REMEDIATION OF WATER AND FOOD FROM TOXIC METALS

(Review Article)

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1. Introduction:

Food security, which includes both the amount and quality of food available, has emerged as a crucial goal for sustainable global development. Food safety and human health have been seriously threatened in recent decades by hazardous pollutants in crops above threshold levels **(Mititelu, *et al*., 2025)**.

Heavy Metal is the metallic chemical element that is hazardous or poisonous at low concentrations. Although it is frequently not strictly defined, the phrase "heavy metal" is frequently used to describe metals with specific weights greater than 5 g cm-3 **(Sharma and Agrawal, 2005).** In general, all harmful metals are referred to as heavy metals in the literature. Aluminum, mercury, cadmium, arsenic, chromium, thallium, lead, and nearly forty additional elements are included in this category. Because of environmental contamination and volcanic activity, these elements are frequently found in the earth's crust, air, and water. These naturally occurring elements permeate into soil and water. However, herbicides, fertilizers, and pollution from industry and the environment might increase their levels **(Tiberian, 2024)**. Although heavy metals can be found in soil, water, and the air, they are not actually added to food. Because of this, any natural product that comes into touch with soil or groundwater may absorb traces of these metals that cannot be eliminated via processing or washing **(Guidance-levels-for-heavy-metals-in-spices&usg, 2025)**. Decades of industrial pollutants entering the soil and water cause these toxins to enter the food chain **(Common Sources of Heavy Metals in Food, 2025)**. One of the main ways that we are exposed to heavy metals is through what we eat and drink. It has been known for centuries that heavy metals and metalloids are hazardous **(George *et al*., 2008)**.

Heavy metal poisoning (toxicity) is brought on by exposure to heavy metals such as arsenic, lead, and mercury. Your organs can't function properly because heavy metals attach themselves to certain areas of your cells. Heavy metal poisoning symptoms can be fatal and cause irreparable harm. **(my.clevelandclinic.org, 2025)**.

Arsenic is found in food at minuscule quantities, like the majority of heavy metals. Even though some plant-based meals may contain arsenic, it is still quite rare. However, excessive arsenic exposure can have negative health impacts **(IFIC, 2024).** Food may contain arsenic from the surroundings in which it is produced, raised, or processed. The natural geographic composition and proximity to the use or production of arsenic-containing items in the past or present can affect the amounts of arsenic in the environment. For instance, pollution from mining, hydraulic fracturing, and coal-fired power plants, as well as areas where arsenic-containing pesticides were previously used on food crops or are being used on non-food crops, have higher levels of arsenic **(FDA, 2025)**. Lung cancer is associated with cadmium exposure through inhalation, which can occur from smoking or occupational exposure. Cadmium builds up in the body with prolonged exposure, which may have an impact on the kidneys, bones, and cardiovascular system. According to the FDA, the most vulnerable areas affected are the kidney and bone.

Cadmium levels in food is kept controlled by the FDA. Nausea, vomiting, diarrhea, and stomach irritation can result from eating foods high in cadmium. The amount, frequency, age, and nutritional status of the individual all affect risk since some nutrients may lessen the effects of cadmium **(IFIC, 2024)**. Food may include cadmium from the surroundings in which it is produced, raised, or processed. Natural geography can affect cadmium levels in the environment. Cadmium levels, for instance, are higher in regions where certain phosphate fertilizers are utilized as well as industrial activities including smelting, electroplating coatings, solar cells, and pigments. Although it is impossible to totally stop cadmium from getting into the food supply, it could be possible to lower levels of cadmium in foods that already contain it by altering manufacturing or agricultural methods. Food makers are legally required to detect instances of increased fossil fuel mining and burning as well as to drastically reduce or eliminate chemical dangers where necessary. Nickel-cadmium (Ni-Cd) rechargeable batteries are one of the current applications for cadmium. The dangers associated with vulnerable subpopulations, such as young children, may also be taken into account. This could entail assisting the manufacturer in resolving the problem and, if required, taking action to keep the product off the market **(FDA, 2025)**.

Depending on how lead-containing products are manufactured or used, food may contain lead. For instance, lead was once widely used in paint, gasoline, plumbing supplies, and many other items, which led to its release into the environment. Lead is still utilized in some items even though its commercial and industrial uses have been phased out. The FDA keeps an eye on and controls the amount of lead in food as there is no known safe threshold of exposure. When necessary, food makers are required by law to drastically reduce or eliminate the chemical risks associated with lead.

Lead toxicity was evaluated by the FDA based on the amount of lead measured in the food and projected consumption to decide whether the level of lead in a product is a potential health risk. Regulation should be implemented if it is discovered that the amount of lead in the food makes it dangerous. This could entail assisting the manufacturer in resolving the problem and, if required, taking action to keep the product off the market **(FDA, 2025)**. Lead use was drastically decreased over time by U.S. restrictions, such as the 1978 ban on lead paint and the 1996 ban on leaded gas. Nonetheless, exposure still occurs today from a variety of sources. In older homes with lead-based paint, lead dust is still a widespread problem. Airborne dust that can be swallowed or inhaled is produced when paint chips or deteriorates. Lead persists in impacted areas due to industrial emissions and previous use of leaded gasoline, which is another major cause of soil pollution. Lead exposure can also come via drinking water, mostly from lead pipes or fixtures that contaminate the water with lead. However, natural water sources like wells or lakes are typically not significant producers. However, the amount of lead in plant-based meals varies depends on the production and cultivation location **(IFIC, 2024)**.

Mercury in food exists in trace amounts of. However, mercury can build up in streams, lakes, and oceans, where it changes into methylmercury, which can accumulate in seafood. Eating seafood is the main way that people get exposed to mercury. However, excessive mercury exposure might have negative health impacts. The standard dose for mercury set by the U.S. Environmental Protection Agency (EPA) is 0.045 micrograms (mcg) per pound of body weight each day. The safe limit, for instance, is 4.5 µg/day for a person weighing 100 pounds and 6.8 µg/day for a person weighing 150 pounds. The majority of people have trace amounts of mercury in their blood, although these levels are usually lower than those linked to negative health effects. The effects of overexposure differ throughout life. Pregnancy-related exposure to methylmercury can damage the developing fetal brain and nervous system, impairing language, motor abilities, memory, and cognition. Children's smaller bodies and quick growth make them particularly vulnerable. Depression, memory problems, muscle weakness, vision or speech problems, balance problems, and metallic taste can all result from prolonged or abrupt overexposure. Medical examination of blood or urine mercury levels is necessary for diagnosis. Exposure to methylmercury has not been linked to cancer or coronary heart disease. The FDA works with the EPA to provide recommendations on fish intake to lower mercury exposure, especially for sensitive groups including small children and pregnant or nursing mothers. Mercury levels are used to classify fish safety and nutritional value are balanced in the recommendations. Adults: Consume two to three servings (a total of eight to twelve ounces) of "Best Choices" fish each week. Additionally, "Good Choices" options for adults are offered at a weekly serving of one ounce. Children: Eat two ounces of the "Best Choices" list each week in age-appropriate portions (1 ounce for children ages 1–3, 2 ounces for children ages 4–7, 3 ounces for children ages 8–10, and 4 ounces for children ages 11 and up) **(IFIC, 2024)**.

2. General Overview:

Because toxic metals are found in the soil, water, or air where food is grown, raised, or processed, these metals can contaminate food. The FDA's efforts to get as **Closer** to **Zero** as possible rely on the substantial success made in lowering exposure to environmental pollutants through food. Due to their smaller bodies and slower metabolisms, newborns and young children are more susceptible to the negative effects of these pollutants, thus we have given priority to foods that they frequently ingest **(FDA, 2025)**

Metal Remediation is the process of eliminating hazardous heavy metals from contaminated soil or water through physical, chemical, or biological means. Because they are frequently more economical and environmentally benign than traditional physical and chemical treatments, **biological techniques** like **phytoremediation** (using plants) and **bioremediation** (using microorganisms) are receiving increased attention **(Kumar *et al.*, 2021)**.

2.1. Bioremediation, or biological remediation:

Removes heavy metals from the environment by using either living or dead microorganisms, such as bacteria, fungus, and algae. Living organisms are used in bioremediation to clean up contaminated areas. Compared to traditional physical and chemical procedures, these techniques are frequently more economical and environmentally benign.

2.1.1.Microbial Remediation: Uses microorganisms (bacteria, fungi, algae) to transform metals into less toxic forms or remove them from the environment.

2.1.2.Mechanism:

2.1.2.1.Bioabsorption: Microorganisms absorb or adsorb heavy metals onto their cell surfaces and bind metals to their surfaces.

2.1.2.2.Bioaccumulation: accumulate them inside their cells internally **().**

2.1.2.3.Biotransformation: Microbes change the chemical form of the metal through metabolic processes (e.g., converting toxic Hg(II) to less toxic, volatile Hg(0)).

2.1.3.Application: The metal-laden biomass can be regenerated or disposed of, or it can be used as a source for metal recovery.

2.1.4.Phytoremediation: Uses plants to remove or stabilize heavy metals. Utilizes plants to remove, stabilize, or degrade contaminants.

2.1.4.1.Phytoextraction: Plants, known as hyperaccumulators (e.g., Indian mustard, sunflowers), absorb metals through their roots and store them in their shoots, which are then harvested and properly disposed of.

2.1.4.2.Phytostabilization: Plants immobilize contaminants in the soil, reducing their movement into groundwater or the food chain.

2.1.4.3.Mechanism: Plants absorb metal ions through their roots, and through processes like phytoextraction (extracting metals), phytostabilization (immobilizing metals in the soil), and phytovolatilization (converting metals into a gaseous form).

2.1.4.4.Application: Metal-accumulating plants like some trees and grasses can be used to clean up contaminated sites.

2.3.Physical remediation:

Involves processes like filtration, ion exchange, and membrane separation to physically remove metals.

2.3.1.Physical Methods

These methods physically remove or stabilize the contaminants, often involving significant site disturbance.

2.3.1.1.Excavation and Off-site Disposal: Contaminated soil is removed and transported to a specialized landfill. This is effective but costly and environmentally disruptive.

2.3.1.2.Solidification/Stabilization: Amendments like lime, cement, or fly ash are added to the soil to change the properties of heavy metals, reducing their mobility and bioavailability through adsorption and co-precipitation.

2.3.1.3.Thermal Treatment: High temperatures can volatilize certain volatile heavy metals, such as mercury and arsenic, for removal and capture.

2.4.Chemical remediation:

Uses chemical treatments like precipitation and coagulation to convert metals into less soluble forms.

2.4.1.Chemical Methods

These approaches use chemical reactions to manage metal contamination.

2.4.1.1.Soil Washing/Leaching: Water or chemical agents (chelating agents) are used to extract metals from the soil. While effective, this method requires careful management to prevent secondary contamination from the extracting agents.

2.4.1.2.Chemical Precipitation: In water treatment, specific chemicals are added to precipitate dissolved metals into a solid form, which can then be separated and disposed of or recovered.

Table 1: Comparison of Methods

Method	Advantage	Disadvantage
Biological	Eco-friendly, low cost, minimal environmental impact	Efficiency can be limited by plant and microbial factors; some methods are slow
Chemical	Highly efficient (98–99%)	High cost, can produce secondary pollution, uses hazardous chemicals
Physical	Can be effective for specific applications	Limited application

2.5.Biochar:

A charcoal-like substance made from burning organic matter, which can be used to adsorb metals in the soil.

2.6.Electrokinetic Remediation:

Uses an electric field to move metal ions through the soil towards electrodes, where they can be collected.

2.7.Health Implications and Clinical Treatment:

Heavy metal poisoning in humans is a serious health concern that can cause severe organ damage.

2.7.1.Chelation Therapy: This is the primary medical treatment for heavy metal poisoning (e.g., lead, mercury, arsenic) in the body. Medications containing chelating agents (e.g., EDTA) bind to the metals, allowing them to be safely excreted from the body. This procedure must be administered and monitored by a healthcare professional due to potential side effects and the specific nature of the chelating agents needed for different metals.

2.8.In-situ and ex-situ techniques:

Some methods are applied directly in the contaminated site (in-situ), while others require excavation and treatment elsewhere (ex-situ).

2.9.Integrated Approaches:

Due to the complex nature of contamination, single methods are often insufficient. Integrated processes, such as combining electrokinetic remediation (using electric fields to mobilize metals) with biological methods (e.g., phytoremediation or bioremediation), are being developed to improve efficiency and address specific site challenges.

The remediation of water and food from toxic metals is a critical environmental issue due to the harmful effects of heavy metals on human health and ecosystems. This response synthesizes findings from various studies, highlighting the sources of heavy metal contamination, the mechanisms of remediation, and the effectiveness of different treatment methods. The integration of research from multiple languages provides a comprehensive view of the current strategies and challenges in addressing this issue.

Sources of Heavy Metal Contamination

Heavy metals are commonly released into the environment through industrial activities such as metal plating, mining, and battery manufacturing (2009), مخيمر، وفاء، الدايل، عمر، العندس، ناصر محمد، الدريهم، عبدالرحمن، حفنى، جميل. • Agricultural practices, including the use of contaminated fertilizers and pesticides, also contribute to the accumulation of heavy metals in soil and water (2023), سعيد، حنان عبدالوهاب. • Urban runoff and sewage sludge can introduce heavy metals into water bodies, exacerbating pollution levels (2023), سعيد، حنان عبدالوهاب.

Remediation Techniques

Conventional Methods

• Traditional methods for heavy metal removal include chemical precipitation, ion exchange, and activated carbon adsorption. However, these methods often face limitations such as high costs and inefficiencies at low concentrations (2011), القضيب، سهام عبدالمحسن، الصقيران، ندى ابراهيم. • Chemical precipitation can be effective but may generate secondary waste that requires further treatment (2021), Bashir, Nagwa F..

Innovative Approaches

• Biosorption, utilizing biological materials such as algae and plant biomass, has emerged as a promising alternative due to its cost-effectiveness and environmental friendliness (2013), Al Zahrani, Abd Allah M.. • Phytoremediation, which involves the use of plants to absorb and accumulate heavy metals from contaminated soils and water, has shown potential in various studies (2020), Ibrahim, Khadiga Gaafar Abd Elaleem, Mohamed, Ahlam S, Enur, Elbushra Elsheikh, Abdalla, Abd Alwahab Hassan, Alawad, Amani Algali. • The application of clay minerals as adsorbents has been highlighted for their high surface area and low cost, making them suitable for heavy metal removal from wastewater (2023), سعيد، حنان عبدالوهاب.

Effectiveness of Remediation Strategies

• Studies indicate that biosorption can achieve significant removal rates for heavy metals, making it a viable option for treating contaminated water (2013), Al Zahrani, Abd Allah M.. • Phytoremediation has been effective in reducing metal concentrations in agricultural soils, thus improving food safety (2020), Ibrahim, Khadiga Gaafar Abd Elaleem, Mohamed, Ahlam S, Enur, Elbushra Elsheikh, Abdalla, Abd Alwahab Hassan, Alawad, Amani Algali. • The combination of different methods, such as using biosorbents alongside conventional techniques, can enhance overall remediation efficiency (2021), Bashir, Nagwa F..

Challenges and Future Directions

• Despite the advancements in remediation technologies, challenges remain, including the scalability of biosorption and phytoremediation methods for large-scale applications (2023), سعيد، حنان عبدالوهاب. • Ongoing research is needed to optimize these methods and develop new materials that can enhance the efficiency of heavy metal removal from water and food sources (2023), سعيد، حنان عبدالوهاب.

Conclusion: The remediation of water and food from toxic metals is a multifaceted challenge that requires a combination of conventional and innovative approaches. While traditional methods have their limitations, biosorption and phytoremediation offer promising alternatives that are both effective and environmentally sustainable. Future research should focus on optimizing these methods and exploring new materials to improve remediation efficiency, ensuring safer water and food supplies for communities worldwide.

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