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Heavy Metal Toxicity in Food Chain

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ABSTRACT

Aim: This article discusses how heavy metals, once introduced into the environment, can travel through various channels such as air, water, and soil. These metals can be taken up by vegetation, ingested by livestock and aquatic life, and ultimately consumed by humans, thereby entering and moving up the food chain. It emphasizes the different ways and mechanisms by which heavy metals are gathered within the human body. **Introduction:** Heavy metal poisoning is a result of the accumulation of heavy metals such as Lead, Mercury, Chromium in body higher than the normal values. Industrial activities, environmental contaminants, dietary sources, excessive medicinal intake, use of inadequately lined food containers, or consumption of lead-containing paints and mining operations can all lead to heavy metal toxicity in individuals. Environmental contamination by such metals is a worldwide issue caused due to rising in urbanisation, pollution, mining activities as it shows harmful effects on human life. **Material and Methods:** Various Books on environment and metal poisoning, Research papers and articles on PubMed, google scholar regarding heavy metal toxicity were referred and evaluated. **Findings:** Heavy metals such as Aluminium, Arsenic, Cadmium, Chromium, Copper, Iron, Mercury, Manganese, Lead etc. are highly toxic and have a tendency to accumulate in body. **Conclusion:** Such accumulation of toxic metals in body causes heavy metal toxicity and show many toxic symptoms on body over a period of time. Thus, there is a need to create awareness regarding the evaluation of quality and authenticity of the food, water, dietary products we consume.

Key Words *Heavy metals, Toxicity, Food, Pesticides, Mining, Food Chain*

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INTRODUCTION

Scientific use of nature and its natural elements does not harm the environment. But in order to get fast profit and more income and fulfil the demand of high population these resources are being misused by humans. There is a noticeable increase in the instances of food contamination. The frequency of adulterated food products entering the market is increasing. Heavy metals have atomic weight above 63.5 and specific

gravity higher than 5.0. Heavy metals are non-biodegradable pollutants and they accumulate in the crops, vegetables and plants. When vegetables cultivated in such contaminated soil are consumed by humans, toxicity occurs due to accumulation of heavy metals in body. Various products used in agriculture such as insecticides, herbicides, fungicides, wood preservatives etc are sources through which metallic impurities enter the food chain. Even if these fruits and vegetables

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are washed before consuming, large amount of such pesticides are used which are not destroyed just by washing with water. In countries like Bangladesh, India, Chile, Uruguay, Mexico, Taiwan millions of people are exposed to arsenic through contaminated ground water¹.

MATERIAL AND METHODS

Various research articles, journals regarding heavy metal toxicity were analyzed and reviewed. Books of forensic medicine and toxicology were referred and interpreted.

- **Concept of Heavy Metals²**

Heavy metals encompass all metallic elements with atomic numbers higher than 23. The primary sources of the eight most prevalent heavy metals – Arsenic, Cadmium, Chromium, Lead, Mercury, Nickel, and Zinc – include industries such as mining, chemical production, paint manufacturing, glass production, fertilizer application, and petroleum refining. These metals can enter the food chain through various pathways.

Heavy metals have the unique property of accumulation over a period of time along a food chain. Heavy metals are emitted both in elemental and compound forms. Environmental pollution by heavy metals is very prominent in areas of mining³.

- **How heavy metals enter food chain³**

When farming or plantation is done on the soil which is polluted by heavy metals, these metals are absorbed by plants and accumulate in their

tissues. Animals which graze on such plants which are contaminated by metals are also prone to toxicity. Humans when eat vegetables or fruits cultivated in such areas indirectly are exposed to such metals and also enter their body through food. Marine animals such as fish breed in this polluted water and thus accumulation of metals occur in their body which when consumed by humans shows toxic symptoms later on. Rice, a staple food consumed in large quantities globally, can absorb arsenic from polluted soil and irrigation water, which poses health risks to those who consume it.

- **Mechanism of Heavy Metal Toxicity**

When heavy metals accumulate in the body, they produce free radicals to affect the host by oxidative stress, damaging biological molecules such as enzymes, proteins, lipids, and even nucleic acids and finally damaging DNA which is the fastest way to carcinogenesis and thus also cause neurotoxicity. Interactions of these heavy metals with simple molecules such as vitamins or macromolecules like proteins interfere with the biochemical functioning of living and can cause anaemia, hormonal deficiency, cancer etc⁴.

- **Sources of excessive heavy metal accumulation in human body**

1. Heavy metals accumulation in soil

Heavy metals pollution of surface and underground water sources results in soil pollution which increases through mining. Such soil collected from mined areas are dumped on land and its contents are taken up by plants which accumulate in their tissues. When such plants are

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eaten by animals or humans it passes the traces of metals to them and it becomes toxic³.

In soil, the concentrations of metals range from traces to as high as 100,000 mg kg⁻¹ which depends on the location and type metal. Large areas of cultivated land have also been reported to be contaminated by Arsenic (As) and Cadmium (Cd) due to agricultural and industrial practices⁵.

The natural availability of metals in soil is enhanced through various processes, including the release of phytosiderophores by plants in the rhizosphere, which naturally regulates the accumulation of metals. But due to acidification by metals this rhizosphere is destroyed which supports the accumulation of metals⁶. In a study of agricultural land of Central Punjab Province of Pakistan with wastewater was reported to increase the buildup of toxic metals such as nickel (Ni), copper (Cu), chromium (Cr), cadmium (Cd) and cobalt (Co) in the soil samples²².

A Research conducted in Bangalore, India, revealed that soil irrigated with sewage water showed the highest levels of chromium, with significant amounts of lead and nickel and cadmium⁷.

2.Accumulation through cosmetics⁸

For the production of cosmetic products like lipsticks, lip gloss, mascara, eye shadows, powder, nail polish etc. various metals such as lead, arsenic are used to enhance the colour of the product. Companies are given certain limits for the maximum quantity of metals in their products

but not all companies follow the standard procedures. According to a study conducted in which quantitative analysis of 16 samples of different companies for presence of toxic metals in cosmetic product lipstick was carried out which concluded that Lead and Arsenic exceed the normal limits more than 20 ppm-40 ppm. Traces of chromium, cobalt and cadmium were found. Such pigments are used as colour additives which enter our body through oral route and skin.

Accumulation through polluted water²

Arsenic, cadmium, chromium, copper, lead, nickel, and zinc are the predominant heavy metals found in wastewater, posing risks to both human health and the environment. Excessive use of inorganic fertilisers leads to accumulation of nitrates in water. These nitrates enter human body and are converted to toxic nitrites by intestinal bacteria which combine with haemoglobin forms methaemoglobin and thus the oxygen carrying capacity of blood is decreased. This condition is known as Methemoglobinemia which causes damage to vascular and respiratory system⁹.

Today many industries discharge their untreated waste water in lakes, rivers nearby their location thus natural water which contains large or trace amounts of toxic metals is being used for drinking, bathing etc by the people living in those areas. The impact of heavy metals on drinking water is cumulative thus it causes poisoning. The increase in iron, zinc, copper concentration in water is due to sewage which originates from the

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galvanised iron pipes or sheets when protective covering is damaged⁴. Agricultural lands in Vadodara, Gujarat, India, that are irrigated with industrial wastewater have been found to contain notably elevated levels of heavy metals compared to those irrigated with tubewell water⁷.

4. Accumulation through Industrial Pollutants

Chemical, pharmaceutical, metallic, glass, paint industries are advised to do pretreatment on the waste water and then release it in the environment but very few industries follow such practices. Hazardous substances introduced into water bodies can negatively impact aquatic life and ecosystems, owing to their inability to break down, enduring presence, poisonous characteristics, capacity to induce oxidative stress, and tendency to accumulate in organisms²³. Biomagnification along food chains leads to the accumulation of heavy metals, which, when consumed by humans, pose subsequent health risks.

5. Effects of Mining

In the mining process, residual metals are often discarded as tailings in exposed or semi-covered pits. These metals can be dispersed by wind, carried away with soil erosion, or washed into waterways, ultimately settling on land and infiltrating groundwater sources. Wells located near the mining sites have been reported to contain heavy metals at levels that exceed drinking water criteria.

Mining operations conducted 50 metres beneath sea level have impacted the quality of groundwater. Water collected in the mines is

pumped into a water treatment plant and then used. Yet the villagers living nearby the mining areas still receive polluted and saline water, well water is also unfit for drinking. In such areas cases of Thyroid disease and Kidney stones are increasing¹⁰.

6. Metals in Dietary Supplements

A dietary supplement is a product which contains vitamins, minerals, herbs etc. The permissible levels of heavy metals are defined by Health regulatory agencies and accordingly instructions are given to the pharmacies.

Herbal remedies and nutritional supplements are often sold without verified certifications to attest to their quality or the presence of hazardous metals¹¹.

In a study done on Toxic metals in food supplements it was concluded that cadmium has high level of concentration in animal based and mineral food supplements as compared to plant-based food supplements. These vitamin and mineral supplements are unknowingly taken in excessive doses and thus accumulation of lead and cadmium and thus becomes neurotoxic.

7. Accumulation through food colour

Food additives are substances that are added to food substances to impart desired characteristics. A study was conducted to evaluate the genotoxicity caused by food colourants in which 8 different varieties of food colours were tested. The results revealed that these food colourants were reported to be toxic to human lymphocytes in vitro. Combination of colours are found to be more toxic¹².

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Arsenic is used in colouring artificial flowers, children's toys, wallpapers and also in cosmetics. Arsenate of lead is used as a fungicide and insecticide. Arsenates of sodium and potassium are used in weed killers, sprays for fruit trees¹³.

8. Effects of heavy metals on medicinal plants

The medicinal properties of plants are altered due to heavy metal toxicity in soil in different locations of the Indian subcontinent which causes health damage¹⁴.

According to analysis done of some medicinal plants in certain areas it was observed that lead was present in all plant species examined. Traces of Cadmium was also found in some other medicinal plant species. The findings generally suggest the variation in mineral levels for the various locations. Studies have indicated that the same species of medicinal plants can accumulate varying levels of heavy metals depending on the environment in which they grow¹⁵.

Heavy metals hamper the growth of the parts of plants. Heavy metals primarily impact the growth of plants by creating free radicals that lead to oxidative harm. When tomato plants are watered with contaminated water, they often exhibit physical abnormalities, such as reduced growth, limited branching, and decreased fruit production⁶.

9. Accumulation in Factory workers.

Heavy metal is widely used in industries. A study was conducted at Karachi lead Acid Battery Factory in which 50 workers were included in trial and tested for blood lead levels. It was found that total 34 workers had raised lead levels along

with other symptoms such as abdominal pain, lethargy, tremors etc¹⁶.

Many workers are susceptible to cadmium exposure during manufacturing and construction workers are most likely to come into contact with high cadmium levels. Exposure can occur during the smelting and refining of metals, battery manufacturing, plastic making and solar panel construction. Exposure to cadmium during activities like welding, painting, and machining of metals is a significant occupational health concern. If workers in arsenic factories do not use personal protection methods like gloves, masks etc arsenic toxicity occurs as this metal gets accumulated in nails and enters body through food while eating.

10. Accumulation through Pesticides

The utilization of pesticides in fruit and vegetable cultivation has enhanced both the quantity and quality of food, thereby improved nutrition and facilitating international trade. Consequently, pesticides are deemed indispensable in agriculture to meet global food requirements. However, despite their advantages, the excessive application of pesticides on fruits and vegetables to safeguard them from pest-related damage escalates the presence of pesticide residues in these food items.

In a study conducted on 160 samples of fruits and vegetables Twenty-one pesticide classes were detected in the fruit and vegetable samples. The most frequent pesticide residue detected were organophosphate, carbamates, pyrethroids¹⁷.

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Research has shown that pesticides can cause both chronic and acute toxicity in humans through various mechanisms. One such mechanism is the deregulation of transporters or enzymes that are involved in the metabolism of xenobiotics, which are foreign substances in the body²⁴. This has effects on cell processes such as growth, differentiation, and survival, including reactive oxygen species, cell damage through subsequent oxidative stress, and DNA damage. In this study it was reported that maximum quantity of pesticides was found in apples, cucumber, grapes¹⁸.

11. Accumulation through seafood

Seafood is an essential source of nutrients for people living near the coastal areas. The occurrence of metallic substances which can cause potential human health risks including heavy metals in seafood, have been widely reported. In terms of human health, the accumulation of toxic metals like Cadmium (Cd), Cobalt (Co), Chromium (Cr), Nickel (Ni), and Lead (Pb) in seafood can lead to neurological disorders, kidney impairment, issues with the circulatory system, and an elevated risk of cancer. High cadmium levels were found in oysters. Organic form of arsenic is also found in fish¹⁹.

Heavy metals in fish can originate from both natural sources, such as volcanic eruptions and weathering of rocks, and anthropogenic sources, which include industrial discharges, mining activities, and agricultural work²⁵. The presence of toxic heavy metals like lead, cadmium,

mercury, arsenic, nickel, and chromium is a major concern for seafood safety because these metals can accumulate in the tissues of fish and other aquatic organisms¹⁹. Certain aquatic animals, such as squid, cuttlefish, and octopus, have a natural tendency to bio-accumulate cadmium up to toxic levels. Similarly, predatory finfishes like Tuna, Marlin, Swordfish, Barracuda, which contribute significantly to India's fish production are associated with high mercury levels²⁶.

12. Food Adulteration²⁰

Trace amounts of metals are found in food raw material such as spices and grains due to adulteration. Examples of food adulteration are adding artificial colours to food, residues of pesticide and DDT on fruits and Vegetables. Calcium carbide is indeed used to artificially ripen fruits, and it's a practice that has raised health concerns. This process can speed up the ripening of fruits like bananas, mangoes, guavas, papayas, tomatoes, and pineapples. Calcium carbide contains toxic materials such as arsenic and phosphorus which causes blindness and skin irritation. Detection of food adulteration is an essential requirement for ensuring both the quality and safety of foods.

• The flow of heavy metals accumulation through food chain

Heavy metal accumulation through – Geogenic sources, metal processing units, fertilizers, industries etc.



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Region of accumulation - Vegetables, plants,
water, soil, seafood etc

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Humans

Table 1 Signs and Symptoms of Heavy Metal Poisoning^{21,13}

Sr.no	Metal	Sources	Signs Of Toxicity
1.	Mercury	Germicide, pesticides, cosmetics, cement, mining.	GIT disturbances, Ulceration of gums, penetrating ulcers of fingers, uraemia, tremors, loss of memory, insomnia, delusions, hallucinations.
2.	Lead	Paint industry, plumbing systems, glass manufacturing, electrical wiring production, battery manufacturing, hair dye products, toys, lead-containing vessels used for water storage, and food stored or cooked in tin containers.	Decreased platelets, constipation, delirium, insomnia, optic neuritis, hallucinations, sterility.
3.	Copper	Intrauterine devices, Dental amalgams, pesticides, birth control pills, improperly tinned copper vessels, tablets.	Nausea, dizziness, headache, vomiting, corneal ulceration, bronchitis, nephrotoxicity, dermatitis.
4.	Arsenic	Weed killers, pesticides	Loss of weight, red and soft gums, congestion of eyes, brown pigmentation on skin, brittle nails, anaemia.
5.	Phosphorus	Fireworks, rat poison	Swelling of jaw, necrosis of gums
6.	Thallium	Glass and dye industries	Hairfall, nephritis, skin rash, mental confusion.
7.	Cadmium	Toys, Ceramics, coal, nuclear and coal power plant,	Diarrhoea, Osteoporosis, vomiting, fragile bones, formation of renal stones, kidney damage, lung damage

DISCUSSION

There is a need that the scientific community, government institutions and society understand the importance of food security and make the legible efforts to for the production and supply of safe food. There is a need to identify various strategies such as encouraging farmers for organic farming, introducing techniques to minimize use of pesticides and improve the irrigation mechanisms. Soil remediation needs can differ from one area to another, thus alternative solutions should be proposed based on the specific conditions of each region. Additionally, the diminishing availability of fresh water due to rising demands, industrial

expansion, and groundwater pollution resulting from mining activities has significantly impacted agricultural productivity. Therefore, it is essential to regularly monitor pesticide residues in freshly consumed vegetables and fruits. Industries must be advised to use techniques such as pre-treatment on wastewater for heavy metal reduction by using ultrafiltration system.

CONCLUSION

When such metals accumulate in body ,over a period of time they become toxic.Treatment for such toxicity very expensive and less available.Thus preventive measures must be taken by people to avoid exposure to toxic

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substances in environment. Awareness must be created among the factory workers to use personal protection equipments such as masks, gloves, handwash etc. Precautions must be taken regarding adulteration and use of colouring agents during buying or consuming food from stores and local market. Similarly while consuming fish and other seafood the source of water body from where it is available in market should be monitored to prevent toxicity.

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