Bioscience Discovery, 17(1):01-08, January - 2026

Open Access, Peer Reviewed, Referred Research Journal

Print & Online available on https://jbsd.in

ISSN: 2229-3469 (Print); ISSN: 2231-024X (Online)

Research Article

Geochemical and Environmental Evaluation of Heavy Metal Contamination in Soils of Jalna District, Maharashtra

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Article Info

Received: 10-09-2025,
Revised: 15-11-2025,
Accepted: 28-12-2025

Keywords: Arsenic, heavy metals, Jalna district, soil contamination, trace elements

Abstract

Results revealed notable spatial variance in heavy metal concentrations across the study area. Elevated levels of Cu, Ni, Zn, Cd, Co, and Cr were observed at several locations, particularly in industrial and semi-urban zones, demonstrating a significant human influence. Iron exhibited naturally high concentrations due to geogenic sources. Arsenic and mercury remained within permissible limits in most samples, suggesting limited contamination. One industrial site exhibited exceptionally high concentrations of multiple metals, recognising it as a hotspot for contamination. The study highlights the necessity of ongoing observation, effective waste management strategies, and implementation of regulatory measures to prevent further deterioration of soil quality and associated ecological risks.

INTRODUCTION

An integral part of the terrestrial ecosystem is soil. and plays a vital role in sustaining plant growth, regulating nutrient cycles, and maintaining ecological balance. In recent decades, soil quality has deteriorated significantly due to increased anthropogenic activities such as industrialization, urbanization, and intensive agriculture (Alloway, 2007). Among various soil pollutants, particularly concerning heavy metals. because of their persistence, toxicity, and ability to accumulate in soils over long periods (Nriagu, 1979).

Metallic elements are referred to as heavy metals with relatively high atomic weight and density that can exert toxic effects even at low concentrations (Kabata-Pendias, 2011). In contrast to organic contaminants, heavy metals do not undergo biodegradation and therefore remain in the environment for extended durations (Alloway, 2007). Some metals such as iron, copper, zinc, and cobalt are essential micronutrients for plants and microorganisms at trace levels, but become toxic when present in excess, whereas metals such as cadmium, lead, mercury, and arsenic are non-essential and highly toxic even at very low concentrations (Alloway, 2007).

The principal human-caused sources of heavy metal pollution in soils include industrial effluents, mining and smelting operations, fossil fuel combustion, vehicular emissions, agricultural fertilizers and pesticides, sewage sludge application, and improper disposal of municipal and industrial wastes (Govil *et al*., 2001). Once introduced into the soil, heavy metals may bind to clay minerals, organic matter, and oxides of iron and manganese. The mobility and bioavailability of metals are significantly influenced by soil characteristics as pH, cation exchange capacity, organic carbon content, and redox conditions (Alloway, 2007).

Soil pollution by heavy metals has detrimental effects for agriculture and food security. Metals such as cadmium, lead, chromium, and nickel can be readily taken up by plants and enter the food chain, resulting in potential health risks to humans and animals (Garcia and Millan, 1998). Long-term exposure to heavy metals has been associated with kidney dysfunction, neurological disorders, skeletal damage, cardiovascular diseases, and carcinogenic effects (De Vries *et al*., 2007).

India's fast industrial expansion combined with unplanned urban development has intensified soil pollution, particularly in semi-urban and industrializing regions (Krishna and Govil, 2005). Elevated amounts have been found in several studies of heavy metals in soils near industrial estates, highways, and agricultural fields receiving chemical inputs (Li *et al*., 2001; Govil *et al*., 2001). Maharashtra, one of the most industrialized states in India, faces increasing environmental pressure due to expanding industrial activities.

Jalna district, located in the Marathwada region of Maharashtra, has witnessed substantial industrial and infrastructural development during the last two decades. The district hosts agro-based industries, mechanical workshops, metal fabrication units, and expanding residential areas. Improper waste disposal practices, untreated industrial discharges, and increasing vehicular traffic are suspected to contribute to soil contamination in the region (Govil *et al*., 2001). However, methodical and data-driven research on soil heavy metal contamination in Jalna district remain limited.

Therefore, the present study aims to (i) determine the concentration of selected heavy metals in soils of Jalna district, (ii) evaluate their spatial distribution across different land-use patterns, and (iii) assess contamination levels by comparison with international soil quality guidelines. The study offers baseline data for environmental monitoring and sustainable land management in the region.

MATERIALS AND METHODS

Study area

The study area comprises selected locations within Jalna district, Maharashtra. The region experiences a semi-arid climate and supports agricultural, residential, and industrial activities. Sampling sites were selected to represent diverse land-use patterns.

Soil sampling

In December 2023, twelve soil samples were taken at random from residential, agricultural, and industrial regions. To simulate surface soil conditions, samples were taken at a depth of around 15 cm. To prevent contamination, clean plastic instruments were utilised.

Sample preparation

Collected soil samples were dried by air at ambient temperature, homogenized, and sieved to remove stones and organic debris. The processed samples were stored in clean polyethylene containers prior to analysis.

Analytical determination

The concentrations of As, Cu, Co, Cd, Fe, Hg, Ni, Zn, Pb, and Cr were determined using typical analytical techniques (Alloway, 2007). Results were expressed as mg kg^{-1} dry soil. Analytical quality control was guaranteed. using reagent blanks, standard solutions, and calibration procedures.

Data evaluation

The measured concentrations were compared with Swedish and Canadian guidelines for soil quality for polluted soils to assess contamination status (USEPA, 2000).

RESULTS AND DISCUSSION

General distribution of heavy metals in soils

The concentrations of heavy metals determined in soil samples from Jalna district exhibited significant spatial variation, reflecting the combined influence of geogenic background and anthropogenic activities (Govil *et al*., 2001). In general, industrial and semi-urban locations showed increased concentrations of metals compared to agricultural areas, indicating the impact of industrial effluents, waste dumping, and urban activities on soil quality.

The concentration data of individual heavy metals are presented in Table 1 and Table 2, while their distribution patterns are illustrated through graphical representations (Fig. 1 and Fig. 2).

3.2 Concentration of As, Cu, Co, Cd and Fe

Arsenic (As)

Arsenic concentrations ranged from 0.08 to 10.7 mg kg^{-1}. Most samples showed low to moderate as levels and remained within the prescribed guideline values (Sweden Environmental Protection Agency, 2002). Slightly elevated concentrations observed in a few samples may be attributed to agricultural inputs or natural mineral weathering processes (Kabata-Pendias, 2011). The relatively uniform distribution of as indicates minimal human-caused pollution in the study area.

Table 1. Concentration of As, Cu, Co, Cd and Fe (mg kg⁻¹) in soil samples

Sample No.	As (mg/kg)	Cu (mg/kg)	Co (mg/kg)	Cd (mg/kg)	Fe (mg/kg)
1	3.25	118	79.4	36.8	67,200
2	3.9	179	7.2	40.1	73,500
3	7.1	97.8	52.1	25.5	45,300
4	6.8	143	74.5	33.1	67,900
5	10.7	161	49.2	22.1	40,100
6	1.5	54.2	65.0	28.1	52,900
7	ND	159	61.5	30.4	49,600
8	ND	166	39.3	20.2	31,500
9	ND	366	94.8	37.1	47,300
10	ND	118	53.3	27.9	46,100
11	0.08	91.5	82.1	31.4	44,900
12	ND	201	67.5	34.2	52,200
CGV	12	63	-	10	-
SGV	100	5	30	0.4	-
SGV	Swedish guideline values for levels in polluted soils (mg kg-1)				
CGV	Canadian soil quality guidelines for polluted soils (mg kg-1)				
N.D.	Not Detected				

Table 1 presents the concentrations of arsenic (As), copper (Cu), cobalt (Co), cadmium (Cd) and iron (Fe) in soil samples collected from different locations of Jalna district.

Copper (Cu)
Copper exhibited a wide concentration range from 54.2 to 366 mg kg^{-1}, with the highest values recorded at industrial locations. Elevated Cu concentrations are commonly associated with industrial effluents, electrical waste, and agricultural chemicals (Govil *et al*., 2001; Li *et al*., 2001). The pronounced enrichment at specific sites indicates localised human-caused inputs.

Cobalt (Co)
Cobalt concentrations varied between 7.2 and 94.8 mg kg^{-1}. Higher Co levels at certain locations may reflect the combined influence of lithogenic sources and industrial activities (Kabata-Pendias, 2011). The observed variability suggests both natural soil composition and contributions brought about by humans.

Cadmium (Cd)

Cadmium concentrations ranged from 20.2 to 40.1 mg kg⁻¹ and surpassed standard values at several locations (Sweden Environmental Protection Agency, 2002). Cadmium contamination is often linked to phosphate fertilizers, industrial wastes, and sewage sludge application (Govil *et al*., 2001). The widespread occurrence of Cd across samples indicates dispersed anthropogenic defect.

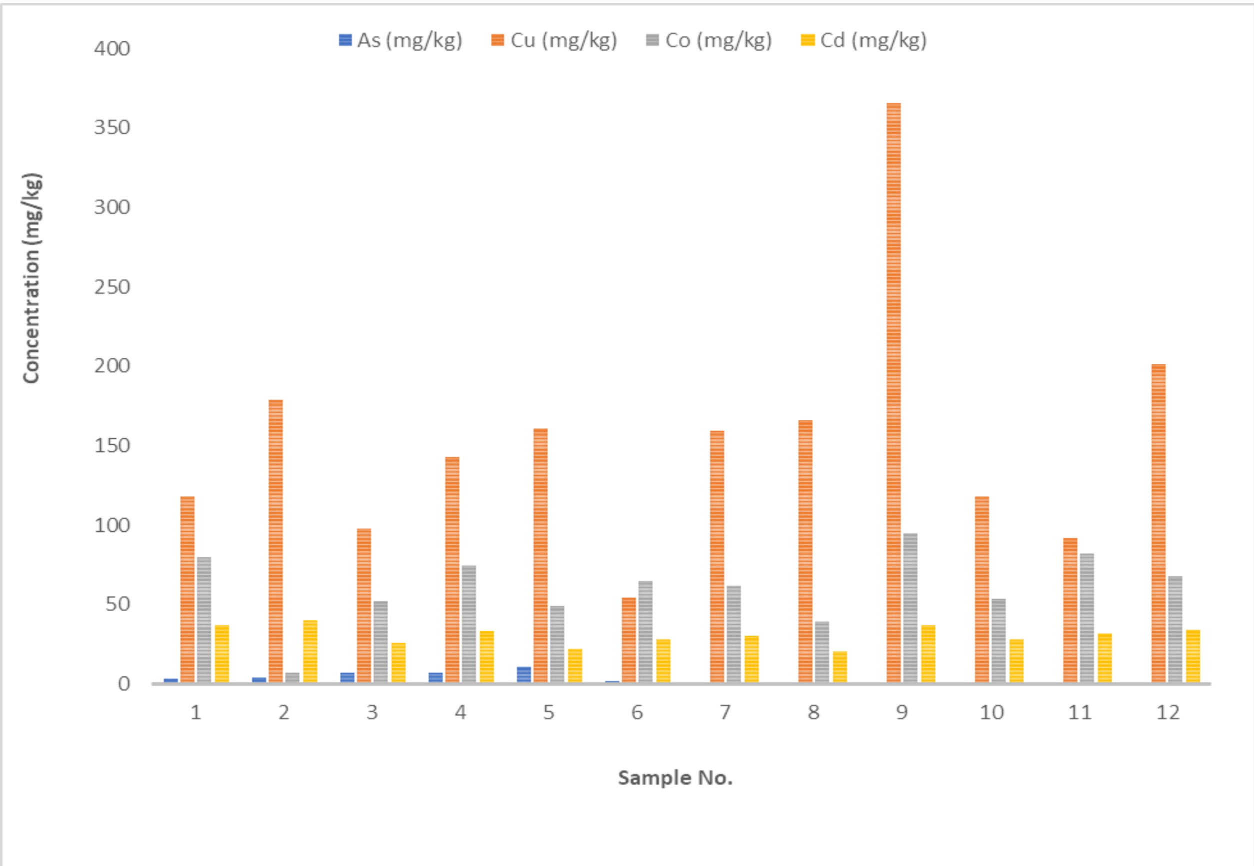
Iron (Fe)

Iron exhibited the highest concentrations among all analysed metals, ranging from 31,500 to 73,500 mg kg⁻¹. Such elevated levels are typical of natural soils and reflect the mineralogical composition of the region (Kabata-Pendias, 2011). Variations in Fe concentration are mainly attributed to geogenic influences rather than anthropogenic inputs.

Graphical representation of As, Cu, Co and Cd

The variation in concentrations of As, Cu, Co and Cd across sampling locations is illustrated in Fig. 1. The graphical representation clearly shows enrichment of Cu, Co and Cd at industrial locations, particularly Sample 9, enhancing localized anthropogenic impact.

Fig. 1. Graphical representation of As, Cu, Co and Cd



Mercury (Hg)

Mercury concentrations in the studied soil samples were relatively low, ranging from 1.2 to 1.6 mg kg⁻¹, and were detected only at a few locations. The limited occurrence and low concentration levels of Hg indicate minimal contamination in the study area. Such levels may be attributed to atmospheric deposition or small-scale combustion activities rather than direct industrial inputs (**Nriagu, 1979**).

Nickel (Ni)

Nickel concentrations exhibited pronounced spatial variability, with values ranging from 80.6 to 701 mg kg⁻¹. Significantly elevated Ni concentrations were observed at industrial locations, suggesting contamination arising from metal processing units, mechanical workshops, and improper disposal of industrial wastes (Govil *et al*., 2001). The wide variation indicates strong localized anthropogenic influence.

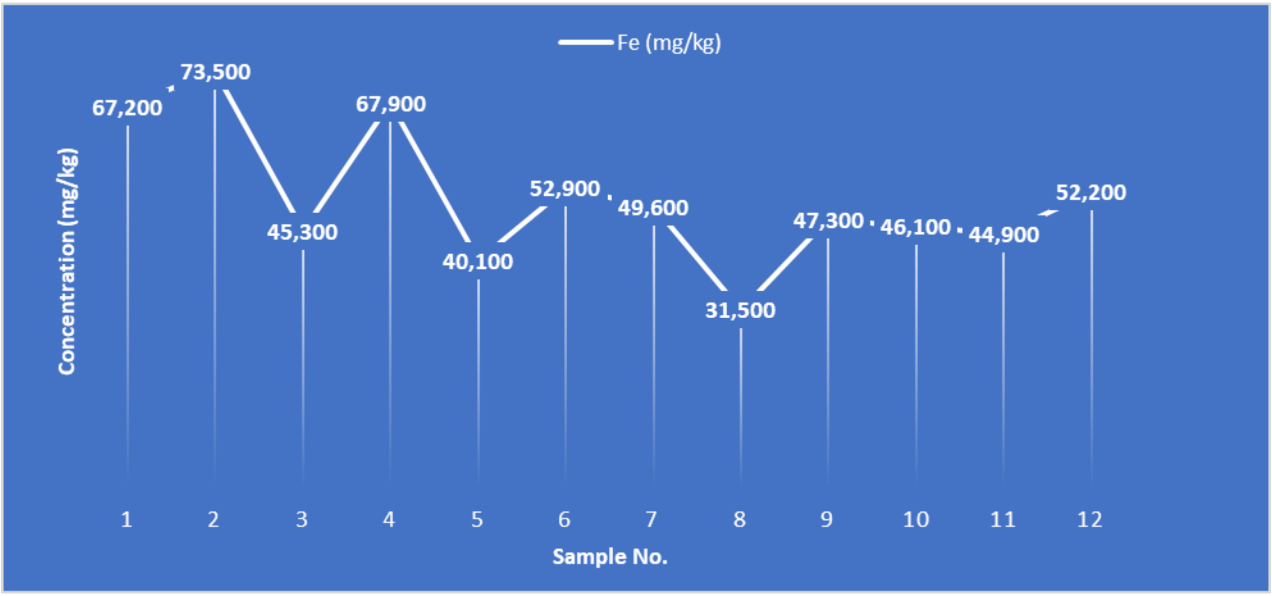


Fig. 1. Variation of As, Cu, Co and Cd concentrations (mg kg⁻¹) in soil samples of Jalna district.

Concentration of Hg, Ni, Zn, Pb and Cr

The concentrations of mercury (Hg), nickel (Ni), zinc (Zn), lead (Pb) and chromium (Cr) in soil samples are presented in **Table 2**.

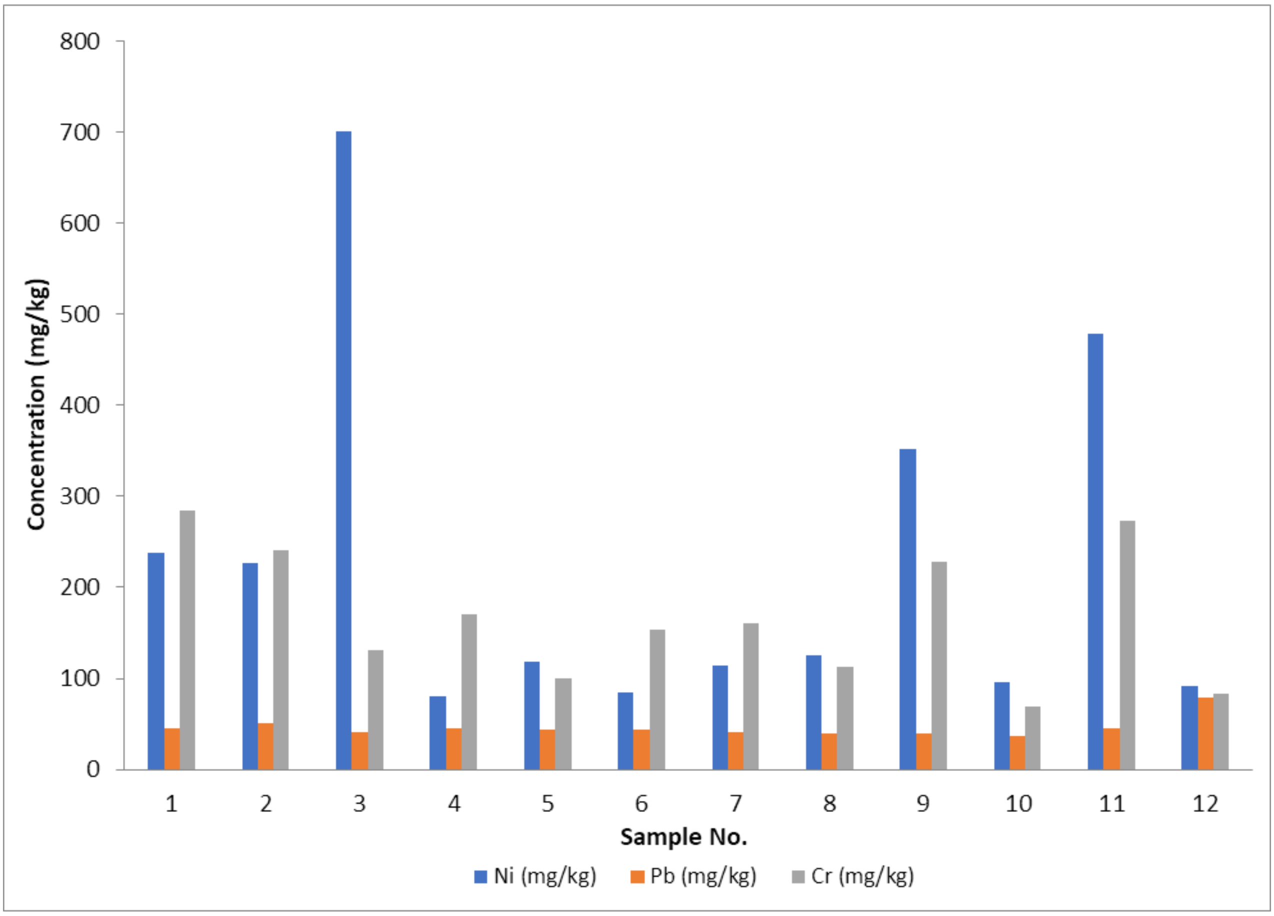
Table 2. Concentration of Hg, Ni, Zn, Pb and Cr (mg kg^{-1}) in soil samples

Sample No.	Hg (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Cr (mg/kg)
1	1.4	238	81.2	45.1	284.3
2	1.6	227	89.4	50.6	240.7
3	1.2	701	64.9	41.0	131.5
4	1.2	80.6	95.7	45.0	170.2
5	1.2	118	137	44.2	100.6
6	1.3	84.7	67.3	43.7	154.1
7	ND	114	158	41.5	160.8
8	ND	125	182	39.2	112.4
9	ND	352	7085	39.8	228.7
10	ND	96.0	75.2	36.7	68.9
11	ND	478	91.6	44.5	273.2
12	ND	92.1	121	78.3	83.1
CGV	6.6	50	200	140	64
SGV	1.0	35	350	80	120
SGV	Swedish guideline values for levels in polluted soils (mg kg-1)				
CGV	Canadian soil quality guidelines for polluted soils (mg kg-1)				
N.D.	Not Detected				

Zinc (Zn)
Zinc showed the widest concentration range among all analyzed metals, varying from 64.9 to 7085 mg kg^{-1}. Exceptionally high Zn concentration recorded at Sample 9 clearly identifies this site as a severe contamination hotspot. Such elevated Zn levels are commonly associated with galvanization processes, industrial effluents, and indiscriminate waste dumping practices (Li *et al*., 2001).

Lead (Pb)
Lead concentrations in the soil samples ranged from 36.7 to 78.3 mg kg^{-1}, indicating moderate contamination across the study area. The presence of Pb is mainly attributed to vehicular emissions, battery waste, urban runoff, and deterioration of lead-containing materials (Govil *et al*., 2001). Although Pb levels were lower than some guideline values, their persistence poses potential long-term environmental risks.

Chromium (Cr)
Chromium concentrations ranged from 68.9 to 284.3 mg kg^{-1} and exceeded guideline values at most sampling locations. Elevated Cr levels are commonly linked to industrial effluents, sewage discharge, and improper waste management practices (Kabata-Pendias, 2011; Amrhein *et al*., 1992). The widespread occurrence of Cr suggests continuous anthropogenic input and highlights the need for effective regulatory control.



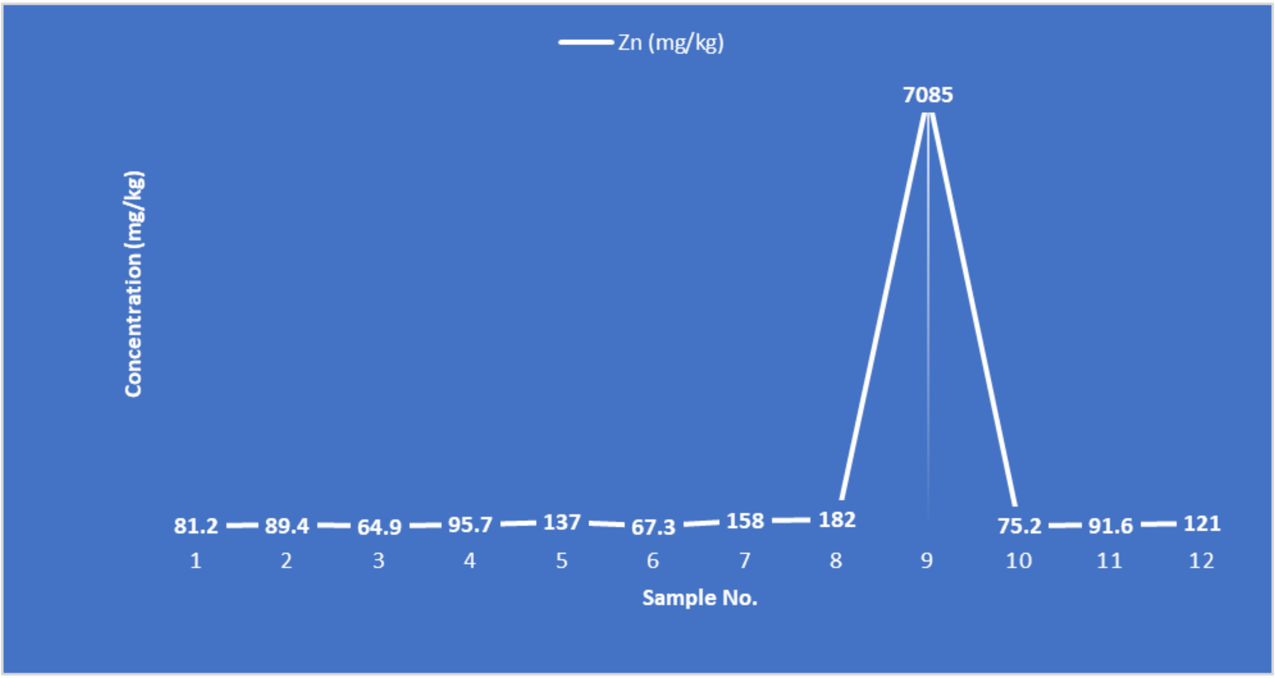


Fig. 2. Variation of Hg, Ni, Zn, Pb and Cr concentrations (mg kg^{-1}) in soil samples of Jalna district.

CONCLUSION

The present investigation reveals that soils of Jalna district are affected by varying degrees of heavy metal contamination. Elevated concentrations of Cu, Ni, Zn, Cd, Co, and Cr at several locations indicate significant anthropogenic influence, particularly from industrial activities, improper waste disposal, and agricultural practices. Arsenic and mercury remained within permissible limits in most samples, suggesting limited contamination from these elements. One industrial site emerged as a major contamination hotspot, exhibiting exceptionally high concentrations of multiple metals.

The findings highlight the urgent need for continuous soil quality monitoring, strict regulation of industrial effluent discharge, and implementation of sustainable land management practices. Remediation strategies should be prioritized at highly contaminated sites to prevent further environmental degradation and potential health risks.

ACKNOWLEDGEMENT

The author acknowledges the laboratory facilities and support provided by the Department of Chemistry, J. E. S. College Jalna.

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Cite this article

Shweta V. Patwari, Rashmi D. Pathrikar, Suresh T. More, Ratnamala T. More and Sunil R. Mirgane. 2026. Geochemical and Environmental Evaluation of Heavy Metal Contamination in Soils of Jalna District, Maharashtra. *Bioscience Discovery*, **17**(1):01-08.