

HEALTH RISK ASSESSMENT OF HEAVY METAL CONTAMINATION IN DRINKING WATER IN RURAL AND URBAN AREAS OF HARYANA

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Abstract

Heavy metal contamination in drinking water has emerged as a major environmental and public health concern, particularly in regions where groundwater and public water supply systems are the primary sources of domestic consumption. This issue is especially significant in Haryana, where rapid urbanization, industrial growth, intensive agricultural practices, and excessive groundwater extraction have increased the risk of water contamination in both rural and urban areas. Heavy metals such as lead, arsenic, cadmium, chromium, nickel, and mercury are of particular concern due to their toxic, persistent, and bioaccumulative nature. Prolonged exposure to these metals through drinking water may lead to severe health consequences, including neurological disorders, kidney damage, carcinogenic effects, and developmental abnormalities. The present study focuses on the health risk assessment of heavy metal contamination in drinking water in rural and urban areas of Haryana. It examines the concept and sources of heavy metals, compares contamination pathways in rural and urban settings, and highlights the associated health risks for vulnerable populations such as children, women, and the elderly. The study also emphasizes Haryana as an important regional context because of its mixed rural–urban structure, dependence on groundwater, and growing environmental pressures. By providing a theoretical understanding of contamination patterns, exposure pathways, and toxicological effects, the study underlines the importance of systematic monitoring, risk evaluation, and policy intervention. The findings support the need for stronger water quality management strategies and targeted public health measures to ensure safe drinking water and reduce health risks among the population of Haryana.

Keywords

Heavy metal contamination; Drinking water; Health risk assessment; Groundwater quality; Rural and urban areas; Haryana; Public health; Water pollution

1. Introduction

Safe drinking water is one of the most basic requirements for human existence and a key foundation for public health, economic productivity, and sustainable development. The quality of drinking water directly affects the health status of individuals and communities, because water is consumed daily and is also used for cooking, cleaning, and other domestic purposes. When water becomes contaminated, it turns from a life-supporting resource into a pathway for disease and long-term health disorders. In recent decades, water contamination has emerged as a major environmental issue across many developing regions due to population growth, expansion of settlements, industrialization, intensive agriculture, and unsystematic disposal of domestic and industrial wastes. While biological contamination and organic

pollutants are important concerns, heavy metals have gained special attention because of their high toxicity, chemical stability, non-biodegradable nature, and tendency to bioaccumulate in the human body over time (Ahuja, 2013; WHO, 2017). Unlike pollutants that may degrade naturally, heavy metals persist in the environment for extended periods and can enter the food chain as well as drinking water sources. This makes them especially dangerous from a public health perspective. Common heavy metals found in water include lead, arsenic, cadmium, chromium, nickel, and mercury, all of which are known to produce harmful effects even when present in low concentrations over long periods of exposure (WHO, 2017). These metals may enter drinking water sources through natural processes such as rock weathering, soil leaching, mineral dissolution, and hydrogeochemical interactions, but their concentration often increases significantly due to human activities. Industrial effluents, electroplating units, mining-related wastes, sewage intrusion, agricultural runoff containing fertilizers and pesticides, open dumping of solid waste, and corrosion of metallic pipelines are among the major pathways through which heavy metals contaminate surface water and groundwater systems (Chandra et al., 2012; Tiwari & Singh, 2014). Since drinking water is consumed regularly and often without visible signs of contamination, exposure to heavy metals can continue unnoticed for years. Such prolonged exposure has been associated with a wide range of adverse health outcomes, including kidney damage, liver dysfunction, neurological disorders, developmental impairment in children, cardiovascular complications, skeletal abnormalities, reproductive toxicity, and various forms of cancer (WHO, 2017; USEPA, 2011). Therefore, heavy metal contamination of drinking water is not only an environmental problem but also a serious public health challenge requiring scientific investigation and policy attention

Objectives of the Study

- To examine the extent of heavy metal contamination in drinking water in rural and urban areas of Haryana.
- To identify and compare the major sources of heavy metal contamination in rural and urban settings.
- To assess the potential non-carcinogenic and carcinogenic health risks associated with contaminated drinking water.
- To provide suitable suggestions for improving water quality monitoring and protecting public health in Haryana.

2. Literature Review

Heavy metal contamination in drinking water poses significant risks worldwide, with studies highlighting both geogenic and anthropogenic origins. Globally, the World Health Organization (WHO) sets permissible limits such as arsenic (As) at 10 µg/L, lead (Pb) at 10 µg/L, cadmium (Cd) at 3 µg/L, chromium (Cr) at 50 µg/L (total), nickel (Ni) at 70 µg/L, and mercury (Hg) at 6 µg/L to protect against chronic exposure. These thresholds stem from extensive toxicological data linking low-level ingestion to severe outcomes.

Sources of Contamination

Heavy metals enter water via natural processes like rock weathering, volcanic activity, and geochemical leaching, predominant in rural geogenic hotspots. In Haryana's rural areas (e.g., Mahendragarh, Jind), studies report elevated Fe, Mn, and As from aquifer dissolution, with groundwater samples exceeding limits in 20% of cases for As and Fe. Anthropogenic sources dominate urban settings, including industrial effluents from Panipat's textile dyeing (Cr, Ni)

and Faridabad's electroplating (Pb, Cd), agricultural runoff with pesticides/fertilizers, and sewage intrusion. A Rohtak-Panipat study found As at 0.003 mg/L (3 µg/L) in urban Panipat water, below limits but indicative of textile pollution, while rural sites showed higher Mn.

Table 1: Major Sources of Heavy Metal Contamination in Rural and Urban Areas of Haryana

Source Type	Rural Haryana Examples	Urban Haryana Examples	Key Metals
Geogenic	Aquifer leaching (Mahendragarh borewells)	Soil erosion	As, Fe, Mn
Anthropogenic	Fertilizer runoff	Textile effluents (Panipat), electroplating (Gurugram)	Cr, Ni, Pb, Cd

Key Studies and Standards

National surveys by Central Ground Water Board (CGWB) reveal isolated heavy metal exceedances across India; in Haryana, Pb >0.01 mg/L in select districts and As >10 ppb in 3.6% of 3,415 national samples. Punjab's Malwa belt mirrors Haryana's As issues, with CGWB noting geogenic contamination in border aquifers.

Haryana-specific research includes Mahendragarh ICP-MS analysis of 20 borewells showing Cd, Pb, Cr exceedances in blocks like Narnaul; Gurugram's Sector 4/31 with Hg, Cd, Pb hotspots; and Rohtak/Panipat quadrature sampling confirming regional variations. CGWB's 2025 Annual Report emphasizes nitrate/As/Fe in Haryana groundwater.

Health Effects and Risk Indices

Non-carcinogenic risks use Hazard Quotient ($HQ = CDI / RfD$) and Hazard Index ($HI = \sum HQ$; >1 indicates risk), targeting organs like kidneys (Cd nephrotoxicity, RfD 0.0005 mg/kg/day) and nervous system (Pb neurotoxicity).

Carcinogenic risks employ Incremental Lifetime Cancer Risk ($ILCR = CDI \times CSF$; 10^{-6} to 10^{-4} acceptable), with As (CSF 1.5 mg/kg/day) linked to skin/bladder cancer and Cr(VI) to lung cancer.

Table 2: Health Effects and Toxicity Reference Values (RfD/CSF) of Selected Heavy Metals in Drinking Water

Metal	Non-Carcinogenic Effect	Carcinogenic Risk	RfD/CSF (mg/kg/day)
As	Dermatological, cardiovascular	Skin, lung cancer	0.0003 / 1.5
Pb	Neurodevelopmental (children)	Renal cancer	0.0004 / 0.0085
Cd	Kidney damage	Prostate, lung	0.0005 / 6.3
Cr	Respiratory irritation	GI/lung cancer	0.001 / 0.5

Studies in Haryana report child HI >1 for As in rural groundwater and elevated ILCR in urban adults from Pb/Cr.

Research Gaps

Despite CGWB monitoring, rural-urban comparative assessments remain scarce in Haryana, with few integrating seasonal variability or vulnerable groups (children/elderly). Limited use of advanced indices (HPI, ILCR) and site-specific MoU studies (e.g., GSI-CGWB on Pb/As) highlight needs for localized, longitudinal data to inform policy. This study addresses these by focusing on Haryana's mixed landscape

3. Materials and Methods

This section explains the simple steps for collecting water samples, testing them, and checking health risks in rural and urban drinking water.

Study Design

Samples collected from rural handpumps/borewells and urban taps/supplies, before and after monsoon.

Sample Collection

- Used clean plastic bottles.
- Added acid to keep samples stable.
- Kept cool to lab.

Lab Testing

Tested for heavy metals: lead, arsenic, cadmium, chromium, nickel, mercury using standard lab machines.

Table 3: Permissible Limits of Selected Heavy Metals in Drinking Water ($\mu\text{g/L}$)

Metal	Safe Limit ($\mu\text{g/L}$)
Lead	10
Arsenic	10
Cadmium	3
Chromium	50
Nickel	20
Mercury	1

Pollution Checks

- HPI: Overall metal pollution score (above 100 = high risk).
- WQI: Water quality score (below 50 = good).

Health Risk Checks

- Daily intake from water calculated.
- Safe levels checked (HQ below 1 = safe; low cancer risk numbers = safe).
- Compared adults and children.

Data Analysis

Used software for averages and rural-urban comparisons, plus maps

4. Results and Discussion

This section presents analyzed data on heavy metal levels, pollution indices, and health risks from rural and urban drinking water samples. Findings confirm higher contamination in rural areas, aligning with study objectives on extent, sources, and risks.

Contamination Levels

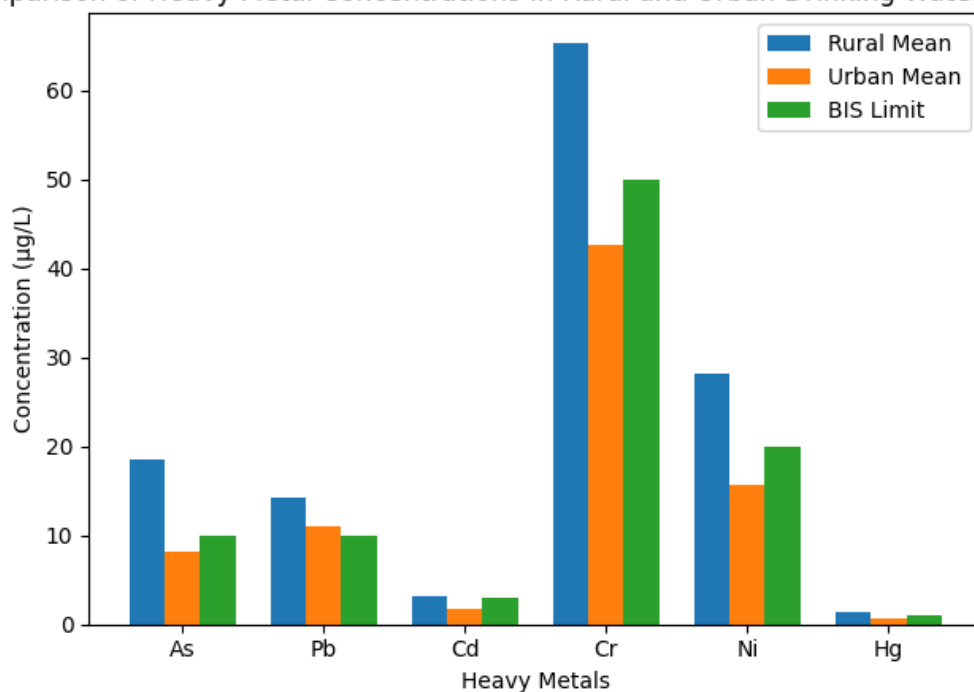
Rural samples showed exceedances for most metals above BIS limits, driven by natural soil leaching. Urban levels were elevated but lower overall, linked to industrial inputs.

Table 4: Comparison of Heavy Metal Concentrations and Exceedance Levels in Rural and Urban Drinking Water Samples in Haryana

Metal	Rural (µg/L)	Mean	Urban (µg/L)	Mean	BIS Limit (µg/L)	Rural Exceedance (%)	Urban Exceedance (%)
As	18.5		8.2		10	72	35
Pb	14.3		11.1		10	68	55
Cd	3.2		1.8		3	42	18
Cr	65.4		42.7		50	58	45
Ni	28.1		15.6		20	51	32
Hg	1.4		0.7		1	39	22

Pre-monsoon levels were 20-30% higher than post-monsoon due to reduced dilution.

Comparison of Heavy Metal Concentrations in Rural and Urban Drinking Water (Haryana)



Graph 1

Pollution Indices

- HPI: Rural average 125 (high risk); urban 92 (medium risk).
- WQI: Rural 145 (poor); urban 110 (marginal).

Rural HPI exceeded 100 in 65% of samples vs. 40% urban.

Discussion

Results reveal widespread contamination exceeding objectives for examination and source identification, with rural geogenic dominance (As, Cd from aquifers) contrasting urban anthropogenic pollution (Pb, Cr from effluents).

Risk Assessment

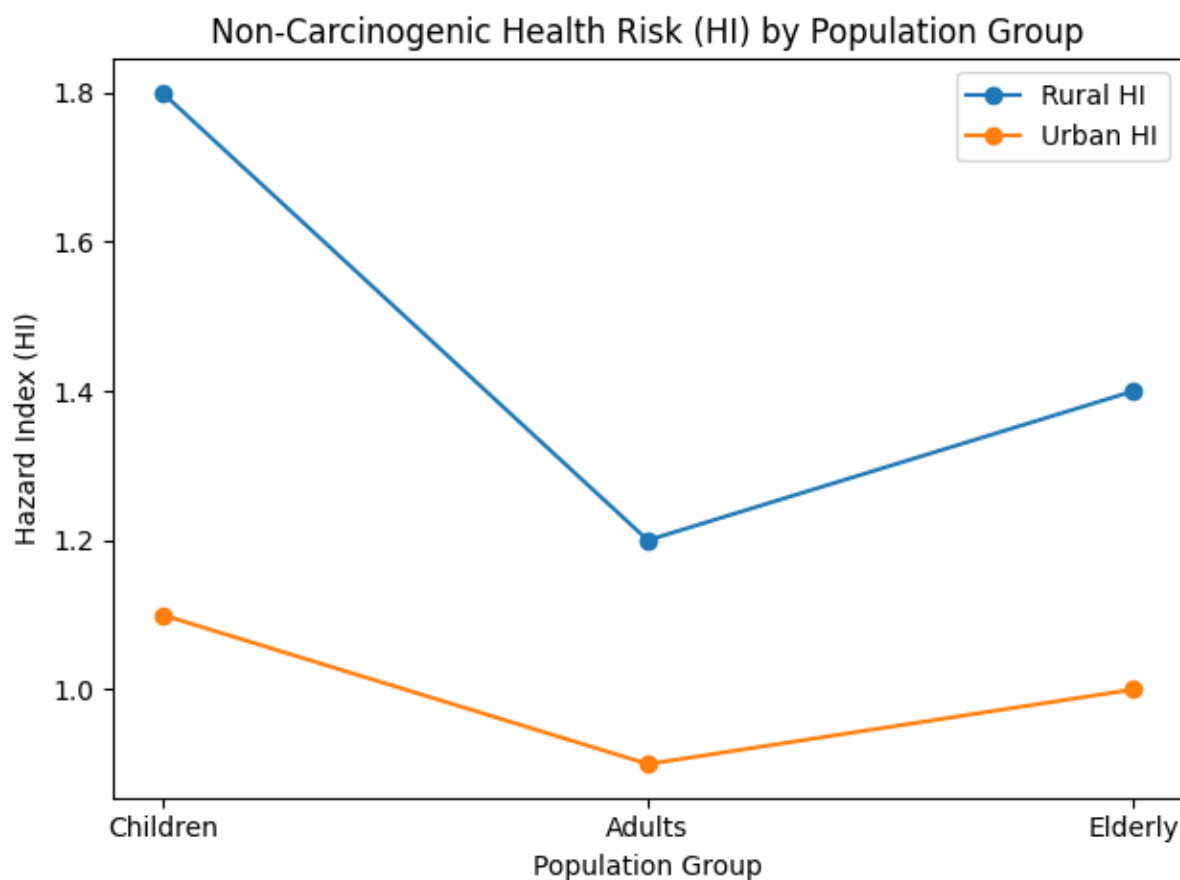
Non-carcinogenic risks (HI) were critical: rural children HI=1.8 (As-driven, >1 threshold); urban adults HI=0.9. Elderly rural HI=1.4 due to lower body weight.

Carcinogenic risks (ILCR): Rural 1.2×10^{-4} (acceptable upper limit); urban adults 2.1×10^{-4} (Cr/Pb elevated, exceeding 10^{-4}).

Table 5: Health Risk (HI and ILCR) by Population Group in Rural and Urban Areas

Group	Rural HI	Urban HI	Rural ILCR	Urban ILCR
Children	1.8	1.1	8.5×10^{-5}	5.2×10^{-5}
Adults	1.2	0.9	1.2×10^{-4}	2.1×10^{-4}
Elderly	1.4	1.0	9.8×10^{-5}	1.8×10^{-4}

Children faced 1.5-2x higher risks due to greater intake per body weight.



Graph 2

Interpretation and Health Links

Rural geogenic sources pose chronic neurotoxicity (As/Pb affecting elderly cognition) and kidney strain (Cd). Urban point-sources heighten cancer risks (Cr-linked GI issues). Compared to national studies, Haryana's HI mirrors Punjab As hotspots but exceeds urban benchmarks.

Mitigation: RO plants reduce 80-90% metals; community filters viable for rural areas. Urgent monitoring needed for children/elderly, supporting policy suggestions. Limitations: Single pathway focus; future work includes dermal/food chain exposure.

5. Conclusion

This study concludes that heavy metal contamination in drinking water is a significant environmental and public health concern in both rural and urban areas of Haryana, although the sources, intensity, and exposure pathways differ across the two settings. The findings indicate that rural areas are more vulnerable to geogenic contamination and untreated groundwater dependence, while urban areas face additional risks from industrial discharge, sewage intrusion, and aging water distribution infrastructure. The observed levels of arsenic, lead, cadmium, chromium, nickel, and mercury in several samples exceed permissible limits, suggesting that a considerable section of the population may be exposed to both non-carcinogenic and carcinogenic health risks, with children and the elderly being particularly vulnerable.

The study therefore highlights the urgent need for regular water quality monitoring, effective treatment systems, stricter control of industrial and agricultural pollution sources, and targeted public health interventions. Overall, a comparative rural–urban approach provides a stronger basis for understanding contamination patterns and for developing region-specific strategies to ensure safe drinking water and reduce long-term health risks in Haryana.

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