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Heavy Metal Contamination in Groundwater of Industrial Areas: A Case Study from Gujarat

Dr. Pawan Kumar Yadav
Consultant (R&D)
Central University of Rajasthan

Abstract

Groundwater, a critical resource for drinking and irrigation, is increasingly under threat due to industrial pollution, particularly in rapidly industrializing regions such as Gujarat, India. This study investigates the extent of heavy metal contamination in the groundwater of selected industrial areas in Gujarat, focusing on key metals such as lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni), which are commonly associated with industrial effluents. Using standard sampling and analysis protocols, groundwater samples were collected from borewells and hand pumps located near industrial clusters in Ankleshwar, Vapi, Vatva, and Rajkot. Atomic Absorption Spectroscopy (AAS) was employed for quantifying metal concentrations, and the results were compared against World Health Organization (WHO) and Bureau of Indian Standards (BIS) limits. A detailed questionnaire-based survey was also conducted among local residents to evaluate public awareness, health impacts, and dependence on groundwater. The findings reveal that heavy metal concentrations in several locations far exceed safe limits, posing serious environmental and public health risks. The study emphasizes the urgent need for policy intervention, industrial regulation, and sustainable water management practices in industrial zones.

Keywords: Groundwater pollution, heavy metals, industrial contamination, Gujarat, lead, cadmium, chromium, environmental health, water quality, atomic absorption spectroscopy, public awareness

Introduction

Groundwater is an indispensable natural resource, especially in developing countries where it supports domestic, agricultural, and industrial activities. In India, over 60% of irrigation and 80% of drinking water needs are met by groundwater. However, rapid industrialization, particularly in states like Gujarat, has led to significant environmental degradation, including the pollution of this critical resource. Industrial units such as those involved in pharmaceuticals, textiles, dye manufacturing, petrochemicals, and metal plating often release untreated or partially treated effluents into nearby soils and water bodies. These effluents contain a wide array of heavy metals that are non-biodegradable, bioaccumulative, and toxic even at trace concentrations.

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni) are of particular concern due to their persistent nature and adverse health effects. Prolonged exposure to these metals through contaminated groundwater can result in neurological disorders, kidney damage, skeletal problems, and increased risk of cancer. Despite the alarming consequences, there is limited enforcement of environmental norms, and monitoring remains sporadic.

This study focuses on industrial clusters in Gujarat, which have been identified as pollution hotspots by the Central Pollution Control Board (CPCB). The research aims to assess the concentration of heavy metals in groundwater sources near industrial estates, analyze spatial variations, evaluate potential health risks, and document the community's awareness and response to water contamination. The findings are expected to inform both local governance and environmental agencies for corrective measures and sustainable groundwater management.

Methodology

4.1 Study Area

The study was conducted in four major industrial zones of Gujarat: Ankleshwar (Bharuch district), Vapi (Valsad district), Vatva (Ahmedabad district), and Rajkot. These areas were selected based on their high density of industrial units and previous records of environmental violations.

4.2 Sampling Strategy

A total of 40 groundwater samples were collected—10 from each industrial region. Samples were drawn from public borewells, hand pumps, and tubewells used for drinking and domestic purposes. Sampling was done in sterile polyethylene bottles, pre-treated with nitric acid to avoid contamination, and stored at 4°C.

4.3 Analytical Methods

The samples were analyzed for heavy metals—Pb, Cd, Cr, and Ni—using Atomic Absorption Spectroscopy (AAS) as per APHA (American Public Health Association) guidelines. Supporting parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and hardness were measured on-site using standard portable kits.

4.4 Risk Assessment

To evaluate the health risk, the Hazard Quotient (HQ) and Hazard Index (HI) were calculated based on USEPA models. HQ >1 indicates potential health risks due to non-carcinogenic exposure. Age-specific risks were considered for children and adults.

4.5 Questionnaire Survey

A structured questionnaire was administered to 200 households (50 from each region) to assess community awareness, dependence on groundwater, health complaints, and local water treatment practices. Data were analyzed using descriptive statistics.

5. Data Analysis

5.1 Heavy Metal Concentration

The analysis revealed that heavy metal concentrations in many samples exceeded the permissible limits set by WHO and BIS:

Metal	WHO Limit (µg/L)	Range Observed (µg/L)	Mean (µg/L)
Pb	10	5 – 98	42.3
Cd	3	0.5 – 6.4	2.1
Cr	50	12 – 168	75.2
Ni	20	8 – 62	28.6

Lead and chromium were found to be the most prevalent contaminants, with over 60% of samples exceeding permissible limits.

5.2 Spatial Trends

- **Ankleshwar and Vapi** showed the highest levels of Cr and Pb, likely due to the presence of dye, electroplating, and chemical industries.
- **Vatva** recorded elevated levels of Ni, correlated with nearby machinery manufacturing units.
- **Rajkot** showed relatively moderate contamination, with some samples within safe limits.

5.3 Health Risk Analysis

The calculated HQ values for Pb and Cr were >1 in over 40% of the samples, especially in children, indicating high health risk. The Hazard Index (HI), representing cumulative risk, exceeded 1 in 22% of all sampled locations.

6. Case Study: Ankleshwar Industrial Estate

Ankleshwar, located in the Bharuch district, is one of Asia's largest industrial clusters with over 1,500 chemical and pharmaceutical units. Field visits revealed improper waste handling, with effluents often being discharged into open drains or unlined canals. Residents in adjoining areas rely primarily on borewell water for drinking and cooking.

Water samples from this area exhibited:

- **Lead levels up to 98 µg/L**
- **Chromium levels up to 150 µg/L**
- **Cadmium levels up to 5.2 µg/L**

Household interviews reported increased cases of skin allergies, gastrointestinal problems, and joint pain. Many residents complained of discoloration and odor in water but continued using it due to the absence of alternative sources. The local municipal body has limited infrastructure for groundwater testing and lacks awareness programs. This case underscores the grave consequences of unregulated industrial activity on environmental and public health.

Questionnaire and Tables

The community survey revealed critical insights into local water usage and perceptions:

Table 1: Groundwater Usage and Awareness (n = 200)

Question	Yes (%)	No (%)
Do you use groundwater for drinking?	89%	11%
Are you aware of any contamination in your water supply?	24%	76%
Have you ever tested your water quality?	12%	88%
Do you use any filtration or boiling before drinking?	31%	69%

Table 2: Health Symptoms Reported by Residents

Symptom	% Respondents Reporting
Skin allergies and irritation	39%
Digestive issues (nausea, ulcers)	45%
Headaches or fatigue	28%
No noticeable symptoms	18%

The majority of respondents had never tested their water or received any information from local authorities regarding its quality. This highlights a major communication and governance gap in public health protection.

Conclusion

The study confirms the widespread presence of heavy metal contamination in the groundwater of Gujarat's industrial zones, particularly for lead and chromium. Concentrations at several sites are alarmingly high, posing severe threats to human health, especially among children. The absence of consistent monitoring, poor waste disposal practices, and lack of public awareness contribute to the growing crisis.

The research underscores the need for:

1. Regular and mandatory groundwater monitoring programs.
2. Strict enforcement of effluent treatment guidelines for industries.
3. Public health campaigns to educate communities about safe water practices.
4. Government intervention to provide alternative water sources in critically affected areas.

The findings call for an integrated approach involving environmental agencies, health departments, local municipalities, and industries to ensure sustainable and safe groundwater usage in industrial regions.

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