Removal of Heavy Metals Using Bio-remedial Techniques

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Abstract Heavy metal pollution has become one of the most significant environmental problems globally leading to ecological imbalance. Different techniques like physical, chemical and biological have been used for removal of heavy metal contaminants from the environment. Some of these have limitations such as cost, time consumption, logistical problems, and mechanical involvedness. Biological strategies, unlike other methods of remediation, are unique in that biological strategies are environmentally friendly and acceptable, the diversity of organisms involved is wide and of diverse capabilities that have not yet been exhaustively exploited and also amenable to genetic modification for accelerated bioremediation. There are several techniques entails with the removal of heavy metals. Therefore, this chapter proposes to present thorough information on some techniques that might be applied for the removal of heavy metals using bioremediation. The encouraging evidence as to the usefulness of microorganisms and their constituents for the remediation of heavy metals from contaminated environment is reviewed in detailed. Recent advances in the application of removal of heavy metals through bioremediation also were highlighted.

Keywords Bioremediation · Remediation · Heavy metals · Techniques

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1 Introduction

The soil contamination through metalloids and heavy metals is a worldwide problem as a result of the accumulation of these compounds in the environment, endangering plants, human health as well as animals. Metalloids and heavy metals are usually there in nature, although the increase of industrialization has cause concentrations to rise compare to the acceptable ones. However, they are toxic and non-biodegradable, this happen at lower concentrations. Deposits accumulate in living beings in addition be converted into dangerous each point in time they are incorporated and pile up more rapidly compared to when they are metabolized. Consequently, the potentially dangerous effects are as a result of persistence in the surroundings, toxicity as well as bioaccumulation in the organisms (Tchounwou et al. 2012; Briffa et al. 2020) (see Fig. 1).

The rigorousness effects depend on the kinds of metalloid or heavy metal. Certainly, several of the heavy metals (such as, Fe, Mn, Ni and Co) at concentrations very low are vital for living organisms, despite the fact that others (includes Pb, Hg and Cd) are nonessential, moreover they are toxic even in trace quantity. It is significant to scrutinize the concentration of metalloids and heavy metals in the ecological system and approve techniques to eliminate them. For this rationale, diverse methods have been created in some years back, these includes: chemical remediation (which includes catalysis, adsorption, solubilization/precipitation, electrokinetic techniques), physical remediation (such as thermal desorption, washing, solidification), biological remediation (viz: phytoremediation,

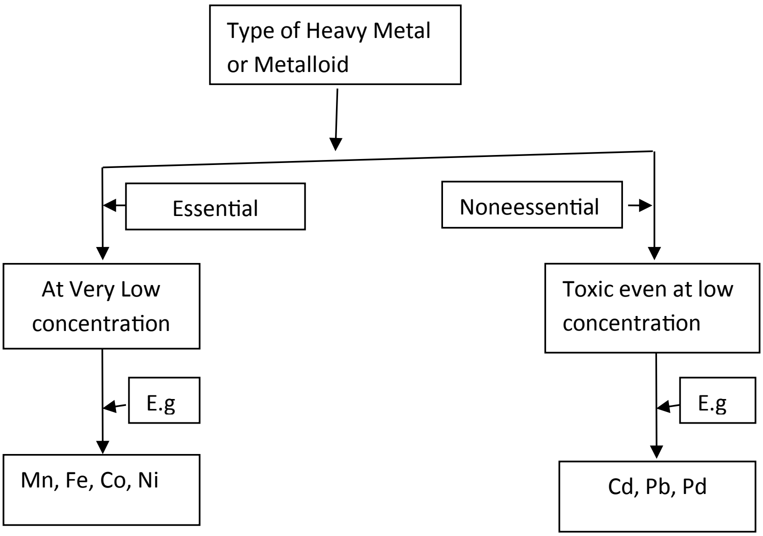

Fig. 1 Type of heavy metal or metalloids concentration

biodegradation, bioventing), and combined remediation (including washing–microbial degradation and electrokinetic–microbial remediation;) (Fig. 2) (Raffa et al. 2021).

In the study of Dhaliwal et al. (2019) revealed the pollution obtained from heavy metal which is part of the severe problems and infects the environment through diverse ways amid the blow of manufacturing in numerous nations. Many techniques such as chemical physical, as well as biological have been utilised for elimination of heavy metal pollution from the environs. However, several of these techniques have constraints which include time consumption, cost, mechanical involvedness along with logistical problems. At the present time, phytoremediation, in situ immobilization of metals as well as biological techniques seem to be to the best way out for removal of metal/metalloids from the soil. They targeted contaminant site for remediation which is to restrict the heavy metal to go through into the soil, food-chain, along with the introduction to human beings. In the other hand, the sort of technique applied for a given location depends on the features such as usual developments take place at the polluted location, type of chemicals, soil type, and the intensity of polluted site.

Typically, heavy metals are channeled to environment through the disposal and processing of heavy metal containing manufactured goods. Pollution of the environment caused through the heavy metal enhances awareness globally as a result of their toxicity in animal, human beings as well as plant along with their inadequate of biodegradability. As soon as the metals are polluting the ecosystem, they possibly will continue for some period depending on the kids of metal that that is present in the site. The process of remediation for heavy metal polluted sites might be ex-situ or in-situ, biological and off-site or on-site, chemical as well as physical. Furthermore, many of these methods applied in mixture through each other intended for more cost-effective and proficient remediation of a heavy metal polluted environment. Remediation using biological means in biotransformation of heavy metals into non-harmful type was look into, in the study. The molecular mechanism of heavy

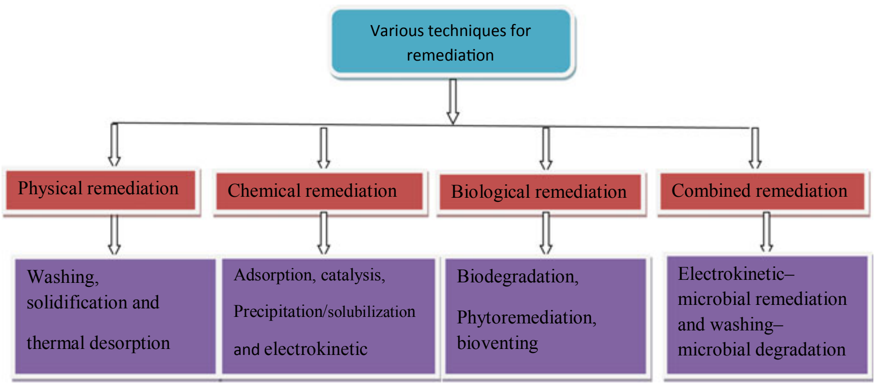

Fig. 2 Types of techniques in bioremediation

metal buildup has often biotechnological insinuations for bioremediation of polluted metal sites (Madhuppriya et al. 2020).

Also, Akhtar et al., (2020) in their study, opined that contamination of heavy metal has turn out to be one of the major momentous environmental problems worldwide leading to environmental disproportion. Several of the techniques such as biological and physicochemical are consider for the elimination of heavy metals. A good number of the physical and chemical techniques are less cost-effective and less eco-friendly, at the same time the biological techniques are not fast in reactions. Nanoparticles, in recent times, have been recommended as proficient substitutes to obtainable treatment techniques, in altogether supply maintenance as well as ecological remediation of compounds generated from anthropogenic activities. Nanotechnologies are persistent way out vectors in our monetary ecosystem. Synthesis of biological nanoparticles has developed noticeably to generate novel resources that are cost-effective, eco-friendly as well as established with enormous significance in wider use in the regions of medicine, agriculture and electronics. Consequently, they focus on a proportional remediation of heavy metals by means of chemical, biological and physical techniques. The nano-structured copper iodide is applied as an adsorbent in the process of eliminating zinc and chromium. The techniques used in the removal of heavy metal in the study are; chemical (UV photocatalysis by the application of CuI), physical (UV light irradiation and adsorption studies by means of CuI) and biological techniques (by means of co-culture bacteria strains). A grouping of biological and chemical techniques was in addition investigated by means of CuI–polyvinyl alcohol nano-composite consists of bacterial co-cultures.

Liu et al. (2018) in a related study, used techniques of ex-situ and in-situ remediation to remedy the heavy metal polluted sites, such as encapsulation, surface capping, soil flushing, landfilling, electrokinetic extraction, soil washing, solidification, stabilization, phytoremediation, bioremediation and vitrification. These remediation methods make use of restraint, removal/ extraction, and immobilization schemes to decrease the pollution effects by chemical, physical, electrical, thermal as well as biological remedy developments. These methods display precise disadvantages, applicability and advantages. In addition, the technique of in-situ soil remediation tends to be more cost-effective compared to ex-situ treatment, and pollutant extraction/removal is more encouraging than containment and immobilization. Among the accessible soil remediation methods, chemical stabilization, phytoremediation and electrokinetic extraction are at the advance phase, whereas some of the others have been adept at complete, field scales. Comprehensive evaluation point out that chemical stabilization proves a momentary soil remediation method, phytoremediation requires enhancement in effectiveness, serious-contamination sites, landfilling and surface capping are related to small, while vitrification and solidification are the most recent remediation alternative. However, treatability studies are vital to decide on practicable techniques for a soil remediation scheme, with considerations of the degree and type of pollution, site characteristics, remediation goals, implementation time, public acceptability and cost effectiveness.

Awasthi et al. (2022) study the penalty of heavy metal pollution progressively mortifying soil eminence in this current era of industry. As a result of this reason, enhancement of the soil eminence is essential. The application of plants to eliminate toxins from the soil, like trace elements, heavy metals, radioactive substances, and organic chemicals, is said to be bioremediation. Fly ash and Biochar techniques are evaluated for efficiency in enhancing the quality of polluted soil. They compiles amelioration methods and how they are applied in the field.

With their toxic effluent, municipal wastewater, or slurry comprising a divers of heavy metals, anthropogenic and industries activities all around us pollute our mineral resources. These hazardous metals, in turn, are posing new health concerns to humans, including allergies, infections, deformities, and diseases. As a result, there is a growing demand for environmentally friendly, systematic, and creative approaches of removing these harmful heavy metals. In dealing with a polluted ecosystem, chemical, biological and physical techniques have not shown to be very effective. These traditional methods have drawbacks in terms of energy consumption, efficiency and cost. Overcoming their limitations, adsorption, a chemical and physical surface phenomena, has emerged as a far more cost-effective, reactive, flexible, and efficient method of removing heavy metals such as chromium, cobalt, nickel, lead, arsenic, mercury, cadmium, copper and uranium. Microbes, industrial waste biomass, lignocellulosic material, metal organic frameworks (MOFs), nanotubes, and nanocomposite substance are all used to fabricate a spectacular adsorbent by modifying their chemical and physical features (Mahendra et al. 2021).

Heavy metal contamination has been detected in soils and rivers as a result of anthropogenic and rapid industrialization activities like the uncontrolled use of fossil fuel burning, wastewater sludge dumping and agrochemicals. Heavy metals are non-biodegradable and have a long shelf life. As a result, remediation is needed to prevent heavy metal mobilization or leaching into the ecosystem, as well as to make heavy metal removal easier. Microbes are used in bioremediation to remove heavy metals. Microbes use a variety of bioremediation processes. These mechanisms are one-of-a-kind in terms of their specialized requirements, benefits, and drawbacks, because their success is largely determined by the types of organisms and toxins associated with the process. plants, Heavy metal contamination causes stress to humans, animals, plants, and other species in the ecosystem. To ensure cost-effective and effective processes, a thorough understanding of the process along with various remediation options at several stages is required (Kapahi and Sachdeva 2019).

2 Physicochemical and Biological Methods for the Removal of Heavy Metals

Since the dawn of time, humanity has used plants and natural materials to combat the threat of heavy metal toxicity in both human health and the ecosystem around them. Affected by exposure to about thirty-five metals have been reported as a result of accidental or occupational exposure. Twenty-three of them are heavy metal bands.

The rising use of heavy metals, especially radionuclides, is causing health problems. The presence of heavy metals in the environment, as well as their impacts on humans further down the food supply chain, poses a health risk. As a result, the abolition of heavy metal has become a top priority. Their study shows systematic of books, patents, and scientific material from widely recognized scholarly databases and search engines on plant-based and natural chemicals against heavy metal contamination are presented. It is thought that a variety of phytoconstituents agents, along with microorganisms, could operate as heavy metal removers in both humans and the environment. Bacteria, algae, fungi, and yeast are among the microorganisms that are utilized to remove heavy metals out aquatic environment (Sharma et al. 2016).

Heavy metal contamination has already been recognized as a global problem since the beginning of the industrial revolution. Because of its poisonous nature, heavy metal pollution poses major environmental and health problems. Heavy metal remediation using traditional techniques is inefficient and results in a huge amount of secondary trash. Biological process, on the other hand, including microorganisms and plants, provide simple and environmentally friendly methods for removal of metal ions, and are thus regarded cost effective and substitute metal removal tools. Reduction, adsorption, or removal of pollutants from the ecosystem using biological resources is referred to as bioremediation (both plants and microorganisms). Microorganisms' heavy metal remediation abilities are derived from self-defense strategies including enzyme production, cellular morphological alterations, and so on. These defense systems include the active participation of microbial enzymes which including oxygenases, oxidoreductases, and other enzymes that impact bioremediation efficiencies. Immobilization methods are also enhancing the technique on a large scale (Jacob et al. 2018).

Toxic heavy metal pollution is one of the most serious environmental challenges, and it has accelerated considerably as a result of shifting industrial activities. This review focuses on the most popular heavy metal phytoremediation techniques, approaches, including biological techniques. It also gives a broad review of the role of microbes in heavy metal environmental remediation in damaged ecosystems. Biological and Physicochemical approaches of heavy metals removal are effective measures, with the latter divided into ex situ and in situ bioremediation. The in situ practice such as biosparging, bioventing, bioaugmentation, phytoremediation and biostimulation. Ex situ bioremediation which includes composting, land farming, bioreactors and biopiles. Bioremediation make use of microorganisms that naturally occur such as *Sphingomonas*, *Pseudomonas*, *Alcaligenes*, *Mycobacterium* and *Rhodococcus*. Bioremediation, in general, requires very little work, is labor-intensive, sustainable, inexpensive, environmentally friendly, long-term, and relatively simple to apply. The majority of bioremediation's drawbacks are related to its slowness and time-consuming nature; also, biodegradation metabolites can occasionally be more harmful than the initial substance. Bioremediation summative assessment may be difficult due to the lack of an acceptable end - point. More research is needed to develop phytoremediation innovations and discover more biological remedies for the bioremediation of heavy metals pollution in various ecosystems (Sayqal and Ahmed 2021).

Nanotechnology has engulfed all aspects of life, encompassing industry, medicine and health, agriculture, environmental challenges, and bioengineering, to name a few. Nanostructure materials have transformed every industry. Environmental contamination is a major worry in today's world, affecting both industrialized and advance nations. To address this issue, a variety of techniques have been implemented. The use of nanotechnology in environmental pollution bioremediation is an approach beyond revolution. Several in-situ (bioslurping, bioventing, phytoremediation, biosparging and permeable reactive barrier) and ex-situ (windrows, biopile, land farming and bioreactors) methods are used to accomplish this. Nanoparticles are appropriate for natural applications due to improved qualities such as reduced time utilization, nanoscale size, high adaptability for Ex-situ and In-situ use, indisputable amount of surface-region to-volume percentage for probable sensitivity, and protection from environment components. To cure contaminants, many nanomaterials and nanotools are available. The qualities of foreign compounds and the pollution location influence each of these approaches and nanotools (Hussain et al. 2022).

Aquaglyceroporins, phosphate transporters, and the effective extruded scheme all take in arsenic, which is then decreased through arsenate reductases via a dissimilatory reduction pathway. Arsenic oxyanions are used by some autotrophic and heterotrophic bacteria for energy renewal. Arsenate can be used as a nutrient by some microbes during the process of cellular respiration. In bacteria, decontamination operons are a prevalent form of arsenic resilience. As a result, bioremediation may be a viable and cost-effective method of removing this contaminant from the ecosystem (Lim et al. 2014).

Adsorption on novel adsorbents, membrane filtration, on exchange, reverse osmosis, electrodialysis, photocatalysis and ultrafiltration were among the physico-chemical removal techniques explored. In terms of application, their benefits and downsides were assessed. Microorganisms have a function in biological methods of treatment by settling sediments in the solution. Industrial wastewater is treated with trickling filters, activated sludge, and stabilization ponds. Bioadsorption is a novel biological technology that uses a variety of low-cost bioadsorbents (forest waste, agricultural waste, algae, industrial waste, and so on) to remove heavy metals from wastewater to the greatest extent possible. Bioadsorption methods, rather than chemical and physical approaches, are the most environmentally acceptable techniques for removing heavy metals from wastewater. Chemical techniques, on the other hand, are the best treatments for harmful inorganic chemicals produced by several industries that cannot be eliminated through biological or physical means (Gunatilake 2015).

Environmental contamination from pesticides and heavy metals has raised worries about toxic potential to a variety of species, therefore their removal from water is critical. The goal of this study was to use physical and biological approaches to remove heavy metals, pesticides, arsenic, Diazinon and Malathion from water. Particle trapping techniques, which had straws to trap tiny and big particles, were used to physically remove the contaminants (Arash et al. 2018).

Biosorption, reduction/oxidation, bioaccumulation, precipitation, leaching, degradation, phytoremediation and volatilization are among the biological methods currently available or potentially available for removing and detoxifying toxic metalloids and heavy metals from contaminated sediments and water (bioaccumulation, biosorption, reduction/oxidation, precipitation, leaching, degradation, volatilization, and phytoremediation). They also go over the alternatives for recovering metals accumulated through biosorbents (with the right desorbing agents) as well as plant biomass and microbial (leaching through biological processes or chemical reagents, and thermal treatment in controlled systems) (Kikuchi and Tanaka 2012).

3 Transport Mechanisms of Heavy Metals

Due to their environmental permanence, mobility and toxicity in soils, heavy metals have sparked a lot of attention. Owing to the increase of mining companies, pesticide use, as well as other sociocultural activities, certain Chinese soils have been poisoned by heavy metals, causing the agro-ecosystem to have become damaged. Their study focus to provide light on the current state of contamination in China, as well as the sources of heavy metals, their transport modes, and the factors that influence their mobility. Additional studies on source identification and heavy metal movement features in soil will be presented in the future (Jing et al. 2018).

Although a set of genes encoding putative transporters have since been discovered, the methods used in the absorption of necessary heavy metal micronutrients are still unknown. The heavy metal (CPx-type) ATPases, the natural resistance associated macrophage protein family, and members of the cation diffusion facilitator family are the three categories of membrane transporters that have been accused in the transport of heavy metals in a variety of microorganisms and therefore could utilize such an important roles in plant. They hope to provide an overview of the main characteristics of these transporters in plants in terms of function, structure, and regulation, based on research in a variety of microorganisms (Lorraine et al. 2000).

There are three types of mercury fragments: semi-mobile mercury (Hg(0)-metal, Hg(0)), mobile mercury (EtHgCl, MeHgCl, and other mercuric compounds) and nonmobile mercury (EtHgCl, MeHgCl), as well as other mercuric compounds) (HgS, HgSe, and Hg_2Cl_2) (Yao et al. 2019).

Membrane transport of non-essential hazardous heavy metals (type 0 heavy metals) clearly defines their absorption, excretion from the body, and distribution, as well as restricts their access to Intracellular target sites. Membranes have a crucial role Several researchers have focused on the toxicity of class 0 metals, and significant data has been gathered on the mechanism(s) of metal transfer through membranes. Metal transport features are not exactly equivalent in cell populations, or even on separate sides with same cell, or under various physiological circumstances, and no single hypothesis to explain this process in all cells has been proposed. However, it's plausible that the various cell mechanisms hypothesized are variants on a few basic motifs (Foulkes 2000).

Adsorption, desorption and ion exchange, mobilization, aqueous complexation, and biological immobilization, mineral dissolution, plant uptake, and precipitation all influence lead dispersion in soil. Simultaneously, chemical mechanisms such as oxidation–reduction reactions, cation sorption on exchange complexes, and chelation with organic matter are responsible for lead dispersion as well as migration in soils (Kushwaha et al. 2018; Palansooriya et al. 2020).

Under fed conditions, two critical processes occur: iron oxide is decreased, and absorbed arsenic is discharged into solution phase; arsenate [As(V)] absorbed on solid phase is lowered to As(III), which is less effectively absorbed than As(V) and thus has a higher potential to separation into solution phase (LeMonte et al. 2017).

Various physical and chemical processes regulate cadmium's behavior in the soil. Rainfall and adsorption reactions help to keep it in the soil. The fundamental mechanism is rainfall, with anions in the forms of $PO_4{}^3$, OH, CO_2, and S_2, with cadmium adsorption on the surface of soil minerals occurring through both nonspecific and specific mechanisms (Zhang et al. 2018; Wang et al. 2022).

The majority of chromium in soils comes from weathered minerals found in ultramafc rocks. The chromite weathering process has two phases: a manganese oxide oxidation reaction to chromium (VI), and a chromium (III) hydrolysis reaction to $Cr(OH)_3$. Furthermore, chromium is found in significant amounts in spinels, clay minerals, and iron oxides (Christopher et al. 2011; Hausladen et al. 2019).

They leach into subsurface fluids, travelling down water routes and finally settling in the aquifer, or they are swept away by run-off into surface waters, causing water and soil contamination. Toxicity and poisoning are common in ecosystems due to coordination and exchange processes. They mutilate their structures and obstruct bioreactions of their functions when consumed, forming stable biotoxic chemicals (Ruangcharus et al. 2020).

4 Impact of Heavy Metals on Human Health and the Environment

Heavy metals can enter the body through the use of the intestinal system, the skin, or breathing. Toxic metals have shown to be a significant health risk, owing to their propensity to harm membranes and DNA, as well as disrupt enzyme activity and protein function. By attaching to free thiols or other functional groups, perturbing protein folding, accelerating the oxidation of amino acid side chains, or/and displacing critical metal ions in enzymes, these metals disrupt native proteins' activities. The biochemical and physiological implications of hazardous metal interactions with proteins and enzymes were accounted for in their study. Because heavy metal poisoning of the ecosystem is one of the most serious worldwide issues, certain detoxifying procedures are also discussed (Witkowska et al. 2021).

Toxic heavy metal pollution of terrestrial and aquatic ecosystems is an environmental issue that is a public health risk. Heavy metals accumulate in the ecosystem as persistent contaminants and harm food systems as a result. The buildup of potentially hazardous heavy metals in biota poses a health risk to their consumers, who include humans. This article examines the various elements of heavy metals as hazardous compounds in depth, with a particular focus on their environmental durability, toxicity for living beings, and bioaccumulative potential. These elements' trophic transmission in aquatic and terrestrial food chains/webs has significant ramifications for animal and human health. The amounts of potentially harmful metalloids and heavy metals in various environmental components and in the resident biota must be assessed and monitored (Ali et al. 2019; Madiha et al. 2022).

Cadmium poisoning has been linked to bone and kidney damage. Cadmium also has been discovered as a human carcinogen that can cause lung cancer. Lead poisoning affects fetuses, babies, and children's growth and neurobehavioral development, as well as raising blood pressure in adults. Mercury is harmful in both its inorganic and elemental forms, but the organic molecules, particularly methylmercury, that accumulate in the food chain, i.e. in predatory fish in lakes and seas, are the primary routes of human exposure. Long-range transboundary air pollution is really only one source of exposure to toxic metals, but due to their potential and persistence for global atmospheric transmission, atmospheric emissions have an impact on even the most remote places (Rafati et al. 2017).

Also, heavy metals can cause toxicity in some organs of the human body including as neurotoxicity, nephrotoxicity, skin toxicity, cardiovascular toxicity and hepatotoxicity, among other things (Saikat et al. 2022).

5 Recent Reports on Removal of Heavy Metals Through Bio-remedial

In the last few decades, rapid industrialization, increased population expansion, hazardous industrial and urbanization practices have all contributed to the growth of ecological pollution. Heavy metals are one of those contaminants that, due to its toxicity, are linked to public health and environmental consequences. Successful bioremediation can be achieved using both "in situ" and "ex situ" techniques, depending on the kind and quantity of contaminants, site conditions, and cost. Recent advancements in artificial neural networks and microbial gene modification aid in improving "in situ" heavy metal bioremediation at contaminated areas. For the efficient elimination of toxic metals using diverse indigenous microorganisms, multi-omics techniques are used (Oindrila et al. 2021).

Because of the damaging effects of long-term environmental contamination, heavy metal pollution poses a major threat to all forms of life in the environment. At low quantities, these metals are very sensitive and can be preserved in food webs, posing a severe public health danger. Several organic contaminants and metals are still not biodegradable and can persist for a long period in the ecosystem. Traditional chemical and physical techniques of remediation are inefficient and result in enormous amounts of chemical waste. Over the years, there has been a growing and strong interest in the equilibrium of dangerous metals. Biosensor bacteria are both environmentally friendly and cost-effective. As a result, microbes have a range of metal sequestration processes that allow them to have higher metal biosorption capabilities (Tarekegn et al. 2020).

Due to increased industrialization as well as certain other anthropological practices, substantial quantities of heavy metals are already being added to the soil and untreated sewage on a daily basis. Several more heavy metals are already non-biodegradable, so they continue to stay in circulation after being discharged into the ecosystem. Certain heavy metals could cause chronic and deadly disorders in people, as well as impact plants and animals metabolism, if their concentrations above the threshold level. Many of the current physical and chemical techniques for removal of heavy metals from industrial effluents, including ion exchange, electro-chemical treatment, reverse osmosis, and precipitation, have not been proven to be cost effective, so a biological perspective might also demonstrate to be a substitute remediation innovation for accumulation of heavy metals. Microbes have developed techniques to resist, metabolize or detoxify heavy metals, including sequestration or active efflux with insoluble or proteins substances. In t heir, it was observed that, the relationship of microorganisms and heavy metals, as well as their uses in heavy metal remediation (Sanjay 2020).

6 Conclusion and Future Trends

Bacteria are one of the most important microbiological options for bioremediation; nevertheless, only a few studies have been conducted in this field, and more comprehensive and comprehensive investigations are needed to get the most out of bacterial systems as "heavy-metal pollution alleviators." Multidisciplinary methods are also required for the effective treatment of various heavy metals employing bioremediation. Further research into heavy metal bioremediation is needed, with an emphasis on strategies that have been proven to change various environmental characteristics and conditions, as well as refining the processes by which the co metabolic pathway to bioremediation works. There's also a requirement to assess appropriate conditions, deterioration rates, and lag times for diverse heavy metal genres. In addition, further research should be done on optimizing diverse environmental circumstances and improving vital growth conditions within site-specific variances. Furthermore, there is a need for current and credible research on bioaugmentation, as well as the specific microbe accountable for heavy metal breakdown and the exact factors involved.

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