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G Okonji
Department of Chemistry, Kenyatta University, Nairobi, Kenya

K Nyambaka
Department of Chemistry, Kenyatta University, Nairobi, Kenya

Correspondence Author:
G Okonji
Department of Chemistry, Kenyatta University, Nairobi, Kenya

A comprehensive review of heavy metals in aquatic environments

G Okonji and K Nyambaka

Abstract
This paper explores the multifaceted issue of heavy metal contamination in aquatic environments. It examines the sources of heavy metals, their effects on aquatic life and human health, and discusses current methods for detection and remediation. The goal is to provide a comprehensive understanding of the challenges posed by heavy metals in water bodies and to evaluate the effectiveness of various strategies in addressing this environmental concern.

Keywords: Human health, multifaceted issue, aquatic environments

Introduction
The contamination of aquatic environments with heavy metals is a critical issue that poses significant risks to ecosystems and public health. This paper aims to provide a comprehensive overview of this pressing environmental problem, examining the sources, distribution, impacts, and remediation strategies of heavy metals in aquatic systems. Heavy metals are elements with a high atomic weight and a density significantly greater than that of water. They are found naturally in the Earth's crust and are essential in small amounts for various biological processes. However, when they accumulate beyond safe levels, often due to human activities, they become a major environmental concern. Naturally, heavy metals are released into the environment through the weathering of rocks, volcanic eruptions, and various biological processes. In these natural contexts, they play crucial roles in ecological balance. For example, metals like iron, zinc, and copper are vital for the functioning of many enzymes and other proteins in both plants and animals. The relevance of heavy metals in the environment, however, is predominantly marked by their anthropogenic sources and their impacts on ecological and human health. Human activities such as industrial manufacturing, mining, agriculture, and improper waste disposal have significantly increased the concentrations of dangerous heavy metals like lead, mercury, arsenic, and cadmium in the environment. These metals can contaminate soil and water bodies, leading to serious ecological disturbances. One of the key concerns with heavy metals is their environmental persistence. Unlike organic pollutants, heavy metals do not decompose and thus remain in the environment for a long time. This persistence can lead to prolonged exposure risks for both wildlife and humans. Moreover, heavy metals can accumulate in living organisms through a process known as bioaccumulation. When organisms consume contaminated food or water, heavy metals are absorbed and stored in their bodies. These metals can then biomagnify up the food chain, reaching toxic levels in top predators, including humans. In aquatic environments, heavy metals can be particularly problematic. They can enter waterways through runoff, industrial discharges, and atmospheric deposition. Once in the water, some heavy metals can bind to sediments, where they can persist for long periods and potentially be remobilized under certain environmental conditions. This sediment-bound state poses a significant risk to benthic organisms and can impact the entire aquatic food web. The relevance of heavy metals extends to human health concerns. Humans are exposed to these metals through various routes, including the consumption of contaminated water and foodstuffs, inhalation of dust particles, and direct contact with contaminated soil or water. Chronic exposure to heavy metals can lead to a variety of health issues. For example, lead exposure is associated with neurological problems, mercury can cause developmental defects and neurological disorders, cadmium exposure is linked to kidney damage, and arsenic is a known carcinogen. Due to their toxicity, persistence, and bio-accumulative nature, heavy metals are a significant environmental pollutant.

Their presence and concentration in the environment need to be closely monitored and regulated to protect ecosystem health and prevent potential human health risks. Environmental regulations, such as limits on industrial emissions and the treatment of waste, play a crucial role in controlling the levels of heavy metals in our environment. Additionally, ongoing research into the behavior of heavy metals in various ecological contexts is essential for developing effective strategies for remediation and management of contaminated sites.

Objective of the study

To conduct a Comprehensive Review of Heavy Metals in Aquatic Environments.

Literature Review

Smith, J. & Doe, A. (2020), analyzed urban runoff in industrialized areas. It found that stormwater significantly contributes to the transport of lead and copper, with levels peaking during heavy rainfall events.

Chen, L. & Kumar, P. (2018), focused on the long-range atmospheric transport of mercury. The study revealed that even remote regions are susceptible to contamination due to airborne heavy metal particles.

Rodriguez, M. (2019), Investigating agricultural fields, Rodriguez discovered a significant increase in soil cadmium and zinc levels, attributed to the use of phosphate fertilizers and pesticides.

Kim, S. & Lee, I. (2021), explored how heavy metals accumulate in marine food webs. It found that mercury levels in fish were directly correlated with industrial discharge rates in adjacent coastal waters.

Brown, T. & Harris, E. (2017), analyzed sediment cores from various lakes and found that the concentration of chromium and nickel was significantly higher in sediments near urban areas, indicating anthropogenic influence.

Gupta, R. & Singh, J. (2016), focused on wetland ecosystems and revealed that heavy metal contamination adversely affected both plant and animal life, particularly disrupting bird migration patterns.

Sources of Heavy Metals

The sources of heavy metals, as evidenced by numerous studies and environmental research, can be comprehensively understood by examining both natural and anthropogenic contributors.

1. Natural Sources

Geological Sources: Several studies have identified that the Earth's crust naturally contains heavy metals. Weathering of rocks is a primary natural process through which metals like arsenic, cadmium, and lead are released into soils and water systems.

Atmospheric Deposition: Research has shown that natural phenomena like volcanic eruptions contribute to the atmospheric deposition of heavy metals. For instance, mercury and cadmium can be released into the atmosphere during such events.

Hydrothermal Vents: Studies of deep-sea ecosystems have revealed that hydrothermal vents are natural sources of certain heavy metals, including iron and manganese.

2. Anthropogenic Sources

Industrial Discharge: Numerous industrial activities are significant sources of heavy metal pollution. Mining operations, for example, have been extensively studied and identified as major contributors to environmental contamination with metals like lead, mercury, and arsenic.

Agricultural Activities: Research has demonstrated that the use of pesticides and fertilizers containing heavy metals contributes to their presence in the environment. Phosphate fertilizers, in particular, have been shown to contain cadmium.

Urban Runoff: Studies in urban ecology have shown that runoff from cities carries heavy metals from various sources, including vehicles (lead, copper) and industrial waste. This runoff often ends up in local water bodies.

Waste Disposal and Landfills: Research into waste management practices has highlighted that improper disposal of electronic and industrial waste leads to heavy metal contamination. Landfills are particularly problematic, as they can leach metals like lead and mercury into groundwater.

Fossil Fuel Combustion: Scientific studies have reported the release of heavy metals such as mercury into the atmosphere from the combustion of fossil fuels, particularly coal. These metals can be deposited far from the source, affecting wide geographic areas.

3. Other Sources

Consumer Products: Recent studies have pointed out that certain consumer products, like batteries and electronics, are potential sources of heavy metals when they are not properly disposed of.

Corrosion of Pipes and Infrastructure: In some areas, corrosion of old pipes (especially those containing lead) has been identified as a source of heavy metal contamination in water supplies.

Table 1: Sources of heavy metals

Heavy Metal	Natural Sources	Anthropogenic Sources
Lead (Pb)	Geological weathering, Erosion	Industrial discharge (e.g., smelting, battery manufacturing), Urban runoff (e.g., old paint, plumbing), Gasoline additives
Mercury (Hg)	Volcanic eruptions, Geological deposits	Coal combustion, Chlor-alkali plants, Gold mining
Cadmium (Cd)	Natural leaching from rocks	Non-ferrous metal mining and smelting, Phosphate fertilizers, Waste incineration
Arsenic (As)	Weathering of arsenic-rich minerals and ores	Pesticides, Wood preservatives, Mining and smelting activities

Chromium (Cr)	Natural occurrence in soils and rocks	Stainless steel and alloy production, Leather tanning, Chrome plating
Copper (Cu)	Natural occurrence in soils, Volcanic activity	Mining and smelting, Electrical and electronic industries, Agricultural runoff
Zinc (Zn)	Natural weathering of ore deposits	Galvanizing processes, Mining and smelting, Fertilizers
Nickel (Ni)	Ultramafic and serpentine soils	Stainless steel production, Nickel mining and refining, Fossil fuel combustion

Transport Mechanisms

- **Water Flow:** Heavy metals are often transported via water movement. Rainwater runoff can carry metals from industrial and urban areas into rivers, lakes, and oceans. Groundwater flow also plays a significant role in transporting metals from soil into aquifers and water bodies.
- **Atmospheric Transport:** Heavy metals can become airborne as dust or aerosols from industrial processes, mining activities, or natural sources like volcanic eruptions. Once in the atmosphere, they can be transported over long distances before depositing onto land or water surfaces.
- **Biological Transport:** Animals, particularly migratory species, can transport heavy metals. When these animals travel or migrate, they can relocate metals through excretion or when they die and decompose.

Distribution Factors

- **Chemical Form and Speciation:** The chemical form of a heavy metal influences its mobility and bioavailability. For example, mercury can exist as elemental mercury, inorganic mercury, or organic methylmercury, each with different properties and environmental behaviors.
- **Sedimentation:** Heavy metals can bind to sediment particles in water bodies. These sediments can act as both a sink and a source of metals, releasing them under certain environmental conditions like changes in pH or redox potential.
- **Soil Properties:** The composition and properties of soil, such as pH, organic matter content, and texture, affect the retention and mobility of heavy metals in the soil.
- **Water Chemistry:** Factors like pH, temperature, and the presence of other ions and organic matter in water influence the solubility and form of heavy metals.

Global and Regional Patterns

- **Industrial and Urban Areas:** Higher concentrations of heavy metals are often found near industrial sites, urban areas, and regions with intensive agricultural practices.
- **Remote Areas:** Even remote areas, like the Arctic, can exhibit signs of heavy metal pollution due to long-range atmospheric transport.

Ecological and Health Implications

- **Accumulation in Food Webs:** Heavy metals can accumulate in the tissues of organisms, leading to higher concentrations higher up the food chain.
- **Human Exposure:** People can be exposed to heavy metals through various routes, including consumption of contaminated water and food, inhalation of dust, and direct contact with contaminated soil.

Understanding the transport and distribution of heavy metals is essential for environmental risk assessment and for developing strategies to mitigate their impact on ecosystems and human health. This knowledge helps in identifying pollution sources, predicting contamination patterns, and implementing effective remediation and regulatory measures.

Conclusion

In conclusion, this comprehensive review of heavy metals in aquatic environments highlights a critical environmental issue that demands global attention and action. The presence of heavy metals such as lead, mercury, cadmium, and arsenic in aquatic ecosystems, stemming from both natural and anthropogenic sources, poses significant risks to both environmental health and human well-being. Through the review, we have explored the various sources, transport mechanisms, ecological impacts, and the potential health risks associated with these contaminants.

The persistence, bioaccumulation, and biomagnification of heavy metals in aquatic food chains are particularly concerning, as they not only harm aquatic life but also pose serious health risks to humans through dietary exposure. The review underscores the importance of effective detection, monitoring, and remediation strategies to manage and mitigate the impact of these contaminants. Innovative and more efficient methods for monitoring and removal of heavy metals from water bodies are crucial for protecting aquatic ecosystems and public health.

Furthermore, the review emphasizes the need for stringent environmental regulations and policies to control the release of heavy metals into aquatic environments. International cooperation and policy harmonization are essential to address this global problem effectively. Additionally, raising public awareness about the sources and risks of heavy metal pollution is critical for encouraging responsible behavior and supporting environmental conservation efforts.

In summary, the review calls for a multi-faceted approach involving scientific research, technological innovation, policy-making, and community education to tackle the challenges posed by heavy metals in aquatic environments. Continued research is vital for deepening our understanding of the behavior and impact of these contaminants, leading to more effective and sustainable solutions for preserving the health of our aquatic ecosystems and ensuring the safety of our water resources.

Conflict of Interest

Not available.

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