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ORIGINAL RESEARCH PAPER

Zoology

CRITICAL REVIEW OF HEAVY METAL POLLUTION IN WATER AND ITS ADVERSE HEALTH IMPLICATIONS

KEY WORDS: Heavy metals, Cancer, Diabetes mellitus, Bioaccumulation, Pollution, Water.

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ABSTRACT

Water is vital to Earth's ecosystems and essential for all living beings. However, heavy metal contamination in water sources is rising, posing serious health risks. Despite technological advancements, heavy metal levels in drinking water often exceed safe limits set by regulatory bodies like WHO, BIS, and EPA. Contaminants such as arsenic, cadmium, nickel, mercury, chromium, zinc, and lead bioaccumulate in the human body, increasing the risk of cancer, diabetes, and cardiovascular diseases. Pollution from domestic, agricultural, and industrial waste further degrades water quality. This review highlights the impact of heavy metal pollution and emphasizes the need for awareness and mitigation.

INTRODUCTION

Pollution disrupts the environment by contaminating soil, food, and water, posing risks to living organisms and ecosystems. Tavakoli-Hosseinabady et al. (2018) state that water pollution by heavy metals, arising from both natural and human sources, is a significant environmental issue with severe health consequences. These dense metals, such as lead, iron, mercury, cadmium, zinc, arsenic, copper, and chromium, frequently surpass the safe concentration limit of 6 g/m^3. According to Singh et al., 2010, Heavy metals are naturally occurring elements that, at high concentrations, pose serious risks to human health and the environment due to their toxicity, persistence, and bioaccumulation. Rai (2009) and Alloway (2013) explored major sources of heavy metal pollution in water including industrial activities, mining, agricultural runoff, and urbanization. Fossil fuel combustion, smelting, municipal waste, fertilizers, pesticides, and sewage discharge are key contributors. Once released into aquatic ecosystems, heavy metals contaminate water, accumulate in sediments, and enter the food chain, exposing humans through ingestion, inhalation, and skin absorption. Shankhla et al. (2016) reported that chronic exposure to metals like lead, cadmium, mercury, arsenic, and chromium has been linked to neurological disorders, renal dysfunction, cardiovascular diseases, developmental issues, and cancer. According to Jarup (2003) vulnerable groups, including children, pregnant women, and communities near industrial sites, face heightened risks. Tang et al. (2019) mitigating heavy metal pollution requires a multidisciplinary approach, including scientific research, environmental monitoring, policy enforcement, and public awareness. Strategies include pollution prevention, remediation technologies, regulatory measures, and sustainable industrial and agricultural practices. Education and outreach initiatives are essential to empower communities to protect their health and environment. This review synthesizes current research on heavy metal pollution in water, highlighting its health impacts and identifying knowledge gaps to support efforts in mitigating its effects. Below is Table 1. Showing the permission limits for heavy metals which WHO (2017) gives.

Table 1. Permissible Limits For Toxic Metals In Water (WHO, 2017)

Heavy Metals	WHO Permissible Limits
Arsenic	0.01(mg/L)
Cadmium	0.05(mg/L)
Chromium	0.003 (mg/L)
Copper	0.02(mg/L)
Iron	0.30 (mg/L)
Lead	0.01 (mg/L)
Mercury	0.001 (mg/L)
Manganese	0.05 (mg/L)
Nickel	0.02 (mg/L)
Zinc	5.0 (mg/L)

Sources of contamination in water

Heavy metals enter water naturally through rock weathering, volcanic eruptions, wildfires, rain, dust deposition, and water interactions with rocks and soil (Gupta et al. (2013); Sheykhi and Moore, 2016). Human activities, including urbanization and industrial growth, further accelerate heavy metal contamination. (Table 2.)

Table 2. Major Sources Of Heavy Metal Contamination In Water

Heavy metals	Sources
Arsenic (As)	Pesticides, fungicides, mining, and coal burning
Cadmium (Cd)	Coal and mineral fertilizers, nuclear fission plants, welding, batteries, electroplating, pesticides
Chromium (Cr)	Tannery industries, textiles, electroplating, mining
Copper (Cu)	Pollution from industrial activities, household sewage, and the erosion of rocks containing copper.
Lead (Pb)	Ores and metal processing, automobile emission, paint industries, mining, burning of coal
Mercury (Hg)	Atmospheric deposition, direct discharge of industrial waste, paint, pesticides
Zinc (Zn)	Soldering, cosmetics, and pigments

MATERIALS AND METHODS

Research on heavy metal contamination in Indian water sources was reviewed using Google Scholar, Science Direct, and PubMed. Studies employed established methodologies to measure cadmium, chromium, copper, mercury, arsenic, lead, nickel, iron, manganese, and zinc levels across various regions. The results were compared against WHO and other regulatory standards, documenting any deviations. This study compiles existing research on heavy metal pollution in water sources.

REVIEW OF LITERATURE

Akcay et al. (2003) studied particulate trace metals in Turkey's Gediz and Buyak Menderes (BM) rivers, finding high levels of Pb, Cr, Mn, and Zn in Gediz and Co, Mn, and Zn in BM.

Comparisons with historical data suggest pollution stems from industrial, agricultural, and domestic waste. Midrar-ul-Haq (2005) analyzed eight groundwater samples from NWFP and eight surface water samples from Karachi, Pakistan, for trace metal contamination (Cu, Cr, Cd, Mn, Ni, Zn). Comparing results with USEPA and WHO standards, the study found elevated levels, particularly in contaminated waters. Tariq et al. (2006) investigated industrial waste from factories in Peshawar, Pakistan, assessing its impact on groundwater. Tests revealed high BOD in wastewater, depleting oxygen levels, while some well water samples exceeded safe limits for Mn, Ni, and Pb. The study suggested factories may be polluting groundwater and recommended proper treatment plants and awareness campaigns. Kar et al. (2008) analyzed surface water from the Ganga River in West Bengal, detecting iron, manganese, zinc, nickel, chromium, and lead. Metal concentrations varied by location, with iron, zinc, and copper highest at Palta, while manganese and nickel peaked at Berhampore. In the next year, Ullah et al. (2009) examined heavy metal contamination in water from 25 locations in Sialkot, Pakistan. Compared to WHO and national standards, water quality was poor, with Zone 1 showing high turbidity, minerals, and metals like Zn, Pb, and Fe. Carcinogenic chromium-VI was also detected, highlighting the need for targeted water treatment. Ahmad et al. (2010) measured heavy metals in the Buriganga River, Bangladesh, across different seasons and locations. They found significant variations in metal concentrations, with some exceeding recommended limits. The study concluded that the river is contaminated with heavy metals such as Cd, Cr, and Ni, which could pose risks to water, sediment, and fish safety. In the next year, Kaur and Mehra (2012) monitored heavy metals in the Yamuna River, Delhi, during summer and winter, finding lead, cadmium, copper, zinc, and cobalt within safety limits. Elevated levels of iron, nickel, and manganese at specific locations were linked to industrial discharges and seasonal temperature variations, highlighting potential industrial pollution. Singare et al. (2013) collected water samples from the Bhavan's College campus lake in Andheri, Mumbai, and found high levels of toxic metals like lead, zinc, chromium, and iron, exceeding safety standards for inland waters. Nickel levels were near the limit. The results highlighted the need for better treatment of sewage and laboratory waste discharged into the lake.

Chandrashekar et al. (2014) reported significant arsenic contamination in groundwater in Thoubal and Bishanpur districts, Manipur, with over 45% of samples exceeding WHO limits, some up to 50 times higher. Mahar et al. (2015) found arsenic levels exceeding WHO limits in over a third of groundwater samples from Rahim Yar Khan, Southern Punjab, Pakistan. Other metals and minerals also surpassed acceptable levels, with higher arsenic concentrations observed near rivers compared to canals or deserts. Ali et al. (2016) found significant heavy metal contamination in the Karnaphuli River, Bangladesh, with As, Cd, and Pb exceeding safe limits for drinking and threatening the river ecology. Elumalai et al. (2017) found that heavy metal contamination in groundwater in Richards Bay and Empangeni, South Africa, likely stemmed from industries, mining, and fertilizer use. Despite an overall good water quality index, lead, copper, and other metals posed a high health risk, making the water unsafe for drinking. Ropar wetland, a vital ecosystem in Punjab (India) faced a serious threat from heavy metal contamination, especially in Cd and Cr . Sharma et al. (2019) found high levels of Cr and Cd in groundwater at Ropar wetland, exceeding safety limits and posing a risk of non-cancerous health issues, particularly for children in winter. The contamination was likely due to monsoon leaching, presenting a potential danger. Kumar and Singh (2020) found that groundwater from the Indus River basin showed arsenic levels exceeding WHO limits in about a quarter of samples, with higher concentrations near the Ravi River, along with elevated Fe, Zn, and Cd levels. This posed a higher health risk for arsenic exposure, particularly to children and adults, highlighting the need for widespread well-testing. Krishan et al. (2021) tested water samples from Punjab, finding most metals within acceptable levels, though some groundwater exceeded arsenic and iron limits, with high iron concentrations in specific areas. Dinakaran et al. (2021) assessed groundwater quality in India's National Capital Region, discovering high levels of zinc, nickel, chromium, lead, and arsenic, with only Uttam Nagar showing acceptable levels, indicating contamination unfit for drinking and posing health risks. Reddy and Sunitha (2022) analyzed groundwater samples from around inactive mines in the Southwest Cuddapah basin, revealing contamination from old mine reservoirs with high levels of arsenic, cadmium, nickel, lead, and strontium exceeding safety limits. They indicated ecological risks and concluded that long-term exposure to this contaminated water could negatively affect both adult's and children's health. According to a recent study, Kaur et al. (2023) studied heavy metal contamination in wastewater drains flowing into the Ghaggar River in Punjab, India, finding high levels of lead, iron, and aluminium exceeding safety limits. The pollution indexes indicated severe contamination, with a high risk of cancer and other health issues for nearby residents. Dogra et al. (2023) examined groundwater in the Ranbir Singh Pura tehsil of Jammu and Kashmir, an area known for basmati rice cultivation, and found that 60% of samples were contaminated with high levels of Cu, Fe, Pb, and Cr, with lead and chromium contamination posing significant health risks to the local population. According to the latest research by Badar et al. (2024) examined groundwater vulnerability to heavy metals in industrial areas in Aligarh, India, finding that 64.7% of samples met safety standards, while 35.3% showed contamination. Sishu et al. (2024) studied water quality in Lake Tana, Ethiopia, and found elevated chromium and iron levels in areas receiving urban drainage, with nutrient levels also slightly above limits, especially during the rainy season, suggesting cause for concern regarding water quality.

Health Risks Associated with Heavy Metal Contamination

Midrar-UI-Haq et al. (2005) discussed the growing issue of water contamination by heavy metals, which continues to exceed regulatory standards globally despite technological advances. The improper disposal of household and industrial waste, along with excessive use of chemicals in agriculture, contributes to the transfer of toxic metals into water sources, posing significant health risks, including cancer. This analysis found that trace metal levels in most areas of India exceed WHO-permitted limits. While some heavy metals are essential for health, they must be present in limited quantities. Mawari et al. (2022) found that drinking water contaminated with heavy metals in Solapur, India, causes digestive issues, anaemia, immune system weakening, developmental problems in children, nerve damage, and reduced sperm count in men. Martin and Griswold (2019), and Sonone et al. (2020) highlighted that arsenic, a carcinogen and poison found in soil, water, and air, increases the risk of various cancers and non-cancerous health issues. High exposure can lead to reproductive problems, vascular disorders, hypertension, diabetes, skin, lung, and bladder malignancies, along with nausea, vomiting, loose stools, and reduced WBC and RBC production. Mahmood et al. (2014) noted that cadmium, a poisonous metal from industrial and agricultural waste, is used in batteries and electroplating. Prolonged exposure can cause serious health issues, including shortness of breath, mucosal membrane disturbance, and pulmonary edema. Martin and Griswold (2009) found that cadmium can cause osteoporosis, affect calcium absorption, and lead to hypercalciuria. Inhalation or ingestion of cadmium can damage the lungs, stomach, and intestines. Chronic exposure, especially during pregnancy, can lead to adverse delivery outcomes, lower birth rates, and kidney disease. Kannan et al. (2021) found that lead exposure from contaminated drinking water is linked to renal failure, brain damage, learning difficulties, hypertension, and reproductive issues. Lead poisoning poses a significant health risk to children, affecting their physical development, nervous system, and academic performance, and is associated with delinquent and anti-social behavior. Bagul et al. (2015) found that while nickel is a necessary trace metal, excessive exposure is carcinogenic and harmful to human health. It can cause cutaneous irritation, exacerbate eczema, and lead to dermal toxicity, hair loss, and cancer. In contrast, Chen et al. (2019) and Kumar et al. (2023) found that while chromium is essential for humans and animals, excessive exposure can lead to lung cancer, dermatitis, skin ulceration, and long-term damage to the kidneys, liver, circulatory system, and nervous tissues. It can also cause respiratory issues like asthma and coughing. Martin and Griswold (2019); and Sonone et al. (2020) found that mercury exposure can cause birth malformations, spontaneous abortions, digestive disorders, periodontal disease, nervous system ailments, brain and CNS damage, and acrodynia, a condition involving rashes and skin peeling on the hands and feet. Iron is a crucial component of human health and serves several bodily purposes. Mahurpawar (2015) found that iron imbalances can lead to symptoms such as weakness, headaches, and shortness of breath, with excessive iron increasing the risk of liver disease, heart failure, and premature death. Excessive manganese exposure can cause neurological disorders similar to Parkinsonism. USPEA (2004) reported that human activities significantly contribute to manganese contamination in groundwater, with concentrations exceeding WHO-allowable levels in certain areas of Pakistan. Narjala (2020) found that elevated zinc levels in water can cause health issues such as abdominal discomfort, skin irritation, nausea, vomiting, anemia, fertility problems, and increased susceptibility to diabetes.

CONCLUSION

This article explores the impact of heavy metals like arsenic, cadmium, chromium, mercury, lead, nickel, and zinc on human health. Contaminated water, often polluted by human activities, poses serious risks to ecosystems and human well-being. Excessive metal concentrations can lead to significant diseases. Fortunately, various water treatment techniques, including coagulation, membrane processes, electrochemical methods, and adsorption, have been developed to remove these contaminants. Effective regulation and identification of heavily contaminated areas are essential. Further research is needed to understand better the pathophysiology and molecular mechanisms associated with these diseases.

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