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Review Article

Heavy Metal Toxicity and Remediation in Human and Agricultural Systems: An Updated Review

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Abstract | Heavy metals (HMs) are harmful and lethal at negligible levels and non-biodegradable in the typical ecosystem and constitutes animal, human and environmental hazards. They are divided into toxic *metals* like Lead, Cadmium, Arsenic, etc. and essential elements like copper, zinc, manganese, iron, nickel and chromium. Additionally, could be categorized into two groups based on the natural and anthropogenic sources releasing origins. Population and industrial expansion led to food contamination with HMs. Poisonous metals can be transferred from irrigation water to agricultural soils, agricultural operations, air pollution, animal feed, and packaging materials. Toxic metals are non-biodegradable, non-thermos degradable, and exceedingly stable in the ecosystem; as a result, they quickly build in various foods. Metal pollution of many foods, including agricultural commodities, and animal protein sources such as fish, milk, meat, and eggs, poses a hazard to food safety and security. Toxic metal pollution of irrigation water, agricultural soils, plants, and animals result in their integration into the food chain, posing a health hazard to humans. Most metals are harmful to animals and humans and accumulate in several organs like the skeleton, hepatic tissue, spleen, and renal tissues. Metals have a deleterious impact on the production of plants and animals. As a result, several remediation strategies have become necessary to limit the hazardous HMs pathway into the food chain and the human body. Metal nanoparticles are employed in beneficial applications, although they are associated with specific hazards.

Keywords | Food contamination, Heavy metals, Nanoparticles, Pollution sources, Remedy, Soil contamination

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INTRODUCTION

Heavy metals (HMs) contamination of chicken meat and its products is crucial for human diets everywhere because they help to address global food issues and provide well-known nutrients like protein, fat, essential amino acids, minerals, and vitamins. They also have a milder flavor that is easier to pair with seasonings and sauces (Al-Maylay and Hussein, 2014). Food pollution with HMs is one of the severe issues worldwide, which causes significant hazards to a person's health. As seen in Figure 1, toxic metals enter the food through various sources, either naturally or through human activities, then can accumulate in human organs and cause severe problems due to their toxicity. Also, HMs can accumulate in the human body through inhalation (Al-Maylay and Hussein, 2014).

Over the past few decades, heavy metal pollution of the environment has been regarded as one of the world's most essential complications (Bakshi et al., 2018). The most abundant environmental HMs are copper (Cu), chromium (Cr), lead (Pb), nickel (Ni), mercury (Cd), cadmium (Cd), arsenic (As), and iron (Fe) (Bakshi *et al*., 2018). Some HMs, like iron and nickel, are vital to survival at trim levels (Bakshi et al., 2018). However, HMs such as Pb, Cd, and Cd are lethal to living creatures at elevated and low levels. They are sponsors of metabolic abnormalities in organisms, particularly customers of food from plants from polluted soil. Environmental contamination from HMs mainly originated from sources like solid and liquid wastes, urban-industrial aerosols, industries, mining activities, and agriculture chemicals (Agbemafle et al., 2020). HMs toxicity could be detected in different degrees depending on its consumption route, chemical formula, dosage, tissue affinity, sex, and age of the host, as well as whether exposure is acute or chronic (Agbemafle et al., 2020). Fish byproducts can transfer heavy metals to poultry feed after being collected from contaminated waters. Also, their toxicity, bioaccumulation, and biomagnification in the food chain can pose a severe threat. Today, poultry feed is produced from various raw materials, including fish byproducts (Agbemafle et al., 2020).

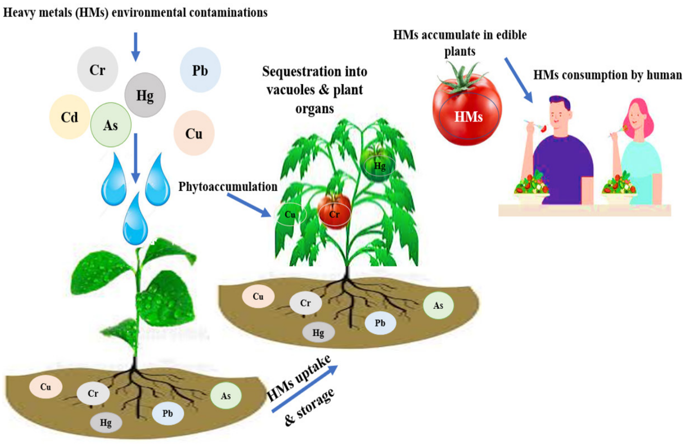

Figure 1: Heavy metals environmental contamination and human health hazards.

Decent human health is linked to a healthy environment. Some dumped materials containing HMs in open dumpsites pose a risk to individuals who touch the polluted soil and plants due to poor waste disposal management (Ugurlu, 2004). Waste generation and disposal were identified as the primary causes of HM's soil contamination. In general, garbage in landfills comes from various sources, is composed of various substances, and is disposed of randomly (Ihedioha et al., 2017). There are no established guidelines for garbage disposal, resulting in a mixture of trash that leaches into the groundwater and soil (Ihedioha et al., 2017).

There is elevating awareness about the risk of soil pollution leading to the entry of harmful materials into food chains via plant uptake, compromising food safety (Ozcan et al., 2016). The buildup of HMs in soil and plants impacts plant physiological functions like photosynthesis, nutrient uptake, and gaseous exchange, resulting in reduced plant development and dry matter precipitation (Gebre and Debelie, 2015; Ozcan et al., 2016). The environmental pollution and health posing caused by HMs are among the top causes of worry across the world. Because lead inhibits hemoglobin manufacture and shortens the lifespan of erythrocytes' circulating, it has a hematological effect and causes anemia (Yilmaz, 2005). Lead is a toxin that builds up over time; its harmful effects include increased blood pressure, renal and brain damage, cardiovascular and reproductive disorders in adults, and reduced intellectual and cognitive development and performance in children. For example, Pb bioaccumulation in the human body disrupts mitochondrial function, limiting breathing, causing constipation, brain enlargement, paralysis, and eventual death (Singh and Kalamdhad, 2011). As observed by Yilmaz (Yilmaz, 2005), Pb is a mainly hazardous metal with no biological function and has a significant detrimental impact on children.

Because of HMs poisonousness at specific levels, translocation across food chains, and non-biodegradability, HMs have a substantial ecological impact, all of which contribute to their precipitation in the biosphere (Sridevi et al., 2012). Soil is a severe environmental origin for maintaining people's property, food, and ecosystem demands (Gebre and Debelie, 2015). Plants cultivated on soil contaminated with municipal, residential, or industrial waste can deliver HMs in the form of mobile ions from the soil solution via foliar uptake or their roots. Plant roots, stems, fruits, grains, and leaves bio-accumulate the absorbed metals (Ugurlu, 2004). HMs such as Cd, Hg, As, and Pb are harmful to plants, animals, and people; when HMs such as Fe, Hg, As, Cd, Mn, Pb, Co, Cu, Ni, and Zn are leached out of dumpsites, they terminated in the soil as the sink (Alloway and Jackson, 1991).

Vegetables are grown in polluted soil absorbing HMs in elevated quantities to reveal probable impacts on agricultural outcomes and revealed in human health hazards (Sridevi et al., 2012). Since HMs are destroyers of the ecosystem and man's health, it is critical to observe these pollutants in the ecosystem regularly. Heavy metal research is critical because minor changes in their level above the appropriate concentration, whether caused by typical or anthropogenic agents, can cause significant ecological and health troubles. This review will investigate the hazardous impacts of HMs levels in the soil and the crops cultivated in the landfill and search their resources and remediation approaches to react with these HMs pollution in the soils to recognize the HMs situation and their influences on the soil and environment.

Biochar, zeolite, yeast, and bacteria have functional groups that can adsorb the toxic metals from soil and water according to the nature of their surface charge (Sayyadian et al., 2019; Wahba et al., 2017). Household treatments were used to minimize metals in food (Abdel-Rahman et al., 2018; Hussien and Nosir, 2017; Sayyadian et al., 2019; Wahba et al., 2017). Nanoparticles of metals have a broad spectrum of technological and environmental usage, like water and soil treatments (Anusa et al., 2017).

Sources of HMs

HMs are everywhere in the ecosystem because of natural and anthropogenic actions (Tables 1, 2; Figures 2, 3 and 4. The sources of HMs to the various ecological media like soil, air, and water are divided into natural and anthropogenic origins (El-Kady and Abdel-Wahhab, 2018). The natural beginnings, such as volcanic eruptions, sea-salt sprays, rock weathering, forest fires, and wind-borne soil particles, as well as biogenic origins, are all typical (Figure 2). The anthropogenic origins include industrial processes, agriculture processes, wastewater discharge, mining processes, metallurgical procedures, and emissions of chimneys and motors (Figure 3).

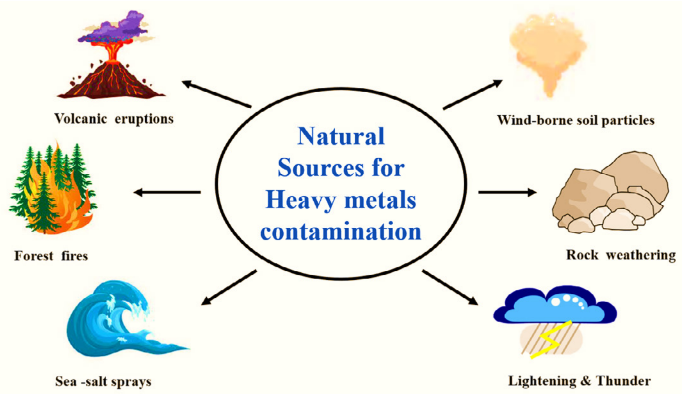

Figure 2: Natural sources for heavy metals contamination.

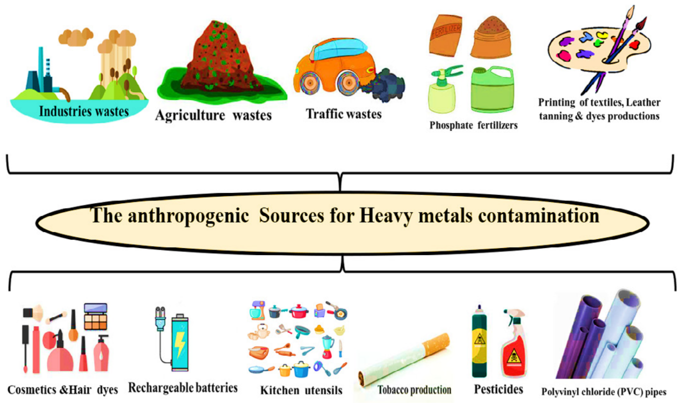

Figure 3: The anthropogenic sources for heavy metals contamination.

Individuals are exposed to them in numerous methods (Bakshi et al., 2018; Sridevi et al., 2012). HMs are ever-lasting ecological, undecomposed contaminants that go into the body via air, water, and food, and biologically collected over time. In the meantime, contamination from human activities has exposed some HMs to the environment (Rasmussen et al., 2007). The existence of HMs in the ecosystem, even at low levels, is still an ecological issue due to their harmfulness. Slight increases in heavy metal concentrations over the safe limit may be caused by natural or manufactured reasons, which are a significant source of

Table 1: Most common heavy metals contaminations and human health hazards.

Heavy metals	Sources of heavy metals	Human health hazards	References
Lead	Thermal power plants, crude petrol, mining, smelting, and paint	Learning difficulties, nervous lesions, fertility problems, Cardiovascular problems, renal dysfunction and hepatic lesions	(Flora *et al.*, 2012; Weisskopf *et al.* 2010)
Cadmium	Burning fossil fuels such as coal or oil and municipal trash such as plastics and nickel-cadmium batteries	Lung, prostate, pancreas, and kidney cancers	(Satarug *et al.*, 2017)
Mercury	Coal-fired power plants, factories, waste incinerators, and mining for mercury, gold, and other metals cause air pollution.	Nervous, renal, and immune systems affections	(Karri *et al.*, 2016; Rafati-Rahimzadeh *et al.*, 2014)
Arsenic	The use of polluted water in food preparation and the irrigation of crops, industrial activities, and the use of cigarettes all pose health risks.	Skin irritation, and lung, bladder, liver, and renal cancers	(Kesici, 2016)
Chromium	Polluted soil, air, water, smoking, and food.	Dermatitis, allergies, ulcers, respiratory, gastrointestinal, neurologic, reproductive problems and and cancers	(Remy *et al.*, 2017)
Nickel	Diesel oil and fuel oil, and the incineration of waste and sewage	Lung fibrous, cardiovascular difficulties, renal illnesses, and degenerative changes in heart muscle and brain, lung, liver, and kidney tissues lead to cancer of the respiratory system and lungs, which in turn leads to sarcoma of bone, connective tissue, and muscles.	(Duda-Chodak and Blaszczyk, 2008)
Copper	Irrigation with polluted waste water	Can affect renal and metabolic functions	(Ahmed *et al.*, 2017)
Zinc	Irrigation with polluted waste water	Respiratory dysfunction	(ÖZKAY *et al.*, 2014)

Table 2: Natural and Anthropogenic sources of heavy metals contaminated soil, plants, and crops.

Heavy metal	Sources		References
	Natural	**Anthropogenic**	
Pb	1. The limestone and dolomites also contribute to lead content in the soil. Besides, shale, mainly black shale, is also a Lead source in the soil 2. The acidic igneous rocks and argillaceous rocks, and sedimentary rocks	1. Lead can be spread in the soil by the mining and smelter sites 2. Paint, gasoline additives, smelting, automobile demolition, and pesticide application 3. Pb can be released in the soil from manufacture/ industrial effluent 4. The following items containing Lead (traditional or folk remedies, candy/food packaging, Batteries, leaded crystal glassware, ceramic glazes, cosmetics, solders, hair colors, jewelry, firearms and ammunition, antique fishing sinkers, tire weights, imported children's toys) 5. Burning coal and oil, domestic sewage effluent, and burning of waste	(Bakshi *et al*., 2018; Ihedioha *et al*., 2017; Khan *et al*., 2008)
Cd	1. Cd can be naturally found in Black shale. 2. Volcanic activity also is the primary natural source of Cd in the soil and atmosphere, Parent material, marine sedimentary rocks, and phosphates	1. Extraction and refining of non-ferrous metals 2. Manufacture and application of phosphate fertilizers 3. Burning of fossil fuel 4. Incineration, domestic sewage, and disposal of waste 5. Tannery industry, electroplating, spent rechargeable as well as the household batteries 6. Cd can be added to the soil by batteries, paint, stained glass, and paper ink that are common in MSW	(Bakshi *et al*., 2018; Ramelli *et al*., 2012; Rezapour *et al*., 2018; Somani *et al*., 2019)
Hg	1. Gaseous emissions from the earth's crust 2. The pyrogenic, sedimentary rocks, and clayey residues	1. The burning of fossil fuel 2. The production of steel, cement, and phosphate 3. The smelting of metals from their sulfide ores	(Bakshi *et al*., 2018; G *et al*., 2004; Khan *et al*., 2008)
Zn	1. Sedimentary rocks and acidic granitic rocks 2. Black shale and clayey sediments 3. Sandstone, limestone, and dolomite	1. Mining activities 2. Steel and Zinc production facilities 3. Combustion of coal and fuel 4. Waste disposal and incineration 5. The use of fertilizers and pesticides containing zinc	(Bakshi *et al*., 2018; Khan *et al*., 2008; Lundberg *et al*., 1997)
Cu	1. Cu is naturally found in different parent rocks and can be abundant in basic igneous rock (basalts) 2. The abundance of Cu also can be found naturally in shale-clay and black shale	1. Non-ferrous metal production, copper smelters, and steel production 2. The municipal incinerators 3. The residue of copper mining, sewage sludge, mineral fertilizers, and pesticides 4. The valorizing and application of bio-solids add cupric to the soil. 5. Cupric contamination of agricultural land can also result from cupric-based fungicides.	(Bakshi *et al*., 2018; Baranowska *et al*., 2005; Khan *et al*., 2008)

worry since they cause substantial ecological and human health issues. As observed in Table 2, anthropogenic origins of HMs pollution include agricultural activities, like herbicides and pesticides polluting irrigation water, and using municipal waste for fertilization aims (Alloway and Jackson, 1991; Bakshi et al., 2018). Also, the anthropogenic source involves mining activities, waste disposal in farmland, sewage discharge, smoking, building materials such as paints, and traffic emissions (G et al., 2004; Su, 2014). The previous findings from studies reported that HMs introduced into the ecosystem by human works are primarily from waste disposals, agricultural work, and industrialization. Budiyanto and Lestari (2017) reported that the coastline region is polluted with hazardous materials due to the direct discharge of about 1,100 tons of solid trash. This massive release of toxins reduces water quality and aquatic life since it contributes to the demise of aquatic organisms such as coral reefs (Budiyanto and Lestari, 2017). Humans and animals are affected by HMs by breathing of dusty soil (Eneje and Lemoha, 2012). Heavy metal contaminants like Cu, Pb and Zn from additives applied in gasoline as well as lubricating oils are also accumulated in vegetation and soils of highway (Eneje and Lemoha, 2012).

Based on Table 2, each heavy metal has its resource and route to contaminate the soil. Whatever the resource variations, HMs track a typical biogeochemical cycle post-

Links Researchers

introducing the ecosystem, although their transportation, residence period, and fate vary from particular conditions (Bakshi et al., 2018). Overpopulated areas, industrial zones, driving zones, and municipal garbage sites contribute to regional pollution (Bakshi et al., 2018). Table 1 demonstrates that the anthropogenic sources of all the metals discussed, including waste disposal and incineration, mining operations, and fertilizer, are identical. Herbicides, pesticides, fungicides, industrial waste storage, and the manufacture of metals and alloys have all contributed to an increase in the amount of HMs in the soil (Bakshi et al., 2018; Khan et al., 2008), which suggests a substantial role in the presence of HMs in the ecosystem.

Bakshi et al. (2018) found that 25,000–125,000 tonnes/year of Hg naturally emission the ecosystem. Only 10,000 tons per year contaminate the ecosystem via smelting and mining, which has been elevated at 2% annually since 1973. According to Luoma and Rainbow (2005) anthropogenic Cadmium pollution is nearly 31 times greater than natural sources, with humans introducing 5.6-38x10^6 kg of Cd into the soil each year, and they have adverse effects (Benvenga et al., 2020; Dourado et al., 2020; Dutta et al., 2021; Balali-Mood et al., 2021; Bandeira et al., 2022; Ohiagu et al., 2022) with different mechanisms.

Air pollution

The primary source of air pollution caused by toxic HMs is vehicle exhausts, notably air pollution with Pb surrounding highway (Awofolu, 2004). The toxic metals are precipitated on soils surrounding highways, then accumulate in cultivated plants. They reported that the levels of Pb, Ni, Co, and Cd in citrus and cabbage decreased with increasing the distance from the agricultural highway, but when far about the highway, the levels decreased. Also, Fruits and vegetables growing at the roadside may be accumulating toxic metals, especially from vehicle emissions, as recommended by Feng et al. (2011); Shahid et al. (2017) disclosed that airborne HMs might be accumulated and absorbed on the leafy parts of the different plants.

Irrigation water

Expanding population, food demand, and lack of irrigation freshwater in some developing countries lead to the irrigation of crops with contaminated water. The regular usage of wastewater for irrigation of crops results in the accumulation of HMs in crops and consequently transported via the food chain to animals and humans, producing probable human health hazards over time (Gupta et al., 2012). The contamination of food such as fruits, vegetables, and crops by HMs may happen due to the release of industrial wastewater and sewage wastewater that contaminates the irrigation water sources such as canals, nearby streams, and rivers (Yadav et al., 2016). To keep the ecosystem and public health, the contaminated water in agricultural uses requires an understanding of the levels and types of water contaminants, particularly toxic metals. Monitoring metal levels in irrigation water are required to safeguard environmental and human health due to its toxic impacts and stability (Nazar et al., 2012). The quality of irrigation water determines the heavy metal contents in wheat grains. The concentrations of Cd, Pb, Ni, and Cu in wheat grains irrigated with fresh water were 0.07, 0.09, 0.22, and 1.04 mg kg^{-1}, respectively; however, that irrigated with drainage water recorded higher levels of Cd, Pb, Ni and Cu as 0.09, 1.18, 0.84 and 1.55 mg kg^{-1}, respectively.

Agricultural practices

Agricultural practices like fertilizers, manures, and sewage sludge are important origins of HMs (De Miguel et al., 1999). Sewage sludge is a primary source of plant nutritive substances and organic material but also a source of HMs. Also, phosphatic fertilizers such as P_2O_5 are essential sources of Ni and Pb in soils and have a considerable acidifying impact on soils and hence increase the mobilization and plant absorption of the metals, which increase the deposition of toxic HMs in crops (Banuelos and Ajwa, 1999). They have elevated Cd, Cr, Cu, Zn, Ni, and Pb levels at 10.1, 29.7, 29.2, 89, 17.9, and 12.2 ppm, respectively (Carnelo et al., 1997). Applying fertilizer and manure in the long term, the levels of Cd, Pb, and As were elevated in the soil and cultivated plant by 125% after harvesting (AlKhader, 2015; Atafar et al., 2010).

Agricultural soils

Agricultural soils are not the only source of nutrients for plant life, but they also transfer many contaminants, such as HMs, to cultivated plants through their roots. Contamination of agricultural soils with HMs, like Pb, Cd, Cu, and Ni, increased dramatically during the last years (Mahmoud and Ghoneim, 2016). The agricultural soils receive many toxic metals from natural and anthropogenic origins (Table 2). HMs may accumulate in agricultural soil due to industrial releases, petrochemicals, wastewater irrigation, atmospheric accumulation, and agricultural operations like fertilizers and pesticides (Elnazer et al., 2015). In this respect, Baranowska et al. (2005) noticed considerable increases in Cd and Pb (mg kg^{-1}) in contaminated agricultural soil, increased 44 and 265 times, respectively. The accumulated metals in grass, milk, cereals, eggs, and fruits were also marvelously increased.

Animal feed

Metal contamination of animal feed and its ingredients represent a central dilemma for animal health and the accumulation of poisonous metals in the food chain, such as meat, egg, and milk. HMs like As, Cd, and Pb contaminate poultry and ruminant feed with different concentrations (Elliott et al., 2017). Consequently, it accumulated in the egg. Higher concentrations of accumulated Pb, Cr, and Se were recorded in egg yolk as 0.701, 0.262, and 0.266 ppm, respectively. Moreover, Makridis et al. (2012) researched the transfer of some HMs (Cr, Cu, Pb, Cd, Zn, and Ni) from livestock feeds to cows and sheep organs such as muscle tissues, liver, and kidney. The higher deposition of Cu, Zn, and Cd was recorded in the liver, muscle tissues, and kidney. Meanwhile, Cr, Pb, and Ni levels were below 0.02 mg kg^{-1} in all animal organs.

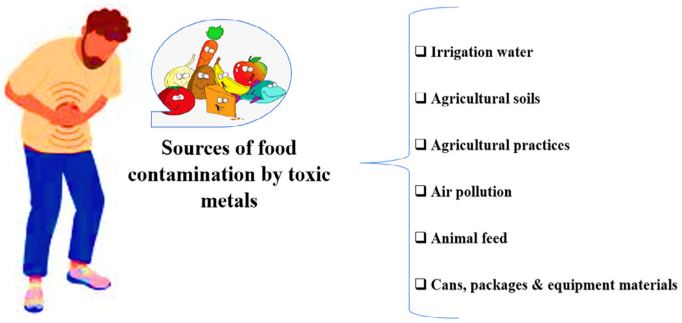

Figure 4: Sources of food contamination by toxic metals.

Cans, packages, and equipment materials

Food industrialization, such as the canning process, led to the metal contamination of canned foods. For example, Pb's leading source of food contamination is solder used in manufacturing cans (Brhane and Dargo, 2014). The toxic metals (Cr, Pb, and Cd) were higher in canned food (tuna, corned beef, sardines, and tomato paste) than in the corresponding fresh food. Also, food packaging papers such as sweet boxes, pizza boxes, coffee cups, and pastry boxes had variable levels of Sood and Sharma (2019). Moreover, the HMs like Zn, Ni, Cu, Cr, Mn, and Pb were migrated from plastic food packaging containers to 3% acetic acid and 0.9% NaCl (Khan and Khan, 2015).

Vulnerable foods for HMs contamination

The common HMs sources in human food are seen in Figure 5.

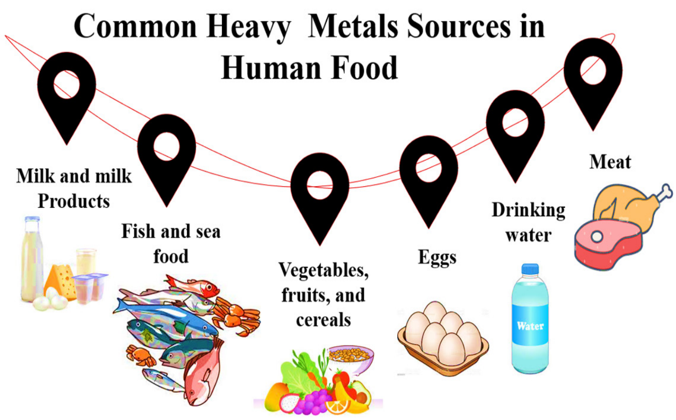

Figure 5: Common heavy metals sources in human food.

Milk and milk products

Milk and its products are a completely food as healthy food. Nevertheless, toxic metals in milk or milk products could harm human health. So, the safety of milk or its products reduces with the rising metal levels (Singh et al., 2020a). Cashman (2011) showed that the levels of HMs in milk and its products depend on the genetic factors of the animal, stage of lactation, metal pollution from the equipment during production, nutritional type of the animal, environmental factors, and manufacturing practices. Dairy animals graze on the polluted plants accumulates the toxic HMs in their cells and milk if lactating (Yahaya et al., 2010). The primary sources of Cu contamination in milk or milk products are animal feed, increased Cu levels in the water, and Cu alloys used in different equipment. Also, the presence of Pb in milk may be a return to industrial air pollution in areas of dairy farms (Malhat et al., 2012). So, HMs are the widespread pollutant found in milk. The significant origins of HMs in animal systems are (1) consumption of polluted water and feed, (2) polluted air, (3) soil, (4) contaminated types of equipment, and (5) improper manufacturing practices (Caggiano et al., 2005). Also, levels of metal in milk increased with increasing the animal age (Mohamadiun et al., 2018). They added that the animal body acts as an effective biological filter and accumulates the metals brought by the feed into the bone tissue rather than the milk.

Fish

Fish meat is a desirable source of nutritional substances such as vitamins, minerals, and high-quality protein. Many environmental pollutants, such as toxic metals, are the primary resources of HMs, contaminating water during discharges of industrial and agricultural wastes like pesticides, coal and oil combustion, plastics, and phosphate fertilizers (Munir et al., 2021; Idowu, 2022; Mawari et al., 2022; Mukhi et al., 2022; Borah and Deka, 2023; Xu et al., 2023). The fish accumulated toxic metals from the water via direct water uptake or absorption via the gills, skin, and gut (Marzouk et al., 2016). Hamada et al. (2018) investigated Hg, Pb, and Cd levels in Nile tilapia fillet samples.

Meat

In Egypt, offal of animals such as heart, kidneys, liver, lungs, rumen, spleen, intestine, and tongue are widely consumed as a food source. The levels of metals in meat depended on the animal's age Darwish et al. (2010) noticed that the water and protein contents of meat decreased with increasing the animal age, while fat and ash contents increased with increasing the animal age, leading to an increase of metal levels in meat. Maximum levels of Cd and Pb were reported in the liver and kidneys of cattle and sheep, while low levels of metals were reported in their muscles. Also, the studied metals in cattle organs were higher than those detected in sheep. The frozen chicken sample had higher Pb and Hg levels at 0.035 and 0.085 mg kg^{-1}, respectively. Meanwhile, the sample of frozen minced beef recorded the highest level of Cd as 0.012 mg kg^{-1}. Food provided to patients at hospitals must be free from poisonous metals (Hassouba et al., 2007). El-Wehedy et al. (2018) determined the toxic metal levels in meats served at Egyptian hospitals, such as cooked meat, cooked chicken, raw meat, and raw chicken. The cooked chicken recorded the highest mean concentrations of As, Cd, and Pb at 0.122, 0.202, and 0.421 mg kg^{-1}, respectively. They added that was no significant difference in metal levels between chicken and beef samples. But the cooked samples had a significant increase in HMs levels compared with raw samples, which may be a return to the evaporation and loss of water in the cooked tissue.

Egg

The egg is economical food and the most nutritious for human health. However, some toxic metals can accumulate in egg (Hussien and Nosir, 2017). The average levels of some metals in egg samples were 0.70, 0.31, 2.12, and 1.61 mg kg-1 for Pb, Cd, Cr and Cu, respectively. The residual concentrations of As, Cd, Cu, Fe, and Pb in brown shell egg samples (Al-Ashmawy, 2013).

Vegetables, fruits, and cereals

The highest accumulation of toxic metals (Cd, Pb, Al, and As) in leafy plants (lettuce and watercress) and tuber vegetables (potato) compared with fruit vegetables (tomatoes, cucumber) was the critical observation of this study (Abdel-Rahman, 2021). Eissa and Negim (2018) studied the translocation of some HMs (Zn, Cu, Pb, Cd, and Ni) from a metal-contaminated soil to lettuce and spinach. They noticed that the accumulated HMs in the roots of lettuce and spinach were higher than those in their shoots. Radwan and Salama (2006) discovered the levels of Pb, Cd, Cu, and Zn in different fruits such as apple, banana, melon, date, grapefruit, peach, orange, strawberries, and watermelon. The detected metals ranged from 0.05 to 0.87 mg kg-1 for Pb, from < 0.002 to 0.05 mg kg-1 for Cd, from 1.2 to 18.3 mg kg-1 for Cu, and from 1.36 to 10.5 mg kg-1 for Zn (Akoury et al., 2023). In the meantime, the maximum levels of Cu in orange, pomegranate and strawberry were 1.9, 5.5 and 3.5 mg kg^{-1}, respectively.

Hazard influences of HMs on crops and soil

The influences of HMs on soil

HMs are one of the significant origins of soil contamination. HMs pollution in the soil is produced by different kinds of HMs, mostly Pb, Cu, Zn, Ni, Cd, and Cr (Hinojosa et al., 2004). Human activities like waste production and throwing in landfills and dumpsites were found as the most common resource of soil contamination with HMs. Heavy metals in the soils surrounded by waste dumps are affected by numerous factors like the kinds of wastes, run-off, topography, and level of scavenging (Järup, 2003). Inadequate waste disposal results in pollution of both groundwater and soil. Paper, ashes, metal scraps, food trash, glass, and ceramics are all part of municipal solid waste. The breakdown or oxidation process transfers HMs from trash into the surrounding soil (Cataldo and Wildung, 1978). Changes in soil fertility and quality, groundwater pollution, biomagnification, and eventually permanent harm to soil biota are all caused by HMs in the soil (Borah et al., 2020).

Historically, consuming foreign compounds like HMs subjected soil systems to physical stress. When soil contains high content, the resulting unhealthy environment negatively impacts all living things (Figure 6 and Table 3). Table 3 talks about the hazard influences of HMs. Table 3 indicates that Lead is a poisonous metal with little mobility but high bioavailability., Lead continues for an extended period on the soil surface (Akanchise et al., 2020). Cadmium and its compounds may migrate through the soil, their movability depending on several parameters, i.e., soil pH and the quantity of organic substance, both of which are affected by the ecosystem (Karaca et al., 2010).

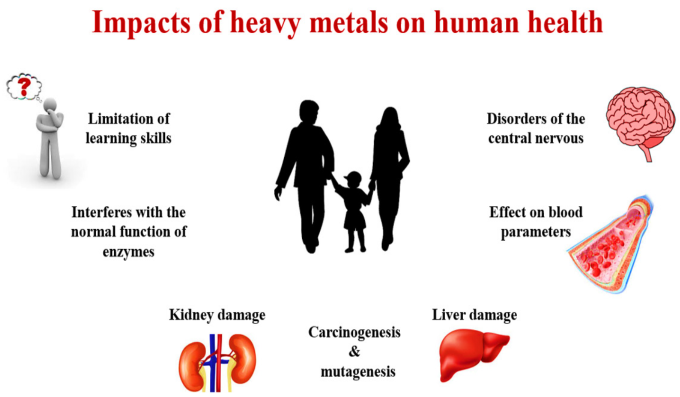

Figure 6: Influences of HMs on public health.

Furthermore, cadmium binds closely to organic material in the soil, where it remains immobile and is absorbed by plants, eventually entering the food chain (Karaca et al., 2010). HMs pollution in the soil is linked to high heavy metal concentrations, inadequate nutritional and organic substance, low water retention capability, and low cation exchange capability based on Singh and Kalamdhad (2011). Furthermore, increased heavy metal concentrations in the soil have harmful effects on the soil biota by interfering with crucial microbial activities and lowering the count of organisms (Singh and Kalamdhad, 2011; Sanaei et al., 2021; Mitra et al., 2022; Nolos et al., 2022; Su et al., 2023; Wang et al., 2023). HMs inhibit the soil enzymes producing microbiota, affecting the enzyme activity in the soil (Karaca et al., 2010; Zaynab et al., 2022).

Table 3: The adverse effects of heavy metal-contaminated soils, plants, and crops.

Heavy metals	Soil	References
	Adverse effects on soil	
Cd	Disable protease, urease, and alkaline phosphatase activity Abnormalities in the metabolic function of organisms. Affect the soil N and S availability for crop production	(Akanchise *et al*., 2020; Bakshi *et al*., 2018; Balkhair and Ashraf, 2016; Karaca *et al*., 2010)
Pb	Reduce urease, catalase, invertase, and acid phosphatase activity in the soil. Abnormalities in the metabolic function of organisms Shortage of soil macronutrients like Phosphorus Disrupts water equilibrium, enzyme function, and mineral nutrition Reducing soil productivity.	(Alloway and Jackson, 1991; Bakshi *et al*., 2018; Fenn *et al*., 2006; Karaca *et al*., 2010; Kumar *et al*., 2019; Somani *et al*., 2019)
Hg	The metabolic activity of organisms was affected	(Akanchise *et al*., 2020)
Zn	Reduce soil fertility Reduce the biomass nitrogen Lack of soil macronutrients such as Phosphorus	(Balkhair and Ashraf, 2016; Fenn *et al*., 2006; Yao *et al*., 2003)
Cu	The bioavailability of S and N decreased in the soil Decrease the activity of Beta glucosidase Decrease the microbial biomass N	(Bakshi *et al*., 2018; Karaca *et al*., 2010)
	Plants and crops	
Cd	Cause numerous irregularities in various plant parts, including roots, shoots, leaves, and fruits, and an enhanced dry-to-fresh mass ratio (DM / FM) in all organs. Adverse effects on sugar amount and amino acids in some plant species are caused by increasing their concentration, indicating inhibition of starch hydrolysis. In *Aeluropus littoralis*, balance the macro- and micronutrients by increasing and decreasing micronutrients. Lead to less photosynthetic carbon assimilation when interacting with different photosynthetic complexes. Interferes with guard cell regulation, affecting the plant's water status; soil contamination hurts photoheating production due to an interruption of the transporter/channel for loading other elements and an imbalance of plant nutrients.	(Bakshi *et al*., 2018; Kumar *et al*., 2019; Singh *et al*., 2020b)
Pb	Seed germination was decreased Disorder in plant metabolism, physiological and morphological characteristics, plant development, and productivity Reduce plant growth. Cause malformation of cellular structure, decreased chlorophyll biosynthesis, hormonal imbalance, and excess production of reactive oxygen species (ROS), which can cause oxidative stress within plant cells and readily attack biological structures and bioactive molecules, resulting in metabolic dysfunction.	(Kumar *et al*., 2019; Singh and Kalamdhad, 2011; Tang *et al*., 2017)
Cu	Reduced the bioavailability of Nitrogen and Sulfur in soil required for plant production Hinder β-glycosidase activity more than the cellulose	(Bakshi *et al*., 2018; Karaca *et al*., 2010)
Zn	Affect the crop yield Affect the growth of pea plants	(Bakshi *et al*., 2018; Balkhair and Ashraf, 2016)

Following Bakshi et al. (2018), By increasing the saturation or supersaturation of the cation exchange sites with heavy metal cations, the contamination of HMs indicates a reduction in the selective absorption of other cations, displaces the protons in the soil solution and lowers pH. Enzymatic activity is inhibited by HM pollution in the soil, which weakens SOM mineralization and the nitrogen cycle (Bakshi et al., 2018).

Also, from Table 2, HMs such as Cd are considered dangerous HMs to enzymatic activities. The data of the research performed by Karaca et al. (2010), found that the low concentration of cadmium does not affect the soil enzyme, while the increase of Cd reduces the activity of soil enzymes. The highest impacts of Cd on enzymatic activity were higher in sandy loam contrasted in loam or clay loam soils. Also, Hemida et al. (1997) found that higher levels of copper and zinc in soil (2 mg/g) inhibit urease activity in the soil.

The hazard impacts of HMs on plants

Plants growing around municipal solid waste landfills are linked to HMs pollution that may impact the food chain (Vongdala et al., 2019). HMs have various adverse plant effects (Table 3 and Figure 7). HMs are unbreakable and affect the environment on a worldwide scale. Depending on their abundance in the environment, some HMs can serve as plant nutrients. For example, human activities dispose of Hg, Pb, Cd, Ag, and Cr have deadly effects even at low concentrations (Kumar et al., 2019). Several variables, including temperature, humidity, organic matter, pH, and nutrient availability, affect the plant tissue uptake and HMs accumulation. According to this study, several metals like Cd, Zn, Cr, and Mn were discovered to be absorbed and deposited in spinach at higher rates during the summer. At the same time, Cu, Ni, and Pb were found to be deposited at higher rates during the winter. According to estimates, the summertime pace of organic matter decomposition most certainly released HMs into the soil solution for potential plant absorption. High sweating was predicted to be the reason for the higher assimilation of HMs like Cd, Zn, Cr, and Mn in the summer. In contrast, high ambient temperature and low humidity were predicted to be the causes of the higher accumulation rate of HMs in the winter (Sharma et al., 2007).

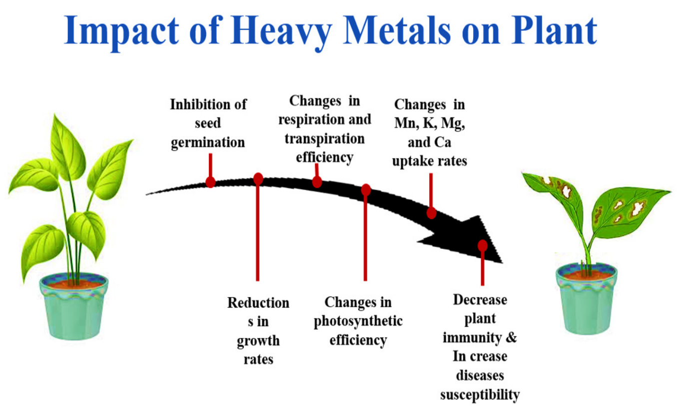

Figure 7: Influences of HMs on plants.

Animal and human health are at risk because of HMs being absorbed by plants and then deposited in food chains. Because they are easily absorbed by plants, infiltrate food chains, or contaminate groundwater, mobile HMs pose serious contamination issues (Sprynskyy et al., 2007). Metal and plant species are a couple of the factors influencing how well plants absorb HMs. According to research by several prior scientists, crops, particularly leafy vegetables grown in HM-polluted soil, shed significant amounts of metals through their leaves (Yongsheng et al., 2011). The replacement of faulty components with poisonous HMs and the inhibition of photosynthetic activities in plant cells are all effects of high levels of HMs that are detrimental to plant growth. HMs can also produce oxidative stress in plants and damage cell structure (Bakshi et al., 2018).

Additionally, HMs impact seed germination and lessen the likelihood of crop production. Compared to other environmental pressures, HMs harm plant growth. Amylase, protease, and ribonuclease are three examples of delayed enzymatic activities caused by Ni poisoning that impact plant germination and growth (Bakshi et al., 2018). Ni can cause a decrease in plant height, root length, chlorophyll content, photosynthetic pigments, and an accumulation of Na^{+}, K^{+}, and Ca^{2+} in plant (Bakshi et al., 2018). Lower nutrient uptakes disrupt plant metabolism. Heavy metals adversely affect the capability to repair nitrogen in legumes, causing chlorosis, poor plant growth, and depression (Singh and Kalamdhad, 2011). The hazard influences of HMs on plants are discussed in Table 3 and Figure 7.

Remediation technics of soil contaminated with HMs

Due to its biochemical and geochemical heterogeneity (Alloway and Jackson, 1991), soil retains heavy metals longer than air and water (Kamari, 2011). Because soil is a biochemical and geochemical heterogeneous complex mixture retains heavy metals longer than air and water. HMs are pristine, and, once introduced to soil, they endure. With HMs, there are several options for recovering contaminated soil (Rebezov et al., 2021a, b, c, d). Chemical, physical, or biological techniques are commonly used in remediation, as seen in Figure 8 and Table 4.

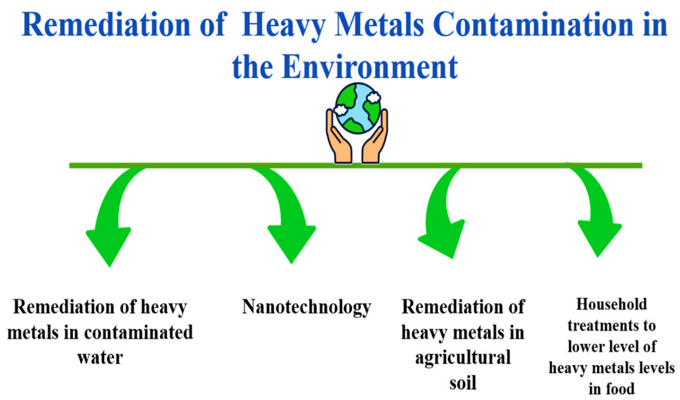

Figure 8: Remediation of HMs contamination in the ecosystem.

Engineering remediation is the first technique used in remediation, as illustrated in Table 4. In engineering remediation, the process involves adding much clean soil to cover or mix with polluted soil (XS et al., 2002). The soil removal and isolation approach are required for severely polluted soil with a small area since it entails removing polluted dirt and replacing it with clean soil. The following approach employs soil electro-kinetic remediation, which is successful in low-permeability soil and creates an electric field gradient on both sides of the electro-lytic tank containing the contaminated soil (Kamari, 2011; Sabatini and Knox, 1992). Another method includes cleaning contaminated soil with specific chemicals to remove HMs complexes and dissolved iron from solid-phase particles

(Su, 2014; El-Nagar and Abdel-Halim, 2021; Wu et al., 2023; Mukherjee et al., 2021; Islam et al., 2022a; Mathur et al., 2022; Sharma et al., 2021; Sodhi et al., 2022). The last approach is clay mineral fixing and adsorption, such as zeolite, bentonite, etc. (Xin and Qixing, 2004).

The bioremediation method, which includes phytoremediation and microbiological remediation, is also shown in Table 4. Growing specific plants in the polluted soil, such as Cruciferae species like the genus Brassica, Alyssums, etc., was part of the phytoremediation process (Xin et al., 2003; Elbasiouny et al., 2021; Jeyasundar et al., 2021; Kumar et al., 2021; Mazarji et al., 2021; Verma et al., 2021; Amuah et al., 2022; Awasthi et al., 2022). The most crucial factor is finding plants with a solid capacity to amass and overcome HMs. These sorts of plants must have a substantial hyper deposition potential for pollutants in the soil. The detoxifying enzyme and nucleic acid are produced and expressed by plants as a means of plant resistance in the phytoremediation process, which is integrated with plant defense against damage (Kumar et al., 2019). Another approach involves plants producing phytochelatins (PSc), which bind to heavy metals (HMs) and sequester the chemicals inside cells so the HMs will not

Table 4: Remediation technics of soil, plants, and crops contaminated with heavy metals.

Techniques	Method	Mechanism	References
Anthropogenic remediation	Soil leaching	As part of this procedure, contaminated soil is cleaned using specific chemicals to remove complexes of heavy metals and dissolved iron from solid-phase particles. The extracted heavy metals are then extracted from the extraction solution.	(Su, 2014)
	Soil removal and isolation	This strategy entails removing contaminated soil and replacing it with clean soil. It is essential for soil in a limited region that is significantly polluted.	96
	Electro-kinetic remediation	This method uses the DC-voltage concept to establish an electric field gradient on both sides of the electro-lytic tank containing the contaminated soil. The processing chamber is positioned at the two poles of the electro-lytic cell and employs electric migration, seepage, or electrophoresis to decrease soil contamination. This technique is helpful in soils with low permeability.	(Kamari, 2011; Su, 2014)
	Replacement of contaminated soil	It involves putting a large volume of clean soil on the surface of contaminated soil or mixing it.	(Su, 2014; XS *et al*., 2002)
	Adsorption	Fixed and adsorbed by clay minerals such as bentonite, zeolite, etc.	(Xin and Qixing, 2004)
Bioremediation	Phytoremediation	Involve cultivating certain plants in polluted soil, such as Cruciferae species such as Brassica, Alyssums, etc. The plant byproducts were used to remove heavy metals from polluted water. The biosorbents derived from the Jatropha plant demonstrated an aptitude for removing metals such as copper and zinc from contaminated water.	(Nacke *et al*., 2016; Kamari, 2011; Su, 2014; Xin *et al*., 2003)
	Microbial remediation	Utilizes several microorganisms (bacteria, archaea, and fungus) to absorb, deposit, oxidize, and reduce heavy metals Saccharomyces cerevisiae can remove Pb, Zn, Cr, Co, Cd, and Cu ions from aqueous solutions. Algae biomass was used as a wastewater treatment method to eliminate Cu, Pb, Cd, and Zn ions	(Davies *et al*., 2001; Farhan and Khadom, 2015; Kamari, 2011; Su, 2014; Utomo *et al*., 2016)
	Nanomaterials	Also, Cu oxide nanoparticles were tested for adsorption of Ni and Cr from aqueous solutions Another application estimated the effectiveness of Fe+3 oxide nanoparticles stabilized with polyacrylic acid on Cd removal from contaminated soil The use of metals and metal oxides nanoparticle induces genotoxicity, oxidative stress, and inflammation and has been identified as a possible human carcinogen.	(Al-Rikaby, 2021; Al Olayan *et al*., 2020; Banerjee *et al*., 2020; Camps *et al*., 2020; Cherkasova *et al*., 2021; Coetzee *et al*., 2020; Genchi *et al*., 2020; Gong *et al*., 2021; Gudkov *et al*., 2021a; Hosseini *et al*., 2019; Islam *et al*., 2022b; Maksimiuk *et al*., 2021; Mohamadiun *et al*., 2018; Rajakumar *et al*., 2021; Shen *et al*., 2023).

interfere with cell metabolism (XS et al., 2002). However, microbial remediation uses a variety of microorganisms, with bacteria, archaea, and fungi serving as the primary bio-remediators, to make the uptake, deposition, oxidation, and reduction of HMs in the soil (Davies Jr et al., 2001; Gudkov et al., 2021b; Maftouh et al., 2023; Shen et al., 2023; White and Dhankher, 2022). Numerous ions in the functional groups of microbial cell surfaces, like nitrogen, oxygen, sulfur, and Phosphorus, could be replaced by metal ions known as coordination atoms. The cationic group-carrying, negatively charged microorganisms used in microbial remediation allow the heavy metal to flow through their cell walls (Akanchise et al., 2020).

CONCLUSIONS AND RECOMMENDATIONS

Metal concentrations in plants, water, animals and people's bodies mirror the high concentrations of HMs in soil. The soil pollution near the landfill suggests that tainted food harms human health. This is a significant problem that must be addressed right away. Since slight alterations in their level above the permissible levels reveal significant ecological and consequent health hazards. Toxic metals can be found in foods such as milk, fish, meat, egg, and crops. Different applications could be applied for lowering the transferred metals to the food chain, such as biochar, zeolite, yeast, bacteria, Jatropha plant, Jojoba plant, and household treatments.

NOVELTY STATEMENT

The present review focused on the hazardous impacts of HMs levels in the soil and the crops cultivated in the landfill and search their resources and remediation approaches to react with this HMs pollution in the soils to recognize the HMs situation and their influences on the soil and environment.

AUTHOR'S CONTRIBUTION

The author prepared and approved the final manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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