

# Assessment of Heavy Metal Contamination and Statistical Evaluation of Industrial Soils in the Pithampur Industrial Area, India

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**Abstract** - Heavy metal contamination in industrial soil is a persistent environmental problem, as these metals do not degrade and accumulate in terrestrial ecosystems over the long term. This study investigated the concentrations, distribution, and contamination levels of six heavy metals (Cu, Ni, Cr, Pb, Mn and Zn) in soil samples collected from fifteen locations in the Pithampur industrial area of Madhya Pradesh, India. The soil pH ranged from slightly acidic to moderately alkaline, reflecting the diversity of industrial influences. The measured concentrations of Ni, Cr and Pb exceeded natural background levels at most locations, indicating significant anthropogenic enrichment. Descriptive statistics and Pearson correlation analysis revealed strong correlations between Ni and Cr, Pb and Cr, and Pb and Ni, suggesting common industrial sources such as metal refining, electroplating, machining, and other manufacturing processes. The overall pollution index (PLI = 0.60) indicated moderate deterioration of soil quality and higher levels of pollution in sulfur-rich areas. These results highlight the necessity for continuous monitoring and improvement of industrial waste management to prevent the accumulation of toxic metals and sustainably maintain environmental quality in the region.

**Key Words:** Heavy metal contamination Industrial soil pollution, Trace metals Contamination factor (CF) Pollution load index (PLI) Statistical analysis

## 1. INTRODUCTION

Rapid industrial growth has contributed significantly to economic development, but it has also introduced serious environmental challenges, particularly the heavy metal accumulation in soil systems. Heavy metals are of major concern because they are non-biodegradable, persistent in nature, and capable of accumulating in soils over long periods, thereby affecting soil quality and ecosystem stability (Alloway, 2013). Unlike organic contaminants, these metals are not biodegradable and accumulate in the soil and can negatively influence plant productivity, microbial activity, and ecological balance (Nagajyoti et al., 2010). It changes the chemical composition of the soil, reduces its fertility, and

poses long-term risks to the health of plants, animals, and humans.

Various studies have investigated heavy metal contamination in industrial regions globally and across India. Industrialization, mining, and manufacturing are major contributors to heavy metal enrichment in soils, leading to ecological and human health risks. These activities release metals like lead (Pb), nickel (Ni), and chromium (Cr) through emissions, waste disposal, and atmospheric deposition (Nriagu & Pacyna, 1988; Sharma et al., 2007). Improper waste management and continuous industrial discharge further accelerate the enrichment of toxic elements in surrounding soils (Gupta et al., 2008). Globally, metals such as Cd, Pb, Cr, Cu Ni, and Zn have been found at concentrations exceeding natural background levels in industrial and urban soils (Tayibi et al., 2009).

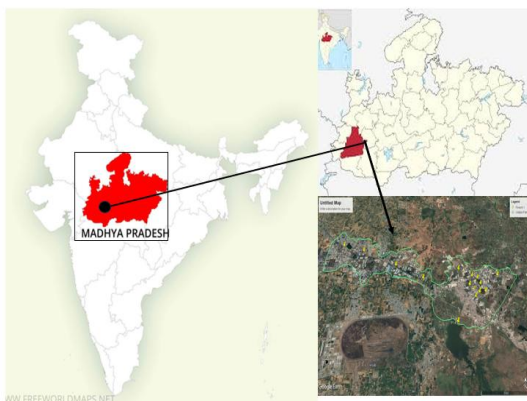
High concentrations of heavy metals in sediments and soils have been detected near major industrial centers in India, such as Vapi (Gujarat), Tarapur (Maharashtra), Patancheru (Telangana), and Pithampur (Madhya Pradesh). Pithampur, also known as the "Detroit of India," is one of the leading industrial growth centers in India, with a strong presence in the engineering, automobile, and pharmaceuticals sectors. It is in the Dhar district of Madhya Pradesh, 30 km from Indore, with over 600 functional industrial units and provides employment to around 32,000 people. The rapid industrialization of the area, with the coexistence of residential and agricultural land, has raised serious concerns about potential heavy metal contamination. Previous environmental monitoring reports and local investigations have detected high concentrations of metals, such as nickel (Ni), chromium (Cr), lead (Pb), and zinc (Zn), in the soil of Pithampur, particularly near industrial areas and wastewater treatment plants. Various sources of contamination include metal processing units, inadequate waste disposal, wastewater from treatment plants, and hazardous waste landfills. Despite these findings, comprehensive and widespread investigations of heavy metal soil contamination in Pithampur are still scarce.

Therefore, systematic, and scientifically sound research is required to understand the extent, distribution, and potential risks of heavy metal soil contamination in the Pithampur industrial area. Such investigations will not only provide fundamental environmental information but also serve as a basis for remediation plans and the development of local environmental policies in the future (Hakanson, 1980; Qin et al., 2019).

## 2. MATERIAL AND METHODS

### 2.1 Study Area

The study was conducted within the Pithampur Industrial Area (PIA) in the Dhar district of the Indian state of Madhya Pradesh (latitude 22°35' E to 22°41' E and longitude 75°35' E to 75°41' E). The region is considered one of the largest industrial centres in Central India and is home to many chemicals, pharmaceutical, automobile, galvanizing, and mechanical engineering companies. The region is characterized by basaltic parent material and alkaline black soil (Vertisol) with moderate clay content and a rich clay texture. The climate is tropical, with an average annual precipitation of approximately 900–1000 mm. The PIA, divided into three different sectors, I, II, and III, is surrounded by agricultural lands, residential areas, and open waste, which can act as reservoirs for atmospheric deposition and runoff from industrial sources. The proximity of industries, wastewater treatment plants, and landfills makes the region ecologically sensitive and prone to heavy metal accumulation in the soil.



**Fig-1:** Map demonstrating soil sampling location

### 2.2 Soil Sampling

A systematic random sampling method was adopted to ensure representative coverage of several sectors in the industry. A total of 15 sampling locations were selected based on their proximity to possible sources of

contamination, such as effluent discharge points, hazardous waste storage facilities, and areas surrounding wastewater treatment plants (WWTPs). The samples were collected from industrial, roadside, and buffer-zone locations of all three sectors using a stainless-steel auger at a depth of 50-10 cm. All samples were kept in clean polyethylene bags, labelled as P+ Number for laboratory analysis.

### 2.3 Sample Preparation

The collected soil samples were air-dried at room temperature for 3-4 days, followed by oven drying at 10°C for 8 h to eliminate moisture. The dried samples were gently pulverized using a mortar and pestle and sieved through a 2 mm mesh to obtain a uniform grain size. All glassware and equipment were washed with acid (10% HNO<sub>3</sub>) and rinsed with deionized water.

### 2.4 Sample Analysis

The pH of soil was measured in a ratio of 1:10 soil-water suspension using a calibrated pH meter. Heavy metal concentrations (Pb, Cr, Ni, Cu, Zn, and Mn) were determined using the USEPA 3050B acid digestion method. Approximately 1 g of each soil sample was digested in a mixture of concentrated HNO<sub>3</sub> and HCl (3:1) for 4 h. The solution was filtered and diluted to 50 mL using deionized water.

### 2.5 Statistical Analysis

The descriptive statistics includes: i) minimum and maximum, ii) mean, iii) standard deviation, and iv) coefficient of variation (CV%). These statistics were calculated to examine the spatial variability of soil parameters. Pearson correlation analysis, a method widely used in soil pollution studies (Zhang, 2006; Li et al., 2013) was applied to recognize relationships among heavy metals to study the possible causes of contamination. Similarly, graphical representations such as boxplots, bar charts, and correlation heatmaps were generated using Origin software and MS Excel.

### 2.6 Contamination Assessment

The contamination factor (CF) and pollution load index (PLI) were calculated to evaluate the degree of heavy metal contamination. The CF for a given metal *i* is defined as:

$$CF_i = \frac{C_i}{C_{b,i}}$$

where  $C_i$  is the measured concentration of metal *i* in soil and  $C_{b,i}$  is the corresponding background value. The majorly cited global background soil values were adopted in this study: Cu = 30 mg kg<sup>-1</sup>, Cr = 80 mg kg<sup>-1</sup>, Ni = 50 mg kg<sup>-1</sup>, Pb =

50 mg kg<sup>-1</sup>, Mn = 500 mg kg<sup>-1</sup>, and Zn = 70 mg kg<sup>-1</sup>. The CF values <1 indicate low contamination, 1-3 indicates moderate, 3-6 indicates considerable and >6 very high contamination. The overall soil quality was assessed using the pollution load index (PLI) which is defined as the nth root of the product of the contamination factors of n metals:

$$PLI = (CF_{Pb} \times CF_{Ni} \times CF_{Cr})^{1/3}$$

PLI <1 suggests no overall pollution, PLI = 1 shows baseline levels, and PLI >1 shows progressive deterioration of site quality.

### 3. RESULTS AND DISCUSSION

#### 3.1 Soil pH Characteristics

The pH values of the soil in the PIA varied from 5.3 to 8.6, indicating slightly acidic to moderately alkaline conditions across the sampling locations. Such elevated pH values are characteristic of industrial environments where continued deposition of cement dust, ash residues lime-rich particulates, and alkaline industrial effluents occurs. Along with industrial inputs, the basaltic parent rock material of the region also contributes to distinctive soil alkalinity. The observed variability in pH (CV ≈ 25%) suggests heterogeneous influence of industrial activities across different locations. High soil pH plays a crucial part in controlling heavy-metal behaviour by reducing solubility and leaching; however, it also promotes long-term metal holding within the soil matrix due to adsorption and precipitation mechanisms. Therefore, alkaline conditions in Pithampur soils may act as a sink for heavy metals, facilitating gradual accumulation over time. The variation of pH with the location is presented in the given figure:

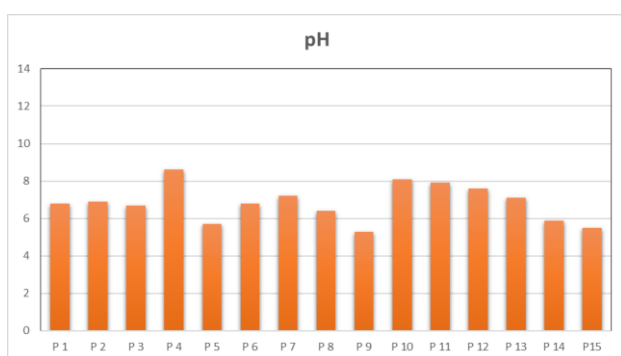


Fig-2: Variation of pH in soils of different location

#### 3.2 Heavy Metals distribution in Soils

The concentrations of Cu, Ni, Cr, Pb, Mn, and Zn measured across the 15 sampling locations demonstrated noticeable spatial variability, reflecting differences in industrial intensity, traffic density, and waste-handling practices within the study area.

Table-1: Heavy metals descriptive statistics

Metal	Min (mg/kg)	Max (mg/kg)	Mean (mg/kg)	SD	CV (%)
Cu	17.4	31.8	24.40	4.53	18.6
Ni	25.9	56.0	43.25	9.80	22.7
Cr	30.0	63.6	45.33	8.92	19.7
Pb	31.1	48.3	39.22	4.30	10.9
Mn	93.2	305.3	180.59	60.75	33.6
Zn	11.7	40.8	23.44	7.54	32.1

Table-2: Analysis of heavy metal at different locations

S. No.	Location	Cu (mg/kg)	Ni (mg/kg)	Cr (mg/kg)	Pb (mg/kg)	Mn (mg/kg)	Zn (mg/kg)
1	P1	18.3	27.9	30	41.3	193.3	40.8
2	P2	21.8	25.9	41.9	37.4	248.3	28.5
3	P3	17.4	28.9	37.5	31.1	305.3	32.6
4	P4	24.5	31.4	38.4	39.4	105.6	19.8
5	P5	25.5	38.3	36.4	42.7	124.7	20.4
6	P6	22.8	46.9	40.1	33.6	189.3	24.3
7	P7	28.6	43.2	56.1	41.3	287.2	18.3
8	P8	17.4	56	39.9	42.3	200	21.9
9	P9	23.8	47.6	63.6	35.3	147.3	28
10	P10	29.6	52.8	49.4	38.5	204.6	22.4
11	P11	24.2	54.8	40.9	41.3	258.1	11.7
12	P12	31.8	47.7	52.2	33.3	168.6	20
13	P13	26.8	42.2	47.6	39.9	93.2	17.7
14	P14	18.8	54.7	51.6	48.3	122.7	31.8
15	P15	24.7	49.6	53.2	35.8	147.7	21.2

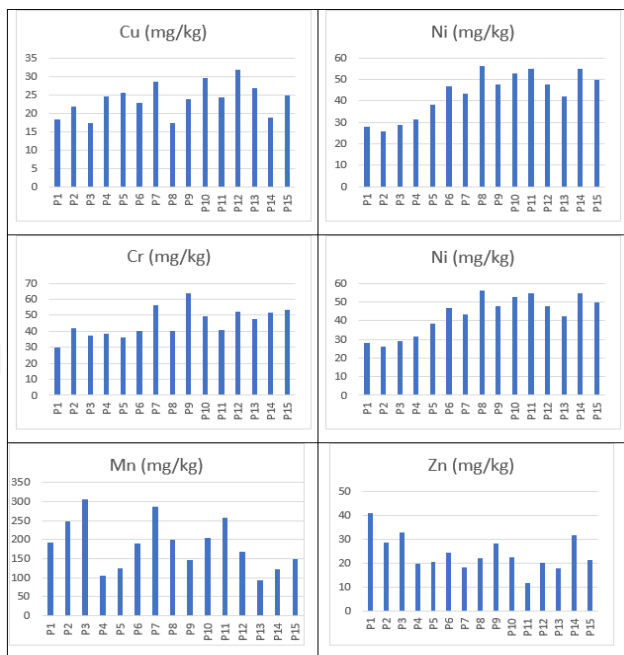


Fig- 2: Comparison of heavy metal concentration in the soil samples

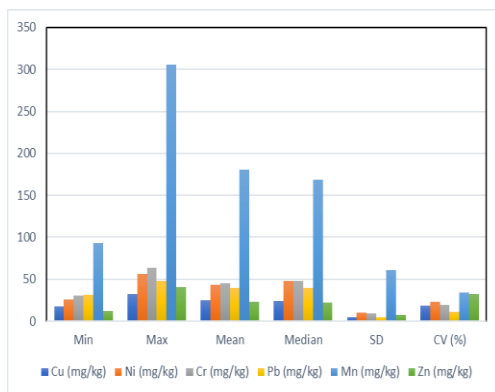


Fig-4: Descriptive statistics of heavy metals

Nickel, chromium, and lead showed relatively elevated mean concentrations compared to the typical natural background levels reported for uncontaminated soils. Similar observations have been widely reported in soils from industrial zones where prolonged industrial activity leads to gradual metal accumulation (Sharma et al., 2007; Luo et al., 2012). The relatively low coefficients of variation for Pb, Ni, and Cr ( $\approx 11\text{--}23\%$ ) suggest widespread and consistent industrial influence, whereas Mn and Zn exhibit higher variability, indicating mixed lithogenic and anthropogenic origins.

### 3.3 Toxic Metal Enrichment (Pb, Ni, Cr)

Because of their toxicity and industrial relevance, Pb, Ni, and Cr were evaluated separately to assess anthropogenic enrichment patterns.

Table-3: Background levels of three toxic metals

Metal	Mean (mg/kg)	Background (mg/kg)	Samples above background
Pb	39.22	25	100%
Ni	43.25	30	93%
Cr	45.33	40	80%

All soil samples exhibited Pb concentrations exceeding natural background values, confirming substantial anthropogenic input. Lead contamination in the study area is likely associated with vehicular emissions, industrial combustion processes, battery-related activities, and paint or pigment usage. Nickel enrichment was observed in nearly all samples, reflecting contributions from metal-plating units, alloy fabrication industries, and machining activities that dominate the Pithampur industrial zone. Chromium concentrations also exceeded background levels at most locations, suggesting inputs from electroplating, metal finishing, and chemical processing industries. The consistent enrichment of these toxic metals confirms that Pithampur soils are affected by ongoing industrial contamination rather than isolated local inputs.

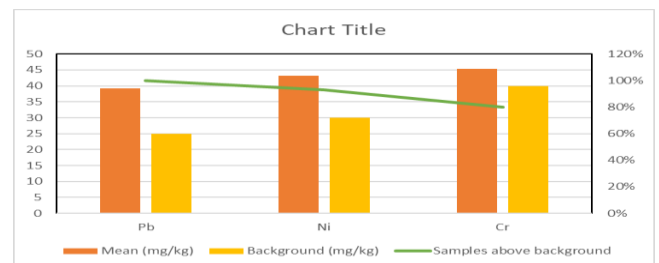


Fig-5: Chart representing background level deviation of toxic metal

### 3.4 Correlation Analysis and Source Identification

To examine relationships among various metals and recognize possible common sources the Pearson correlation analysis was applied. Strong positive correlations were observed between Ni-Cr ( $r = 0.85$ ), Pb-Cr ( $r = 0.72$ ), and Pb-Ni ( $r = 0.68$ ). These strong associations indicate a shared origin, most likely related to metallurgical operations, electroplating, engineering workshops, and industrial surface coatings. Moderate correlations involving Cu, Zn, and Mn suggest mixed sources, including industrial emissions, vehicular wear, lubricants, and natural soil constituents. The negative correlation between pH and most metals indicates that alkaline conditions reduce the immediate metal mobility. However, immobilization increases the potential for long-term accumulation, rather than eliminating the risk of contamination. The correlation heatmap visually

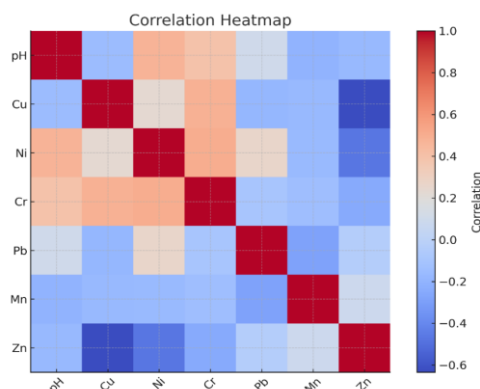
strengthens these relationships by evidently clustering Ni, Cr, and Pb, emphasizing their common anthropogenic origin. The correlation matrix is given below:

**Table-4:** Correlation matrix of heavy metals

Param	pH	Cu	Ni	Cr	Pb	Mn	Zn
pH	1	-	-	-	-	-	-
Cu	0.28	1	0.51	0.56	0.62	0.33	0.48
Ni	0.40	0.51	1	0.85	0.68	0.46	0.52
Cr	0.28	0.56	0.85	1	0.72	0.58	0.49
Pb	0.31	0.62	0.68	0.72	1	0.45	0.61
Mn	0.22	0.33	0.46	0.58	0.45	1	0.39
Zn	0.35	0.48	0.52	0.49	0.61	0.39	1

**Correlation Interpretation**

- The strong association of Pb–Ni (0.68), Pb–Cr (0.72) and Ni–Cr (0.85) indicate a common industrial source of contamination, probably metal-finishing, electroplating, and engineering industries. The correlations of Cu–Pb, Mn–Cr, Zn–Pb acclaim multi-source contamination including vehicular emissions, and paint industries. The following correlation is represented in the given figure.



**Fig-6:** Correlation heat maps

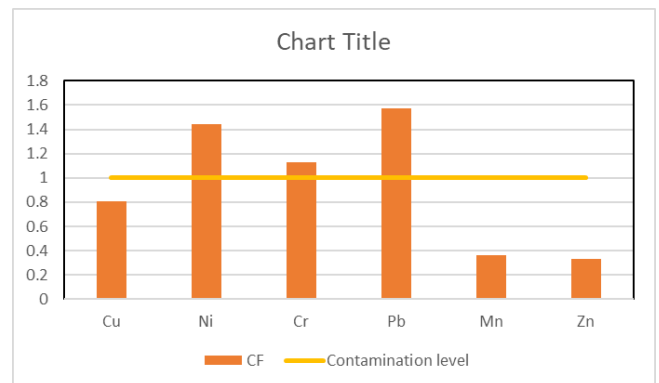
**3.5 Contamination Factor (CF) and Pollution Load Index (PLI)**

Contamination Factor values provide insight into the degree of anthropogenic enrichment relative to background

concentrations. Nickel, chromium, and lead show CF values greater than 1, confirming moderate contamination of industrial source. In contrast, Cu, Mn, and Zn show lower CF values, indicating secondary or mixed sources. The calculated Pollution Load Index (PLI = 0.60) indicates overall soil quality degradation due to anthropogenic activities.

**Table-5:** Contamination factor of heavy metals

Metal	CF	Contamination level
Cu	0.81	Low
Ni	1.44	Moderate
Cr	1.13	Moderate
Pb	1.57	Moderate–High
Mn	0.36	Low
Zn	0.33	Low



**Fig-7:** Contamination factor and contamination level of heavy metals

Although the PLI suggests that contamination is not yet severe at a regional scale, the elevated CF values and metal enrichment patterns indicates a progressive contamination trend, particularly at specific high-impact locations.

**3.6 Integrated Interpretation and Environmental Implications**

The collective analysis of descriptive statistics, toxic metal enrichment, correlations, and pollution indices states that industrial activities have a significant impact on the soils of the PIA. The enrichment of lead (Pb), nickel (Ni), and chromium (Cr) above natural levels observed at most sampling sites indicates continuous industrial emissions rather than irregular pollution events. While the highly alkaline soils decrease metal movement, they promote their adsorption and long-term accumulation, thus increasing the

risk of chronic soil degradation. Overall, the results indicate that the soils of Pithampur are moderately contaminated with toxic metals. Therefore, continuous environmental monitoring, improved emissions management, and stringent procedures for industrial waste disposal are essential to prevent further environmental degradation (Alloway, 2013; Tchounwou et al., 2012).

#### 4. CONCLUSION

This study demonstrates a comprehensive assessment of heavy metal contamination in the soils of PIA. The assessment is based on pH analyses, metal concentration measurements, quantitative correlations, and contamination indicators. The soil exhibits a slightly acidic to moderately alkaline pH, influenced by both natural lithology and industrial emissions. Elevated concentrations of lead, nickel, and chromium, exceeding reference values, confirm the presence of anthropogenic sources such as galvanizing, road construction, steel manufacturing, and chemical processes. The strong correlations between the metals indicate the presence of common industrial sources, particularly for nickel, chromium, and lead.

The contamination factors (CF) suggest low contamination levels for these metals, while the impact of copper, manganese, and zinc is minimal. This reflects the interplay between geogenic and industrial sources. Although the combined pollution index (CPI) (0.60) indicates the absence of severe pollution, environmental degradation is increasing in the most affected areas. This upward trend, coupled with ongoing industrial activity, suggests a probable risk of long-term accumulation if mitigation measures are not strengthened. Therefore, it is necessary to improve air quality management, implement an effective waste management system, and regularly monitor soil quality to prevent further degradation in the PIA.

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