ASSESSMENT OF HEAVY METAL CONTAMINATION AND GEOCHEMICAL BEHAVIOR IN GROUNDWATER NEAR INDUSTRIAL ZONES OF MORADABAD, INDIA

[*1]Shivam Agarwal,

[1]Assistant Professor, Teerthanker Mahaveer University College of Paramedical Sciences, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India-244001.

shivamagarwal50283@gmail.com[1]

Corresponding Author: Shivam Agarwal,
Email: shivamagarwal50283@gmail.com

Abstract
Background: Industrial activities release significant quantities of heavy metals into the environment, contaminating groundwater and posing serious health risks. Moradabad, known for electroplating, brassware manufacturing, and allied industries, is vulnerable to such contamination.
Materials and Methods: A total of 50 groundwater samples were collected from bore wells and hand pumps across industrial and adjoining residential areas. Lead (Pb), cadmium (Cd), and hexavalent chromium (Cr^{6+}) concentrations were determined using Atomic Absorption Spectrophotometry (AAS), while pH and sulfate (SO_4^{2-}) were measured using standard APHA methods. Statistical analysis included descriptive statistics and Pearson's correlation (SPSS v26).
Results: Mean concentrations of Pb (0.051 ± 0.010 mg/L), Cd (0.010 ± 0.002 mg/L), and Cr^{6+} (0.071 ± 0.015 mg/L) exceeded BIS permissible limits in several samples. pH ranged from 6.6 to 7.8 (mean 7.1 ± 0.3) and sulfate averaged 148.6 ± 27.5 mg/L. Significant correlations were observed between Pb and Cd ($r = 0.825$, $p < 0.001$) and between SO_4^{2-} and Cr^{6+} ($r = 0.689$, $p < 0.001$), indicating common industrial sources. A negative correlation between pH and Cr^{6+} ($r = -0.472$, $p = 0.002$) suggested increased chromium mobility under mildly acidic conditions.
Conclusion: Groundwater in Moradabad's industrial vicinity is contaminated with Pb, Cd, and Cr^{6+}, primarily from anthropogenic sources such as electroplating and alloy manufacturing. Continuous monitoring, industrial effluent control, and community-level awareness programs are essential to mitigate health and environmental risks.

Keywords: Heavy metal contamination, groundwater quality, industrial pollution, geochemical behavior, Moradabad, India

Introduction

Groundwater serves as a critical source of drinking water, agricultural irrigation, and industrial operations, particularly in regions with limited access to safe surface water (1). However, increasing industrialization and unregulated anthropogenic activities have led to a substantial decline in groundwater quality, primarily due to the leaching of toxic contaminants, including heavy metals (2). These metals—especially lead (Pb), cadmium (Cd), and hexavalent chromium (Cr^{6+})—are non-biodegradable, persistent in the environment, and capable of bioaccumulating through food chains, posing significant ecological and human health risks (3). In industrial cities such as Moradabad, Uttar Pradesh, India, the situation is particularly critical due to widespread metal processing industries, including brassware manufacturing, and electroplating units (4). These activities contribute to potential heavy metal contamination in the subsurface aquatic systems, either through direct discharge of industrial effluents or via leaching from improperly disposed solid and liquid waste (5). While numerous studies have assessed groundwater quality in urban environments, there is a dearth of localized assessments focused on the chemical behavior of heavy metals and their interaction with geochemical parameters in Moradabad . Therefore, this study aims to evaluate the concentration of selected heavy metals (Pb, Cd, Cr^{6+}) and key water quality indicators (pH and sulfate) in groundwater samples collected from industrially influenced zones.

Materials and Methods

The study was conducted in the industrial zones of Moradabad, Uttar Pradesh, India—an area well known for its metal-based industries, particularly brassware manufacturing and electroplating, which are potential sources of heavy metal contamination. A total of 50 groundwater samples were collected from borewells and hand pumps located near potential contamination sources. Samples were collected in acid-washed HDPE bottles, pre-rinsed with the respective water source. To preserve heavy metals, samples were acidified in situ with concentrated HNO_3 ($pH < 2$) and stored at 4°C until analysis.

The study focused on five parameters: Pb, Cd, hexavalent Cr^{6+}, pH, and SO_4^{2-}. Heavy metals were quantified using Atomic Absorption Spectrophotometry (AAS) following APHA (2017) protocols. pH was measured in the field using a calibrated portable pH meter, while sulfate was estimated via turbidimetric method using spectrophotometry.

Descriptive statistics (mean, SD) were applied to all parameters. Shapiro-Wilk tests assessed normality. Pearson's correlation was used to determine relationships among variables, and one-way ANOVA was conducted to evaluate the influence of pH on Pb concentration. Statistical analyses were performed using SPSS to ensure accurate interpretation of geochemical behavior.

Result and Discussion

The analysis of groundwater samples revealed concerning levels of heavy metal contamination in the study area **(Table 1)**. Pb concentrations averaged 0.051 ± 0.010 mg/L, exceeding the Bureau of Indian Standards (BIS) permissible limit of 0.01 mg/L in the majority of sampling locations. Cd was detected at a mean level of 0.010 ± 0.002 mg/L, surpassing the BIS guideline value of 0.003 mg/L in several sites. Cr^{6+} exhibited the highest contamination, with a mean concentration of 0.071 ± 0.015 mg/L, also above the BIS limit of 0.05 mg/L. Such elevated levels strongly suggest significant anthropogenic inputs, particularly from industrial activities such as electroplating, alloy manufacturing, and improper battery disposal practices in the region (6). These findings are consistent with reports by Prajapati et al. (2025) and Meena and Meena (2023), who also observed elevated Pb, Cd, and Cr^{6+} levels in groundwater near industrial clusters in northern India, linking them to effluent discharge and solid waste leaching (7,8).

Table 1: Descriptive Statistics of Heavy Metal Concentrations in Groundwater (n = 50)

Parameter	**Mean ± SD (mg/L)**	**BIS Permissible Limit (mg/L)**
Lead (Pb)	0.051 ± 0.010	0.01
Cadmium (Cd)	0.010 ± 0.002	0.003
Chromium (Cr^{6+})	0.071 ± 0.015	0.05

BIS = Bureau of Indian Standards. All values expressed in mg/L.

Physicochemical assessment indicated that pH ranged from 6.6 to 7.8, with a mean of 7.1 ± 0.3, reflecting mildly acidic to slightly alkaline conditions. Although these values fall within the acceptable BIS range (6.5–8.5), even slight reductions in pH may increase the solubility and mobility of certain metals, particularly chromium **(Table 2).** Sulfate (SO_4^{2-}) concentrations averaged 148.6 ± 27.5 mg/L, remaining within the BIS permissible limit of 200 mg/L, yet higher levels at specific locations point towards industrial effluent contributions. Similar sulfate enrichment associated with industrial discharge was reported by Agrawal et al. (2021) in groundwater around electroplating industries (9).

Table 2: Descriptive Statistics of Physicochemical Parameters (n = 50)

Parameter	Mean ± SD	BIS Permissible Limit
pH	7.1 ± 0.3	6.5–8.5 (acceptable range)
Sulfate (SO_4^{2-})	148.6 ± 27.5 mg/L	200 mg/L

pH is dimensionless. Sulfate values are reported in mg/L.

Correlation analysis provided further insight into the geochemical relationships **(Table 3)**. A strong positive correlation between sulfate and Cr^{6+} ($r = 0.689$, $p < 0.001$) supports the hypothesis of a shared industrial source, most likely chrome-plating operations that release both sulfate-rich effluents and chromium compounds. A strong association between Pb and Cd ($r = 0.825$, $p < 0.001$) suggests co-leaching or a common waste source, in agreement with observations by Bai et al. (2024) in industrial zones with alloy processing units (10). Additionally, a weak but statistically significant inverse correlation between pH and Cr^{6+} ($r = -0.472$, $p = 0.002$) indicates that slightly acidic conditions could enhance the solubility of chromium species, increasing their potential mobility and bioavailability—an effect also noted by Chowdhury et al. (2024) in contaminated aquifers (11).

Table 3. Pearson's correlation coefficients (*r*) and significance values (*p*) between heavy metals and physicochemical parameters in groundwater samples (n = 50).

Parameter 1	Parameter 2	r (Pearson)	p-value
SO_4^{2-}	Cr^{6+}	0.689	<0.001
Pb	Cd	0.825	<0.001
pH	Cr^{6+}	–0.472	0.002

Pb	Cr^{6+}	0.392	0.006
Cd	Cr^{6+}	0.375	0.008

Positive *r* values indicate direct relationships; negative values indicate inverse relationships. A $p < 0.05$ was considered statistically significant.

Overall, the combination of elevated heavy metal concentrations, supportive physicochemical conditions, and significant correlations points to industrial effluents as the dominant source of contamination. These results align with previous studies across industrialized regions of India and emphasize the urgent need for stricter effluent management and continuous groundwater monitoring to mitigate health and ecological risks.

Conclusion

The present study highlights significant heavy metal contamination in groundwater near industrial zones of Moradabad, with Pb, Cd, and Cr^{6+} concentrations in several locations exceeding BIS permissible limits. The strong positive correlations between Pb–Cd and SO_4^{2-}–Cr^{6+} point toward common industrial origins, particularly electroplating, alloy manufacturing, and battery-related activities. The observed inverse relationship between pH and Cr^{6+} further indicates that slightly acidic conditions may enhance the solubility and mobility of chromium species, exacerbating contamination risks. These findings emphasize the urgent need for regular groundwater quality monitoring, stringent enforcement of industrial effluent treatment regulations, and remediation measures to protect public health and environmental sustainability.

Reference

1. Murray W. Importance, characteristics, and challenges of groundwater.
2. Sharma R, Kumar R, Agrawal P, Bhardwaj I, Kaushik C, Gupta G. Groundwater extractions and climate change. In 2021. p. 23–45.
3. Balali-Mood M, Naseri K, Tahergorabi Z, Khazdair MR, Sadeghi M. Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. Front Pharmacol. 2021 Apr 13;12:643972.
4. Admin. Main Industries and Major Industrial Centers of Uttar Pradesh [Internet]. UPPCS MAGAZINE. 2025 [cited 2025 Aug 8]. Available from: https://uppcsmagazine.com/main-industries-and-major-industrial-centers-of-uttar-pradesh/
5. Okonji G, Nyambaka K. A comprehensive review of heavy metals in aquatic environments.
6. 1.-BIS-Presentation-on-IS-10500-2012-Drinking-Water-1.pdf [Internet]. [cited 2025 Aug 8]. Available from: https://master-jalshakti-ddws.digifootprint.gov.in/static/uploads/2024/03/1.-BIS-Presentation-on-IS-10500-2012-Drinking-Water-1.pdf
7. Meena R, Meena SK. A Comprehensive Assessment of Heavy Metal Contamination and Their Correlation in Groundwater Samples Collected from Kota District of Northern Rajasthan, India. IJSRM. 2023;25(1):70–9.
8. Prajapati A, Tanwar D, Yadav S, Bajar S. Assessment of heavy metal contamination and seasonal variability in groundwater of Indian NCR: Geospatial and statistical approach. Cleaner Water. 2025 Dec 1;4:100107.
9. Agrawal P, Singhal S, Sharma R. Heavy Metal Contamination in Groundwater Sources. In 2021. p. 57–78.

10. Bai Z, Hou X, Li X, Wang Z, Zhang C, Gui C, et al. Hydrogeochemical Characteristics and Sulfate Source of Groundwater in Sangu Spring Basin, China. Water. 2024 Jan;16(20):2884.
11. Chowdhury S, Mazumder MAJ, Al-Attas O, Husain T. Heavy metals in drinking water: Occurrences, implications, and future needs in developing countries. Science of The Total Environment. 2016 Nov 1;569–570:476–88.