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Review Article

Adverse impacts of heavy metal pollution on soil and plant growth in agriculture

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Abstract

Agriculture is important for human beings because it provides food, employment, and other necessities, and pollution in agriculture causes several problems. Heavy metals are always at the top of the list regarding concerns about agriculture pollution. Heavy metals reach in agriculture from various sources but the uses of agrochemicals like fertilizers and pesticides in agriculture are the most common sources. The most common heavy metals are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn). Heavy metal pollution in agriculture threatens human and animal health, pollutes groundwater, causes plant phytotoxicity, and reduces agricultural productivity and soil health. Heavy metals enter the food chain mostly through the soil, where they are absorbed by plant roots. Once they enter the food chain, they pose a serious risk to each organism linked to that food chain. Heavy metals create imbalances in several crucial processes in plants and soil ecosystems. Heavy metal degradation takes too much time in soil and remains in the soil for a very long time. Heavy metal degradation from the soil ecosystem may be accomplished through the use of bioremediation.

Keywords agriculture, bioremediation, fertilizer, heavy metals, pesticide

Introduction

The environment is getting more contaminated because of the significant economic rise and quick growth and development in many sectors such as agriculture and other industries [1]. Pollutants in agriculture are due to toxic compounds that come from artificial and natural sources. Heavy metals are the most common agricultural pollutants threatening the soil ecosystem and seriously harming its structure and function. There are numerous sources of heavy metals, including industry, domestic, and agricultural management practices. The main sources of heavy metals in the agricultural sectors are the applications of agrochemicals such as chemical pesticides and fertilizers [2]. Several agrochemicals like herbicides, insecticides, weedicides, fungicides, and fertilizers such as phosphorus, nitrogen, and lime fertilizers are the primary causes of heavy metals pollution in agriculture. Heavy metals pollution risk has recently been rising quickly and causing chaos, particularly in the agricultural sector, as they accumulate in the soil and different parts of plants [3].

The agriculture sector is constantly contaminated by different types of heavy metals which are found in our surroundings. At low concentrations, a few heavy metals such as Fe, Zn and Ni, are necessary for the existence of all forms of life. Pb, Cd, and Hg are those types of heavy metals that are harmful to living things both in high and low amounts. They cause metabolic abnormalities in living organisms, particularly those who consume food from crops cultivated in contaminated soil [4]. Heavy metals are present in the environment and have significant ecological implications because of their toxicity at certain concentrations, movement through food chains, and inability to biodegrade, which leads to their accumulation in the biosphere [5]. When plants grow on soil that has been contaminated with heavy metals, they start to absorb the metals through their roots. After absorption heavy metals get bio-accumulated into different plant parts like root, stem, fruit, leaf and seed [6]. When heavy metals enter agriculture, they do not easily degrade and remain in the soil for extended periods, continuously contaminating the agrosystem. Heavy metal pollution remediation strategies are urgently needed. Bioremediation can be used in heavy metals remediation because it is environmentally friendly. This review paper discussed heavy metals and their sources, their impact on agriculture, and bioremediation.

Source of heavy metals in the environment

Heavy metal pollution can arise from a variety of sources, including natural, industrial processes, domestic, agricultural management practices, and so on (Figure 1). The biggest source of heavy metals by natural source is rock weathering. The nature of the rock and the surrounding circumstances generally have an impact on the weathering process, and these factors also greatly affect the both composition and concentration of heavy metals. Volcanic eruptions release huge amounts of Al, Zn, Mn, Pb, Ni, Cu, and Hg, along with toxic and dangerous gases [7-8]. Industrial sources like mining and refinement cause heavy metal pollution. The use of mercury in gold mining is one of the common sources of Hg emissions into the environment [9-10]. The primary reason for the heavy metal pollution in ponds, lakes, and rivers is most likely effluents from domestic use [11-12]. Opened dumps or landfills, industrial discharge, and incinerated trash are further sources of heavy metal pollution [13-16].

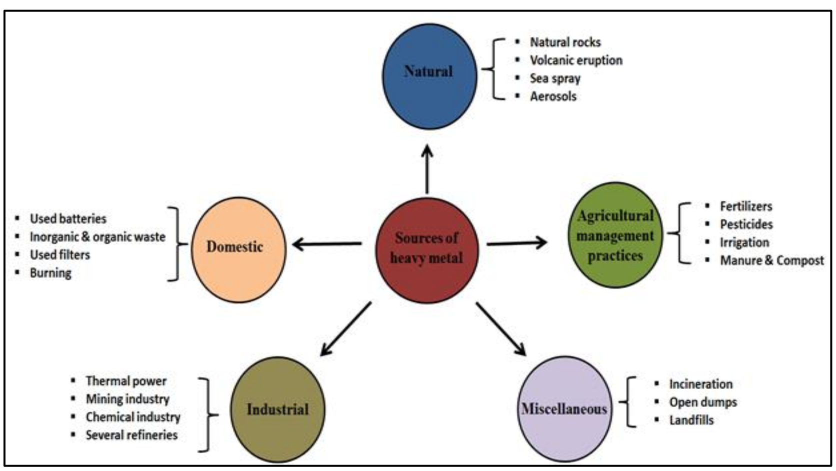

Figure 1. Sources of heavy metal pollution

Agriculture management practices such as the use of fertilizers, pesticides, manure, compost and irrigation by using polluted water are the main sources of heavy metals in agriculture. These practices are mainly used to enhance agricultural production. Sometimes these practices can increase the heavy metals levels in soil, making the soil too toxic to support the growth and development of plants. Heavy metals negatively affect the soil ecosystem by affecting soil microorganisms, soil health, soil fertility, soil pH, organic matter and many more important factors. Free radicals generated by heavy metals enhance intracellular reactive oxygen species (ROS) and oxidative stress, which damages biological molecules such as proteins, nucleic acids, lipids, and enzymes. DNA damage, cell damage, hormonal deregulation, and the inhibition of enzyme activity are examples of physiological problems due to the defect in all these molecules that can negatively impact plants and sometimes death of the entire plant (Figure 2) [17].

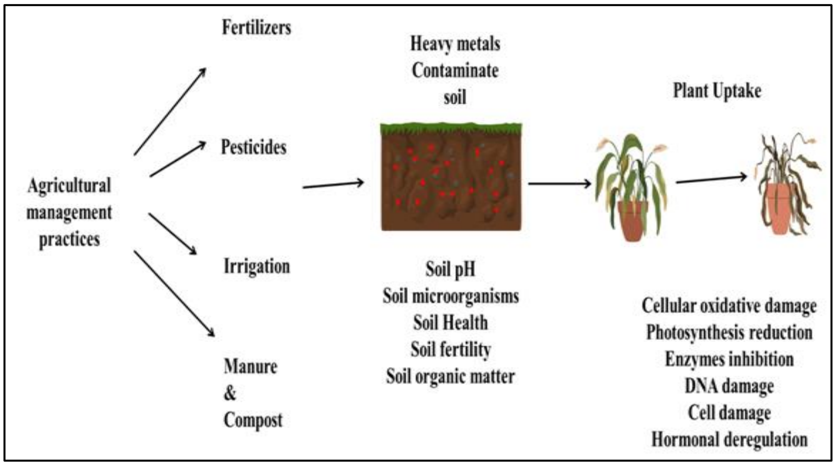

Figure 2. Heavy metals pollution through different agricultural management practices

Source of heavy metals in agriculture

More than 10 billion people expected by 2050, there will likely be a greater demand for food production as global population growth continues [18]. In agriculture, farmers employ a variety of agrochemicals to meet the growing population's demand for food. Agrochemicals are used to increase and protect agriculture from different types of pests. The rapid advancement of technology has exposed the environment to a variety of chemical toxicants in recent times [19-20]. Approximately 50,000 phytopathogen species, 9000 pest species, and 8,000 types of weed species negatively affect agricultural production [21]. Pesticides are synthetic chemical compounds or a mixture of compounds used to manage pests in agriculture and other different areas [22]. Pesticides control different types of pests quickly as compared to other methods and increase agriculture production. Uncontrolled chemical pesticide use causes the toxic chemicals to bioaccumulate in food chains and has detrimental effects on not only humans, plants, and microbes, but the environment as a whole. The whole ecosystem becomes unbalanced due to the detrimental effects of pesticides and their residues.

Heavy metal pollution or heavy metals elevated concentrations in the soil ecosystem are mainly caused by pesticide application in agriculture. Pesticide residues and heavy metals remain in the environment (soil, water and living organisms) for a long time and contaminate the environment for an extended period. These pollutants are also connected to a variety of illnesses, including hypersensitivity, cancer, asthma, hormone problems and several others. They can also result in congenital defects, lower birth weight, and even death [23-24]. The longevity of the toxicants in ecosystems and their accumulation in food chains are the causes of the adverse impacts on the environment and health of humans [25]. The accumulation of heavy metals within human tissues can affect the central nervous system and contribute to the development of disorders such as epilepsy, headaches, and comas [26]. The application of various pesticides, including fungicides, herbicides, insecticides, and weedicides, is one of the primary causes of heavy metal pollution in agriculture (Figure 3).

Fertilizers are used in agriculture to supply different types of key nutrients to boost plant growth and development, and crop production. Fertilizers not only play a positive role in agriculture but these also cause negative effects.

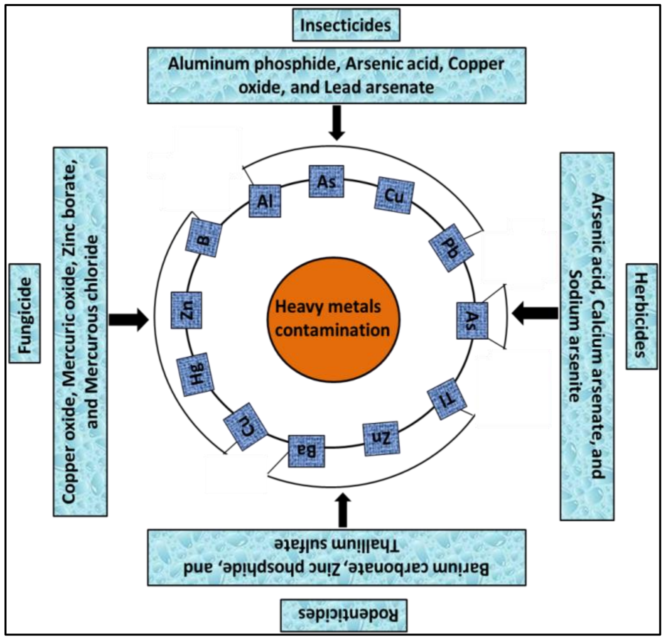

Figure 3. Different types of pesticides in heavy metals pollution

The overuse of fertilizers leads to the pollution of heavy metals in the agricultural crop and soil. Although phosphorus fertilizers are frequently used to supply phosphorus to plants, they also play a major role in heavy metals accumulation in the soil ecosystem [27]. Long-term overuse of excessive fertilizer leads to heavy metal deposition in the soil, which lowers soil fertility and thus inhibits plant growth and development and productivity [28]. Fertilizer application over an extended period of time increases the possibility for Cu, Zn, and Cd to accumulate in agricultural soil [29]. Inorganic fertilizers and liming substances release heavy metals in the soil which are then absorbed by plants [30].

Impact of heavy metals in agriculture

There are permissible limits/MRL values set for soil and plant for each heavy metal. Heavy metals with high MRL value are considered to be secure. Pb, Zn, and Cu have the highest permissible limits in soil, whereas Cd has the lowest. The permissible limits show that even at lower concentrations, the buildup of Cd in the soil poses a greater risk than that of Cu, Zn, and Pb. Heavy metals have many detrimental effects on agricultural soil, plant growth and development (Table 1). Heavy metals pollution in soil caused a lack of nutrients and organic matter, poor water-holding capacity, and a poor cation exchange capacity [31]. The soil biota is negatively impacted by the increased concentration of heavy metals in the soil because it interferes with essential microbial processes and reduces the quantity and activity of microorganisms. Heavy metals also affect soil enzyme activity by changing the microbial community's enzyme-synthesizing capabilities. Some heavy metals can function as plant nutrients, depending on how prevalent they are in the soil. Conversely, some are spread by human activity and can be harmful even in trace concentrations, such as Hg, Pb, Cd, Ag, and Cr [32].

Several variables, including temperature, humidity, soil organic matter, soil pH, and nutrient availability, affect the absorption and collection of heavy metals in different tissues of plant. [33]. When heavy metals are present in high amounts, can affect plant growth, create oxidative stress, and alter the structure of cells by substituting hazardous heavy metals with defective components and

Table 1. Detrimental effects of heavy metals on agricultural soil, plant growth and development

S.N.	Heavy metals	Effect of Heavy metals		Reference
1	Lead (Pb)	Effects on soil	Disrupt water balance and soil mineral nutrition, as well as the activity of soil enzymes such as phosphatase, urease, catalase, and invertase.	[4, 34, 41]
		Effects on plants	Adverse effects on seed germination, seedling growth, the growth of roots and stems, and the expansion of leaves	[8, 42-43]
2	Cadmium (Cd)	Effects on soil	Adverse effects on the soil enzymes activity such as alkaline phosphatase, urease, and protease, as well as a reduction in the amount of N and S in the soil	[4, 34]
		Effects on plants	Chlorosis, wilting, epinasty of the leaves, stunting of plant growth, rolling of the leaves, and reduction in biomass accumulation, plant growth, and crop quality	[18, 43- 45]
3	Zinc (Zn)	Effects on soil	Reduction in soil nutrients such as Phosphorus, and microbial biomass N and affect soil fertility	[46-48]
		Effects on plants	Negative effect on crop yield	[46]
4	Copper (Cu)	Effects on soil	Reduce the nutrients availability in soil, such as N and S, and lower β-glycosidase activity and microbial biomass N	[4, 34, 48]
		Effects on plants	Adverse effects on germination, growth, photosynthesis, and antioxidant activity.	[49]
5	Mercury (Hg)	Effects on soil	Alter the metabolic function of soil organisms	[50]
		Effects on plants	Reduction in germination, seedling growth, plant height, biomass accumulation, and hypertrophy of root and coleoptile	[51-52]
6	Chromium (Cr)	Effects on soil	Alters microbial activity and reduces soil fertility	[53]
		Effects on plants	Reduction in plant height, dry weight, seed germination, nodulation, and crop yield; chlorosis and necrosis	[54-55]

obstructing photosynthetic processes in plant cells [4]. Seed germination is impacted by heavy metals, which also decreases the likelihood of a successful harvest. Heavy metal toxicity affects some enzymes such as amylase, protease, and ribonuclease which have an impact on plant germination and growth. Heavy metals can impact in plant's height, reduce root length, reduce chlorophyll content, and decrease photosynthetic pigments and the accumulation of heavy metals in plants. Chlorosis, stunted development, and depression are caused by heavy metal's potentially harmful effects and phytotoxicity in plants. Heavy metal effects are also linked to decreased nutrient uptake, disturbed plant metabolism, and a decreased capacity for molecular nitrogen repair in leguminous plants [31]. The capacity of heavy metals and their compounds to travel through soil is dependent on several variables, including the soil pH and the organic matter, which are both impacted by the surrounding environment. Additionally, heavy metals strongly adhere to organic matter, remain stable in the soil, are uptake by plants and enter into the food chain [34].

Heavy metals are resistant to deterioration and remain for a long time if they are not eliminated by leaching or absorbed by plants [35-36]. Agricultural soils are often polluted with heavy metals and high concentrations can be quite harmful to plants [3]. Heavy metals such as Cd, Pb, As, Hg, and Cr are extremely toxic and harmful to plant health [37-38]. These elements can imbalance some cellular processes in plants, such as respiration, ion homeostasis, pigment biosynthesis, photosynthesis, enzyme activity, gene regulation, sugar metabolism, nitrogen fixation, etc., at comparatively low concentrations [39-40]. On the other hand, they also cause symptoms of mineral deficiencies in plants if the concentration falls below particular threshold values [40].

Current status of heavy metals in agriculture

Currently, the main sources of heavy metal pollution in the environment appear to be unique circumstances like increasing urbanization and increased industrial, municipal, agricultural, and technological applications, in addition to certain geogenic and meteorological elements. However, the problem is more prevalent in many developing countries, due to a lack of awareness regarding the detrimental effects of these elements on both crop and human health. Currently, agricultural soil is polluted by heavy metals from different sources including the use of pesticides, fertilizers and other harmful chemicals (Table 2).

Table 2. Different sources of heavy metals in agricultural soil

S.N.	Source	Type	Heavy metals	References
1	Fertilizers	N, P, K and Lime fertilizer	Cr, Cd, Cu, Zn, Ni, Mn, and Pb	[56-58]
2	Pesticides	Insecticides and fungicides	Cu, Zn, Cd, Pb, and As	[3, 9, 58].
3	Farmyard manures and composts	-	Zn, Cu, Ni, Pb, Cd, Cr, As, and Hg	[59-62]

In modern agriculture, agrochemicals are an essential component of crop productivity. Heavy metal (Cd, Pb, Cu, Zn, Cr and Ni) pollution in agriculture is caused by a variety of fertilizer types, including phosphorus, nitrogen, and lime fertilizers. Heavy metals are present in different concentrations in these fertilizers (Table 3) [63-64]. Phosphorus fertilizers had the highest concentration of heavy metal pollutants of any other fertilizers [65-66]. The pollutants Cd, Co, Cu, Pb, Zn, Cr, and Ni can be found in superphosphate fertilizers. According to a study, in comparison to soil without phosphorus fertiliser, Zn concentrations were higher in both the treated soil and the plants that grew in it [67]. It has been shown that the use of phosphorus fertilizers causes the Cd level of the soil to steadily rise [65, 68]. Pb and other heavy metal pollutants can be found in Cu, Fe, and Zn sulphate fertilizers in addition to phosphorus fertilizers [56, 69-70]. According to a study based on green house trials, the accumulation of several heavy metals in the soil was dramatically increased by the frequent application of chemical fertilizers [66].

Table 3. Concentrations (mg•Kg^{-1}) of Haevy metals in different agricultural fertilizers

S.N.	Heavy metals	N-Fertilizers	P-Fertilizers	Lime fertilizer
1	Cd	0.05–8.5	0.1–170	0.04–0.1
2	Pb	1-15	1-300	2-125
3	Cu	2–1450	7.0–225	20-1250
4	Zn	1-42	50–1450	10-450
5	Cr	3.2–19	66–245	10–15
6	Ni	7–34	7–38	10–20

Approximately one-third of all agricultural goods worldwide are protected by pesticides [71]. Over the past few years, over 2 million tons of pesticides have been used worldwide, 47.5% of these chemicals are herbicides, 29.5% are insecticides, 17.5% are fungicides, and the other 5.5% are other pesticides [72]. Fruit production would decline by 78%, vegetable production would decline by 54%, and cereal production would decline by 32% in the absence of pesticide use [73]. It has been demonstrated that several pesticides which are widely used in agriculture have considerable amounts of heavy metals in their active components (Figure 3). There have been many suggestions that the heavy metal components contaminate pesticide products during production, and some of them are purposefully introduced as nano-pesticides to boost their effectiveness [74-75]. Cu-containing fungicides are copper sulphate and copper oxychloride, Cu-containing insecticides are copper acetoarsenite, and a Pb-containing insecticide is lead arsenate. Cu, As, Pb, Hg, Cr, Zn, and Ti are among the heavy metals that are frequently discovered in the active components of pesticide products [76]. Heavy metals are also found as impurities in pesticides. Pollutants like Cd, Hg, As, Cu, Zn, and Pb are present in several pesticide formulations used [77]. In glyphosate-based herbicides As, Cr, Co, Pb, and Ni as pollutants are present [74]. A similar study found heavy metals such as Zn, Cu, Cr, Co, Pb, and Tl (thallium) as pollutants in insecticides [78].

Remediation of heavy metals

Heavy metals tend to accumulate over time and are difficult to degrade once they are in the soil. Heavy metals are retained in the soil for a longer period than in air or water because soil is a heterogeneous, complex material with a biochemical and geochemical makeup. For heavy metals remediation, there must be required environmentally friendly remediation techniques. Bioremediation is a process or a strategy to exclude harmful undesirable pollutants from the environment by using biological organisms. In agriculture, heavy metals enter in soil and plants through using different types of agrochemicals. When these chemicals are used in agriculture fields in excessive amounts by farmers, they become pollutants in agriculture, with ecological impacts that require remediation. There are several methods for degradation such as chemical treatment, volatilization and incineration. There are certain drawbacks to these methods such as acid and alkali production, potentially harmful emissions, negative impacts on soil fertility, and not being very environment friendly. Overall, most of the physical and chemical degradation is expensive and inefficient [79].

The primary goal of bioremediation applications in agriculture is the conversion of hazardous compounds from soil into less toxic compounds through the use of living organisms. The bioremediation approach utilizes the metabolic capacity of living organisms such as microorganisms to degrade pollution from the soil and has been proposed as an alternative due to its low cost, environment friendly, not cause secondary pollution and higher efficiency relative to other physical and chemical treatments [80-81]. There are several types of bioremediation methods according to the living organism involved such as bacterial bioremediation, mycoremediation, phytoremediation, and phycoremediation (Figure 4). Bacterial bioremediation: Bacteria such as *Ohrobactrum sp.*, *Arthrobacter sp.*, *Bacillus sp.*, *Pseudomonas sp.*, *Flavobacterium sp.*, and several other bacterial species are used [82-88]. Mycoremediation: Fungus such as *Penicillium sp.*, *Aspergillus sp.*, *Trichoderma sp.*, *Verticillium sp.* and so on is used in degradation [89-92]. Several ions present in the microbial cells surface functional groups such as nitrogen, oxygen, sulphur, and phosphorus, can be changed out for metal ions known as coordination atoms. Heavy metal goes through the cell membrane of microorganisms that are negatively charged and carry the cationic group [93]. Phytoremediation: Plants such as *Azolla*, *Lemna*, *Potamogeton*, *Spirodela*, *Wolfia, Wolfialla*, *Eichhornia* and so on plants can degrade pollutants. These plants can accumulate a higher amount of heavy metal and tolerate these pollutants. Phycoremediation: algae such as *Chlorophyceae sp.*, *Scenedesmus sp.*, *Chlamydomonas sp.*, *Stichococcus sp.*, *Chlorella sp.* etc. used in degradation [93-94].

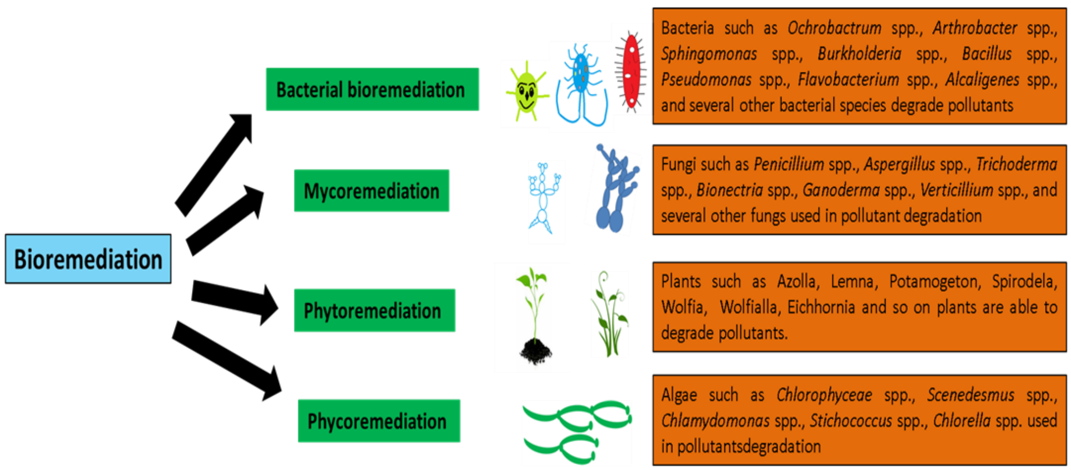

Figure 4. Bioremediation of pollutants by using different types of living organisms

Conclusion

To enhance agricultural production, farmers use different types of agrochemicals in agriculture. These chemicals improve production but also cause several negative effects and contaminate the agrosystem. Heavy metals and residues of these chemicals do not easily break down and create several problems in agriculture. To minimize the risks as much as possible, the heavy metals pollution problem requires bold and workable solutions. The bioremediation approach is a biotechnological-based technique that can remediate heavy metals without hurting agrosystems. There is more research is needed on bioremediation techniques in heavy metal pollution and suitable living organisms must be used based on heavy metal pollution. Reducing the application of agrochemicals in agriculture and educating farmers about the issues that arise from heavy metal pollution are two main factors in preventing heavy metal pollution.

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