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Health Effects of Heavy Metal Contamination in Drinking Water

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Systematic Review Article

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ABSTRACT

Water is essential for life, be it the life of animals, plants or human beings. It's our prime duty to protect, manage and preserve the quality of water. Uncontrolled anthropogenic activities have resulted in contamination of fresh water resources thereby affecting the health of living beings. Rampant industrialization is a major environmental problem on the global scale for the pollution of fresh water with toxic effluents containing heavy metals. Contamination of surface water by heavy metals is the greatest quality issues because of their toxic nature, increased release and negative impact on the health of human beings. Water-borne diseases remain one of the major health concerns in the world. Heavy metals are individual metals and metal compounds that can impact human health. Exposure of humans to metals such as antimony, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, tin, zinc, etc results in chronic and acute toxicities. The toxicity of heavy metals depends on their concentration, period of exposure and route of exposure. Humans are exposed to heavy metals either by inhalation from the atmosphere, intake through drinking water, or by ingestion through the skin by dermal contact. The present review describes the analysis of 'heavy metal contamination in drinking water' with reference to definition, sources, health effects on humans and preventive measures. This study suggests that, the best way to get rid of heavy metal contamination in drinking water is to

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remove toxic heavy metals by using the best water purification system. Also, the ground water resources must be monitored for quality assessment, source identification and bioremediation of heavy metals.

Keywords: Health; heavy metals; pollution; drinking water; bioaccumulation; toxicity.

1. INTRODUCTION

"Water is the basis of life and plays a significant role in human development and survival" [1]. "Safe drinking water brings about healthy bodies, food security, poverty reduction and extended development of a population both socially and economically" [2]. "Water can be polluted generally by either contamination and/or degradation of water quality" [3]. "Contamination occurs due to domestic and public wastes, industrial waste, and mining activities; whereas degradation results due to the development, use and reuse of water sources and rock-water interaction" [4].

"The overload of aquifers with pollutants derived from agriculture, industry, waste and industrial waters, domestic and industrial landfills, infiltration of pollutants from the surface and from intrusion of saline water affect the groundwater quality. Poor water quality and sanitation is a major health concern in the world and cause many waterborne diseases. Outbreaks of endemic and epidemic diseases in both developed and developing countries lead to loss of life and economic costs to individuals and communities" [5,6].

Gautam et al [7] noted that, ''heavy metal (HM)'' refers to any metal and metalloid element that has a relatively high density ranging from 3.5 to 7 g cm^{-3} and is toxic or poisonous at low concentrations. They were also described as, metals with atomic weight greater than iron. Heavy metals include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), thallium (Tl), and zinc (Zn). They are found widely in the earth's crust, non-biodegradable in nature and are also known as 'trace elements' [8]. "HM is necessary to maintain body metabolism but toxic to the body when they are present in higher concentrations" [9]. "Humans are exposed to these metals by ingestion (drinking or eating), inhalation (breathing), and ingestion through the skin by dermal contact" [10,11].

"HM have high density and also the biological importance in trace amounts. Metals such as Chromium III, Cobalt, Copper, Iron, Manganese, Molybdenum, Selenium, and Zinc are nutritionally essential metals in small quantities but are toxic in higher quantities" [12,13]. "The biological importance of HM includes enzyme functioning (vanadium and manganese), hormone functioning, production (selenium), cellular growth (nickel), and metabolic growth (arsenic). Metals such as lead, cadmium and, mercury are poisonous even in small quantities. The toxicity of heavy metals depends on concentration, period of exposure and route of exposure" [9].

"HM have a high atomic weight and a density at least 5 times greater than that of water" [14]. "They are of two types, essential and non-essential. Essential HM are less toxic at low concentrations and act as coenzymes in biological processes (for example: Cu, Co, Fe, Zn). Non-essential HM is highly toxic even at very low concentrations, non -biodegradable and cause severe toxic effects to living organisms (example: As, Cd, Cr, Hg, Pb)" [15].

"HM is released into water bodies through sediment re-suspension, desorption, reduction or oxidation reactions, and the degradation of organic tissues" [16]. "They are ubiquitous materials and prevalent contaminants in polluted environments, and their properties such as chemical stability, bioaccumulation, non-degradable nature, and long-lasting negative impacts have piqued public interest" [17]. "The increased concentration of dissolved metals in water may threaten the aquatic ecosystem and human health" [18].

"HM like cobalt, copper, iron, manganese, molybdenum, and zinc are essential in the human body but are toxic at high concentrations. Other metals like lead, mercury and plutonium are toxic even in low concentrations" [2]. "They are added into the water bodies through urban runoff, agricultural and industrial effluents, sewage discharge, mining and natural phenomena such as the seepage of underground minerals and soil erosion" [19]. "Surface water pollution by trace elements is one of the greatest quality issues because of their

toxic nature, increased release and negative impact on human beings" [20].

"Increased anthropogenic activities result in contamination of water resources" [21]. "Water gets polluted with HM and metalloids through release from the mine tailings, disposal of high metal wastes, growing industrial areas, leaded gasoline and paints, usage of fertilizers inland, animal manures, e-waste, sewage sludge, pesticides, wastewater irrigation, coal, etc. Exposure of humans to HM has been linked to chronic and acute toxicity with the manifestation of various symptoms" [22].

Beyene and Berhe [23] reported that, "metal pollution affects the quality of water bodies and threatens the health and life of animals and human beings". "Further, in many parts of the world, HM concentrations in drinking water are higher than international guideline values" [24]. "High concentrations of aluminium, antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc in water makes it not potable and cause an adverse effect on human health" [10,25].

Balali-Mood et al [26] reported that, "human exposure to HM leads to acute or chronic poisonings due to bioaccumulation with toxic effects on a variety of body tissues and organs" [27]. "HM disrupts cellular mechanisms such as growth, proliferation, differentiation, damage-repairing processes, and apoptosis" [28]. "Toxicity of HM causes ROS generation, weakening of the antioxidant defense, enzyme inactivation, and oxidative stress" [29]. "Other toxic effects of HM on different body organs include: gastrointestinal and kidney dysfunction, nervous system disorders, skin lesions, vascular damage, immune system dysfunction, birth defects, and cancer" [30].

Tchounwou et al. [14] stated that, "the use of HM in industrial, domestic, agricultural, medical and technological applications has potential effects on human health". "Toxicity of HM depends on factors such as the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals. HM pose a significant danger to living organisms, humans, and environments because of their severe toxicity, and strong accumulation ability" [31].

According to Alidadi et al. [32], "safely managed water sources can still be polluted by toxic elements due to the poor domestic treatment system, use of chemical materials in the water treatment system, pipeline corrosion, leaching of elements from pipes of water distribution, and use of improper storage containers and poorly maintained filtration for drinking water at home" [33,34]. "Drinking water containing HM above the maximum permissible limits causes potential risks to human health and the environment" [35]. "Long-term exposure to HM in drinking water, such as arsenic, cadmium, and chromium, has consistently been linked to various cancers like skin, lung, and kidney cancer" [36]. This review provides an analysis of 'heavy metal contamination in drinking water' with reference to definition, sources, health effects on humans and preventive measures.

1.1 Structure the Review Paper

Table 1. Structure of the review paper

Section	Details
I	❖ Introduction, Definition & Structure of the review paper
II	❖ Literature Search Methods
III	❖ Sources of heavy metal contamination in surface water • Agriculture source, Anthropogenic sources, Atmospheric source • Domestic sewage, Heavy metal intake through water • Industrial source, Mining source • Natural sources, Urbanization
IV	❖ Effects of heavy metal contamination in drinking water on human
V	❖ Preventive measures of heavy metal contamination in drinking water

2. METHODOLOGY

This review summarises and analyses primary information created and provided by other academic and professional researchers who studied heavy metal contamination in drinking water and its effects on human health. A literature review was conducted using search terms such as, heavy metals, sources, drinking water, and health hazards on humans in relevant studies on EMBASE, Google Scholar, Medline, NCBI, PubMed, Science Direct, Scopus, and Web of Science databases. This review paper analysed a total of 42 research articles published in reputed journals.

3. SOURCES OF HEAVY METAL CONTAMINATION IN SURFACE WATER

Rajasekaran and Abinaya [37] noted that "the main sources of heavy metal pollution in surface water include electroplating, painting and surface treatment industries". "Toxic metals are dispersed in the environment through industrial effluents, organic wastes, refuse burning, and transport and power generation. Hazardous metals reported in industrial effluents are arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc" [38].

Kumar et al. [39] reported that, HM contamination of water resources results mainly from industrial zones, mine exit, aluminium wastes, lead-based fuel, and coatings, agricultural use of fertilizers, sewage sludge, chemical fertilizers, irrigation with wastewater, rock, and electronic wastes. "In surface water of the Sosian river, Eldoret town, Uasin-Gishu County Kenya, contamination of lead occurs by point and diffuse sources from industries and urban associated activities like car washes, garages, scrap metal dealers, electronics and battery recyclers, along with pollution from town effluents and vehicle emission" [2].

Sonone et al. [8] and Singh et al. [22] stated that sources of heavy metal contamination in surface water are either natural (volcanic eruptions, weathering of metal-containing rocks, sea-salt sprays, forest fires, and natural weathering processes), or anthropogenic (agriculture activities, biomedical waste, electronic waste, electroplating, industrial effluents, mining, power plants, etc) (Table 2 and Table 3).

Table 2. Sources of heavy metal contamination in surface water

Types of source	Details of contamination	Reference
Agriculture source	Fertilizers and pesticides, eutrophication of fresh water bodies. Leaching of metals in soil and water.	Tchounwou et al. [14]
Anthropogenic sources	Industrialization, urbanization, agriculture, human activities, domestic sewage, solid waste burning, coal and oil combustions, pyro-metallurgical processes and mining.	Gautam et al. [7]
Atmospheric source	Small pollutants particles from the air. Sulphuric acid, sulphur dioxide, petroleum products, and nitrogen dioxide.	Zhang et al. [34]
Biomedical waste	Release of heavy metals and polycyclic aromatic hydrocarbons (PAHs).	Vetrimurugan et al. [35]
Domestic sewage	Untreated domestic sewage with toxins, nitrogen, phosphorous, nitrite and nitrate.	Sankhla et al. [19]
Electronic waste/ E-waste	Release toxic chemicals with heavy metals (Pb, Cd, Hg, As, Ni), and also persistent organic compounds (Brominated flame retardants (BFRs) and phthalates). Polychlorinated biphenyls (PCBs), nonylphenol (NP), and triphenyl phosphate (TPPs).	Waleed and Mohammed [31]
Electroplating	Discharges toxic materials through water containing high amounts of heavy metals such as nickel, iron, lead, zinc, chromium, cadmium and copper.	Vhahangwele et al. [40]
Heavy metal intake through water	Mined ores during manual dressing. Accumulation of toxic HM in tissues of plants, animals and human due to drinking water contaminated with HM.	Singh et al. [22]

Types of source	Details of contamination	Reference
Industrial source	Residue and effluent from the industries, water tank leakages, dumping beside marines, radioactive waste and atmospheric deposition. Discharge of manufacturing effluents without treatment inside the water bodies.	Muhammad et al. [17]
Mining source	Leaching of HM through mining sources. Mobilization of HM by acid mine drainage.	Mudgal et al. [6]
Natural sources	Volcanic eruptions, weathering of sedimentary rocks, leaching into rivers, lakes, and oceans.	Singh et al. [22]
Power plants	Release of toxic heavy metals: arsenic, selenium, lead, mercury, boron, and cadmium.	Abdel-Rahman [10]
Urbanization	Overpopulation and unhealthy conditions. Release of solid waste, liquid waste, plastic waste, and human excreta without any treatment.	Sonone et al. [8]

Table 3. Common sources of heavy metal ions in surface water

Heavy metal ions	Common sources of surface water contamination	Reference
Arsenic (As)	Arsenic-based preservatives, pesticides, fertilizers, untreated effluents, mining, oxidation of pyrite (FeS), and arsenopyrite (FeAsS)	Mudgal et al. [6]
Cadmium (Cd)	Phosphate fertilizers and the waste incineration process. Paints, pigments, electroplated parts, batteries, plastics, synthetic rubber, photographic and engraving process, photoconductors, and photovoltaic cells, pesticides.	Abdel-Rahman [10]
Chromium (Cr)	Leather industry, tanning, and chrome plating industries. Steel fabrication, electroplating, Textile.	Narjala [9]
Copper (Cu)	Copper polishing, Plating, Printing, Fertilizers, tanning, and photovoltaic cells.	Zhang et al. [34]
Iron (Fe)	High intake of iron supplements & oral consumption.	Sonone et al. [8]
Lead (Pb)	Old and new usage of lead products. Processing of gold ore. Recycling of used lead products. PVC pipes in sanitation, agriculture, recycled PVC lead paints, jewellery, lead batteries, lunch boxes, etc.	Kannan et al. [13]
Mercury (Hg)	Volcanic emissions, forest fires, and burning of fossil fuels in power plants. Combustion of coal, municipal solid waste incineration, fish, mining, paint industry, paper industry. Thermometers, barometers, and blood pressure monitors.	Vhahangwele et al. [40], Kumar et al. [39]
Silver (Ag)	Refining of copper, gold, nickel, zinc, jewellery, and electroplating industries	Tchounwou et al. [14]
Zinc (Zn)	Brass manufacturing, Oil Refining, Plumbing, Soldering, cosmetics, and pigments.	Singh et al. [22]

4. EFFECTS OF HEAVY METAL CONTAMINATION IN DRINKING WATER ON HUMAN

Munene et al. [2] stated that though HM is essential in the human body but are toxic at high concentrations; whereas lead, mercury, and plutonium are toxic even in low concentrations. Exposure to HM metals is followed by bioaccumulation in the soft tissues of the human body and results in interference with blood cell growth, liver and kidney damage, problems with the circulatory system, and transmission of nerve impulses [11,38].

According to Mawari et al. [18] in industrialized city of Solapur, Maharashtra, India, people drinking water contaminated with HM suffer from frequent loose stools, gastric discomfort, and frequent abdominal pain. Exposure to excessive levels of HM can result in anaemia, immunotoxicity, developmental toxicity, anorexia, vomiting, diarrhoea, nerve damage, reduction in sperm count and volume [2].

Narjala [9] recorded that, exposure to higher concentration of HM leads to severe damage to the cellular system and nonessential heavy metals are major cancer- causing agents. Drinking water contaminated with HM results in an increase in illnesses, skin disorders, cancer, harmful to lactating mothers, fetuses and children, and even deaths [41]. A detailed account of the hazardous effects of drinking water contaminated with heavy metals on human health is presented in Table 4.

Table 4. Human health effects of water contaminated with heavy metals

Heavy metal	Human health effects	Reference
Antimony (Sb)	• Increase in blood cholesterol. • Decrease of glucose levels.	Achparaki et al. [41]
Arsenic (As)	• Nausea, vomiting, loose stools, gastric discomfort, and abdominal pain. • Decreased production of RBC and WBC, and abnormal heart rhythm. • Damage to blood vessels, and sensation of “pins and needles” in hands and feet. • Darkening of the skin. • Appearance of small “corns” or “warts” on the palms, soles, and torso.	Gautam et al. [7], Martin and Griswold [11], Sonone et al. [8], Mawari et al. [18]
Barium (Ba)	• Vomiting, abdominal cramps, diarrhoea, difficulties in breathing, numbness around the face, and muscle weakness. • High blood pressure, changes in heart rhythm or paralysis and possibly death.	Martin and Griswold [11]
Cadmium (Cd)	• Known human carcinogens. • Severe damage to the lungs. • Irritates the stomach: vomiting and diarrhoea. • Kidney disease, lung damage, fragile bones. • Prostate cancer	Martin and Griswold [11], Narjala [9]
Chromium (Cr-VI)	• Known human carcinogens. • Irritation to the lining of the nose; nose ulcers; runny nose; and breathing problems: asthma, cough, shortness of breath, or wheezing. • Skin ulcers, redness and swelling of the skin. • Damage to liver, kidney, circulatory and nerve tissues. Dermatitis and perforation of the skin.	Martin and Griswold [11], Narjala [9], Kumar et al. [39]
Cobalt (Co)	• Haematological, cardiovascular and hepatic. • Endocrine.	Narjala [9]
Copper (Cu)	• Abdominal disorders. • Metabolic activity abnormalities. • Gastrointestinal distress. • Liver or kidney damage.	Achparaki et al. [41], Narjala [9]
Iron (Fe)	• Vomiting, diarrhoea, abdominal pain. • Dehydration & lethargy. • Brain damage, reduction of mental processes.	Fernandez-Luqueno et al. [24], Narjala [9]
Lead (Pb)	• Headache, irritability, stomach discomfort and nerve damage. • Abrupt psychosis, disorientation, and loss of consciousness. • Cognitive impairment: Memory loss, slower reflexes, and worse comprehension. • Lowers IQ in children.	Mahurpawar [38], Martin and Griswold [11], Sonone et al. [8], Kannan et al. [13],

Heavy metal	Human health effects	Reference
	• Miscarriage in pregnant women. • Damage the testis and reduce sperm production. • Encephalopathy, peripheral neuropathy, central nervous disorders, and anemia.	Kumar et al. [39]
Manganese (Mn)	• Central and Peripheral Neuropathies	Mahurpawar [38]
Mercury (Hg)	• Irritability, shyness, tremors, changes in vision or hearing, and memory problems. • Lung damage, nausea, vomiting, diarrhoea, increases in blood pressure, skin rashes, and eye irritation. • Permanently damage the brain, kidneys, and developing foetuses. • Sclerosis, blindness, deafness, gastric problems, and renal disorders.	Martin and Griswold [11], Narjala [9], Sonone et al. [8]
Nickel (Ni)	• Cutaneous irritation, dermal toxicity, eczema. • Cancer, Dramatis.	Mahurpawar [38]
Selenium (Se)	• Nausea, vomiting, and diarrhoea. • Selenosis: Hair loss, nail brittleness, and neurological abnormalities. • Respiratory tract irritation, bronchitis, difficulty breathing, stomach pains, and coughing.	Fernandez-Luqueno et al. [24], Martin and Griswold [11]
Silver (Ag)	• Arygria: A blue-gray discoloration of the skin and other body tissues. • Breathing problems, lung and throat irritation, and stomach pains. • Mild allergic reactions: Skin rash, swelling, and inflammation in some people.	Achparaki et al. [41], Kent Ro Systems [42], Martin and Griswold [11]
Tin (Sn)	• Central Nervous System disorders. • Visual defects, EEG changes, and pneumoconiosis.	Mahurpawar [38]
Zinc (Zn)	• Gastrointestinal disorders. • Kidney & Liver abnormal functioning	Narjala [9]

5. PREVENTIVE MEASURES OF HEAVY METAL CONTAMINATION IN DRINKING WATER

Kent Ro Systems [42] reported that, the best way to get rid of heavy metal contamination in drinking water is to remove toxic heavy metals by using the best water purification system. The ground water resources must be monitored for quality assessment, source identification and bioremediation. It is necessary for all concerned to adopt sustainable utilization of the available water resources [37].

Munene et al. [2] noted that, water from the waste water treatment before being released to the river is treated through adsorption or ion treatment to reduce the amount of heavy metal in the river water. To ensure the public health and safety, integrated strategies for the prevention of pollution, effective waste management, and public awareness should be practiced. Collaborative efforts between policymakers, scientists, and health professionals are crucial to minimize heavy metal contamination and safeguard human health.

6. CONCLUSION

Results of this study indicate that the human population working in or living near an industrial site which utilizes the heavy metals and their compounds increases the risk of exposure and subsequent health hazards. It is recommended that regular monitoring of drinking water should be enforced around the industrial hub as metal accumulation can be toxic to consumers when they are present in excess, and if found elevated appropriate action to reduce exposure should be taken. Further, future research should be conducted on ways to minimize the discharge of heavy metals into the environment and to protect the ecosystem from their hazardous effects.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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