Assessment of Heavy Metal Toxicity in Industrial Workers

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ARTICLE DETAILS	ABSTRACT
	This study assesses hazardous heavy metal exposure among industrial workers in Gujarat by analyzing nail samples using Energy Dispersive X-ray Fluorescence (EDXRF). As nails can reflect long-term accumulation of toxic substances, they serve as effective non-invasive indicators for monitoring chronic exposure. Nail samples were collected from workers in industrial settings, particularly in the steel and diamond industries, along with a control group to establish baseline values. The results revealed notable variations in the percentage of heavy metals such as Iron (Fe), Zinc (Zn), Copper (Cu), Silver (Ag), and Barium (Ba), especially in samples from steel industry workers, suggesting occupational exposure. Elevated concentrations of certain metals indicate a potential health risk due to prolonged industrial contact. This research contributes to a better understanding of chronic metal exposure risks, provides preventive recommendations, and emphasizes the need for regular health monitoring and improved occupational safety protocols. The findings aim to guide policy and workplace interventions to safeguard worker health in Gujarat's industrial environments

1. INTRODUCTION

Heavy metals are defined as metallic elements that have a relatively high density compared to water (Mehra & Juneja, 2005). It adversely affects the living beings as well as the environment when

their concentration exceeds safe threshold. Some heavy metals, such as iron (Fe), zinc (Zn), and copper (Cu), are essential for biological functions in trace amounts, others like lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) have no beneficial role in the body and are highly toxic even at low concentrations (Mierzyńska et al., 2024). There are 35 metals that are of concern for us because of residential or occupational exposure, out of which 23 are heavy metals: antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc (Mierzyńska et al., 2024). In spite of traces of some heavy metals required for physiological process, over poisoning could be caused by the accumulation since they could be harmful to major organs like kidneys, liver, brain, lungs, and blood composition. Prolonged exposure to heavy metals has been associated with a number of degenerative conditions that can impact the muscular and neurological systems.

Heavy metal poisoning or toxicity can arise from the body's accumulation of dangerous metals interfering with essential cellular functions. These metals bind to various cell components, disrupting organ function and leading to major health problems. Prolonged exposure can result in life-threatening symptoms and irreversible damage if treatment is not received. Trace metal molecule buildup in the body makes the negative effects worse by impairing cell's ability to perform vital tasks. The process of toxicity depends on various factors such as dose, route of exposure (inhalation, ingestion, dermal absorption), and duration of exposure (Alissa & Ferns, 2011). Prompt diagnosis and treatment are crucial to prevent serious health consequences.

High industrial activities are the major means of heavy metal contamination, putting workers at high exposure risks. In the manufacturing, mining, welding, battery, and chemical industries, toxic metals such as lead, mercury, cadmium, and arsenic are often handled. Workers are exposed in these industries through contact with metal dust, fumes, or contaminated surfaces, therefore increasing risks of toxicity.

Nail as a Biomarker for heavy metal exposure:

Nails are hard, keratinized structures containing approximately 80% hard α-keratin and 20% soft α-keratin, which gives them their resilience and strength. A fingernail takes approximately 6 months to replace itself fully, whereas a toenail takes from 12 to 18 months. Fingernails have an average rate of growth of 0.1 mm a day, or roughly 3 mm a month. Lead, cadmium, arsenic, and mercury are some of the heavy metals to which nails can become chronically exposed due to their slow and continuous growth. Because nails record a record of systemic exposure, they are ideal biomarkers for long-term monitoring, whereas blood or urine provide evidence of exposure at the present time. With time, the nails can

accumulate trace elements such as heavy metals like lead, cadmium, arsenic, and mercury due to their persistent and slow growth.

Nails are ideal biomarkers for long-term monitoring since they provide a record of systemic exposure history, as opposed to blood or urine, which reflect current exposure. Nail sampling is also convenient, low-risk, and non-invasive, thus making it applicable for occupational health assessments and population studies. Due to these, nails serve as a reliable and effective biological matrix for the assessment of long-term heavy metal exposure, particularly among industrial workers.

This research aims to evaluate hazardous metal exposure in industrial workers by analyzing nail samples, thus contributing to the understanding of chronic exposure risks and the development of preventive measures for improvement in occupational health and safety in industrial environments in Gujarat.

Objectives:

- To collect and analyze nail samples from industrial workers at Gujarat using Energy Dispersive X-ray Fluorescence (EDXRF) to determine heavy metal content.

- To assess the extent of chronic heavy metal exposure among industrial workers based on the analyzed samples.

- To evaluate the range of heavy metal concentrations in the sampled population and identify specific metals prevalent in the industrial environment.

- To propose preventive measures and improve workplace safety standards aimed at mitigating heavy metal exposure in the industrial sector.

- To provide recommendations for reducing occupational exposure and improving health monitoring systems for industrial workers.

2. RESEARCH METHODOLOGY

- A total of 22 nail samples were collected from various industrial workers in the Gujarat state of all aged above 20 yrs, comprising:
    - ✓ 10 samples of workers from the Metal industry
    - ✓ 12 samples of workers from Diamond industry.

- Also, 10 control samples were collected from non-occupational exposers.

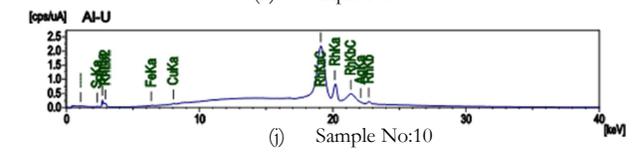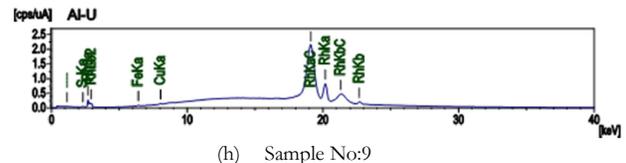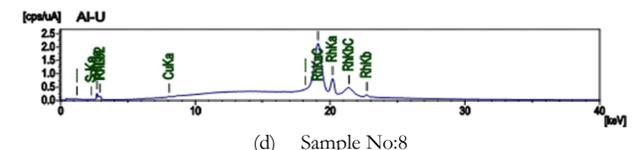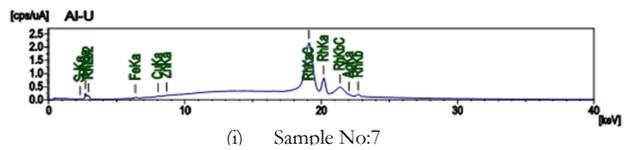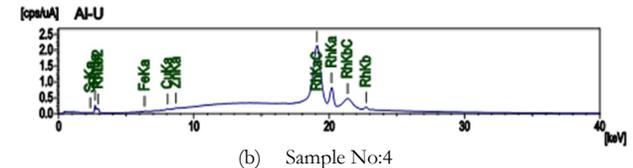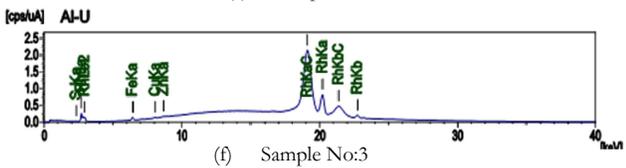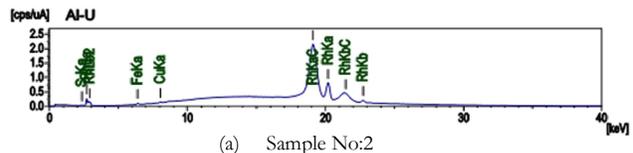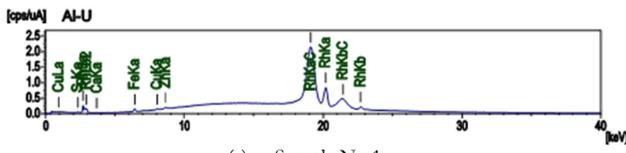- The study was conducted with proper ethical clearance from the relevant committee.

Wet acid digestion method using Nitric acid and hydrogen peroxide were used to prepare the samples for the analysis. The procedure involves:

- 20 – 30 mg of clean and dried sample is being weighed.
- 0.5 ml of Conc. Nitric acid (HNO_3) was added to each sample
- The sample was then left to stand at room temperature for the entire night for the initial digestion.
- After that the samples were placed in the drying oven for 1hr at 60 °C
- After cooling, 0.2 mL of hydrogen peroxide (H_2O_2) were added to each sample and were placed once more in the drying oven at 60 °C for an extra hour.
- Finally, the Digested samples were diluted with 10ml of distilled water.

Instrumentation: The nail samples that were completely digested were analysed using Energy Dispersive X-ray Fluorescence (EDXRF).

3. RESULT AND DISCUSSION:

Steel Industry

(e) Sample No:1

(a) Sample No:2

(f) Sample No:3

(b) Sample No:4

(g) Sample No:5

(c) Sample No:6

(i) Sample No:7

(d) Sample No:8

(h) Sample No:9
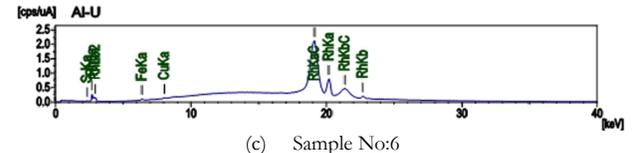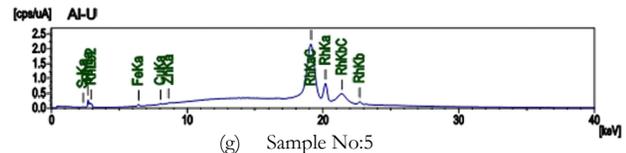
(j) Sample No:10

Percentage of heavy metals present in steel industry:

*Table 3.1: Representing the percentage of heavy metals present in the steel industry sample*

Sample No:	Fe (%)	Zn (%)	Cu (%)	Ag (%)
1	6.408	2.452	1.137	-
2	4.600	1.061	1.851	-
3	7.357	1.131	1.704	-
4	1.760	0.949	2.106	-
5	5.137	1.243	1.615	-
6	5.282	1.204	2.157	-
7	3.667	0.962	1.636	8.356
8	1.432	0.953	1.847	-
9	1.954	0.843	1.247	-
10	2.090	0.871	1.744	6.050

Graph 3.1 EDXRF Spectral Results for Nail Samples – Steel Industry Workers

Iron was detected in all 10 samples, with the percentage ranging from 1.432% to 7.357%. The highest iron was in Sample 3 (7.357%), followed by Samples 1 and 6. Individuals in the steel or heavy metal industry often have these elevated levels. Samples 4, 8, 9, and 10, however, showed relatively lower Fe levels, reflecting low exposure or environmental contact. The concentration of zinc in every sample varied between 0.843% and 2.452%. Sample 1 contained the highest concentration, and Sample 9 contained the lowest. Although zinc concentrations appear to be relatively stable and moderate, there might be a slight change based on environmental factors or different levels of exposure. Copper levels ranged from 1.137% to 2.157% and was present in all the samples. Silver was detected only in Sample 7 (8.356%) and Sample 10 (6.050%). These are significantly elevated levels and strongly suggest specific exposure to silver. The absence of silver in the remaining samples further reinforces that this is not due to general environmental exposure, but rather to occupational or localized contact.
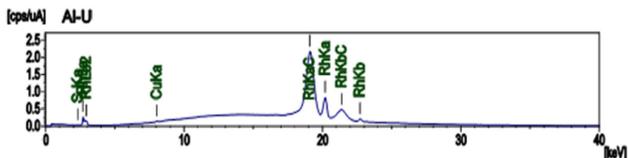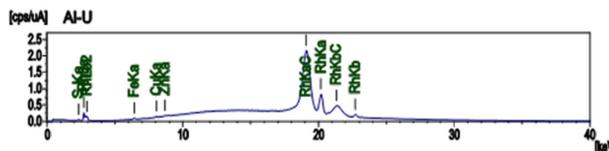
Diamond Industry:
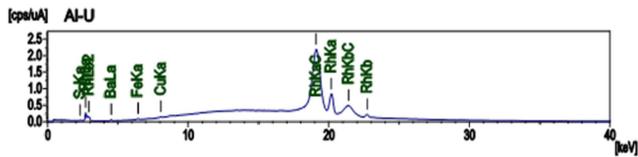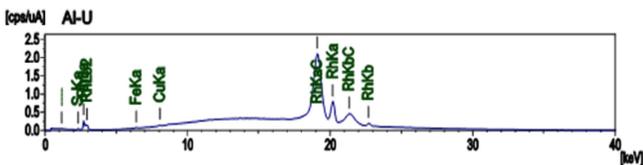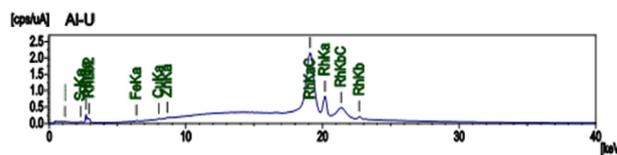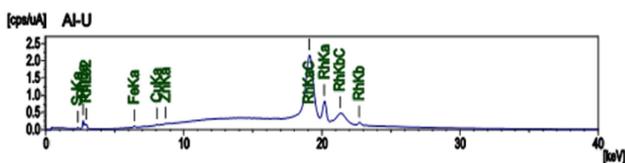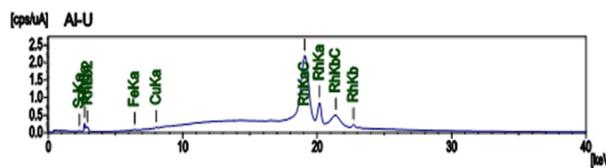
(b) Sample No:1`
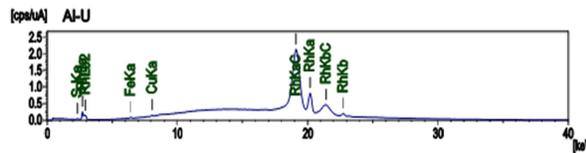
(a) Sample No:2
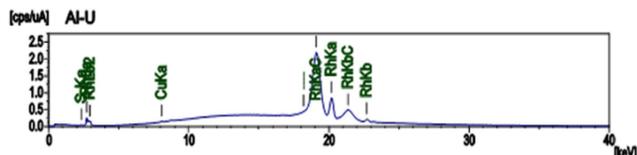
(d) Sample No:3

(c) Sample No: 4

(f) Sample No:5
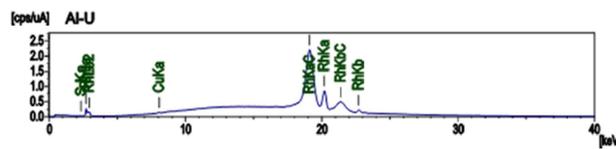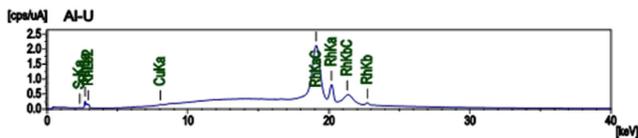
(e) Sample No:6

(h) Sample No:7`

(g) Sample No:8

(j) Sample No:11

(i) Sample No:12

(l) Sample No:9
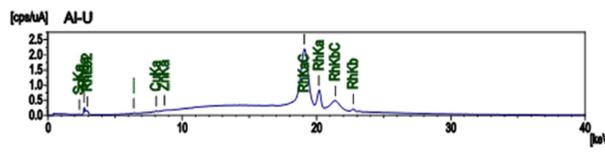
(k) Sample No:10

Graph 3.2: EDXRF Spectral Results for Nail Samples –Diamond Industry Workers

Table 3.2: Representing the percentage of heavy metals present in the
diamond industry sample

Percentage of heavy metals present in the diamond industry:

Sample No:	Fe (%)	Zn (%)	Cu (%)	Ba (%)
1	2.135	0.832	1.755	24.727
2	1.871	0.728	1.333	-
3	1.477	0.924	1.533	-
4	2.576	0.728	1.278	-
5	1.829	1.016	1.544	-
6	1.760	0.678	1.136	-
7	2.037	0.836	1.585	-
8	-	0.852	1.901	-
9	-	0.916	1.797	-
10	-	0.870	1.772	-
11	1.587	0.963	2.012	-
12	-	0.826	1.450	-

Iron (Fe) was detected in 8 out of 12 samples, ranging from 1.477% to 2.576%. Sample 4 included the highest level of Fe (2.576%), suggesting higher exposure to iron-rich environments. The absence of Fe data in Samples 8, 9, 10, and 12 might be an indication of unmeasured values or below detection limits. Zinc (Zn) levels were detected in all 12 samples, ranging from 0.678% to 1.016%. Overall, Zn concentrations were fairly consistent, indicating uniform low-to-moderate exposure. Copper (Cu) was also present in all 12 samples, with values ranging from 1.136% to 2.012%. Barium (Ba) was detected only in Sample 1, at a notably high level of 24.727%. This is a significant outlier compared to the rest of

the dataset, where Ba was either absent or undetectable. Such a high concentration may suggest specific and unusual exposure, possibly due to contact with barium compounds.

Control Samples:
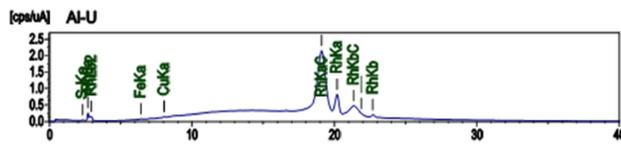
(a) Sample No:1
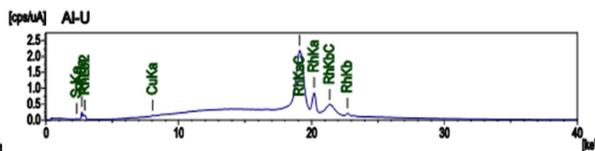
(b) Sample No:2
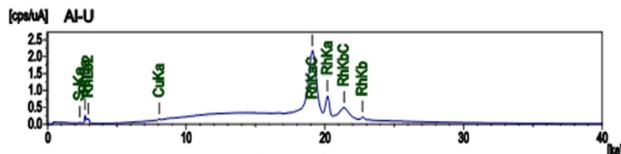
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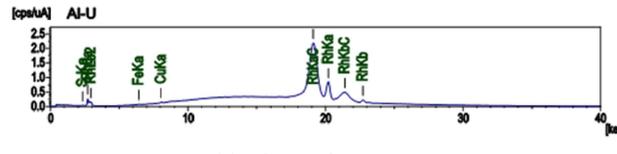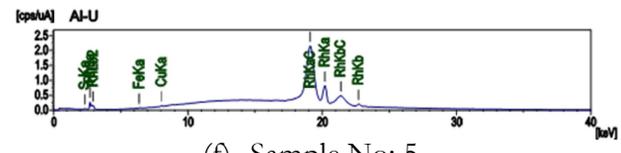
(c) Sample No: 4
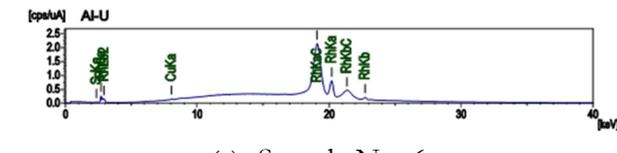
(f) Sample No: 5

(g) Sample No: 6
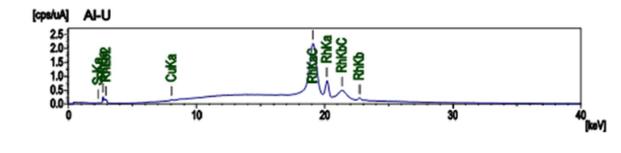
(e) Sample No: 7
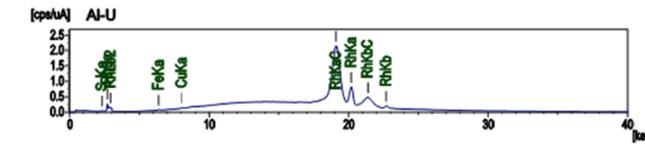
(j) Sample No: 8
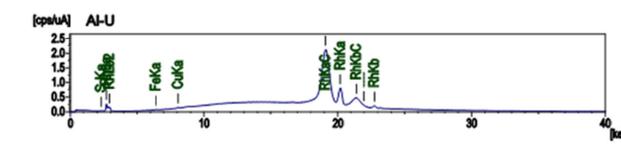
(i) Sample No: 9
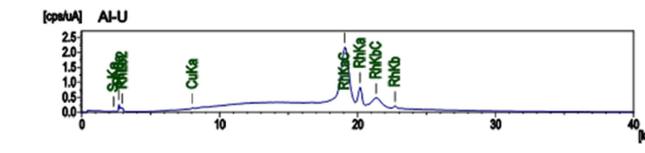
(h) Sample No: 10

Percentage of heavy metals present in the control samples:

Graph 3.3: EDXRF Spectral Results for Nail Samples – Control samples

Table 3.3: Representing the percentage of heavy metals present in the control sample

Sample No:	Fe (%)	Zn (%)	Cu (%)
1	1.541	0.774	1.665
2	0.906	0.790	1.192

3	0.846	0.855	1.514
4	1.053	0.757	1.669
5	1.249	0.980	1.846
6	1.198	0.792	1.485
7	0.954	0.833	1.515
8	-	0.707	1.584
9	0.880	0.798	1.574
10	1.113	0.801	1.321

The above analysed control samples, is collected from the individuals that are not exposed to industrial environments which help to establish the normal/background levels of metal concentrations (Fe, Zn, and Cu) in the population for comparative toxicological assessment. Iron (Fe) was detected in 9 out of 10 samples, with concentrations ranging from 0.846% to 1.541%. These are the naturally occurring physiological levels of iron and are likely influenced by dietary intake and individual metabolic factors. The total iron concentration in the control group remains within a narrow range, which suggests that there was no unusual exposure. The one missing value may be due to trace levels that are too small or to non-detection. All ten samples contained zinc (Zn), with a comparatively constant quantity ranging from 0.707% to 0.980%. This stability suggests that the control population's zinc content is stable and unaffected by the exposure to the environment or workplace. All the 10 samples also contained copper (Cu) with the percentage from 1.192% to 1.846%. Copper being an essential trace element, which is most often present in the human body, it revealed slightly higher baseline values compared to the other two metals analysed. The minimal variability and the fact that copper appeared in all the samples justify this data as a control reference.

Mean Percentage and Standard Deviation of Heavy Metals in Different Industry.

For each of the heavy metals (Fe, Zn, and Cu) in the control group, mean percentage and standard deviation were established to provide an accurate baseline to enable informative comparison with the exposed population. These statistical methods are used to calculate the central tendency and natural

variability of metal concentration among individuals that are not exposed to industrial environments. Standard deviation indicates the amount of variability or uniformity among the control group, while the mean percentage reflects the average normal level of every metal.

This approach is required in order to distinguish between increased levels due to occupational or environmental exposure and expected biological variability. Values that are significantly different from this statistically determined baseline, particularly those that are more than the mean ± standard deviation, can be interpreted as possible indicators of metal buildup or toxicity. Thus, identification of these criteria enhances the scientific merit of the study and allows for an objective evaluation of heavy metal exposure within different populations.

Metal	Group	Mean %	SD (%)
Fe	Steel Industry	3.968	2.1058
	Diamond Industry	1.908	0.3449
	Control Sample	1.082	0.2229
Zn	Steel Industry	1.166	0.4712
	Diamond Industry	0.847	0.1004
	Control Sample	0.808	0.0723
Cu	Steel Industry	1.704	0.3254
	Diamond Industry	1.591	0.2650
	Control Sample	1.536	0.1832
Ag	Steel Industry	7.203	1.6305
	Diamond Industry	-	–
	Control Sample	-	–

Ba	Steel Industry	-	–
	Diamond Industry	24.727 (Only Present in one sample	NA
	Control Sample	-	–

Table 4.4 Representing the Mean Percentage and Standard Deviation of all the heavy metals that is present in different samples

- **Steel industry:**

The nail samples collected from workers within the steel sector indicated the highest overall average values for Fe (3.968%), Zn (1.166%), and Cu (1.704%) with standard deviation of 2.1058%, 0.4712%, and 0.3254%. These average values provided a measure of variability across this group of occupations independent of exposure, which could be classified as medium level of variation of metals accumulation exposure in relation to occupational groups. The higher average concentrations are due to the work, which may have effects from the type of work, which likely would take place over a more prolonged duration of exposure to; metallic surfaces, exposure to machinery, and incidental contamination from working adjacent to other processes likely dealing with metals. The presence of the variation particularly relating to iron, indicates there wasn't continuity of exposure across participants. Possible variability could be due to different types of work performed, variations in durations of exposure & the use of personal protective equipment (PPE).

The presence of silver (Ag) with a 7.203% mean concentration and a relatively high standard deviation (SD) of 1.6305% was noteworthy in this sample group. The control group samples, and samples from the diamond industry did not contain silver, indicating that the exposure occurred in the steel industry environment. Sources of exposure could be through soldering, industrial activities that involve utilizing silver alloys, or contact with equipment that has silver-plated components. The high mean with moderate variability shows a need to monitor exposure to silver, especially for those in specific occupations that are monitored within the steel industry.

- **Diamond industry:**

The means for heavy metals for the diamond industry group were lower, Fe at 1.908%, Zn at 0.847%, and Cu at 1.591%. The heavy metals also had a relatively lower standard deviation (Fe was 0.3449%, Zn

was 0.1004%, and Cu was 0.2650%), indicating less deviation across individuals. These results may suggest regulated or consistent occupational exposure across all employees, or it may be lower naturally due to the type of work, even though occupational exposure does occur in the diamond sector. There were also no samples from this group that contained any silver, unlike in the steel industry.

A very high level of 24.727% barium (Ba) was detected in one person from the diamond company, which is likely some sort of "anomaly", since Ba was not detected in the other samples. It may be due to specific to the task, or to local contamination. In this case, it was not possible to calculate a standard deviation for Ba in this group because of the anomalous nature of the detection.

- **Control Group:**

The control group revealed the lowest mean for any of the elements measured with the least dispersion or variation and represented people who had no known occupational exposure to heavy metals. The mean concentrations of iron (Fe) were 1.082% with a standard deviation (SD) of 0.2229%, zinc (Zn) were 0.808% (SD: 0.0723%), and copper (Cu) (SD: 0.1832%). The findings demonstrate not an occupational exposure, but rather a natural physiological background exposure most likely from dietary intake from foods, environmental exposure, or as a result of some metabolic activity.

The consistency of the group as a baseline reference for comparison is further supported by the consistently small standard deviations across the three metals indicating little variability between individuals. As would be expected in populations that do not work in occupations that are traditionally considered to have potential for high metal exposures, the results show a consistent and steady mode of build-up of the metals.
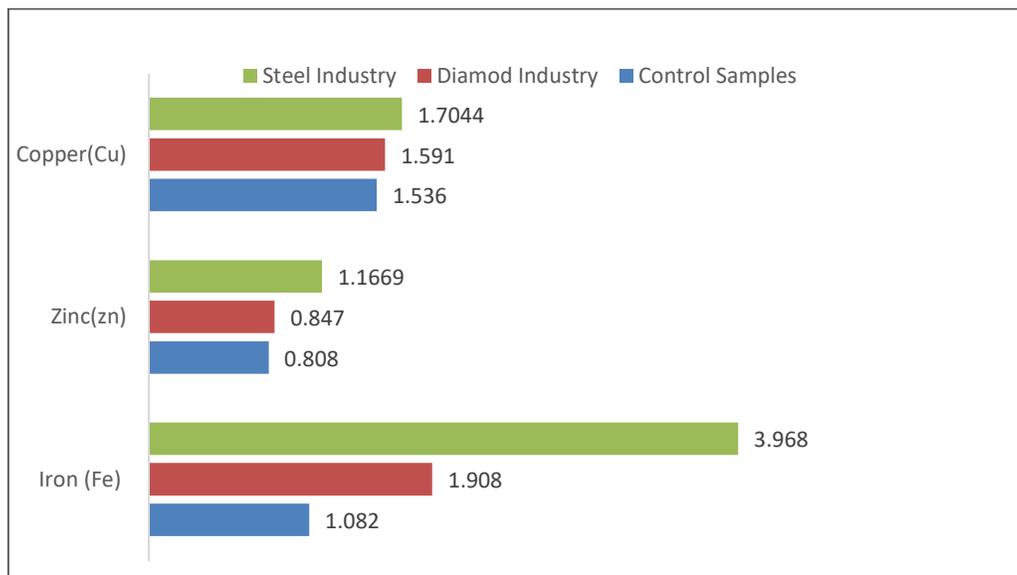
The above Graph shows the mean percentage of three metals - Iron (Fe), Zinc (Zn), and Copper (Cu) - in samples collected from three categories: Steel Industry workers, Diamond Industry workers, and Control Samples. It highlights the Possibility of occupational exposure to heavy metals in industrial environments, especially in the steel sector, where workers appear to have elevated levels of Fe, Zn, and Cu compared to the control population. The data suggests a correlation between workplace environment and metal accumulation in the body.
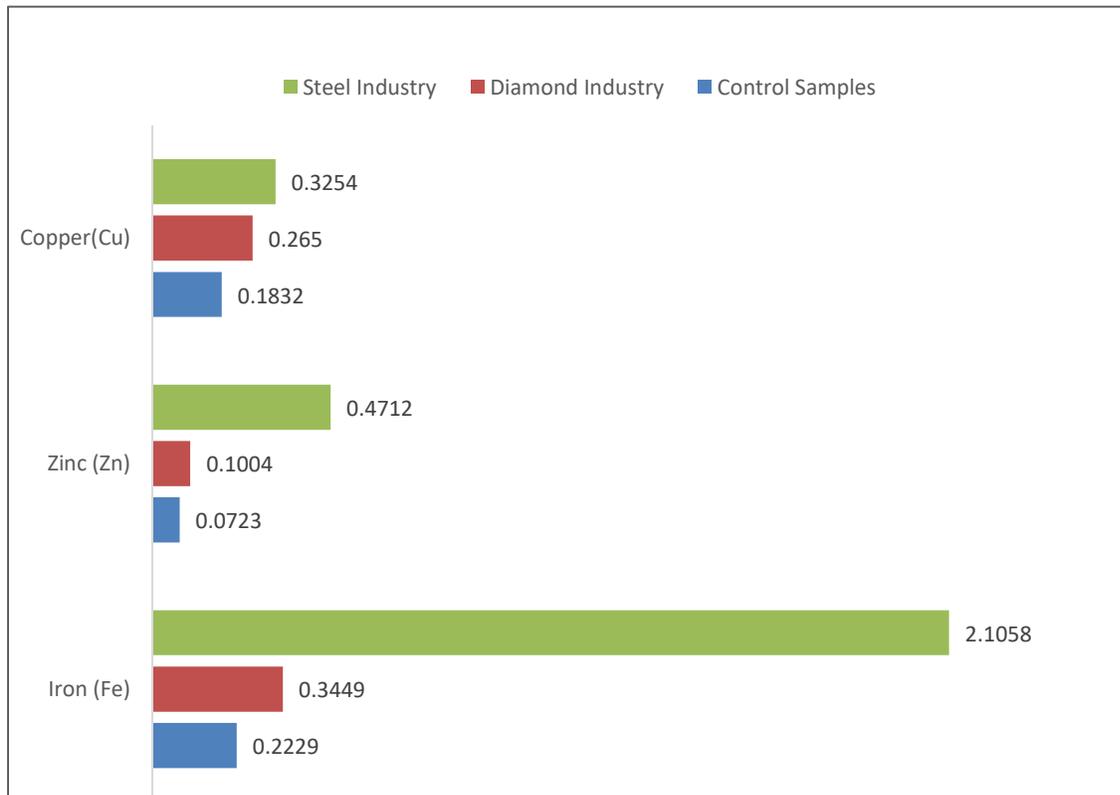
Graph 3.5 Representing the Standard Deviation (SD) of Iron (Fe), Zinc (Zn) & Copper (Cu) in the samples.

The above graph shows the standard deviation (SD) as a percentage of three metals - Iron (Fe), Zinc (Zn), and Copper (Cu) – in sample collected from three categories: Steel Industry workers, Diamond Industry workers, and Control Samples. This shows the possibility of occupational exposure, especially in the steel industry, not only increases the mean levels of metals but also causes a wider range of exposure levels among workers.

Exceptional Findings:

While iron (Fe), zinc (Zn), and copper (Cu) were focused in this study, the EDXRF analysis also detected the presence of the other heavy metals:

- Silver (Ag) was detected in the samples of the steel industrial workers nails (With the Mean % of 7.203 and also shows the Standard variation of 1.630 5%). This might be associated with specific occupational procedures in steel processing.

- Barium was found in one sample from the diamond industry. The occurrence of Ba could be associated with the use of barium-containing compounds in abrasives, industrial machinery, or processing chemicals used specifically in cutting and polishing diamonds. It might be related with the isolated contamination or task-specific exposure.

Discussion

This research discussed the application of Energy Dispersive X-ray Fluorescence (EDXRF) spectroscopy in forensic toxicology with a focus on industrial worker heavy metal detection.

The investigation employed nail specimens, a non-invasive biological matrix, to analyze chronic exposure to heavy metals, as opposed to traditional methods which often require invasive methods or sample destruction. Due to the keratinous tissues, nails have the ability to incorporate and retain metals over extended periods, offering a timeline of exposure and making them ideal for analysis. Compared to other biological matrices such as blood or urine, nails are easier to collect, store, and transport, while also posing minimal ethical and health risks, which further validates their forensic and practical value.

The analysis revealed variations in heavy metal concentrations between the test groups such as steel industry workers, diamond industry workers, and a control population. The statistical analysis with mean and standard deviation assisted in measuring the extent of exposure and demonstrated evident differences in exposed versus unexposed groups. According to these findings, the paper advises various preventive strategies like regular use of personal protective equipment (PPE), better workplace ventilation, regular health monitoring by non-invasive biomonitoring, and worker awareness programs in order to minimize exposure risks. The study provides useful insights into the occupational health hazards created by industrial settings and justifies the necessity of robust safety measures and health monitoring systems to facilitate long-term employee welfare.

Preventive Measures

- Personal Protective Equipment (PPE): To reduce direct contact and inhalation of heavy metal particles, ensure gloves, masks, goggles, and protective clothing are mandatory.

- Workplace Ventilation: To minimize exposure to airborne metal dust, enhance air circulation and install effective exhaust or air filtration systems.

- Regular Health Monitoring: To detect early signs of metal buildup, conduct regular medical check-ups, including biological monitoring (e.g., blood, nail, or hair testing).

- Training and Awareness Programs: Educate employees about the risks, causes, and effects of heavy metals on their health and the necessity of taking precautions.

- Rotational Shifts and Workload Management: Restrict the duration of time spent by employees in high-risk zones or implement shift rotation to reduce exposure durations.

- Workplace Hygiene Practices: Avoid the consumption of metal pollutants by encouraging washing hands before meals and resisting from eating and drinking within the workplace.

4. CONCLUSION

Nails are an important non-invasive biomarker for the evaluation of long-term exposure to harmful elements like heavy metals, as they grow slowly and can contain trace elements that accumulate over time. In the current research Heavy metal analysis of 32 samples was conducted which includes 10 samples from steel industry, 12 samples from diamond industry and 10 samples from individuals with no known occupational exposure, serving as the control group.

This analysis was done by using Energy Dispersive X-ray Fluorescence (EDXRF) as a simple and effective analytical method for qualitative detection of elemental composition in biological samples. The result shows that each group contained varying levels of iron (Fe), zinc (Zn), and copper (Cu). Additionally, the presence of Silver (Ag) and Barium (Ba) was also detected in the samples. These rare observations emphasize the importance of extensive elemental screening in determining the risks of occupational exposure.

The concluding points from the study are the following:

- The Study shows that the steel industrial workers show the highest mean concentration of Iron (Fe).
- Variation in Fe values was shown by standard deviation graphs, especially for steel workers, suggesting a spread of exposure levels that can be due to work responsibilities, duration of work exposure, or adherence to safety measures.
- Zinc (Zn) and copper (Cu) were also present in all three groups, but at higher concentrations in industrial workers compared to the control group.

- Elevated metal concentrations, especially Fe, shows the chronic exposure among steel workers.

- High levels of zinc (Zn), copper (Cu), and iron (Fe) are toxic to health despite being essential trace elements required for normal physiological functions. Eventually, oxidative stress, organ dysfunction, and systemic toxicity can be caused by prolonged and uncontrolled exposure.

The findings identify the importance of implementing protective equipment, periodic health monitoring, and strict safety measures in the workplace. Chronic exposure may have significant health impacts and reduce worker welfare if the necessary precautions are not observed.

In conclusion, the study not only validates the efficacy of EDXRF in detecting heavy metal toxicity but also reinforces the importance of nail analysis as a viable, non-invasive diagnostic tool. It paves the way for more comprehensive exposure surveillance programs, which are essential for safeguarding the health of industrial workers and enhancing the role of forensic science in occupational health risk management.

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