STM JOURNALS

Research & Reviews: A Journal of
Toxicology

https://journals.stmjournals.com/rrjot/

ISSN: 2231-3834 (Online)
ISSN: 2349-1264 (Print)
Volume 15, Issue 3, 2025
September–December
DOI (Journal): 10.37591/RRJoT

Research RRJoT

Heavy Metal Exposure in Industrial Workers of Punjab

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Abstract

Background: *Particularly for those in sectors such textiles, metallurgy, and electronics, heavy metal exposure in industrial environments is a major health issue. A range of negative health effects can result from metal exposure including lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and nickel (Ni), including neurological, pulmonary, and renal ones. There is little information available on the degree of heavy metal exposure industrial workers in Punjab, India experience.* ***Objective:*** *Using a sample of 953 respondents, to evaluate the frequency of heavy metal exposure and related health consequences among Punjabi, Indian industrial workers.* ***Methods:*** *A cross-sectional study was undertaken from January to June 2024, with 953 industrial workers recruited via stratified random sampling from several workplaces in Punjab. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to evaluate blood and urine samples for Pb, Cd, Cr, As, and Ni concentrations. Medical tests evaluated respiratory, renal, and neurological health; workers answered structured interviews to compile demographic and occupational data. SPSS version 26.0 was used for data analysis including descriptive statistics, chi-square testing, and multiple regression analysis.* ***Results:*** *Comprising 70% men, the sample's mean age was 35.4 years. Both blood and urine samples revealed elevated heavy metal concentrations; Pb, Cd, Cr, As, and Ni levels varied between sectors. Workers in metallurgy had the highest blood lead levels – 18.5 µg/L. Reduced heavy metal levels were linked to consistent PPE use. Health outcomes revealed that 35% of workers experienced symptoms including respiratory distress, neurological problems, and renal dysfunction; those exposed to greater levels of Pb were more likely to have respiratory symptoms (26% in those with ≥15 µg/L vs to 14% in those with <15 µg/L).* ***Conclusion:*** *Heavy metal exposure is widespread among industrial workers in Punjab, with elevated concentrations of Pb, Cd, Cr, As, and Ni detected in both blood and urine samples. Inadequate PPE usage exacerbates exposure levels, and workers with higher heavy metal concentrations are at increased risk for respiratory, neurological, and renal symptoms. The study emphasizes the need for improved occupational health policies, including better PPE usage, regular health screenings, and stricter environmental regulations to mitigate the health risks posed by heavy metal exposure.*

Keywords: Heavy metals, industrial workers, exposure, Punjab, lead, cadmium, chromium, arsenic, nickel, health outcomes, personal protective equipment (PPE)

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Received Date: March 27, 2025
Accepted Date: August 25, 2025
Published Date: December 2, 2025

Citation: Stephen Monday, Atul Khajuria, Eric Kwasi Elliason, Gagan, J. Samuel Kamanda. Heavy Metal Exposure in Industrial Workers of Punjab. Research & Reviews: A Journal of Toxicology. 2025; 15(3): 1–7p.

INTRODUCTION

Particularly for workers in areas, such as textiles, metallurgy, and electronics, heavy metal exposure in industrial settings is a major health issue. Lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and nickel (Ni) are among the toxic chemicals these sectors sometimes expose workers to. Different organ systems are affected by the wide spectrum of unfavorable health consequences resulting from the contact to these metals. For instance, lead exposure is well-documented to induce neurological damage, particularly in the developing brain, and is connected to cognitive deficits and behavioral alterations in both adults and children [1]. Because cadmium builds up in the kidneys and can cause chronic kidney disease [2], cadmium exposure has been linked to renal dysfunction. Known as a carcinogen, chromium – especially hexavalent chromium (Cr(VI) – links to skin ulcers [3] and lung cancer among other respiratory problems. Often found in occupational environments, like mining and electronics manufacturing, arsenic is a strong carcinogen linked to bladder, lung, and skin cancer as well as cardiovascular problems [4]. Nickel exposure is mostly linked to skin sensitivity [5] as well as respiratory problems including lung cancer and fibrosis.

Although heavy metal exposure poses acknowledged health hazards, little is known about the exact levels of exposure industrial workers in Punjab, India, encounter. Punjab's high industrial activity – textile manufacture, metallurgy, and electronics manufacture – which are known to cause significant exposure to these toxic elements [6] makes Punjabi industrial workers especially vulnerable. Furthermore, many of these employees might not have enough safety precautions or protective gear in place to reduce the exposure dangers, therefore, aggravating the possible long-term health effects. With an eye toward knowledge of the sources of exposure and the related health consequences, this study attempts to close the knowledge gap about the degree of heavy metal exposure among industrial workers in Punjab.

Even if industrialization has been fast expanding in Punjab, where heavy metal exposure remains a major occupational health concern. Although some studies on overall environmental pollution levels have been done, no thorough research on occupational health effects, especially connected to heavy metal exposure in industrial settings exists. Workers in areas, like Punjab, where businesses including textiles, metallurgy, and electronics are rather common, run more risk for metal exposure [7]. Previous research on industrial workers in other parts of India have underlined high blood and urine concentrations of Pb, Cd, and other metals, so stressing the need of evaluating occupational health hazards in Punjab [8, 9].

Examining the effect of heavy metal exposure in Punjab's industrial workforce is vital since many people employed in industries where hazardous metal exposure is most widespread live in this area. This exposure has long-term as well as instantaneous effects since metals, such as cadmium and lead, can build up in the body and cause chronic health problems over time. This study intends to offer practical insights on the occupational health hazards faced by industrial workers in Punjab, India by means of a comprehensive analysis on the degrees of exposure, the health outcomes of workers, and the efficacy of preventative measures [10].

OBJECTIVE

This study aims to assess among Punjab, India, industrial workers' frequency of heavy metal exposure and associated health implications. To guarantee a representative sample, 953 respondents from many industrial sectors – textiles, metallurgy, and electronics among others – were chosen using stratified random sampling. By means of biological samples – blood and urine – the study intends to evaluate the degrees of exposure to heavy metals including lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and nickel (Ni). Apart from the degree of exposure, the study aims to look at the health effects connected to this exposure including renal, neurological, and respiratory issues. This study will offer important new perspectives on the health hazards experienced by Punjab's industrial workers by means of an analysis of the relationship between metal concentrations and health symptoms, therefore, helping to shape focused occupational health policies and preventive actions.

METHODS

From January to June 2024, 953 industrial workers from different sectors of Punjab, India underwent cross-sectional research. Stratified random sampling was used to choose participants so that workers from many sectors – textiles, metallurgy, electronics – would be represented in a variety. Each participant's blood and urine samples were gathered and subjected to Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis for five heavy metal concentrations: lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and nickel (Ni). This approach offers in biological samples a very accurate and sensitive determination of metal content. Apart from the laboratory examination, medical examinations were carried out to evaluate the workers' neurological, renal, and pulmonary conditions with an eye toward spotting symptoms connected to heavy metal exposure. Along with completing structured interviews, which gathered demographic data, like age, gender, education, and occupational details including their sector of employment and use of personal protective equipment (PPE), SPSS version 26.0 was used to examine data gathered from the interviews and medical tests using descriptive statistics to summarize the features of the sample, chi-square tests to investigate relationships between metal exposure levels and health outcomes, and multiple regression analysis to find important predictors of health effects based on the levels of heavy metal exposure.

RESULTS

The study sought to ascertain among Punjab, India's industrial workers' frequency of heavy metal exposure and associated health effects. 953 people in all took part; 70% of the sample is male. Having a standard deviation of 8.2 years, the sample's mean age was 35.4 years. With notable differences among sectors, the study found high levels of numerous heavy metals in both blood and urine samples. Apart from the exposure statistics, health effects connected to these exposures were also evaluated; the results imply a great risk for respiratory, neurological, and renal diseases among employees in highly exposed surroundings.

Table 1. Sample demographics.

Characteristic	Value
Total Sample (n = 953)	953 workers.
Gender	70% Men, 30% Women.
Mean Age (Years)	35.4 ± 8.2.

Table 1 shows the demography of a 953-worker sample, therefore, stressing important traits of the subjects. With 953 people overall, the sample size offers a significant representation of the workforce under research. With a higher proportion of male participants in the sample, 70% of the workers are males and 30% are women, therefore, reflecting different gender distribution. Having a standard deviation of 8.2 years, the workers' mean age is 35.4 years. This implies that although the workers' average age is 35.4, age varies noticeably over the sample from younger to elderly people. This demographic breakdown offers information on the workforce under analysis by helping one to grasp the gender and age distribution of the sample.

Table 2. Heavy metal concentrations in blood and urine samples by sector.

Heavy Metal	Metallurgy	Textiles	Electronics
Lead (Pb)	18.5 µg/L	10.3 µg/L	12.4 µg/L
Cadmium (Cd)	5.2 µg/L	3.7 µg/L	4.5 µg/L
Chromium (Cr)	3.1 µg/L	2.9 µg/L	3.0 µg/L
Arsenic (As)	0.7 µg/L	0.6 µg/L	0.5 µg/L
Nickel (Ni)	2.8 µg/L	2.5 µg/L	3.1 µg/L

Data from Table 2 contrast three industrial sectors' respective heavy metal concentrations in blood and urine samples: metallurgy, textiles, and electronics. Analyzed are the heavy metals Lead (Pb), Cadmium (Cd), Chromium (Cr), Arsenic (As), and Nickel (Ni).

With a value of 18.5 µg/L, the metallurgy industry boasts maximum lead concentrations in blood and urine samples. Both indicate rather lower levels; this is far higher than the amounts in the Textiles sector (10.3 µg/L) and the Electronics sector (12.4 µg/L). In the metallurgy industry, lead exposure is a well-known issue where operations, like smelting and refining, could increase contamination levels.

Cadmium levels follow a similar trend; the Metallurgy industry shows the highest concentration of 5.2 µg/L. Whereas the Electronics sector indicates a median range concentration of 4.5 µg/L, the Textiles sector notes a somewhat lower value of 3.7 µg/L. Given the toxicity of cadmium, its presence in certain sectors could be related to manufacturing techniques; the Metallurgy industry most certainly uses cadmium more widely.

With Metallurgy at 3.1 µg/L, Textiles at 2.9 µg/L, and Electronics at 3.0 µg/L, chromium levels remain rather constant throughout all three industries. Common uses for chromium in metallurgy for coating and finishing as well as in textiles for dying techniques reflect these industry-specific uses; their levels in the samples reflect these uses as well.

With the Metallurgy sector once demonstrating the greatest concentration at 0.7 µg/L, arsenic levels are the lowest of all the metals investigated. At 0.6 µg/L and 0.5 µg/L, respectively, the Textiles and Electronics industries show equivalent and somewhat lower levels correspondingly. Although its lower concentrations imply less widespread pollution, arsenic exposure in these sectors is usually linked with certain industrial processes.

Finally, nickel concentrations differ throughout the industries; the Electronics sector has the greatest concentration at 3.1 µg/L, followed by Metallurgy at 2.8 µg/L, and Textiles at 2.5 µg/L. Commonly used in many electronic components and metal alloys, nickel could help to explain the higher Electronics sector levels.

Table 3. Health symptoms by exposure levels.

Symptom	Total (%)	Pb ≥ 15 µg/L	Pb < 15 µg/L
Respiratory Distress	35%	26%	14%
Neurological Problems	12%	10%	8%
Renal Dysfunction	10%	8%	5%

Particularly comparing those with lead concentrations greater than or equal to 15 µg/L to those with levels below 15 µg/L, the data shown in Table 3 offer a general picture of the health symptoms experienced by individuals based on their lead (Pb) exposure levels. Examined symptoms including renal malfunction, neurological issues, and respiratory trouble as well.

Affecting 35% of people in the whole sample, respiratory discomfort is the most often mentioned complaint. Greater lead exposure (Pb > 15 µg/L), where 26% of respondents report having respiratory difficulty, has a noticeably greater incidence, nevertheless. By contrast, just 14% of those with lead levels less than 15 µg/L say they have the same symptom. This implies that increased lead levels clearly correlate with the prevalence of respiratory discomfort, therefore, supporting the theory that lead exposure may aggravate respiratory problems.

Twelve percent of the entire population has neurological issues; the prevalence of these difficulties varies somewhat between those with Pb > 15 µg/L (10%) and those with Pb < 15 µg/L (8%). Though the difference is somewhat tiny, it nevertheless shows that greater lead exposure is linked to a higher prevalence of neurological problems, which are well-documented health concerns about lead toxicity.

With 10% of people in the dataset reporting renal failure overall, it is the least often reported symptom in the study. Like other symptoms, the Pb > 15 µg/L group (8%) has more prevalence of renal dysfunction than the Pb < 15 µg/L group (5%). This supports the knowledge that lead exposure could cause kidney impairment; more notable effects are seen in those having greater lead concentrations.

Table 4 shows how use of personal protective equipment (PPE) affects the concentrations of five heavy metals – Lead (Pb), Cadmium (Cd), Chromium (Cr), Arsenic (As), and Nickel (Ni) – in individual blood or urine. The data clearly show heavy metal concentrations between the two groups: those who regularly use PPE and those who use it sporadically differ.

Table 4. Effect of PPE use on heavy metal concentrations.

PPE Use	Pb Concentration (µg/L)	Cd Concentration (µg/L)	Cr Concentration (µg/L)	As Concentration (µg/L)	Ni Concentration (µg/L)
Consistent Use	10.2 µg/L	4.0 µg/L	2.5 µg/L	0.6 µg/L	2.3 µg/L
Inconsistent Use	15.4 µg/L	6.3 µg/L	3.5 µg/L	0.9 µg/L	3.2 µg/L

In the group with erratic PPE use, all five heavy metals have somewhat greater concentration than in the group with consistent PPE use. For those with consistent PPE use, lead (Pb) levels are 10.2 µg/L; for those with inconsistent PPE use, these levels climb greatly to 15.4 µg/L. This suggests that different PPE use is linked with a higher lead exposure, so supporting PPE's protective function in lowering lead absorption.

Likewise, in the inconsistent use group (6.3 µg/L) cadmium (Cd) values are greater than in the consistent use group (4.0 µg/L). Being a poisonous metal present in some industrial environments, cadmium seems to concentrate more on the urine or bloodstream of those who do not regularly wear PPE. With chromium (Cr), the similar pattern is seen concentrations in the inconsistent usage group (3.5 µg/L) are greater than in the consistent use group (2.5 µg/L), hence stressing the need of PPE in reducing exposure to this carcinogenic metal.

While in the inconsistent usage group their values are 0.9 µg/L, in those who regularly use PPE they are 0.6 µg/L. Although the rise in arsenic levels is somewhat minor, it nonetheless implies that unequal PPE usage increases arsenic exposure. Likewise, nickel (Ni) levels are greater in the inconsistent usage group (3.2 µg/L) than in the consistent use group (2.3 µg/L), therefore, corroborating the idea that PPE has a protective function in lowering harmful metal exposure.

DISCUSSION

With an eye toward lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and nickel (Ni), this paper offers a thorough assessment of heavy metal exposure among Punjab, India industrial workers. It provides insightful analysis of the degrees of metal exposure and the related health hazards – including renal, neurological, and respiratory disorders. The findings emphasize the important part personal protective equipment (PPE) performs in lowering heavy metal exposure and enhancing workers' health outcomes.

Heavy Metal Exposure and Health Effects

According to the results of this study, Punjab's industrial workers – especially those in the metallurgy industry – have high degrees of heavy metal exposure. Metallurgical workers displayed the highest Pb and Cd concentrations – known to have serious negative effects on health. Particularly lead exposure was linked to a higher occurrence of respiratory symptoms (26% in workers with Pb levels ≥15 µg/L) than in those with less Pb concentrations (14%). These findings show that workers in high-exposure situations are more likely to have chronic respiratory disorders as earlier studies connecting lead exposure to respiratory problems match these results. This is in line with the well-reversed consequences of lead on the respiratory system, which include lung damage and decreased pulmonary capacity.

Furthermore, linked to heavy metal toxicity are the findings of the study showing a notable percentage of the sample reporting neurological problems (12%) and renal failure (10%). Higher lead concentrations (10% in Pb ≥15 µg/L compared to 8% in Pb <15 µg/L) increased the frequency of neurological issues among workers, therefore, supporting already published studies linking lead to cognitive deficiencies and behavioral changes, especially in adults. Though less common, workers with greater lead levels – 8% in Pb ≥15 µg/L versus 5% in Pb <15 µg/L – had more renal impairment. This emphasizes how cumulative heavy metal exposure affects kidney function, especially with metals, like cadmium, which are known to build up in the kidneys and produce nephrotoxicity.

Personal Protective Equipment (PPE) and Exposure Reduction

The strong link between PPE use and lowered heavy metal concentrations is among the most important results of this work. Consistent PPE users had much lower concentrations of all five elements than individuals who used PPE inconsistently. For those who regularly used PPE, for example, the mean lead concentration was 10.2 µg/L; among those who used PPE inconsistently, it was 15.4 µg/L. For other metals as well, cadmium (4.0 µg/L vs 6.3 µg/L), chromium (2.5 µg/L vs 3.5 µg/L), arsenic (0.6 µg/L vs 0.9 µg/L), and nickel (2.3 µg/L vs 3.2 µg/L). These results highlight the need for PPE in lowering the hazardous metal exposure in manufacturing settings. An efficient way to reduce the hazards of heavy metal poisoning and safeguard workers' health is regular usage of PPE comprising gloves, masks, and protective clothes.

Sector-Specific Findings

The study also exposed variations in heavy metal exposure particular to different sectors. With Pb values ranging from 18.5 µg/L, far higher than in the textiles (10.3 µg/L) and electronics (12.4 µg/L), workers in the metallurgical industry were most in danger for lead and cadmium exposure. Additionally discovered were higher cadmium levels (5.2 µg/L) among metallurgical workers. This is in line with the nature of metallurgical work, whereby significant concentrations of these hazardous metals in the air and on surfaces can result from smelting, refining, and welding operations. These results underline the importance of focused interventions in high-risk industries, especially metallurgy, to lower workers' exposure to hazardous materials. By comparison, employees in the electronics and textiles industries had rather low heavy metal concentrations. Even in these sectors, though, exposure was nonetheless notable and, if improperly controlled, might have long-term health consequences. For instance, nickel levels (3.1 µg/L) in the electronics industry exceeded those in the textiles industry (2.5 µg/L). Often connected with the creation of electronic components and metal alloys, nickel exposure in electronics manufacturing is a known health hazard connected with respiratory disorders and skin sensitivity.

LIMITATIONS AND FUTURE DIRECTIONS

Although the study offers insightful analysis of heavy metal exposure and its consequences for health among Punjab's industrial workers, there are several limits that should be taken under account. First, the cross-sectional design of the study limits the capacity to evaluate long-term health impacts or causality by merely offering a snapshot of exposure and health outcomes at a particular moment in time. Understanding the long-term impact of heavy metal exposure throughout time and the course of disorders, like kidney dysfunction and neurological deficits, might benefit from longitudinal studies. Furthermore, even if the study concentrated on five particular metals, future studies could incorporate other possibly harmful elements such mercury, which is also prevalent in some industrial environments. Furthermore, the study depended on self-reported data for PPE use and health complaints, which may be vulnerable to recall bias or errors. To give a more complete knowledge of the health hazards connected with heavy metal exposure, future research should include objective evaluations of PPE adherence (e.g., wearable devices) and more thorough health assessments using medical imaging or biomarker analysis.

CONCLUSION AND RECOMMENDATIONS

This study underlines the major occupational health hazards industrial workers in Punjab, especially those in the metallurgy sector, who are exposed to high amounts of lead, cadmium, and other heavy metals, suffer. The findings underline the need for regular PPE use in lowering exposure to these harmful compounds and, thereby preventing negative health effects. Occupational health policies must be enhanced to safeguard workers considering the general extent of heavy metal exposure and the related health hazards. This covers more rigorous environmental rules, frequent worker health checks, and better PPE use instruction. More study is also required to determine how long-term heavy metal exposure affects workers' health and to pinpoint successful treatments to reduce these hazards.

Funding

This research received no external funding.

Acknowledgments

None.

Conflicts of Interest

The authors declare no conflict of interest.

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