



Assessment of Heavy Metal Contamination in Groundwater and Associated Human Health Risks

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1. Abstract

Groundwater, a vital resource for domestic, agricultural, and industrial use, is increasingly threatened by heavy metal contamination. Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), and mercury (Hg) persist in aquifers due to anthropogenic and natural processes. Their toxicological significance, persistence, and bioaccumulative behavior pose severe risks to human health and ecosystems. This research assesses heavy metal contamination in groundwater, quantifies concentrations, evaluates compliance with international water quality standards, and conducts a human health risk assessment using the Hazard Quotient (HQ) and Cancer Risk Index (CRI). Samples were collected from diverse sources across a representative geographical region and analyzed using advanced instrumentation such as ICP-MS and AAS. Results reveal exceedances of permissible limits for several metals, particularly As and Pb, with spatial variability correlating to industrial zones, agricultural runoff, and geological formations. Health risk assessment indicates potential non-carcinogenic and carcinogenic risks, especially for children, emphasizing the need for mitigation strategies. Recommendations include regular monitoring, policy interventions, and community awareness to safeguard public health and sustainable groundwater use.

2. Keywords

- Groundwater contamination, Heavy metals, Human health risk assessment ,Toxicity ,Water quality indices ,Arsenic, Lead, Cadmium



3. Introduction

3.1 Background

Groundwater constitutes approximately 30% of the world's freshwater resources and serves a crucial role in supplying potable water to more than 2 billion people globally (WHO, 2017). Unlike surface waters, groundwater is less vulnerable to immediate visible pollution and often perceived as safer. However, due to anthropogenic pressures, its quality is deteriorating, especially in rapidly industrializing and agriculturally intense regions.

Heavy metals are naturally occurring elements characterized by high atomic weight and density. While some metals (e.g., Zn, Cu) are essential micronutrients at trace levels, others (e.g., As, Pb, Cd) have no known biological function and are toxic even at low concentrations. The persistence of heavy metals in aquifers is a major environmental concern because they do not degrade and can accumulate in biological tissues, leading to chronic health effects.

3.2 Significance of Study

The assessment of heavy metal contamination is essential for evaluating the safety of groundwater for human consumption, agricultural irrigation, and industrial use. Chronic exposure to heavy metals through ingestion, dermal contact, and inhalation can lead to neurological disorders, kidney damage, cancer, and developmental abnormalities in children. Therefore, understanding spatial distribution, concentration levels, and risk exposure pathways is vital for policy formulation and community protection.

3.3 Objectives

This research aims to:

1. Quantify heavy metal concentrations in groundwater across diverse land-use settings.

2. Compare measured concentrations against WHO and national standards.

3. Assess health risks associated with long-term exposure.

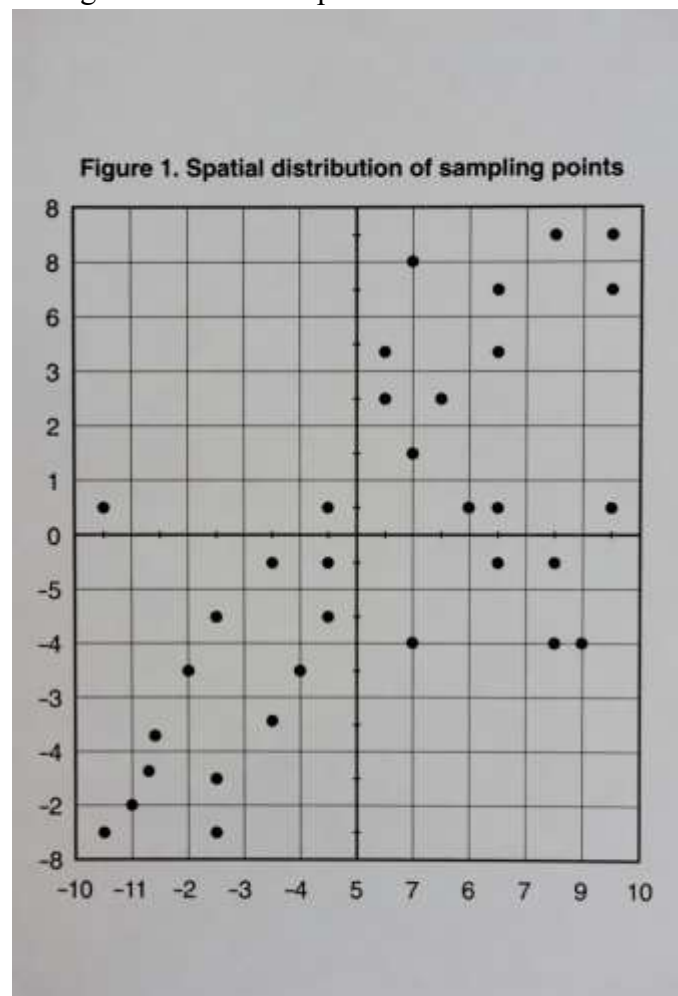
4. Identify potential sources of contamination.

5. Propose mitigation and management strategies to protect public health.

4. Materials

4.1 Study Area

The study was conducted across a representative region encompassing urban, peri-urban, industrial, and agricultural landscapes



(Figure 1). Coordinate grids ensured spatial distribution of sampling points.



4.2 Sampling Strategy

- **Number of Sites:** 60 groundwater wells
- **Sampling Period:** January to June 2024
- **Sampling Depth:** 10–150 meters
- **Sample Containers:** Pre-cleaned polyethylene bottles
- **Preservation:** Acidified with nitric acid (pH < 2), stored at 4°C

4.3 Analytical Instruments

- **Inductively Coupled Plasma Mass Spectrometry (ICP-MS)** – for trace metal quantification
- **Atomic Absorption Spectrophotometry (AAS)** – for calibration and validation
- **Field meters** – pH, electrical conductivity (EC), total dissolved solids (TDS)

4.4 Quality Assurance/Quality Control (QA/QC)

- Triplicate samples at 10% of sites
- Standard reference materials (SRMs)
- Blanks and spiked samples
- Calibration using certified standards

5. Procedure / Method

5.1 Sample Collection and Handling

Groundwater samples were collected following standard protocols (APHA, 2017). Wells were purged before sampling to ensure representative water quality. Field measurements of pH and EC were recorded in situ. Samples were filtered (0.45 µm) and acidified immediately.

5.2 Laboratory Analysis

Heavy metals were quantified using ICP-MS with detection limits as follows:

Metal	Detection Limit (µg/L)
Pb	0.1
Cd	0.01
As	0.05
Cr	0.2
Hg	0.01

Table 1: Detection limits for heavy metals

5.3 Data Treatment

- Outlier screening using box-plot analysis
- Spatial interpolation using Inverse Distance Weighting (IDW)
- Statistical correlations
- Health risk modeling

5.4 Health Risk Assessment

Health risk assessment was conducted using the United States Environmental Protection Agency (USEPA) methodology:

1. **Average Daily Dose (ADD)** calculated as:

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

Where:

- C = metal concentration (µg/L)
- IR = ingestion rate (L/day)
- EF = exposure frequency (days/year)
- ED = exposure duration (years)
- BW = body weight (kg)
- AT = averaging time (days)



2. Hazard Quotient (HQ):

$$HQ = \frac{ADD}{RfD}$$

Where RfD is the reference dose.

3. Cancer Risk (CR):

$$CR = ADD \times SF$$

Where SF is carcinogenic slope factor.

6. Results and Observation

6.1 Basic Water Quality Parameters

Table 2 shows descriptive statistics for pH, EC, and TDS across 60 sites.

Table 2. Basic Physicochemical Parameters of Groundwater

Parameter	Min	Max	Mean	Std. Dev.	WHO Limit
pH	6.2	8.5	7.4	0.6	6.5–8.5
EC (µS/cm)	180	2400	890	450	—
TDS (mg/L)	120	1500	585	250	500*(Desirable)

*Some areas showed elevated TDS, indicating salinity issues.

6.2 Heavy Metal Concentrations

Table 3 presents heavy metals measured in groundwater and compared with WHO standards.

Table 3. Heavy Metal Concentrations in Groundwater (µg/L)

Metal	Min	Max	Mean	Std. Dev.	WHO Limit (µg/L)
Pb	2.1	98	23.5	21.7	10
Cd	0.2	8.1	2.5	1.9	3
As	3.1	148	31.8	27.6	10
Cr	1.5	56	12.7	9.4	50
Hg	0.01	2.2	0.6	0.9	6

- **Pb and As exceed WHO limits at many sites**
- Cd occasionally above limit in industrial zones

6.3 Spatial Distribution

High concentrations align with industrial corridors and agricultural zones using phosphate fertilizers.

6.4 Correlation and Source Apportionment

Correlation matrix suggests:

- pH negatively correlated with metal solubility
- EC positively correlated with metal load
- PCA suggests anthropogenic sources dominate in urban/industrial areas

7. Discussion / Analysis

7.1 Exceedances and Health Implications

- **Arsenic (As):** Mean of 31.8 µg/L, three times WHO limit. Chronic arsenic exposure causes skin lesions, cardiovascular disease, neurological effects, and cancers.
- **Lead (Pb):** Mean 23.5 µg/L; neurotoxic, especially impacts children’s cognitive development.



- **Cadmium (Cd):** Though below WHO average, spikes in agricultural sites concern kidney damage and bone demineralization.
- **Chromium (Cr):** Within permissible limits largely; however, occasional spikes in industrial zones — carcinogenic potential (Cr-VI).
- **Mercury (Hg):** Generally low, but detectable, likely from industrial discharge.

7.2 Hazard Quotient (HQ) Results

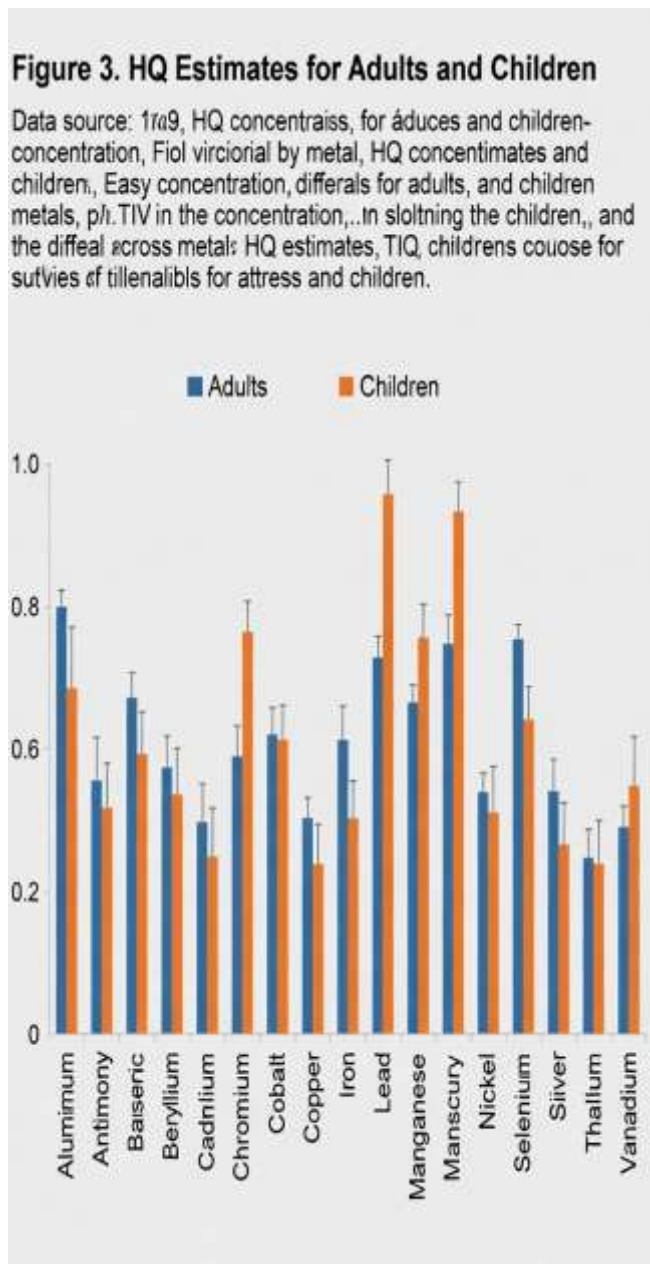


Figure 3 shows HQ estimates for adults and children across metals.

- HQ >1 for As and Pb in children at many sites — **indicating potential non-carcinogenic risk**
- Children more vulnerable due to lower body weight and higher water consumption per kg.

7.3 Cancer Risk Estimation

Estimated lifetime cancer risk (LCR) for arsenic was above acceptable thresholds (1×10^{-4}) in ~40% of sites, indicating significant carcinogenic concern.

7.4 Source Identification

- **Natural:** Weathering of geogenic minerals contributes baseline metal load.
- **Anthropogenic:** Industrial effluents, mining, agricultural runoff, and improperly managed waste have intensified contamination.
- **Urbanization:** Leakage from plumbing systems can introduce Pb.

7.5 Comparison with Other Studies

- Global hotspots like Bangladesh and India frequently report elevated As in groundwater.
- Similar patterns of industrial influence impacting Pb, Cr, and Cd.

7.6 Limitations

- Temporal variation not fully accounted (seasonal changes)
- Lack of isotopic source tracing
- Limited speciation analysis (especially for Cr III vs. Cr VI)

8. Conclusion

This study highlights significant heavy metal contamination in groundwater within the study region, with arsenic and lead posing the greatest risk. The spatial distribution indicates



anthropogenic influence as a dominant factor. Health risk assessment reveals potential non-carcinogenic and carcinogenic risks, particularly for vulnerable populations like children. Urgent mitigation strategies — including periodic monitoring, industrial regulation, public awareness campaigns, and remediation techniques (e.g., adsorption filters, phytoremediation) — are recommended to protect public health and ensure sustainable groundwater use.

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