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Health Effects of Heavy Metal and Methods of Removal: A Review

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ABSTRACT

The accumulation of heavy metals (HMs) has become a serious environmental problem because the ecosystem is characterized by the expansion of man-made and natural sources of metals. Human exposure to HMs has remarkably increased as a result of industrial activity in the 20th century. Pb, Cd, As, Cr, and Hg are the most prevalent HMs that pose a risk to humans. Poisoning can be chronic or acute following exposure to food, water, or air. Numerous organs and tissues are harmed by HMs, which bioaccumulate. A comparison of the mechanisms of action of HMs revealed that they exert toxicity via comparable pathways, including the inactivation of enzymes, production of reactive oxygen species, and development of oxidative stress. The conventional approaches for HM removal are inadequate when the concentration of HMs is no more than 100 mg/L. Secondary pollutant production, increased energy and chemical requirements, and reduced cost-effectiveness are some disadvantages of the above methods. Detoxifying HMs via microbial bioremediation is now possible because bacteria and fungi have superior capacities for bioaccumulation and biosorption over other microorganisms. The present work discusses the toxicity and absorption processes associated with HMs to improve the treatment of metal poisoning and increase our knowledge of the detrimental effects of HMs on body organs. It aims to increase knowledge and provide resources for the careful choice of bacteria remediation technology for detoxifying heavy metals. Sustainable microbial treatments could provide essential and economical approaches for lowering Heavy Metal cytotoxicity.

Introduction:

Heavy metals (HMs) are metallic substances with densities higher than occur water [1]. Typically, HMs are defined as elements with densities at less than five times greater than that of H_2O [2]. Under the assumption that heaviness and toxicity are connected, not only Metals that are heavy but also certain metalloids, like, may be toxic at low exposure levels [3]. Numerous HMs, such as Cd, Cr, Co, Cu, Pb, Hg, and Ni, are biologically nonessential and detrimental to aquatic environments [4].

Anthropogenic sources, which include the mining, nonferrous metallurgical, chemical, and electroplating industries, commonly release hazardous metals, including HMs, into the environment [5].

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The amount and duration of exposure to such harmful compounds determine the level of toxicity that they exhibit. How HMs enter the food chain and affect humans is depicted in Figure 1. Long-term exposure to HMs via skin contact, inhalation, and the ingestion of contaminated food could result in several illnesses in humans and other species [6].

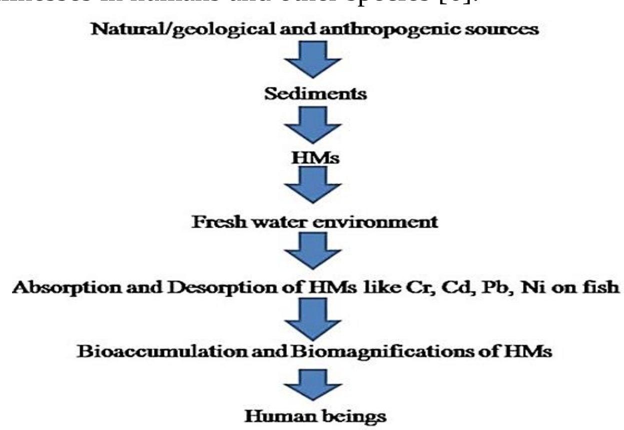

Figure 1. Sources and effects of HMs on People as they pass via the food chain [7].

Numerous sources, such as urbanization, mining, pesticide plants, sewage plants, chemical industries, and biomedical and unsafe agricultural practices, discharge HMs into the environment (Figure 2) [8].

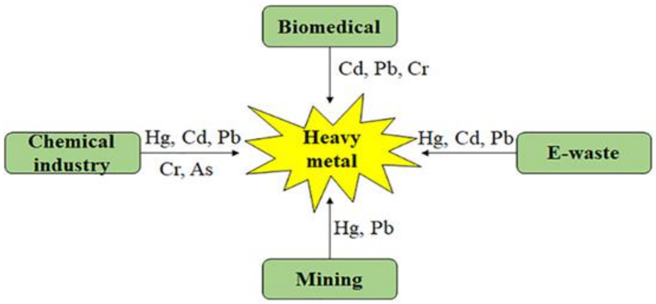

Figure 2. Origins of HM pollution [8].

Terrestrial ecosystems and their biodiversity are heavily dependent on soil. Plants, microorganisms, and animals can accumulate HMs, which are common pollutants in the soil environment. The European Environment Agency (EEA) has established limit values for soil pollutants for certain HMs, namely, Cd (0.44 ppm), Hg (0.20 ppm), Cr (0.20 ppm), Pb (0.48 ppm), and As (0.11 ppm) [9, 10]. The World Health Organization (WHO) has prescribed tolerable amounts of HM pollutants in drinking water of 0.005 ppm for Cd, 0.001 ppm for Hg, 0.05 ppm for Cr, 0.05 ppm for Pb, and 0.05 ppm for As [11, 12]. Given that elevated levels of HMs could lead to health issues, the WHO and Food and Agriculture Organization of the United Nations have established maximum ingestion limits. The following are the maximum permissible concentrations of HMs in vegetables: 0.05 mg/kg Hg for all vegetables, 0.3 mg/kg for root vegetables, 0.2 mg/kg Cd for leafy vegetables, 0.1 mg/kg for other vegetables, 0.15 mg/kg Pb, 0.1 mg/kg As, and 0.1 mg/kg Cr [13, 14].

Health effects of HMs on humans

Based on their different sources and locations, metallic elements—natural environmental components that are found in the Earth's crust—have different proportions [15]. Their existence is special because once they are in the environment, their complete removal is difficult [16]. Owing to the detrimental effects, biomagnification qualities, and long-term accumulation of HMs, HM pollution has received considerable attention even at low concentrations. HMs are recognized as some of the most hazardous substances among the several types of pollutants in the environment [17, 18]. When HMs are present in the environment, the possibility that living organisms will ingest such dangerous compounds and that they will accumulate in different body organs, such as the liver, kidney, and bone, increases. Additionally, the accumulation of toxic metals causes severe damage to several body systems, such as the circulatory, skeletal, neurological, immunological, and endocrine systems [19, 20]. Several diseases that are related to HM toxicity are shown in Figure 3.

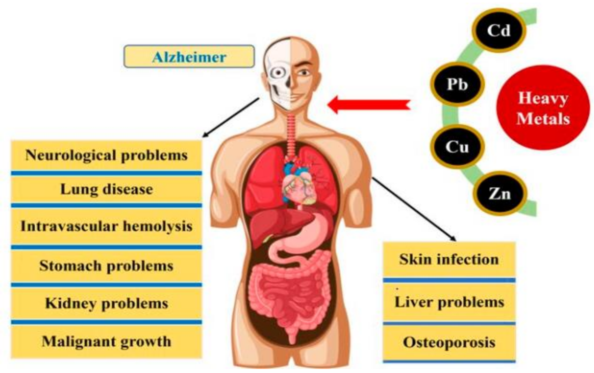

Figure 3. Effects of HM toxicity on human health [21].

People worldwide are exposed to HMs through drinking, eating, or inhaling them. Those who work in or near facilities that use such metals and their compounds are at considerable risk if they live close to an area in which such metals are illegally released. The fishing and hunting methods used in subsistence lifestyles might also increase exposure risks and have detrimental effects on health. The effects of such dangerous compounds on human health are now a major concern because of their frequent exposure. The severity of the problems caused by the release of hazardous metals into the environment has increased due to the expanding use of various metals in industries and human daily lives as a result of modern applications [22]. Runoff, acid rain, and erosion can transport HMs to different parts of soil and water bodies. The formation of HMs and their effects on human exposure are depicted in Figure 4. HMs are dangerous to biological systems because they can create reactive oxygen species (ROS) and form connections with sulfhydryl groups. Glutathione depletion and oxidative stress are symptoms of the deactivation of important macromolecules caused by the aforementioned phenomena. After exposure to dangerous metals, the body undergoes various processes, such as potential interactions or obstructions of certain metabolic pathways [23]. Various negative effects on animal and human populations are consequently observed. Organ failure, hormone imbalances, metabolic abnormalities, compromised immune system function, congenital abnormalities, and cancer are among the numerous medical disorders that are included in the diseases mentioned above [24, 25]. Consequently, several international organizations have established regulations concerning the levels of metals in drinking water, food, and the environment. The following section describes the sources and human health toxicity of several HMs (Figure 4).

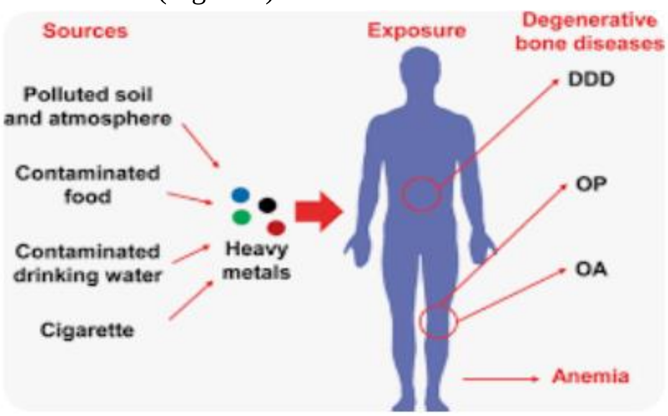

Figure 4: Human organ damage and oxidative stress after exposure to HMs [26].

HM toxicity to humans

As, which is a hazardous metal, can be found in air, water, and a range of geological formations. It is related to several detrimental health effects over long and short terms and has been demonstrated to have carcinogenic properties in humans [27]. During As biotransformation in humans, a number of As molecules become methylated, which can lead to the formation of harmful metabolites, such as dimethyl arsenic acid (DMA) and monomethylmalonic acid (MMA). Reduced respiration, enzyme activities, and mitotic division are the outcomes of the disruption of cell thiol groups [28]. An elevated risk of cardiovascular disease, especially hypertension, is associated with As exposure. Pregnancy-related hypertension is affected by exposure to As and its metabolites, namely, DMA and MMA [29]. Findings have demonstrated that pregnant women who have low DMA concentrations have increased diastolic, systolic, and major arterial pressure values.

The mercury is a dangerous HM that is present throughout the environment. It might undergo methylation, a process that can produce methylmercury (MeHg), which can collect in the food chain. Seafood consumption is related to human exposure to Hg [30]. Hg in the forms of MeHg and Hg^{2+} lowers overall antioxidant capacity and increases nitrite and lipoperoxidation concentrations [31]. Several studies have demonstrated that children exposed to Hg may experience serious side effects. Hg exposure during pregnancy negatively affects a child's growth; this negative effect might be linked to a reduction in the parasympathetic control of a child's heart autonomic function [32]. Hg exposure and blood pressure readings in childhood are positively correlated [33]. Increased Hg levels and adult dyslipidemia are also positively correlated [34]. Numerous investigations on the effects of Hg on hepatic function have shown that exposure to Hg results in a remarkable increase in liver enzymes [35].

Lead is a dangerous HM that tends to build up in different body tissues., such as bones, the bloodstream, and the majority of organs [36]. Numerous neurological conditions, including Parkinson's disease, amyotrophic lateral sclerosis, Alzheimer's disease, and attention deficit hyperactivity disorder, are connected to Pb exposure [37]. Owing to the established connection between CVD and diabetes, Pd is considered a danger factor for vascular problems in patients with diabetics [38]. The effects of Pb exposure on kidney and liver functions; WBC count; and aspartate transaminase, serum urea, creatinine, hemoglobin, hematocrit, and ALT concentrations have been reported to be more noticeable when blood Pb levels are high than when Pb is present at low concentrations [39]. Many investigations have closely assessed the effects of Pb on children. The results of these investigations revealed that Pb exposure has a detrimental effect on the physical development of children, especially that of boys [40]. Exposure to Pb might alter sex hormone levels, which could affect reproductive system functionality [41].

Human health might be affected by Cr accumulation in the organs of the body [42]. Cr has a substantial effect on bronchial epithelium, possibly via the abnormal modification of cytoskeletal proteins, apoptosis, and energy-consuming proteins [43]. The effects of Cr on the development of fetuses throughout pregnancy have been studied [44]. Cr may negatively affect fetal growth. Cr, a carcinogen, is related to lung cancer development [45]. Skin hyperpigmentation may occur due to exposure to elevated Cr concentrations [46].

Cu is an important micronutrient for humans. However, elevated Cu levels could have harmful and toxic effects [47]. Cu accumulation results in the clumping and mutation of mitochondrial proteins, decreasing primary antioxidant enzyme activity and increasing toxic ROS production [42][48]. An association exists between an increase in Cu and fibrosis in renal tissues [49]. Cu has a negative effect on male fertility, decreasing the number and motility of sperm [50]. Exposure to Cu has been linked to obesity [45, 51]. Cu disrupts the equilibrium of key elements, such as Fe, Ca, and Mn, thereby promoting oxidative stress, which can ultimately lead to neurodegenerative disorders [52].

Ni is widely dispersed across air, water, and soil, among other environmental compartments [53]. The harmful effects of Ni on humans, especially in relation to pregnancy, have been studied. Preterm birth is positively correlated with Ni exposure in pregnant women [54]. Ni concentrations in urine are higher in people with diabetes than in those without [55]. Maternal exposure to Ni is linked to congenital cardiac abnormalities in offspring [56]. Ni is associated with immunological diseases, type I hypersensitivity, and type IV immune reactivity in those who experience Ni-related chronic systemic symptoms [57].

The effects of ^{235}U and ^{238}U have been studied. A recent ecological study examined the possible link between prolonged exposure to U in drinking water and increased risk of colorectal, kidney, and lung cancers in both sexes [58]. U absorption results in alterations in gene expression, DNA strand breakage, and an increase in ROS, all of which have negative clinical effects [59]. Hexavalent UO_2^{2+} accumulates in bone and kidney tissues. This accumulation was observed to cause chronic and acute kidney injury and increase the risk of ontogenesis and osteosarcoma [60]. Unintentional exposure to U through contaminated water or food could lead to bone marrow disease or a decline in hematological function, which might subsequently have several systemic effects [61].

Cd is a dangerous HM that is harmful to human health [48]. Numerous inflammatory markers are produced as a result of the release of antithrombotic chemicals triggered by the effects of Cd on the vascular endothelium [62]. Vijayakumar *et al*. [63] investigated the biological effect of Cd on prostate cancer, specifically examining the development and metastatic behavior of this malignancy, and its influence on basal breast tumors. The antioxidative defenses of breast tumor cells could be compromised by Cd exposure, potentially resulting in the initiation of ROS generation [58, 64]. Additionally, nephron degradation and Cd accumulation occur in the proximal tubule [65].

Fe is highly important for several biological processes, such as DNA replication, mitochondrial respiration, and oxygen transport, which are all essential for the survival of nearly all living organisms. ROS, which can harm proteins, DNA, and cellular membranes, are produced when Fe, a redox-active metal, is present [66]. Fe represents a vital element in human physiology and share in many cellular metabolic functions, such as O_2 transport [67]. Iron deficiency anemia represents the most common type of anemia worldwide [68]. Iron deficiency may have a detrimental effect on immune system development and function [69]. Pregnancy-related deficiencies might endanger the fetus and mother [70]. Conversely, excessive Fe is related to an increased risk of oxidative stress and cellular damage and elevated risks of gestational diabetes, cardiovascular disease, and neonate issues [71].

V is present in water, soil, and air, among other environmental compartments. Numerous organs and tissues, including the lung, kidney, lymphoid organs, central nervous system (CNS), and immune system, experience physiological and histological alterations due to this HM [72]. Exposure to V is associated with a number of detrimental health effects, including immunotoxicity, mutagenicity, kidney toxicity, hematologic and biochemical changes, developmental and reproductive toxicity, immunotoxicity, and neurotoxicity [73]. V affects the cardiovascular, digestive, and respiratory systems [74]. The intranasal pathway absorbs small amounts of V, which can lead to olfactory impairment. This condition results in decreased dopaminergic neurotransmission to the olfactory bulb and decreased olfactory bulb volume [75].

More than a hundred chemical and inorganic compounds contain the naturally occurring mineral Co [76]. Exposure to Co has been linked to lower respiratory tract infections and upper respiratory tract inflammation, such as bronchitis and rhinitis. Exposure to specific compounds simultaneously can cause fibrotic changes in pulmonary tissue, which can then trigger asthma [77]. Numerous negative outcomes, such as pulmonary fibrosis, hepatotoxicity, and carcinogenesis, may arise from Co exposure [78]. Different problems of the brain system, including bilateral nerve deafness, optic atrophy, neuropathies, and memory loss, can be caused by exposure to Co [79]. Co may have an adverse effect on the heart, leading to solitary cardiomyopathy, hypertension, and reversible ECG changes [80].

The toxicity of Tl is greater than those of Cd, Pb, or Hg [81]. Anorexia and headaches are two signs of chronic TI poisoning, which can arise from long-term exposure to low levels of TI [82]. In severe cases, respiratory muscle paralysis might result in a coma [83]. The development of hair loss with follicular contraction is a hallmark of TI poisoning. Other symptoms include problems with digestion, pain, mental health, and the cardiovascular system [84]. Tl poisoning throughout pregnancy is related to an increased risk of low birth weight, fetal fatality, and premature birth [85].

Human intoxication pathways after exposure to HMs

The acidic environment of the stomach causes HMs to become acidified when consumed through drinking or eating. Under acidic conditions, As^{3+} , Zn^{2+} , As^{2+} , Cd^{2+} , and Pb^{2+} all oxidize and attain their corresponding oxidative states. These states have the capacity to establish robust, enduring bonds with biological molecules, including enzymes and proteins [86]. Concentration-dependent As-induced protein aggregation raises the possibility that HMs are sources of protein aggregation. Furthermore, various proteins with considerable functional enrichment associated with stability, protein synthesis, protein folding, and metabolic processes have been seen in aggregates [87]. The capacity of such drugs to stimulate protein accumulation in vivo is potentially influenced by their unique biological pathways and how well cells absorb and export them. Figure 5 shows the different mechanisms that lead to HM intoxication. After human exposure to Pb^{32}, the intracellular second messenger system is altered, hindering the functions of the CNS. Figure 6 illustrates the process through which high blood lead levels cause various disorders in humans.

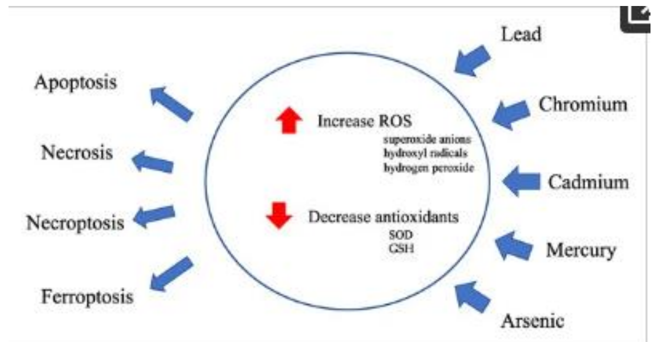

Figure 5. Human intoxication pathways after exposure to HMs [88].

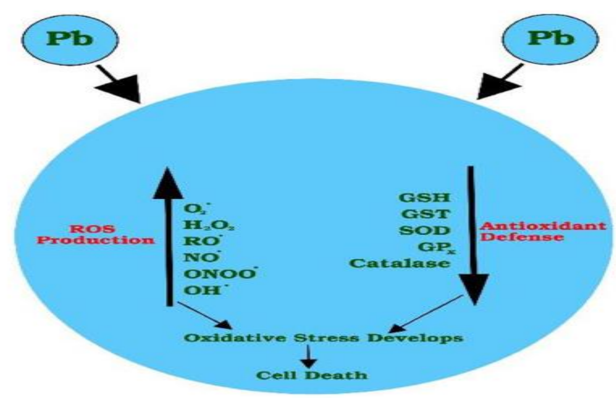

Figure 6. Processes that result in high blood Pb concentrations in humans can cause various disorders [89].

Methods for the remediation of HMs

Numerous physical techniques for removing HMs, including methods based on adsorption, electrokinetics, membrane filtration, photocatalysis, granular activated carbon, and soil washing [90], have been reported. These techniques involve treating contaminated systems on the basis of the physicochemical properties of metals. Chemical precipitation, flotation, coagulation, ion exchange, and flocculation are all components of the chemical process. Although these methods are effective at removing HMs, the overuse of chemicals complicates sludge disposal and increases the risk of secondary pollution [91]. The integrated chemical–biological treatment method is a cost-effective and environmentally friendly way to treat wastewater that contains HMs. Many researchers worldwide have reported that using this integrated method instead of chemical or biological treatment is beneficial and has shown notable outcomes in HM elimination [92].

This type of integrated system, as a polishing step, frequently consists of biological treatment followed by chemical treatment and vice versa. The ultimate goal of bioremediation, which utilizes living organisms to convert harmful contaminants into nontoxic contaminants, is to restore contaminated areas to their natural form without posing additional threats to the ecosystem. The ability of numerous living organisms, such as bacteria, fungi, actinomycetes, and plants, to purify soil contaminated with HMs and pesticides represents a potential breakthrough in environmental science [93, 94].

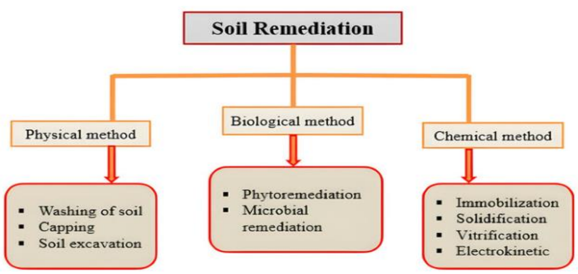

Figure 7. Summary of the benefits and drawbacks of remediation technologies [90].

Conclusions

HMs have negative effects on food security and agricultural production, and HM toxicity has become a major environmental concern. The accumulation of HMs in the environment has negative effects on plant development, People health, and marine environments because HMs are toxic. HMs might enter the human body through several ways, including through food or drink consumption, air inhalation, or skin contact. HMs are kept and accumulate in the human body after absorption. Numerous harmful effects on different human tissues and organs are caused by the accumulation of toxic metals in biological systems. Various physical and chemical methods have been proposed as possible solutions to address the pollution generated by HMs. Therefore, combined remediation technologies for large-scale applications should be developed. Within the framework of real-world implementation, one can learn from local and foreign experiences and improve the prudent use of advanced technology. Scientific and community-based remediation strategies must be employed to mitigate the negative effects of HMs. Additionally, evaluating novel seeks as preventative measures against organ toxicity caused by HMs will benefit future research.

Conflict of interest

The authors declare that they have no competing interests.

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الآثار الصحية للمعادن الثقيلة وطرق إزالتها: مراجعة

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الخلاصة:

أصبح تراكم المعادن الثقيلة مشكلة بيئية خطيرة لأن النظام البيئي يتميز بتوسع المصادر الطبيعية والصناعية للمعادن. وقد زاد تعرض الإنسان للمعادن الثقيلة بشكل كبير نتيجة للنشاط الصناعي في القرن العشرين. ويعد الرصاص والكادميوم والزرنيخ والكروم والزئبق من أكثر المعادن الثقيلة انتشارًا والتي تشكل خطرًا على البشر. ويمكن أن يكون التسمم مزمنًا أو حادًا بعد التعرض للغذاء أو الماء أو الهواء. وتتضرر العديد من الأعضاء والأنسجة بسبب هذه المعادن الثقيلة التي تتراكم بيولوجيًا. وقد كشفت مقارنة آليات عمل هذه المعادن أنها تنتج السمية عبر مسارات مماثلة، بما في ذلك تعطيل الإنزيمات وإنتاج أنواع الأكسجين التفاعلية وتكوين الإجهاد التأكسدي. وتعتبر الطرق التقليدية لإزالة المعادن الثقيلة غير كافية عندما لا يزيد تركيز المعادن الثقيلة عن 100 ملغ/لتر. ومن بين عيوب هذه الطرق إنتاج الملوثات الثانوية وزيادة متطلبات الطاقة والمواد الكيميائية وانخفاض الفعالية من حيث التكلفة. من الممكن الآن إزالة سموم المعادن الثقيلة من خلال المعالجة الحيوية الميكروبية نظرًا لأن البكتيريا والفطريات تتمتع بقدرات فائقة على التراكم الحيوي والامتصاص الحيوي مقارنة بالكائنات الحية الدقيقة الأخرى. لتحسين علاج التسمم المعدني وزيادة معرفتنا بالتأثيرات الضارة التي تخلفها المعادن الثقيلة على أعضاء الجسم، يناقش العمل الحالي عمليات السمية بالإضافة إلى امتصاص المعادن الثقيلة المرتبطة بها. يهدف هذا البحث إلى زيادة المعرفة وتقديم الموارد لاختيار تكنولوجيا المعالجة الميكروبية المدروسة لإزالة سموم المعادن الثقيلة. يمكن أن توفر المعالجات الميكروبية المستدامة نهجًا حاسمًا وفعّالاً من حيث التكلفة للحد من سمية المعادن الثقيلة.

الكلمات المفتاحية: التمعدن الحيوي، الامتصاص الحيوي، المعالجة الحيوية، التحول الحيوي، سمية المعادن الثقيلة.