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Review Article

Heavy Metal Pollution in India: Current Trends and Perspectives

Chitralekha Kotian

Department of Chemistry, Royal College of Arts, Science and Commerce, Mira Road, Thane, Maharashtra

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ABSTRACT

Heavy metal pollution represents a critical environmental and public health concern, particularly in rapidly developing regions of the world such as India. The increased rate of industrialization has accelerated the rate of release of heavy metals in the environment. This issue reverberates through various sectors, affecting not only the ecological balance but also the health and well-being of communities. Research on heavy metal pollution in India offers insights for policy-making, environmental management, and public health initiatives, addressing sources, distribution, ecological impacts, and health risks. A substantial body of research has documented the primary anthropogenic sources of heavy metals, which include industrial discharges, vehicular emissions, agricultural practices, and unregulated waste disposal. Observations show alarming concentrations of metals such as lead, arsenic, mercury, and cadmium in soil, water, and air in various regions across India Additionally, the health repercussions for local populations have been a focal point of research, with several studies linking heavy metal exposure to chronic diseases, neurological disorders, and developmental issues in children. Several environmental studies have been carried out in the earlier years of the century focusing on the contamination and the remediation methods. The current review paper aims to give an overview of the heavy metal pollution status in India for the past decade. A brief discussion on the regulations governing heavy metal pollution in India is included in the paper.

Key Words: Heavy Metal, India, Pollution, Control Measures

INTRODUCTION

The excessive accumulation of metallic elements like lead, mercury, cadmium and arsenic in the various compartments of the environment arises from industrial activity, mining, agricultural practices and poor waste disposal. These metals can be hazardous even in minimal concentrations affecting air soil and water and thereby affecting flora and fauna. Tchounwou PB et al[1] mention that a variety of anthropogenic activities are responsible for heavy metal pollution. These activities include mining, metallurgy fossil fuel combustion. The use of pesticides and fertilizers which contain heavy metals in trace amounts is another source of concern. Construction and demolition activities in urban areas also result in emission of metal particulates in the environment. The presence of these non-biodegradable elements in the environment leads to toxic effects on wild life and human population. Neurological disorders and developmental issues observed in infants and children and incidents of cancer and organ failure have attributed to metals such as Lead and Mercury in the study carried out by Hsueh et al[2]. The presence of heavy metals has far reached implications as it disturbs soil microbiota aquatic ecosystems leading to a decrease in biodiversity. The deterioration of these natural resources has garnered the attention of scholars, policymakers, and public health advocates, highlighting the pressing necessity to comprehend contamination processes and their consequences. The central study issue is to the extensive effects of heavy metal contamination on ecological integrity and public health, with communities next to industrial areas or agricultural fields being disproportionately impacted by heightened concentrations of these contaminants.

The harmful effects of heavy metals like Lead, Cadmium, Mercury on agricultural soil and resources were highlighted in initial studies of early 1990s., Later research studies in the late 1990s observed increase pollution levels near industrial zones. The deliberations then shifted to the effect on public health in the 2000s. Studies conducted on environmental Pollution index (EPI) revealed alarming levels of pollution in water systems of states like Gujarat and Punjab. Since 2010, there has been a growing body of study dedicated to creative methodologies for evaluating and rehabilitating polluted sites, with certain researchers investigating the efficacy of bioremediation approaches to alleviate the impacts of heavy metals in soil and water. Recently, the impact of heavy metal pollution on exacerbating climate change has garnered attention, linking environmental degradation to economic sustainability and food security. The diverse tales underscore the critical necessity for comprehensive policy and community engagement to effectively tackle heavy metal contamination. The current study provides an overview of the status of heavy metal pollution in India in the last decade. It also discusses India's policies and plans for heavy metal pollution control.

Status of Heavy Metal Pollution in India

Heavy metal contamination is a substantial problem in India, resulting from unrestrained urbanization, industry, and inadequate water management techniques. The current section gives an overview of the status of heavy metal pollution in the country in the last 5 years. Studies done by Ramsha et al[3] reveal that heavy metals, such as cadmium (Cd), lead (Pb), and arsenic (As), frequently exceed safe concentration limits in various water bodies across the Investigations in the Gadilam River watershed have uncovered alarming levels of these pollutants, raising concerns regarding their impact on public health and aquatic ecosystems. Soil pollution intensifies the issue, as heavy metals accumulate due to industrial activity, mining operations, and agricultural practices. Research from the Thondi coast and surrounding regions indicates that metals such as chromium (Cr) and manganese (Mn) often exceed permissible limits, causing adverse impacts on both flora and fauna as reported by studies of Nariah Natash et al, Perumal, K., Antony et al, Shweta Kumari et al, T. P. Nafeesa et al [4-7].

A study done by Kshatriya, D et al[8] analyzed freshwater samples from 30 sources in Meghalaya throughout three seasons, revealing elevated concentrations of heavy metals, including cadmium, copper, zinc, and chromium. The monsoon season exhibited the highest concentrations, with levels of Cadmium, Copper, and Chromium surpassing national requirements. Pollution evaluations indicated substantial contamination, with elevated levels detected in metropolitan regions. The report advocates for corrective actions to maintain a robust aquatic ecosystem, emphasizing the reduction of heavy metal contamination and the enhancement of aquatic health.

The soil-rice system in the lower Brahmaputra Valley, Northeast India, was examined by Baruah, S. G et al[9] for heavy metals utilizing Nemerow's pollution index and the potential ecological risk index. The research revealed that 95% of the soil exhibited acidic characteristics, with 27.3% classified as extremely polluted and 34.8% as moderately polluted. The non-carcinogenic risk was elevated due to arsenic, whereas the carcinogenic risk was significant for Mahsuri and Moynagiri. The highest hazard index was recorded for Bahadur, while the lowest was noted for Ranjit.

This research paper by Upadhyay V et al[10] quantifies heavy metal contamination in Kanpur district, India, employing US EPA methodology and risk assessment based on epidemiological studies. The carcinogenic risk for adults was 3.87×10^{-7}, while for children it was 3.01×10^{-6}.

The study by Gupta, N et al[11] found that the consumption of vegetables in Jhansi, including fenugreek, spinach, eggplant, and chili, can lead to significant health risks due to the buildup of heavy metals. The study found that anthropogenic activities were a significant source of these metals, with target hazard quotients for Cd, Mn, and Pb exceeding one. The study recommends ongoing surveillance of soil, irrigation water, and plants to prevent excessive buildup in the food chain.

A correlation of heavy metal concentration and their toxicological hazards was carried out on the surface sediments of northwestern Karnataka, southern India by Mir, I.A et al[12].Heavy metals are enriched 1-3 times compared to the upper continental crust, exhibiting large concentrations in the central regions of Kudalgaon, Devarayi, Tavargatti, and Ganeshgudi. Arsenic concentrations are elevated in the settlements of north-eastern Alnavar, Kakkeri, Tavargatti. Chromium and Arsenic were found to be metals of great concern in the region.

The research by Samal, P et al[13] assesses heavy metal contamination in the deltaic regions of the Mahanadi River basin. The average concentrations of Co and Pb surpassed the global mean, with enrichment factors suggesting anthropogenic contamination from agricultural land attributable to extensive pesticide application. The oral uptake of produce from contaminated agricultural land increased the carcinogenic and non-carcinogenic risk. The non carcinogenic risk was attributed to Chromium and lead, The carcinogenic risk is due to Chromium metal

The heavy metal concentration of three water bodies Indus Beas Sutlej rivers and Harike wetland was assessed in this study by Kumar, V et al[14].Statistical methods were used to analyze the data from 2013 to 2017. The contamination pattern of river Beas was found to be different. The Pb content in river Beas exceeded guidelines for drinking water. Harike Wetland and Sutlej River were found to be critically polluted as per the heavy metal pollution index.

Using the Heavy Metal Pollution Index (HPI), this study by Chaudharı, M et al[15] evaluated the level of heavy metal contamination in Gujarat's groundwater over the entire state. To evaluate contamination levels, other pollution indicators were presented, including the Degree of Contamination, Metal Index, Heavy Metal Evaluation Index, and Water Pollution Index.

The Yamuna River, essential to Delhi, is among the most contaminated in the nation, with 85% of its pollution originating from home and industrial sources as per the study by Malik, Darshan et al[16]. The river's water quality is significantly compromised by untreated effluents, rendering it inappropriate for bathing, aquatic life, and residential use. The river's state is very concerning, necessitating stringent measures to maintain its purity and avert additional pollution.

A study conducted in Srinagar city by Qayoom, U et al[17] evaluated heavy metal concentrations in sewage and sludge from wastewater treatment plants, revealing that while heavy metal levels complied with discharge limits, physico-chemical parameters such as suspended solids, ammonia, biochemical oxygen demand, and total phosphorus surpassed effluent disposal standards.

A study conducted in South India by Adimalla, N et al[18] analyzed pollution levels of six heavy metals in urban soils and estimated health concerns for both adults and children The results indicated a correlation between lead and zinc with traffic sources, although lead and cobalt exhibited moderate contamination levels. The non-carcinogenic danger of heavy metals to humans is predominantly attributed to chromium (Cr) and lead (Pb), whereas the carcinogenic risk is chiefly affected by chromium (Cr).

Heavy metal levels in soils in the Manali industrial region of Chennai, Southern India, were analyzed by Krishna, A.K et al[19] to assess contamination from industry and urbanization. The soil was found to be contaminated with a high concentration of Chromium, Copper, Nickel, Zinc, and Molybdenum. Other elements were comparable to Earth's crust or indicated metal depletion. The elevated enrichment factors for several heavy metals in the soil samples suggest significant contamination, likely associated with local industrial activities. Contamination sites pose significant environmental risks to terrestrial and aquatic ecosystems, potentially leading to ecotoxicological impacts. Secure garbage disposal is necessary to mitigate environmental degradation.

The study by Mukherjee, I et al [20] evaluates heavy metal contamination in groundwater in a semi-arid region of Birbhum district, India, focusing on ecological and human health concerns. The results showed the presence of target heavy metals in groundwater, with concentrations exceeding permitted limits. Minors in the area showed greater vulnerability to carcinogenic and non-carcinogenic disorders, primarily through oral exposure. The study recommends using treated groundwater, as ingestion is the primary pathway for heavy metal exposure.

The research study by Lakshmanna, B et al[21] of 30 sites in Nizampatnam Bay and Lankevanidibba found high levels of heavy metals in coastal waters. The concentrations of cadmium, cobalt, chromium, iron, manganese, lead, and zinc were analyzed using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-OES). The findings suggest that coastal waters are contaminated with these metals, a result of industrial waste discharge and anthropogenic activities. The concentration of cadmium (Cd) exhibits heightened contamination across all sample locations. The study also provides a comparison between pre-monsoon and post-monsoon levels of these metals.

An investigation of the quantity of metals in groundwater samples taken from the southwestern Cuddapah Basin in India was conducted by Reddy, Y et al[22] using a comprehensive heavy metal contamination technique and ecological risk evaluation. The samples were taken from areas near dormant mines. The metal pollution of drinking water was evaluated using the Heavy Metal Pollution Index (HPI), the Heavy Metal Evolution Index (HEI), and the Pollution Degree (DOC). The research revealed that 90% of samples posed significant to severe ecological risks in both seasons. Effective remedial measures are necessary to prevent metal contamination in groundwater.

In three areas of West Bengal, India: Durgapur, Kolkata, and Bolpur, this study by Ghosh, B et al [23] explores the dispersion of particle-bound heavy metals and the related health concerns. The findings revealed differences in heavy metal concentrations among localities; industrial areas showed higher levels. Principal component analysis found distinct metal co-variation patterns suggestive of sources including natural contributions, vehicle traffic, and industrial pollution. Except for Bolpur the total non-carcinogenic hazards in Kolkata and Durgapur exceeded the risk level set by the US EPA.

This study by Shraddha Mohanty et al[24] aimed to examine the amounts of potentially harmful heavy metals (Cd, Pb, Ni, Cr, Hg, and as) in locally cultivated food crops (rice, pulses, and vegetables) in areas of Cuttack district, India. The concentrations of heavy metals in the crop samples were ranked as follows: Pb > Ni > Cd > Cr > As > Hg.

The research by Bhuyan R et al [25] evaluated heavy metal levels in the surface sediments of the Bharalu River in India. Findings indicated that lead levels surpassed sediment quality standards, presenting a possible environmental hazard. Lead enrichment was moderate to severe, with lead as the principal source. Pollution indices indicated that downstream locations were more contaminated than upstream areas. Human activities, chiefly urban effluents and waste disposal, were recognized as the principal contributors of metal contamination.

Laws and Regulations governing Heavy Metal Pollution in India

In India, the principal legislation governing heavy metal pollution includes the Water (Prevention and Control of Pollution) Act, 1974, and the Environment (Protection) Act, 1986, which require industries to implement effluent treatment facilities and comply with discharge standards established by the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) to mitigate heavy metal contamination in aquatic environments. Furthermore, the Food Safety and Standards (Contaminants, Toxins and Residues) Regulations, 2011, delineate permissible thresholds for heavy metals in food products, thereby safeguarding consumer health. Essential aspects of heavy metal pollution legislation in India are summarized below[26-29].

- The Water (Prevention and Control of Pollution) Act, 1974, and the Environment (Protection) Act, 1986, serve as the primary legal frameworks for regulating industrial pollution, including the discharge of heavy metals, through consent systems and oversight by the CPCB and SPCBs.
- Effluent Treatment Plants (ETPs): Industries must establish and maintain ETPs to process their wastewater prior to disposal, ensuring adherence to prescribed effluent criteria for heavy metals.
- The Food Safety and Standards (Contaminants, Toxins and Residues) Regulations, 2011 delineate allowed thresholds for heavy metals, including lead, cadmium, mercury, arsenic, and chromium, in food products.
- The Food Safety and Standards (Packaging) Regulations, 2018 govern the migration of heavy metals from packaging materials into food products.
- The Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) are tasked with overseeing industrial effluents and enforcing compliance through penalties and legal actions against offenders.
- Illustrative instances of heavy metal regulations:
- Regulation on Lead Content in Paints: Provisions are in place to restrict the lead concentration in residential and decorative paints.
- Regulations on hazardous substances: The Public Liability Insurance Act, 1991 mandates that proprietors of hazardous substances are accountable for incidents resulting in injury to individuals or damage to property.
- The National Green Tribunal (NGT) is crucial in resolving environmental disputes, especially those concerning heavy metal contamination, and possesses the authority to issue compliance orders.

A brief overview of the various pollution control boards and their responsibilities are mentioned in the table below:

Regulatory Body	**Responsibility**
Central Pollution Control Board (CPCB):	Responsible for monitoring industrial effluent discharge and ensuring compliance with stipulated environmental standards set by the Acts mentioned above.
State Pollution Control Boards (SPCBs):	Implement the regulations at the state level, monitoring industries and taking action against violations.
Food Safety and Standards	Sets permissible limits for heavy metals in food products through the "Food

Authority of India (FSSAI):	Safety and Standards (Contaminants, Toxins and Residues) Regulations, 2011".
Lead in paints	"Regulation on Lead contents in Household and Decorative Paints Rules, 2016" limits the lead content in paints used for household and decorative purposes.
Industrial effluent treatment:	Industries are required to install effluent treatment plants (ETPs) to treat wastewater before discharge into water bodies.
Monitoring of heavy metals in water bodies:	CPCB and SPCBs regularly monitor water bodies to assess heavy metal levels.
National Green Tribunal (NGT):	Can intervene in cases of severe heavy metal pollution and issue orders for remediation

CONCLUSION

The literature review of heavy metal contamination status in India over the last decade indicates that the mitigation efforts have not borne fruit. Evidence indicates an increased worry over the health burdens and impacts associated with these metals. Environment Protection acts are all encompassing and provide a way to tackle the problem rampant heavy metal contamination. However environmental protection legislation alone is typically insufficient to comprehensively tackle heavy metal pollution. Though it establishes a legal framework for regulating emissions, it frequently necessitates additional implementation, monitoring, and more stringent enforcement to effectively address the problem, particularly in relation to intricate sources and pathways of heavy metal contamination. Overseeing and enforcing adherence to laws can be challenging, particularly in regions with constrained resources or where industries may be disinclined to comply with directives. The identification of the source of contamination is difficult due to intricate pathways of heavy metals in the environment. Thus, effective management and control is difficult. The challenges with regard to enforcement of regulations can be tackled by establishing more rigorous restrictions on allowable heavy metal concentrations discharged in to the environment. Stakeholders have to informed about the hazards of heavy metal exposure so as to promote responsible behavior. Collaborations have to be established to create efficient pollution mitigation solutions and promote sustainable behaviors. The current study therefore recommends continuous surveillance of affected areas, stricter regulations and collaborations between industry and academia for effective and innovative solutions.

Declaration by Author

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