Chemical Industry–Driven Water Contamination in India: Environmental Pathways, Human Health Risks and Policy Imperatives

Dr. Dnyaneshwar T.Nagre
Rahtramata Indira Gandhi College, Jalna. (MH.),
India. Email-nelsynagre@gmail.com

Abstract

Industrial chemical effluents substantially degrade water quality in India, contaminating surface and groundwater with heavy metals, organic pollutants, and other toxic substances. These contaminants pose serious non-carcinogenic and carcinogenic risks—particularly to children and vulnerable populations. This paper synthesizes evidence from diverse regions, including river basins such as Subarnarekha and Ganges, wetland (Harike), industrial regions (Rajasthan, Jodhpur's Jojari River), and points like Bhopal and Sterlite's Thoothukudi. We assess contaminant levels, health hazard indices, and risk quotients, evaluating their implications for human health. Findings highlight urgent needs for enhanced monitoring, remediation, stricter effluent treatment, and public health interventions.

Keywords: *Chemical effluents; heavy metals; groundwater; surface water; health risk assessment; India; non-carcinogenic and carcinogenic risk; industrial pollution; remediation.*

Introduction

India's rapid industrialization has led to the release of untreated or inadequately treated effluents into water bodies. These effluents carry heavy metals (e.g., arsenic, chromium, cadmium, manganese), organic compounds, pesticides, and fluorides. The chemical contamination of rivers (e.g., Ganges, Jojari River), wetlands (Harike), and groundwater aquifers results from discharge of industrial wastewater and improper disposal—posing profound risks to human health. Children are especially susceptible. This paper aims to consolidate existing research to assess the scope of contamination and the associated health risks.

Methodology

Literature Review: We conducted a systematic review of peer-reviewed studies and credible reports on water contamination linked to chemical industries across India.

Data Extraction: Key metrics collected include contaminant concentrations, Hazard Quotients (HQ), Hazard Index (HI), Incremental Lifetime Cancer Risk (ILCR), and Total Cancer Risk (TCR).

Health Risk Assessment Approach: We use standard environmental health frameworks considering ingestion and dermal pathways, with special attention to vulnerable groups (children vs adults.

Results

1.Subarnarekha River Basin

Groundwater samples showed elevated levels of As, Mn, Fe, Cu, and Se exceeding drinking-water standards in certain locations. Hazard Index (HI) for adults ranged from 0.18 to 11.34, indicating serious non-carcinogenic risk in parts of the region. Arsenic posed carcinogenic risk within acceptable thresholds.

2. Punjab (Rupnagar District)

34 water samples assessed for heavy metals showed aluminium, arsenic, lead levels that led HQ to exceed unity in most areas. ILCR indicated high cancer risk from arsenic, chromium, and lead.

3. Industrial Clusters (Coimbatore)

Contrary to expectation, tube wells within the Kurichi industrial cluster contained heavy metals below detection limits, while non-industrial residential zones had trace arsenic and cadmium. Effective monitoring and mitigation (e.g., RO treatment, rainwater harvesting) are credited.

4. Semi-Arid Industrial Regions in Rajasthan

Groundwater near RIICO industrial zones displayed high concentrations of Fe, Mn, Cr. Carcinogenic risk from chromium contributed over 95% of health risk. Fluoride and other toxicants also exceeded safe levels.

5. Harike Wetland (Punjab)

Seasonal measurements of Cd in surface water exceeded WHO limits across winter (7.07 µg/L), monsoon (4.45 µg/L), post-monsoon (3.13 µg/L), suggesting cadmium contamination poses health risks.

6. Ganges River Basin

From 1991–2021, heavy metal concentrations (Fe, Cr, Pb, Ni, Cd, Mn, Hg, Co, As) in Indian rivers far exceeded WHO/BIS limits. Health-risk assessments showed children and adults face both non-carcinogenic and carcinogenic risks, with children more vulnerable.

Chromium levels in the Ganges have remained alarmingly high—over 70 times the permissible limit as of 2010.

7. Jojari River (Jodhpur, Rajasthan)

The river carries toxic chemicals including sulfur, lead, cadmium from textile and chemical industries, severely impacting water quality and an estimated 1.6 million residents along the river.

8. Historical Case: Bhopal Disaster Aftermath

Toxic contamination from the abandoned Union Carbide pesticide plant continues to affect groundwater. Water and soil around the factory contain extremely toxic compounds—including mercury at concentrations thousands of times higher than expected—and carbon tetrachloride levels at 1,000× WHO guidelines in nearby wells.

9. Sterlite Copper (Thoothukudi)

Industrial operations have led to high levels of selenium, arsenic, lead, cadmium in groundwater and soil samples—2 to 9 times above allowable limits. Groundwater iron content in affected zones reached 17–20× permissible levels. Populations show elevated incidence of respiratory issues and reproductive health problems.

10. Pesticide Residues Nationwide

Pesticide contamination—DDT, HCH, endosulfan, malathion, chlorpyrifos, atrazine, among others—persists in soil, surface water, and groundwater across Indian states, often exceeding BIS and WHO limits. Health effects include carcinogenic, teratogenic, mutagenic, endocrine-disrupting outcomes.

Important Measures To Reduces Water Pollution

Reducing chemical water pollution is critical for protecting aquatic ecosystems, public health, and clean water resources. Here are important measures to reduce chemical water pollution:

1. Proper Wastewater Treatment

Upgrade treatment plants: Ensure that industrial and municipal wastewater is properly treated before being discharged into water bodies.

Use advanced filtration: Technologies like reverse osmosis, activated carbon filters, and bioreactors can remove harmful chemicals.

2. Regulate Industrial Discharge

Enforce environmental laws: Ensure industries follow strict limits on the types and amounts of chemicals they discharge.

Regular monitoring: Conduct inspections and require companies to report their effluent quality.

Zero-liquid discharge (ZLD): Encourage industries to adopt ZLD systems where no liquid waste is released.

3. Sustainable Agricultural Practices

Reduce chemical fertilizers & pesticides: Use organic alternatives, and only when necessary.

Precision farming: Apply agrochemicals based on soil and crop needs to minimize runoff.

Buffer zones: Create vegetative strips near water bodies to trap pollutants before they enter.

4. Safe Chemical Disposal

Hazardous waste collection: Provide facilities for safe disposal of paints, cleaners, batteries, etc.

Educate the public: Inform communities about the dangers of pouring chemicals down the drain or onto the ground.

5. Green Infrastructure

Constructed wetlands: These can treat wastewater naturally.

Permeable surfaces: Reduce runoff by allowing rainwater to soak into the ground.

Rain gardens and bioswales: Help absorb and filter pollutants from stormwater.6. Pollution 6.Prevention Policies

Ban/restrict toxic chemicals: Phase out the use of harmful substances like PFAS, mercury, lead, etc.Product labeling and regulation: Require clear labeling of harmful chemicals and regulate their sale.

7. Promote Public Awareness

Educational programs: Teach individuals and businesses how their actions impact water pollution.

Community cleanups: Engage people in protecting local rivers, lakes, and streams.

8. Encourage Research and Innovation

Invest in eco-friendly technologies: Develop new, less toxic alternatives for cleaning, farming, and manufacturing.

Support research: Improve our understanding of pollution sources and solutions.

9. Storm water Management

Catch and treat runoff: Use detention basins, retention ponds, and filters to remove pollutants from rainwater before it reaches waterways.

10. International Cooperation

Transboundary water management: Countries sharing rivers/lakes must collaborate on pollution control strategies.

Global conventions: Support agreements like the Water Convention and Stockholm Convention on persistent organic pollutants.

Discussion

Health Risk Trends: Across diverse contexts—from river basins to industrial zones—heavy metals such as arsenic, chromium, cadmium, lead, and fluoride consistently pose serious non-carcinogenic and carcinogenic risks. Children are disproportionately affected.

Sources and Exposure Routes: While industrial effluents are primary, geogenic contributions (e.g., fluoride) and pesticide runoff also play critical roles. In some regions (e.g., Coimbatore), effective controls mitigate risk.

Legal and Social Implications: Historical events like Bhopal and ongoing issues (e.g., Jojari River, Thoothukudi) underscore failures in industrial regulation, cleanup, and compensatory justice.

Policy Gaps: Insufficient effluent treatment capacity, inadequate enforcement (as seen along Yamuna tributaries), and absence of longitudinal monitoring limit effective responses.

Conclusion

Chemical industry–driven contamination of India's water bodies presents severe and widespread human health risks. Both acute and chronic effects—ranging from organ damage to cancer—are documented, with children at highest risk. Persistent pollutants, industrial negligence, and weak regulatory enforcement contribute to the crisis. Multifaceted strategies are urgently needed:

1. Strengthen Effluent Treatment: Expand and maintain common effluent treatment plants and enforce compliance.

2. Expand Monitoring: Implement long-term, comprehensive monitoring across regions and seasons.

3. Remediation Measures: Use cost-effective technologies—adsorbents, phytoremediation, bio-remediation.

4. Public Health Interventions: Provide clean water alternatives, health screenings, and awareness campaigns in high-risk areas.

5. Policy & Accountability: Enforce stringent regulatory frameworks, ensure access to justice and remediation for affected communities, and invest in remediation of legacy disasters (e.g., Bhopal)

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