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A Comprehensive Review on Sources of Potentially Toxic Metals and Their Impact on Aquatic, Terrestrial Animals and on Humans

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Abstract: *Potentially toxic metals such as Zn, Cu, and Co are an integral part of human life as they are part of several essential enzymes and metalloenzymes, while metals Pb, Cd, Cr, Hg and metalloid arsenic are nonessential but highly toxic. The Earth's crust is the natural source of potentially toxic metals, which enter the environment through various geological and anthropogenic processes. Due to anthropogenic activities and the persistence of these metals potentially toxic metals are present in all the compartments of the environment (groundwater, surface water, potable water, seawater, soil, vegetables, fruits, crops, fish, seafood etc.). Due to industrialization, urbanization, and indiscriminate anthropogenic activities, the concentration of these toxic metals is increasing in water, soil, and food sources. World Health Organization (WHO) has classified these metals as one of the major pollutants of the 21st century. Dermal absorption and ingestion are the primary pathways for the uptake of these metals by aquatic animals (E.g., fish, and seafood), while plant uptake occurs via absorption from soil or through air/dust particles. Inhalation of air/dust particles, ingestion of contaminated water, beverages, and food and dermal uptake by skin from contaminated water are the main pathways of uptake of these toxic metals by mammals. If these toxic metals in the aquatic animal body are accumulated beyond tolerable limits it may cause growth retardation, liver lesions, kidney damage and infertility. Both the quality and quantity of crop yield are adversely affected when these toxic metals are accumulated in plants. In humans and other mammals these metals generate reactive oxygen species, inhibit enzyme activities, and cause DNA structural and functional impairments. Accumulation of these metals alters liver, kidney and lung functions. Prolonged exposure to these metals negatively impacts the central nervous system and causes neurological degenerative diseases (Alzheimer's disease, Parkinson's disease). The health impact of the potentially toxic metals on aquatic and terrestrial animals and on humans is recorded in this review.*

Keywords: potentially toxic metals, plants, aquatic animals, humans, environment

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INTRODUCTION

Worldwide, the greatest concern of the 21st century for environmental scientists and policymakers is environmental pollution and food safety. Pollutants are those substances which are present in the environment that adversely impact the health of humans and other animals, and environmental welfare. There are numerous pollutants; potentially toxic metals are one of them. Metals Cu, Zn, Co, Ni, Cr, Mn, Fe, Ba, Hg, Cd, Pb, As, Mo, and Sn which have densities >5g cm-3 and atomic weights ranging from 64 to 201 are called potentially toxic metals. Based on their biological roles the potentially toxic metals are classified as essential (iron, zinc, copper, cobalt, manganese, and nickel) and nonessential (lead, cadmium, mercury, arsenic) metals. For several cellular biological functions and numerous enzymatic activities across all living organisms, including humans, aquatic and terrestrial animals, and plants the metals iron, zinc, copper, cobalt, manganese, and nickel in addition to amino acids, vitamins, lipids, and carbohydrates are essential. Nonessential metals (lead, cadmium, mercury, chromium arsenic (metalloid) are not required even in small amounts by plants, humans and other animals for different metabolic activities. These pollutants directly or indirectly are generally used at home, in agriculture, industries, and electronic products and in medicines (Gberindyer et al., 2022). So these toxicants contaminate various environmental media i.e. air, water, soil as well as food and medicinal products. Deficiency of essential metals causes diseases, while accumulation of essential or nonessential metals beyond the permissible limit becomes toxic. Accumulation of these toxicants even in small amounts initiates organ dysfunction in humans and other terrestrial animals' (Ohiagu et al., 2022). The toxicities of metals depend on metal concentration, exposure route, age, gender, and nutritional status of humans/animals. The survey of literature denotes that in spite of government efforts in rural India about forty million people drink potentially toxic metals, arsenic, fluoride, etc. contaminated water. On exposure, these metals are accumulated via the blood circulation system in humans and animals. The toxic effect of these metals accumulation in humans or animals is due to the formation of lipophilic ions formed by covalent bonding between metals organic groups and non-metallic elements of cellular macromolecules (Balali-Mood et al., 2021). The potentially toxic metals cause DNA structural and functional impairments as these metals interact with DNA and nuclear protein, these changes lead towards the cell cycle modulation, apoptosis, and carcinogenesis (Jomova et al., 2025; Mousavi et al., 2024). Behavioural changes leading towards violence, learning and perception difficulties are reported in those children who are exposed to a low dose of potentially toxic metals for a longer period (Adolescent Health, 2021; Mahajan, 2020). The present review aims to provide the latest research studies on the impact of potentially toxic metals on aquatic animals, plants, terrestrial animals and humans. The results of this study will help policymakers and environmentalists to provide techniques to minimize the impacts of these metals.

Sources of Potentially Toxic Metals;

The potentially toxic metals enter the environment through both natural processes and anthropogenic activities.

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Natural sources:

(a) Weathering of rocks: Rocks contain potentially toxic metals in the form of hydroxides, sulfides, oxides, silicates, and phosphates. These metals can also form chelates with organic compounds. These metals from rocks enter the environment through rock weathering, corrosion of metal, and soil erosion.

(b) **Airborne sources**: Volcanic ash produced during explosive volcanic eruptions, forest fires, and wind-borne soil particles contain a high level of As, Cu, Cr, Ni, Pb, Zn and other toxic gases which enter the environment. As per estimation (Nieder and Benbi, 2022) globally approximately 25,000 Mg of arsenic/year enters the environment due to volcanic and microbial activities.

Anthropogenic activities:

Refuse of coal burning, mining, metal smelting, power plant waste, agricultural activities, industrialization, and electronic waste are some major sources of potentially toxic metals in the environment due to anthropogenic activities.

Mining: Mining waste produced during metal extraction (Au, Ag, Pt etc.), which is needed for agriculture, housing, telecommunication, music, pharmaceutical industries, and space exploration from minerals containing metals As, Cd, Cu, Zn, U, Hg, Al, Mo. Deposition of these metals outside the mining area releases these metals into the environment (Escot-Espinoza et al., 2024; Nieder and Benbi, 2022; Kierczak et al., 2021). Leng et al. (2023) during their studies found As 0.0-464; Pb 13.3-854; Cd 0.0-30.5; Cr 21.1-405; Cu 0.85-1990; Ni 0.0-225 and Zn 42.6-1700 mg/kg around the mining area in china. The survey of the literature denotes that from 70 countries only due to gold mining about 1000Mg of Hg (approximately 30% of total Hg released in the environment) is released in the environment per year out of which 400 Mg is as airborne elemental Hg (Dmuchowski et al., 2020).

Electroplating: Electroplating is the technique used on metals for corrosion protection, lubricity, abrasion and wear resistance, and aesthetic qualities. Besides other sectors, this technique is also used in defence and space sectors to protect the metal from corrosion and to protect the surface physical properties of materials (Kirichenko et al., 2020). Potentially toxic metals viz., Cr, Ni, Zn, Cd, Cu, Pb, and Hg are introduced in water, air and solid waste via electroplating industries.

Agricultural activities: Inorganic and organic fertilizers (livestock manures, composts, municipal sewage sludge), added in soils for increasing soil productivity, wastewater and sewage water used for irrigation of the agricultural field, and pesticides applied for crop protection contain potentially toxic metals (Cr, Cd, Cu, Zn, Ni, Mn, Pb, and As) as impurities. These metals enter the environment via agricultural fields.

Biomedical waste: Several medical devices, instruments, materials used in healthcare facilities, body fluids, blood, cotton, bandages, plaster casts, syringes and other sharps contain potentially toxic metals lead, mercury, cadmium, chromium, and zinc. On Incineration the biomedical waste these metals enter the environment through ash and fly ash byproducts. As incineration occurs at very high temperatures some toxic metals are also released into the air as vapors (Selman et al., 2021).

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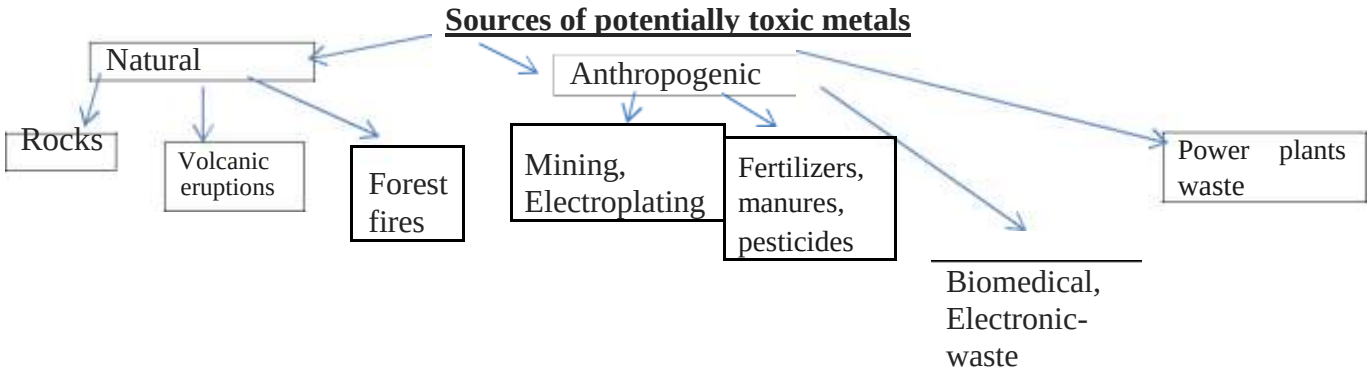
https://bjmas.org/index.php/bjmas/index

Electronic waste: In the last 20 years, the production of electronic gadgets and electrical equipment has increased manifolds worldwide causing the accumulation of e-waste. In 2022 it was estimated that global e-waste was 62 million tons which are expected to be 82 million tons by 2030 (In India the e-waste in 2023-2024 was 1.751 million tons), out of which only 22.5% is recycled (Wang et al., 2020). The e-waste produced per capita is maximum in Europe (16.2 kg; followed by America (13.3 kg), Asia; (5.6kg) and Africa (2.5 kg). Due to lower recycling costs and less stringent environmental regulations in developing countries, developed countries export a significant proportion of their electronic waste to developing nations (Forti et al., 2020). The electronic waste contains phthalates, polychlorinated biphenyls, nonylphenol, flame retardants and potentially toxic metals such as mercury (Hg), arsenic (As), cadmium (Cd), and nickel (Ni) (Yaashikaa et al., 2022; Kumar and Gupta, 2021; Alabi et al. 2021). These toxic metals from the e-waste enter the environment (soil, sediment, groundwater, and surface water) (Chakraborty et al., 2022).

Power Plants: Waste generated from fossil fuel-burning power plants contains substantial amounts of potentially toxic metals such as arsenic, cadmium, chromium, lead, mercury, nickel, and zinc. Studies have shown that these metals through atmospheric emissions, wastewater discharge, and solid waste enter into the environment ((Kravchenko et al., 2025).

Other Sources:
Smoking and chewing tobacco by humans is also one of the sources of potentially toxic metals arsenic, cadmium, lead, nickel, and chromium in the environment, human and animal body. These potentially toxic metals are also used as fillers and coolants in plastic, the most widely used substance of the 21st century worldwide. The decay and decomposition of plastic cause the entry of these toxic metals into the environment (Jiang et al., 2023; Turner and Filella, 2021).



Routes of Contamination: Entry of potentially toxic metals into animal and human bodies primarily through the gastrointestinal tract, skin, and via inhalation.

(i) **Ingestion (via gastrointestinal tract)**: Uptake of toxic metals via ingestion occurs through the consumption of contaminated plants and food (including vegetables, fruits, meat, and seafood such as fish), drinking water from polluted sources (e.g., industrial or soil runoff), and intake of contaminated beverages. In children, uptake of metals via ingestion also occurs when they consume contaminated soil. In the human body, these

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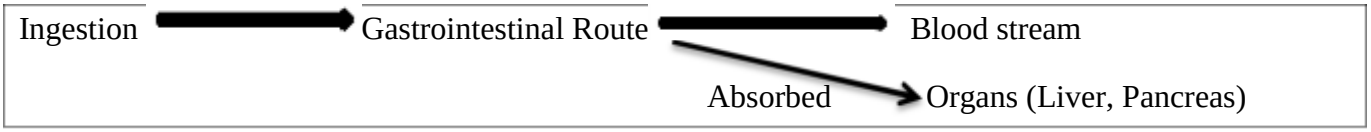
potentially toxic metals via the absorption process are accumulated in the bloodstream and different organs (mainly in the pancreas, and liver).



(ii) Skin absorption: : Some toxic metals penetrate the skin when there is a break in the skin barrier. In mammals, the bioaccumulation of these metals is mostly reported in keratin-rich tissues such as the epidermis, hair, hair follicles, and nails. Penetration via skin occurs mainly in aquatic animals, in workers who handle these toxic metals or via bathing (Nyiramigisha. et al., 2021).

(iii) **Inhalation:** Inhalation of toxic metals occurs during breathing in contaminated air or dust (in industrial areas). During inhalation nanoparticles containing toxic metals are deposited in the respiratory tract from the respiratory tract reach to lungs and bloodstream.

Inhalation → Respiratory Tract → Lungs → Absorption → Blood Stream

In humans and animals, the potentially toxic metals are primarily accumulated in bones, skin, hair, myocardial tissues, and internal parenchymal organs (liver, kidney, and pancreas).

Impact of potentially toxic metals on the plant;

Potentially toxic metals in plant systems are entered mainly via roots and leaves. The uptake and accumulation of these pollutants in plant tissues depend on soil pH, soil organic matter, humidity and metal concentration. Accumulation of these metals in plants causes morpho-physiological and anatomical changes due to the generation of reactive oxygen (Sun et al. 2023; Li et al., 2022). Accumulation of potentially toxic metals prevents plants from growing normally as these metals compete for absorption by roots with essential nutrients and in plant tissues disrupt the essential physiological processes (photosynthesis), metabolic processes (cellular structure, enzymatic activities) (Liza et al., 2020). Potentially toxic metals in plants inhibit the photosynthesis process, cause chlorosis, and necrosis, and alter water balance, nutrient deficiency, and enzymatic activities (Tang et al., 2020; Naz et al., 2022). These metals in plant cells induce more generation of reactive oxygen species which adversely impacts cellular proteins, lipids and nucleic acids. The disruption of the structure and function of proteins in plants is due to the interaction of metals with the –SH functional group of proteins. Cadmium accumulation in some plant species inhibits starch hydrolysis adversely impacting the sugar content of plants; arsenic accumulation causes discolouration and wilting of plants with retardation in plant height and leaf area (Nyiramigisha et al. 2021).

Impact of potentially toxic metals on aquatic animals:

Accumulation of the potentially toxic metals in surface water not only adversely impacts the water quality (dissolved oxygen concentrations, pH, turbidity etc.) but also disturbs the aquatic equilibrium causing bioaccumulation of these metals in aquatic organisms (Shou et al., 2022; Yu et al. 2020).

Print ISSN: 2517-276X
Online ISSN: 2517-2778
https://bjmas.org/index.php/bjmas/index

Accumulation of these metals in aquatic organisms' tissues and organs negatively impacts the animal's health (Djedjibegovic, et al., 2020) as these metals after interacting with sulfur, nitrogen, and oxygen of biological particles alter the functioning of enzymes, hormones and proteins (Shahjahan et al., 2022). These metals retard the growth of animals, damage the liver and kidney, and negatively impact the reproductive and respiratory systems and hatching rates was the findings of Jamil Emon et al. (2023); Al Mazed et al. (2022); Franco-Fuentes et al. (2021), and Mohamed et al. (2020). Accumulation of these metals induces apoptosis, autophagy, and inflammation in some fish species and seafood (Dey et al., 2024). Potentially toxic metals in aquatic animals damage DNA causing genetic problems; and adversely impact animal's immune systems (Taslima et al.2022). Enzyme function, blood parameters, behaviour, growth, improper skeletal structure and reproduction in fish are negatively impacted by bioaccumulation of copper in high amounts (Wang et al., 2020; Kawade et al., 2020); liver degeneration, hemorrhagic hepatocytes, degenerated and necrotic renal tubes, melanomacrophages, bone fractures, severe pain and malformations in aquatic animals are due to cadmium accumulation (Naz et al., 2020; Fazio et al., 2022). Bioaccumulation of chromium in fish causes renal and bronchial disorders with disruption of the gills, liver and kidney (Suchana et al., 2021; Islam et al., 2020). Bioaccumulation of arsenic and zinc in fish causes behavioural changes like restless swimming, air guzzling and haematological disorders according to the findings of Pichhode and Gaherwal, (2020). Several researchers (Jantawongsri et al., 2021; Hajirezaee et al., 2021; Zulfahmi et al., 2021) have reported that lead accumulation in aquatic animals impacts the gill and liver. They also found that in some aquatic animals' glucose and malondialdehyde levels in blood increase and growth is inversely proportional to the amount of lead accumulated.

Impact of potentially toxic metals on terrestrial animals:

Potentially toxic metals enter the terrestrial animals (cattle, wild animals) via drinking potentially metal-contaminated water, feeds, vegetables, grass or meat. These metals are accumulated in muscles, liver, and kidney. Accumulation of these metals beyond permissible limits causes reproduction problems, retarded immunity, and decreased production (Verma et al., 2023; Sethy et al. 2020). Arsenic in the animal body predominantly accumulates in the liver and is then transported to the kidneys, spleen, and lungs. Gastrointestinal, nervous, and cardiovascular problems in animals are due to the accumulation of arsenic. When arsenic accumulates in the body beyond permissible limits, it can lead to a range of toxic effects including restlessness, abdominal pain, muscle loss, anaemia, respiratory distress, vomiting, emaciation, and thickening of the phalangeal epiphyses (Gupta et al., 2021). Afzal and Mahreen, (2024) reported that arsenic accumulation also causes opaque or brittle hair and aberrant fetal development. In animals, bioaccumulation of lead beside bones, liver, and kidneys also occurs in the brain as the lead can cross the blood-brain barrier. In animals' induction of oxidative stress, neurotoxicity, liver and kidney dysfunctions, gastrointestinal damage, disruptions in enzyme systems, cramping, and diarrhoea are caused due to lead poisoning (Mukherjee et al., 2022; Cuomo et al., 2022). Slivinska et al. (2020) and Okereafo et al. (2020) during their research studies found that if the lead is bioaccumulated in cattle beyond its tolerable limit it may cause several diseases such as eyesight loss, weight loss, disruption in the immune system, depression, coma and eventually death. Accumulation of cadmium in animals damages the liver, and lung and causes hypertension, hepatic injury, and kidney dysfunction; in some animals' weight loss, in-appetence, hoof and hair abnormalities are also reported. Congenital defects abortion, anaemia, nephropathy,

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Online ISSN: 2517-2778
https://bjmas.org/index.php/bjmas/index

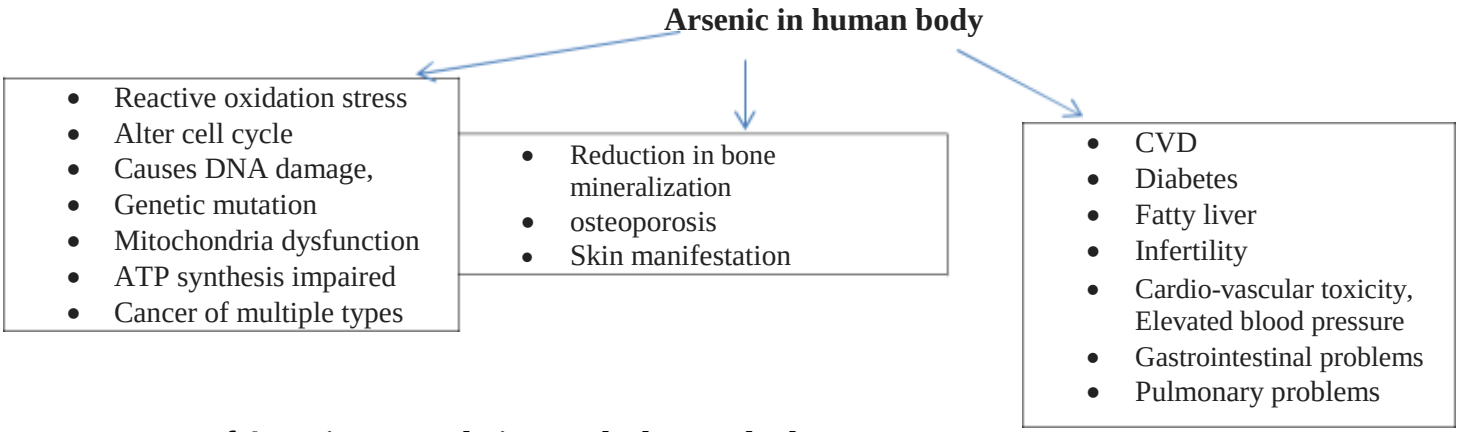
bone demineralization, and congenital are also reported in some cattle species (Tsai et al., 2022; McLaughlin et al., 2021; Oraby et al., 2021; Balali-Mood et al., 2021). Excessive salivation, dehydration, diarrhoea accompanied by gastric pain, incoordination, and anorexia is reported in animals by Quevedo et al. (2022) and Elliott et al., (2020) when the concentration of copper an essential metal in the animal body crosses the permissible limit. In cattle and buffaloes accumulation of copper also causes hemoglobinuria, reduced ruminal movements, and icteric mucus membrane. Hinde, (2021) has reported that copper accumulation also impacts estrogen receptors.

Impact of potentially toxic metals on humans:

In the human body, potentially toxic metals are bioaccumulated through the food chain (vegetables, fruits, grains, fish, and seafood, milk, and milk products), water and air. Though some metals viz., Zn, Co, Cu, Fe, Mn are essential for different catabolic mechanisms metals Pb, Cd, Hg and metalloid arsenic are not only toxic but also non-essential. Accumulations of these metals beyond their permissible limit initiate arrays of organ dysfunction (Sonoe et al., 2025; Ohiagu et al., 2022).

Arsenic Toxicity:

Arsenic a metalloid occurs in the form of As^{3+}, As^{5+} and As^{0} and is known as king of poisons and poison of kings. Arsenic accumulation in the human body activates NADPH oxidase in the plasma membrane which triggers the formation of reactive oxidative stress resulting in cardiovascular impairment (ischemic heart diseases, atherosclerosis, hypertension, and ventricular arrhythmias), hepatotoxicity, and nephrotoxicity. Reduction of arsenite (AsH_3) in the human body leads to several cancers and increased risk of a number of noncancerous effects (Doerge et al., 2020). When specific proteins interact with arsenic their function and conformation are changed altering the interaction with other functional proteins (Genchi et al., 2022; Thakur et al., 2021; Briffa et al., 2020).



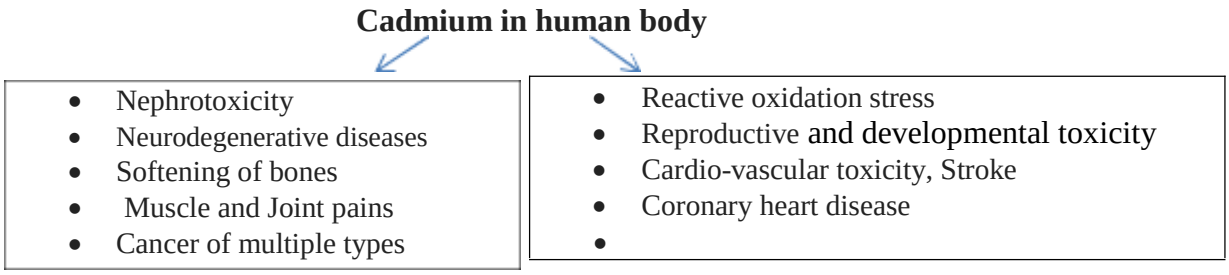
Impact of Arsenic accumulation on the human body

Cadmium toxicity:

Cadmium, a nonessential and potentially toxic metal, enters the human body primarily through the consumption of contaminated food and water, as well as through smoking and chewing tobacco. Once absorbed into the bloodstream, cadmium is transported by proteins such as albumin and

Print ISSN: 2517-276X
Online ISSN: 2517-2778
https://bjmas.org/index.php/bjmas/index

erythrocytes, and it tends to accumulate in vital organs, particularly in the liver, kidneys, and gastrointestinal tract. Within cells, cadmium disrupts DNA repair mechanisms, induces apoptosis, and elevates oxidative stress by impairing cellular differentiation and proliferation (Rasin & Sreekanth, 2023). It also causes chromosomal aberrations, including mutations and deletions. Chronic cadmium exposure contributes to skeletal demineralization by impairing collagen synthesis (Lei et al., 2024). Furthermore, prolonged exposure adversely affects calcium and vitamin D_3 metabolism, leading to decreased bone density and the onset of osteoporosis. Epidemiological studies have shown a strong association between cadmium exposure and cardiovascular diseases. Verzelloni et al. (2024) reported a significant positive correlation between cadmium levels and an increased risk of heart failure, stroke, and coronary heart disease. Additionally, cadmium is recognized for its carcinogenic potential. Sonoe et al. (2021) and Afzal & Mahreen (2024) have reported a high probability of prostate and liver cancers in humans due to cadmium exposure for a long period. Cadmium accumulation is also implicated in reproductive and developmental toxicity (Mitra et al., 2022).



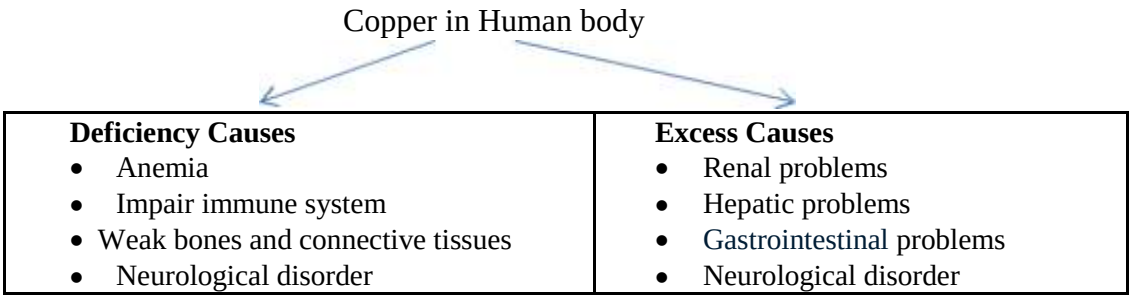
Impact of Cadmium accumulation on the human body

Copper toxicity:

Copper an essential metal for humans, plants and other animal's metabolism enters the human body via water, food and air. For cellular homeostasis in the human liver and various other organs, copper is needed in trace amounts. If the concentration of copper in the human body deviates from the prescribed limit causes health problems (Teschke, 2024). Copper in the human body causes breaks in DNA strands and DNA base oxidation due to the generation of reactive oxidation stress. Excessive accumulation of Copper causes Wilson's and Menke's disease, a genetic disorder leading to cirrhosis (Sánchez-Monteagudo et al., 2021). Excessive copper accumulation in the liver causes Jaundice and hepatic necrosis. If in the human body, there is excessive copper and iron it causes atherosclerosis and neurodegenerative diseases (Alzheimer's disorder) (Filimon, 2021; Kumar et al., 2021). Human exposure to copper for a longer period may lead to gastrointestinal symptoms such as nausea, abdominal pain, vomiting, diarrhea, and hematemesis. Ulcers and bleeding in the gastrointestinal tract may occur if the accumulation of copper is excessive. Neurological disorders like dizziness, headache, convulsions, lethargy, depression, fatigue, irritability, excitation, difficulty in focusing, and coma are also reported due to prolonged exposure to copper (Hinde, 2021; Quevedo et al., 2022). Elliott et al (2020) have reported that accumulation of copper beyond permissible limits may cause nephropathy and azotemia. They have also found a significant positive correlation between the concentration of copper accumulated and renal tissue fibrosis. Bioaccumulation of copper in the

Print ISSN: 2517-276X
Online ISSN: 2517-2778
https://bjmas.org/index.php/bjmas/index

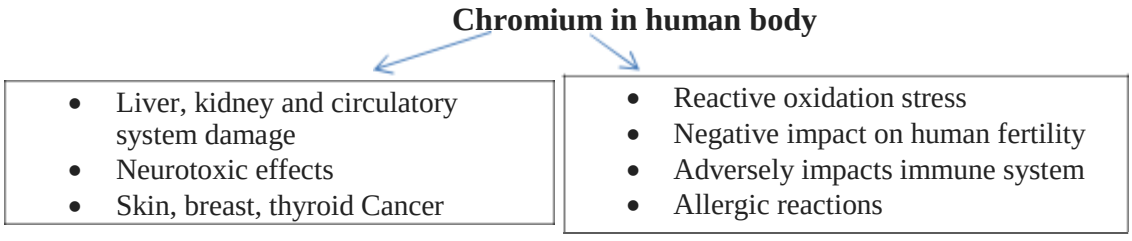
human body beyond tolerable limits may damage muscle tissues leading to muscle pain, osteoarthritis, osteoporosis and osteomalacia. Some researchers have also reported that prolonged copper accumulation can lead to infertility in humans (Lin et al., 2024).



Impact of Copper on the human body

Chromium toxicity:

The major sources of chromium in the environment are mining from the earth's crust, seawater, electroplating, textiles and tanneries. In the environment and biological systems, chromium exists as Cr^{3+} and Cr^{6+}. Accumulation of hexavalent Cr^{6+} impacts human health negatively. Studies have shown that accumulation of Cr^{6+} damages the liver and causes histopathological changes such as parenchymatous degeneration, necrosis and steatosis of hepatocytes (Chang et al., 2023; Xu et al., 2020). Xu et al. (2020) also reported that chromium accumulation elevates the reactive oxygen stress level and lipid peroxidation and suppresses protein synthesis. Cr (VI) also damage DNA and decreases the activities of antioxidant enzymes with mitochondrial dysfunction (Mitra et al., 2022). Zhang (2021) during their research studies found that accumulation of Cr adversely impacts the immune system of humans and other mammals. Zhao et al. (2022) found that the accumulation of Cr in the body is one of the reasons for obesity. Skin, breast and thyroid cancer are also impacted by the accumulation of chromium (Caini, et al. 2023; Mérida-Ortega et al. 2022; Hu et al. 2021). Accumulation of Cr (VI) in the human body decreases sperm quality and quantity by damaging the testicular, reducing pregnancy by ovarian failure prematurely (Sazakli, 2024).



Impact of Chromium accumulation on the human body

Lead toxicity;

Lead a toxic non-essential metal for humans enters the environment via mining, automobile exhaust, old toys, candy, metal plating, battery industries, lead-based paints, fertilizers and pesticides. A

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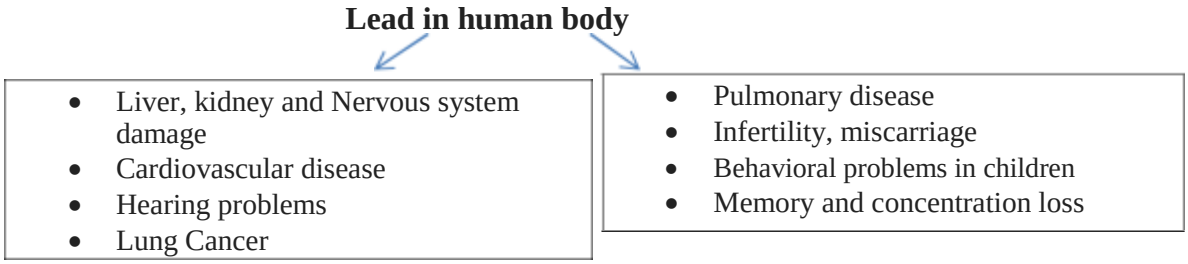
Online ISSN: 2517-2778
https://bjmas.org/index.php/bjmas/index

survey denoted that global lead exposure is one of the causes of premature death of about 900,000 adults (Olufemi et al., 2022). The half-life period of lead in blood is 30 days from where it diffuses to the brain, kidney and liver and then as lead phosphate to bones, teeth and hair. Accumulation of lead in the human body affects the kidneys most (Ishaq et al., 2021). Prolonged accumulation of lead leads to proximal tubular dysfunction, hyperplasia, renal failure, interstitial fibrosis and glomerulonephritis (Mitra et al. 2022). Lead which is considered a neurotoxin on accumulation impacts the nervous system and may cause paralysis, coma, or even death (Collin et al., 2022). Disruption of central nervous system (CNS) functions, and alteration of the ionic mechanisms of neurotransmitters are the two reported pathways of the neurotoxicity caused by lead accumulation in children (Collin et al., 2022). Mandal et al. (2022) have reported that lead accumulation affects the immune system enhances allergies, and infectious diseases and causes autoimmunity. Reproductive issues including infertility, neurological disorders, developmental delays, asthma, anaemia, and weakness are also reported due to lead accumulation (Mukherjee et al., 2022; Silivinska et al., 2020; Okerafo et al. 2020). Moore et al (2021) during their research studies found that lead accumulation in children causes metabolic diseases. Poor academic performance, behavioural problems, stomachache, and anaemia are also reported in children due to lead accumulation by Rasnick et al. (2021); and Sharma et al. (2021).



Impact of lead accumulation on the human body

Mercury toxicity;

Mercury is one of the top 10 chemicals of public health concern (WHO, 2020). Anthropogenic activities such as mining, fossil fuel combustion in power plants and residential areas, cement and steel production, oil refining, biomass burning, and waste incineration are the primary sources of mercury release into the environment (Barregar et al., 2022). In the environment, mercury is found in inorganic (Hg^{2+}) and organic (Me-Hg) forms, both the inorganic and organic forms are toxic to humans and animals (de Souza et al., 2025). Mercury causes neurotoxicity and neurodegenerative diseases such as dysfunction of the visual and tactile sensory systems, dysfunction of neural stem cells, and compromised motor coordination with neurodevelopmental abnormalities and paralysis (Bittencourt et al., 2023; Raposo et al., 2020). Renal diseases e.g. neuropathy, hydronephrosis, glomerulonephritis, and Renovascular hypertension have been reported in humans due to mercury exposure (Basu et al., 2023; Taux et al., 2022; Briffa et al., 2020). Sánchez-Alarcón et al. (2021); and Yang et al., (2020) during their research studies found that mercury accumulation causes genotoxicity i.e. may disturb the chromosomal separation, DNA damage adversely affects DNA repair process, and breakage of DNA strands with free radical production. Human exposure to mercury impacts the central nervous system and alters immune cell formation and function (Philibert et al., 2022; Branco

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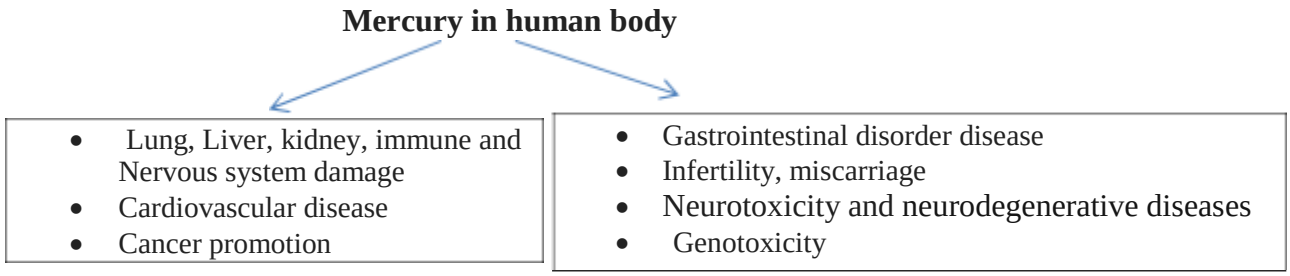
https://bjmas.org/index.php/bjmas/index

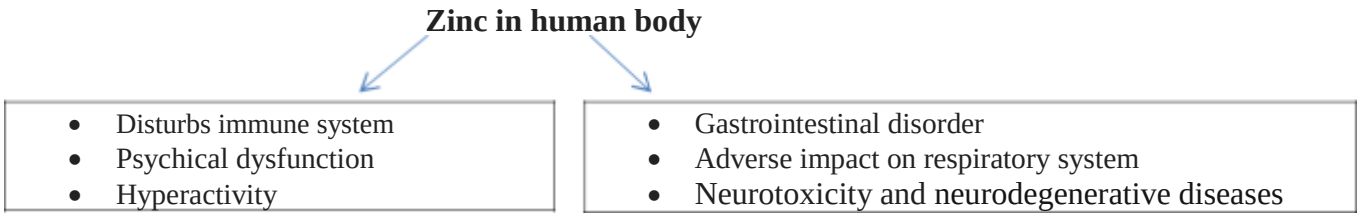
et al., 2021; Muhammad et al., 2020). Cardiotoxicity such as damage in the cardiac muscle and pumping problems are reported by Pavan et al. (2022); Guzzi et al. 2021) due to mercury exposure. Lung function is also negatively impacted by mercury (Miao et al., 2023). A review of the literature denotes that the accumulation of mercury in the human body promotes cancer (Wu et al. 2024; Zulaikhah, et al., 2020).



Impact of mercury accumulation on the human body

Zinc toxicity:

Zinc is an essential nutritional element for humans, as it forms a component of several metalloenzymes, hemoprotein enzymes, and nuclear enzymes. It plays a vital role in various structural, catalytic, and regulatory functions in the human body, including immune response; wound healing, and cell growth (Sikora and Ouagazzal, 2021; Chasapis et al. 2020). The deficiency and excess of zinc in the human body causes health problems. When there is a deficiency of zinc in adult humans it adversely impacts the immune system. Retarded growth and development is observed in children during zinc deficiency. Wessels et al. (2021) found that zinc deficiency also causes early hair loss. Zinc deficiency also retards cell growth, cell division and development (Trame et al., 2023). Deficiency of zinc also causes skin rashes, changes in the sense of taste and smell and impaired wound healing (Avan et al., 2022; Agren et al., 2021). Zinc deficiency can lead to a significant decline in testosterone levels by impairing testosterone synthesis mechanisms in the body. Accumulation of zinc beyond permissible limits causes gastrointestinal diseases such as vomiting, abdominal cramps, diarrhoea and nausea (Skalny et al., 2021; Chen et al., 2021). The excess accumulation of zinc causes neurological effects enhances the death of nerve cells and causes nerve diseases such as seizures, global ischemia, Alzheimer's disease (AD), Parkinson's disease (PD) and multiple sclerosis (MS) (Li et al., 2023; Pradhan, et al. 2023; Medvedeva et al., 2022): Castro et al., 2022). In the human body if zinc concentration is very high it retards the absorption of copper and iron decreases leading to their deficiency.



CONCLUSION

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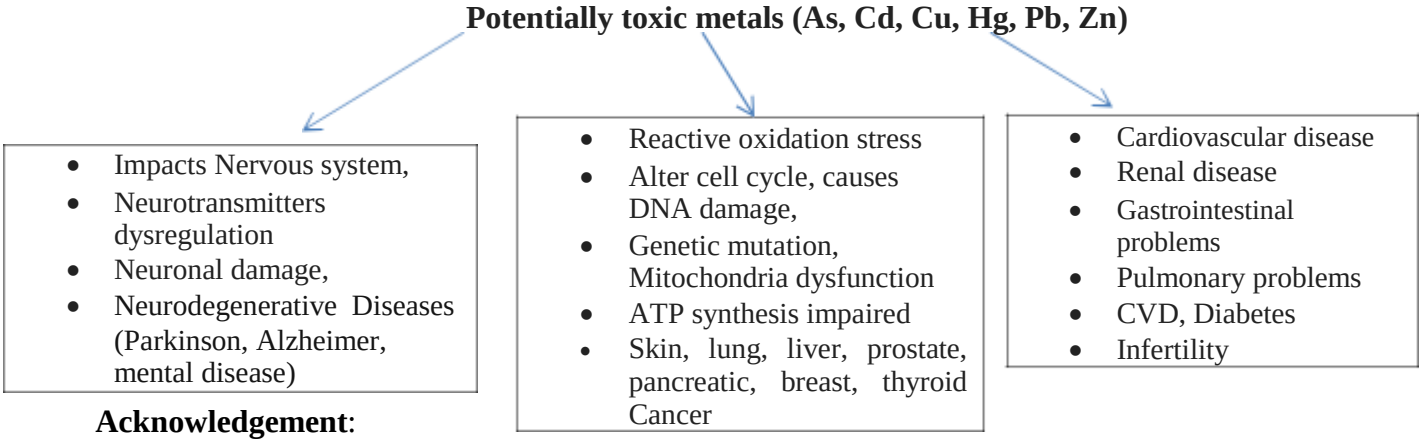
Metals such as Zn, Co, and Cu are essential nutrients for plants, animals and humans as they maintain a number of biochemical and physiological functions in the body. However, when the concentration of these potentially toxic metals in the plants, animal or human body crosses the physiological tolerance limits becomes toxic. One of the major challenges to scientists and environmentalists today is to minimize the negative impacts of these toxic metals on crop produce, human health livestock health and productivity. Contaminated water and food are the primary sources of accumulation of these metals in aquatic organisms. The accumulation of these metals in fruits, vegetables, fodder and crops occurs due to the absorption of these metals by plants from the contaminated soil and contaminated water used for irrigation. Bioaccumulation of these metals in livestock and humans occurs through the consumption of contaminated food and water and via exposure to polluted air. In the human or animal body, these metals disrupt the redox potential by inducing oxidative stress. Livestock are exposed to these toxic metals through contaminated feed, fodder, forage and water mainly due to anthropogenic environmental pollution. Additionally, some geographic regions naturally contain soil and water with elevated concentrations of potentially toxic metals, posing a natural source of poisoning in animals. Once consumed, heavy metals persist in the body for extended periods, and depending on the exposure level they can cause acute or chronic toxicity, and the symptoms may range from clinical or subclinical or even subtle manifestations. The health risks and extent of physiological damage from potentially toxic metals exposure are influenced by the route of exposure, duration, dose, and the age of the exposed species. Literature reports indicate that these toxic metals adversely impact the human nervous system, and cause neuronal damage and neurodegenerative and cardiovascular diseases. Furthermore, damage to organs liver, kidney, and lungs has been documented. Cancers of the prostate, lung, skin, liver, and pancreatic are also linked with exposure to these metals.



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