao et al., 2016)
Bacillus Sp. *SFC*	Cr	(Ontañon et al., 2018)
Vibrio fluvialis	Hg	(Saranya et al., 2017)
Micrococcus Sp.	Cu	(Marzan et al., 2017)
Enterobacter cloacae	Co	(Jafari et al., 2013)
Pseudomonas azotoformans JAW1	Cd	(Choińska-Pulit et al., 2018)
Pseudomonas azotoformans JAW1	Pb	(Orji et al., 2021)
Klebsiella Sp. USL2D	Pb	(Orji et al., 2021)
Streptomyces Sp.	Pb	(Hamdan et al., 2021)
Oceanobacillus profundus	Pb	(Motaleb et al., 2020)

It has been stated that fungi, among other microorganisms, may effectively remove heavy metals from the environment at a minimal cost through bioaccumulation and biosorption. A wide variety of chemical groups found in fungi have the ability to draw in and sequester metals from biomass. Proteins, lipids, and structural polysaccharides that provide metal-binding functional groups make up cell walls.

Table 3: Various Fungi species and heavy metal removed by them

Potential Fungi	Heavy Metal	References
Aspergillus niger	Cr	(Priyadarshini et al., 2021)
Aspergillus fumigates	Pb	(Priyadarshini et al., 2021)
*Penicillium chrysogenum*XJ-1	Cd	(Priyadarshini et al., 2021)
Trichoderma brevicompactum QYCD-6	Cr	(Zhang et al., 2020)
Trichoderma brevicompactum QYCD-6	Pb	(Bano et al., 2018)
Trichoderma brevicompactum QYCD-6	Cu	(Zhang et al., 2020)
Trichoderma brevicompactum QYCD-6	Cd	(Zhang et al., 2020)
Sterigmatomyces halophilus	Pb	(Bano et al., 2018)
Acremonium persicinum	Cu	(Mohammadian et al., 2017)
Aspergillus flavus	Cu	(Kanamarlapudi et al., 2018)
Penicillium simplicissimum	Cu	(Mohammadian et al., 2017)
Penicillium Sp.	Co	(González et al., 2019)
Paecilomyces Sp.	Co	(González et al., 2019)

6. MICROBIAL MEDIATED BIOREMEDIATION OF HEAVY METALS

Microbial-mediated bioremediation utilizes microorganisms, such as bacteria, fungi, and algae, to interact with heavy metal contaminants and facilitate their removal from water. Microorganisms can employ several mechanisms, including biosorption, bioaccumulation, and biotransformation, to sequester or detoxify heavy metals. Biotransformation mechanisms enzymatically modify heavy metal ions, converting them into less toxic or less mobile forms. Microbial-mediated bioremediation is versatile, cost-effective, and environmentally sustainable, making it a widely used approach for treating heavy metal-contaminated water.

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Microorganisms possess diverse enzymes capable of breaking down a broad spectrum of environmental contaminants (Qurbani and Hamzah, 2020). Depending on the type of contamination and the surrounding conditions, microbial bioremediation can occur in either anaerobic or aerobic environment (Motteran et al., 2022). By giving microbial populations the right circumstances and nutrition, one can increase breakdown rates and cleanup efficiency (Wang et al., 2023).

Surface complexation involves the binding of heavy metal ions or pesticide molecules to functional groups present on the surface of microbial cells. Microbial cells through interactions can adsorb or absorb the heavy metals onto the binding sites on the cellular surface depending on the kinetic equilibrium and metal composition at the surface of the cell. Biosorption is influenced by electrostatic interactions, redox reactions, ion exchange, precipitation, and surface complexation (Figure 2). The metabolic cycle of the cell does not affect this process. Surface complexation enhances the removal of contaminants from water by effectively immobilizing them on the microbial cell surface.

Ion exchange is a mechanism by which heavy metal ions are exchanged with other ions present in the surrounding solution. After the active uptake of heavy metal, the ions pass through plasma membrane into cytoplasm (Bioaccumulation method), the cell undergoes physical, chemical and biological processes and also intracellular and extracellular processes. Processes such as ion exchange, adsorption, and covalent bonding occur due to the chemiosmotic gradient across the cell without the use of ATP are found to be the crux of biosorption. Ion exchange facilitates the uptake and concentration of heavy metals by microbial cells, thereby reducing their concentration in the water phase. Biosorption mechanisms are based on two factors: cell metabolism and the location within the cell where metal is removed. The microbe after uptake of metal, transforms the metal changing it from toxic to harmless form, while this transformation of metal the microbe tolerates the high concentration of metal or a combination of metals. The way that bacteria interact with their surroundings is greatly influenced by their surface features.

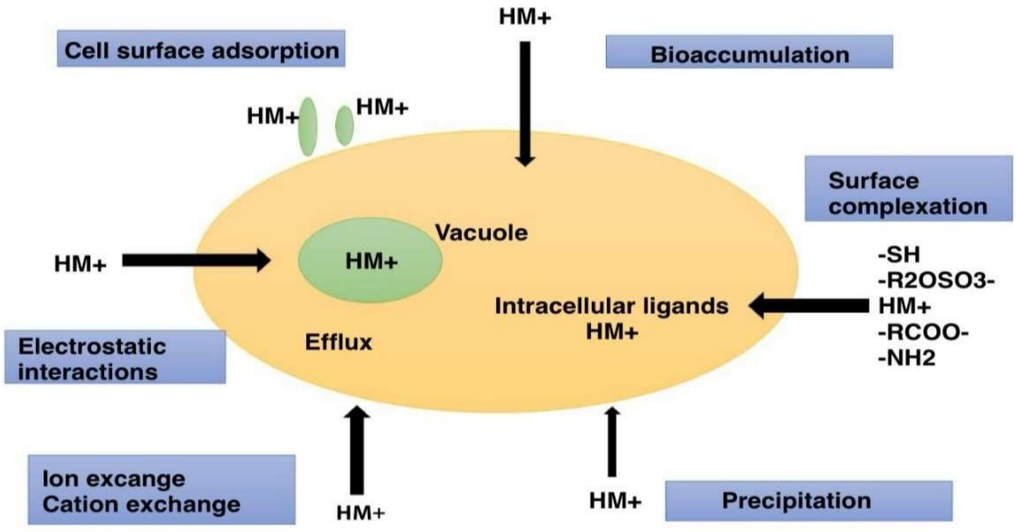

Figure 2: Mechanisms of heavy metal uptake by microorganism

7. PHYTOREMEDIATION OF HEAVY METALS

Phytoremediation involves using plants to remove, stabilize, or degrade contaminants. Several plant species can accumulate heavy metals or organic pollutants within their tissues via mechanisms such as phytoextraction and phytodegradation (Shen et al., 2022). One type of phytoremediation called phytoextraction involves absorbing pollutants in plant branches and allowing them to accumulate until they can be extracted and removed from the area. Conversely, phytodegradation uses root systems and the microorganisms that are associated with to help break down soil pollutants (Sabreena et al., 2022). Phytoremediation is a commonly employed technique for mitigating organic contaminants, heavy metals, and metalloids in soil and water (Roe and Farlane, 2022).

Phytoremediation utilizes plants to uptake, accumulate, and detoxify heavy metals from water and soil. Plants have the ability to absorb heavy metals through their roots and translocate them to aboveground tissues, where they can be harvested and removed from the environment. Heavy Metals uptake through phytoremediation technology involves several processes like Phyto stabilization, Phytodegradation, Phytoextraction, Phytodegradation, Phytoaccumulation and Phytovolatilization.

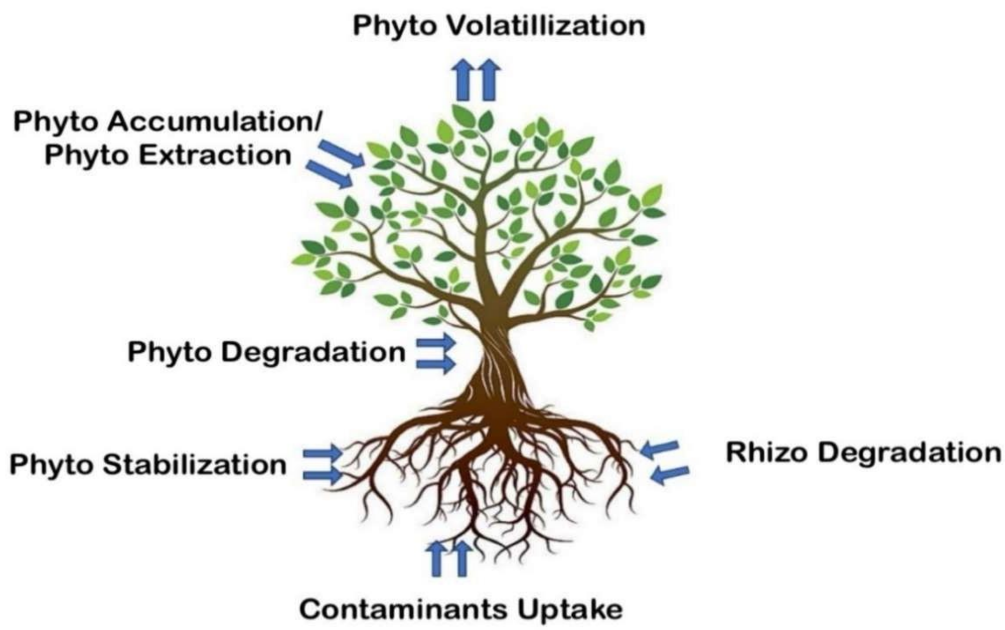

Figure 3: Mechanisms of phytoremediation technology

7.1 Phytoextraction: Phytoextraction involves the uptake and accumulation of heavy metals from water or soil by plants, followed by their translocation to the aboveground parts of the plant for harvest and removal. The roots and shoots are picked to eliminate soil pollutants (Ali et al., 2013). According to Chandra and Kumar (2017), twelve appropriate native plants growing on sludge were shown to be able to acquire iron. It was found that *A. spinosus L.* was a Zn and Mn shoot accumulator. Except for *A. spinosus L*. and *Ricinus communis*, all plants were found to be leaf accumulators for Fe, Mn and Zn. Lajayer et al. (2019) have demonstrated the promising potential of ornamental plants for phytoextraction of heavy metal from polluted environments. Once the plants have accumulated significant metal concentrations, they can be harvested and disposed of, effectively removing the contaminants from the environment. Phytoextraction is suitable for treating heavy metal-contaminated water bodies, especially in areas with moderate to high metal concentrations and accessible plant biomass for harvest.

7.2 Phytostabilization: It involves the use of plants to immobilize heavy metals in the root zone or soil, thereby, decreasing their bioavailability in the environment (Yan et al., 2020). They are therefore unable to enter the food chain or migrate to groundwater (Ali et al., 2013). The suitability of employing four woody plants in conjunction with organic amendments to Phyto-stabilize zinc smelting slag was examined by Luo et al. (2019). The findings demonstrated that direct planting of plants boosted nutrient accumulation and decreased the bioavailability of heavy metals (Cu, Zn, and Cd) from waste slag from zinc smelting. *Helianthus petiolaris* is an aromatic plant, and Saran et al. (2020) conducted a phyto stabilization demonstration to find out how well it might grow in heavy metal containing soils. *H. petiolaris* may grow in soils containing up to 500 mg/Kg Pb2 and 50 mg/Kg Cd2 in terms of Phyto stabilization, collecting more than three times the soil's Cd content in the aerial portions and translocating significant amounts of Pb to the aerial parts and translocating large amounts of Pb to the aerial parts. By stabilizing heavy metals in the root zone, phyto stabilisation reduces the risk of ground water contamination and ecosystem exposure. Phyto stabilisation is particularly suitable for treating heavy metal-contaminated soils and sediments adjacent to water bodies, providing long-term containment and remediation of pollutants.

7.3 Rhizofiltration: It utilizes the roots of plants to filter heavy metals directly from water, removing contaminants and improving water quality. The pollutants, especially the heavy metals and organic wastes, are degraded and breakdown and transformed into less or non-toxic chemicals in the rhizosphere. The utilization of different kinds of microbes improves this process as well. It involves the absorption, adsorption, and precipitation of pollutants from the substrate, which first take place in the root surface through different interrelated physicochemical processes, such as chelation, ion exchange, and chemical precipitation through root exudates, among others. Metal uptake in the roots occurs under the same mechanisms as in the phytoextraction process. However, because the contamination mostly accumulates in root tissue, the rhizofiltration mechanism is unable to effectively translocate within the plant. The pollutant is chelated by phytochelatins and metallothionein and then stored in the vacuoles and apoplast, where it forms a covalent bond with the cell walls, following its uptake and mobilization. According to a study by Benavides et al. (2018), *Zea mays* has a greater capacity for absorbing and accumulating mercury. Two species of *Phragmites australis* and *Kyllinganemoralis* were planted in a rhizofiltration device at a sewage treatment plant in KwaZulu-Natal, a province in South Africa, and the device's effectiveness was evaluated in extracting heavy metals from municipal wastewater.

7.4 Phytovolatilization: Plants are used to convert different pollutants into less hazardous volatiles, which are then released into the atmosphere through the foliar system. Pollutants are removed and fractionated within plant air spaces during phytovolatilization, and then they diffuse into the atmosphere. According to Yan et al. (2020), this idea can be applied to eliminate organic contaminants in addition to heavy metals like Se, Hg, and As. *Pteris vittate* has been shown by Sakakibara et al. (2010) to be capable of metabolizing arsenic into volatile forms. Harvesting or eliminating heavy metal pollution involves pulling them out of the soil and dispersing them as gaseous molecules (Yan et al., 2020). *Alternanthera philoxeroides, Artemisia princeps, Bidens frondosa, Bidens pilosa, Cynodon dactylon, Digitaria sanguinalis, Erigeron canadensis and Setaria plicata* converts Cd, Mn, Pb and Zn into volatile forms (Yang et al., 2014). *Acanthus ilicifolius* L. converts Cd into volatile forms. (Shackira and Puthur, 2017).

Table 4: Various Plant species and contaminants removed by them

Plants	**Contaminants**	**References**
Sedum plumbizincicola, *Zea mays L., Sorghum bicolor (L.)*	Cd, Zn	(Deng et al., 2016)
Tamarindus Indica	Cd	(Udoka et al., 2014)
Alternanthera philoxeroides, Artemisia princeps, Bidens frondosa, Bidens pilosa, Cynodon dactylon, Digitaria sanguinalis, Erigeron canadensis and Setaria plicata	Cd, Mn, Pb and Zn	(Yang et al., 2014)
Salix and Populus	Cd, Pb, Zn	(Za´rubova´ et al., 2015)
Salvia sclarea L	Cr, Fe, Ni, Pb	(Chand et al., 2015)

Acanthus ilicifolius L.	Cd	(Shackira and Puthur ,2017)
Athyrium wardii	Pb	(Zhao et al., 2016)
Festuca rubra L.	Cu	(Radziemska et al., 2017)
Solenum nigrum L. and Spinacia oleracea L.	Pb, Cu, Cd and Cr	(Dinesh et al., 2014)
Ricinus communis	Fe, Mn and Zn	(Lajayer et al., 2019)
Helianthus petiolaris	Pb and Cd	(Saran et al., 2020)
Zea mays	Hg	(Benavides et al., 2018)
Festuca rubra L.	Pb, Zn	(Galende et al., 2014)

8. CHALLENGES IN MICROBIAL MEDIATED BIOREMEDIATION AND PHYTOREMEDIATION:

Remediating heavy metal contamination in water poses several challenges, including, complexity of contaminants heavy metal contamination in water often involves multiple pollutants with varying chemical properties, solubilities, and toxicity levels, making remediation efforts more challenging. Bioremediation is only applicable to the removal of biodegradable contaminants (Harekrushna and Kumar, 2012) hence leaving the non-biodegradable contaminants like plastic in the environment. Heavy metals can persist in the environment for long periods and exhibit mobility, leading to their accumulation in sediments and biota. Remediation of heavy metal contamination in large water bodies or industrial sites requires scalable and cost-effective approaches. Biological processes are highly influenced by many factors like the presence of metabolically active microorganisms, suitable environmental factors which can aid microbial growth and an appropriate level of nutrients and contaminants. The survival of microorganisms is based purely on the environmental conditions in which they thrive (Shishir et al., 2019). In Phytoremediation plant types, root region, environmental conditions, root composition and elemental species, as well as the soil physio-chemical and biological properties, all have an effect on heavy metal buildup and dispersal within plants. Choosing a single species to build a phytoremediation system is another crucial step. Since many pollutants differ in their chemical structure and properties, we must take several considerations into account. This is a crucial system constraint for phytoremediation. The coexistence of bacteria near plant roots in soil and water systems has been observed to impact the absorption mechanisms in multiple instances. The inability of the root cells to absorb the substance is a major factor in the low absorption and mobilization of the pollutants. To improve remediation, agronomic practices have been introduced (pH adjustments, chelators and fertilizers are some of the things that can be done). Other crucial elements to take into account include the phosphorus concentration, organic matter, and pH of the soil. To minimize Pb absorption by plants, the soil pH can be changed with lime to between 6.5 and 7.0 (Fahr et al., 2013).

9. CONCLUSION AND FUTURE PERSPECTIVES

One effective method for clearing polluted areas is bioremediation. The concept of bioremediation is not new. A lot of new applications are being developed, though, and some are still quite new. When microorganisms are able to biodegrade the specified pollutant and the essential nutrients, including trace elements, nitrogen, phosphorus, and electron acceptor. Whichever facet of bioremediation is employed, this approach provides a productive and economical means of treating contaminated ground water. Compared to many pollutant removal techniques, which convert pollutants into benign compounds and aid in the development of ecologically safe production and disposal processes, biotechnology is a more cost-effective and environmentally beneficial methodology. Microorganisms are a very rewarding option to manage and remediate the polluted environment, and the application of genetic engineering through their exploitation to reduce the toxic load in the environment is paving the way for the future of maintaining environmental quality. In terms of cost and sustainability, bioremediation technology is a good choice in comparison to other traditional technologies. Bioremediation, like other approaches, has inherent limitations. Some microbes are unable to degrade harmful metals that are resistant to microbial attack, such as high aromatic hydrocarbons or chlorinated organics, and are hence biodegradable. In order to make bioremediation effective in all unfavorable circumstances, future research should concentrate on integrating an interdisciplinary approach with disciplines like engineering, nanotechnology, microbiology, geology, ecology, and chemistry.

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11. AUTHOR CONTRIBUTION

D, H.J; analysis, writing, drafting, review and editing.

J.G.S; Supervision, resources and formal analysis.

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13. CONFLICT OF INTEREST

We have declared that no competing interests exist.

14. ETHICAL APPROVALS

This study doesn't include any experiment on animal or human subject.

15. DATA AVAILABILITY

All the data are available within the review article.

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