

Occupational Exposure to Incinerator-Emitted Heavy Metals among Healthcare Workers: A Plasma Biomonitoring Study in Southwestern Nigeria

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Abstract

Purpose

In many developing countries including Nigeria, incineration of hospital waste remains one of the major waste treatment options in many developing countries, including Nigeria, yet it is a major factor contributing to occupational exposure to heavy metals emissions.

Methods

This study investigated the concentration of selected heavy metals in blood plasma of workers that are occupationally exposed to hospital waste incinerator emissions in Federal Teaching Hospital, Ido-Ekiti, Ekiti State, Nigeria. Sixty-four (64) venous blood samples were collected and analyzed. Forty-two (42) were the exposed group and twenty-two (22) were the non-exposed group.

Results

The mean concentration of metals in blood plasma followed the order $\text{Fe} > \text{Cu} > \text{Cr} > \text{Zn} > \text{Cd} > \text{Ni} > \text{Co} > \text{As} > \text{Pb} > \text{Hg}$. There exists a significance difference ($p < 0.05$) between exposed and the non-exposed groups. The concentration of Cd, Hg, Pb, As, and Ni were observed to be elevated among the occupationally exposed workers. There was a strong inter-elemental correlation between Cd-Cu ($r = 0.80$), Cu-Fe ($r = 0.79$), and Pb-As ($r = 0.70$). This study revealed higher accumulation among younger workers (≤ 30 years) and female participants.

Conclusion

This study presents biomonitoring evidence that hospital waste incineration in low-resource settings contributes to occupational exposure to toxic heavy metals. The findings from this study emphasize the need for routine biomonitoring of occupationally exposed workers and eco-friendly technologies that will mitigate the toxic effect of hospital waste incineration and its health risks.

Highlights

- Occupationally exposed healthcare workers near the hospital incinerator showed high levels of toxic heavy metals which includes Ni, As, Cd, Hg, and Pb, all of which exceeded WHO permissible limits.
- Iron (Fe) and Copper (Cu) were the most prevalent metals detected, while Hg and Pb were the lowest, yet still above safe levels in exposed workers.
- Strong positive correlations among Cd–Cu, Cu–Fe, and Cd–Cr suggest co-exposure from a common incineration source and possible synergistic toxic effects.
- Younger workers (≤ 30 years) and female workers showed higher bioaccumulation of heavy metals, reflecting demographic vulnerability among younger and female workers

1. Introduction

Wastes that are generated due to medical procedures are commonly referred to as medical or hospital wastes (Giakoumakis et al. 2021; Attrah et al. 2022). Heavy metals, radionuclides and other toxic complex substances are major constituent of hospital wastes (Attrah et al. 2022; Shuangliu et al. 2024). The importance of healthcare services cannot be over emphasized and at the same time medical wastes can pose both occupational and environmental health risks in a developing country like Nigeria due to dependence of incineration (Abah and Ohimain 2011; Oyekale and Oyekale 2017).

One of the major source of air pollutants in Nigeria hospitals is incinerator (Ghali et al. 2023). Reports have shown that emissions from medical waste incineration constitutes pollutants such as, furans, dioxins, heavy metals, acidic gases and radionuclides (Cai et al. 2023). Persistence release of these toxic substances to the environment can result in bioaccumulation in human tissues due to exposure through different pathways, even at a very low concentration (Briffa et al. 2020; Oros 2025).

According to World Health Organization (WHO) about 85% of medically generated wastes poses no hazard threat and that the remaining 15% might pose a significant threat if they were being managed poorly below the required policy or unethically (Kenny and Priyadarshini 2021; Aziz et al. 2022). Healthcare workers that are occupationally exposed to the hazardous emission from the medical waste incinerators can show acute toxicity, chronic illness and long-term generative illness (Cook et al. 2023). The health risks may be higher among workers that works in in hospitals that are exhibit poor waste regulatory policies and practices (Giakoumakis et al. 2021; Ghali et al. 2023; Chen et al. 2024 Jomova et al. 2024).

Many existing literatures examined the concentration of these toxic substances in environmental media such as soil, vegetation, air and flying ashes around incinerator sites (Campo et al. 2019). Many of the existing studies has made significant contribution to pathway of pollutants but only few of addressed the human exposure (Shetty et al. 2023). Therefore, there exist limited biomonitoring and biomarker studies of heavy metals among workers that are occupationally exposed to the emissions and activities of hospital waste incinerator (Mauriello et al. 2017). Larger percentage of existing studies assessed non-incineration sources such as industrial effluent, dietary intake and vehicular emissions which makes gaps to exists regarding healthcare workers that are occupationally exposed to emissions from medical waste incinerator (Nematollahi et al. 2025). In addition to the stated gap, only few studies take into the consideration the demographic vulnerability, synergistic toxicity and spatial proximity to exposure of heavy metals emitted from medical waste incinerator (Ranzi et al. 2011).

In order to conduct a very robust health risk assessment and to develop a plausible health intervention, it is therefore necessary to address the aforementioned gaps. This study determines the levels of heavy metals in the blood plasma of workers that are occupationally exposed to emissions emanating from hospital waste incinerator of Federal Teaching Hospital, Ido-Ekiti, Nigeria. This study also stratified the data and assessed the demographic vulnerability, inter-elemental correlation within the exposed and non-exposed group.

This study establishes that emissions from medical waste incinerators contributes to pathway health risks by heavy metals. The results from this work are expected to contribute to the formulation of occupational safety policy that will promote and guide the safe use medical waste incinerators in Nigeria where the use of advanced waste technology is lagging behind.

2. Materials and methods

2.1 Study design and study area

This study employed the use of cross-sectional biomonitoring design to analyze the levels of heavy metals in blood plasma of healthcare workers that are occupationally exposed to the activities of medical waste incinerator at the Federal Teaching Hospital, Ido-Ekiti (FETHI), Ekiti State, Nigeria. The hospital is located on latitude 7.8434° N and longitude 5.1877° E in Ido-Ekiti, Ekiti State in South-western part of Nigeria. The hospital has a bed capacity of four hundred and fifty and generates medical waste that is approximately equal to 0.73 kg per bed per day. The hospital whose major waste treatment is incineration is a major tertiary facility that serves as teaching hospital for the medical student of Federal University Oye-Ekiti.

2.2 Study population and participant selection

The population studied in this work consisted of health care workers that has their offices or department located with a radius of 100 to 300 meters from the where the medical waste incinerator is located. Workers that have been working for a minimum of six months were considered to be eligible for this study. Those excluded from this study are workers with a report of chronic cases confounding the exposure of heavy metal outside the health care institution considered in this study.

In order remove possible exposure misclassification that may arise from treating the exposed group as a spatially homogenous, the group (n = 42) was explicitly stratified according to their departmental proximity to the incinerator. The high proximity exposure zone (< 150m) consists of personnel in the waste management department and the creche department which are characterized by their proximity and routine interaction with ambient plume settling within the zones.

The exposure of the workers is an average of 8.0 hours/day for 5 days in a week, which involves direct contact with residues of flying ashes and the ground-level emissions. The workers at creche department do not handle waste but they are located in in a facility within 120 m directly downwind of the un-scrubbed stack. They are exposed through inhalation of ambient air and during supervising outdoor children's activities. The moderate proximity exposure zone (150m -300m) consists of workers in Intensive Care Unit (ICU), Clinical Audit and Facilities (CAF) and Medical Health (MH) Department. These groups occupied spaces at a localized distance from the medical waste incinerator. The exposed cohort consist of security, administrative and clinical personnel whose offices or routine were within the dispersion radius secondary to the source. These are workers that do not handle waste directly but they are exposed to the diluted plume through natural ventilation system during their 8-hours work shifts.

The control group (n = 22) 23,000 meters away, was purposefully selected from a demographical location that was totally out of atmospheric wind dispersion and plume deposition. This cohort had no routine interaction with activities and emissions from the medical waste incinerator. In order to compare and minimize residual confounding epidemiologically, the control group was chosen to match the socio-economic, dietary and climatic baseline of the exposed group. Physiological metrics such as systolic/diastolic blood pressure and pulse rate was used to confirm that the unexposed group has no statistically significant variance from the exposed cohort (p > 0.05).

Table 1
Demographic, Lifestyle, and Physiological Characterization of the Study Cohorts.

Parameters	Exposed Cohort (n = 42)	Control Cohort (n = 22)	chi ² value	p-value
Age (Years; Mean ± SD)	38.4 ± 6.2	39.1 ± 5.8	-0.435	0.665
Sex Ratio (Male/Female)	13/29	7/15	0.012 ⁺	0.913
Dietary Profile (Omnivorous %)	95.2%	95.5%	0.004 ⁺	0.950
Active Smoking History (%)	0.0%	0.0%	-	-
Systolic BP (mmHg; Mean ± SD)	122.4 ± 8.5	121.8 ± 7.9	0.272	0.786
Diastolic BP (mmHg; Mean ± SD)	79.6 ± 5.3	78.9 ± 6.1	0.472	0.638
Pulse Rate (bpm; Mean ± SD)	74.2 ± 6.8	75.0 ± 5.9	-0.457	0.649
<i>Note: ⁺ indicates Chi-square test for categorical variables; all other rows analyzed via Independent Samples t-test. Statistical significance set at p < 0.05.</i>				

Table 1 presents the independent statistical analyses which confirmed that there exists no significant variance (p > 0.05) in the demographic lifestyle, demography and physiological parameters (Systolic/Diastolic blood pressure and heart rate) between the exposed and the control groups. This lack of variance shows that the control and the exposed groups share identical socioeconomic, dietary and regional environmental backgrounds

2.3 Ethical considerations

The ethical approval for this study was obtained from the Ethics Committees of the Federal Teaching Hospital, Ido-Ekiti with approval number ERC/2021/11/18/689B. The informed consent was obtained from all participants prior to sample collection, and all procedures were conducted in accordance with the Declaration of Helsinki on research involving human subjects.

2.4 Blood sample collection and preservation

Sterile disposable syringes fitted with 21G × 1½ needles was used to collect five milliliters (5 mL) of venous blood from each participant via antecubital venipuncture. The collected blood was transferred into pre-labelled heparinized tubes to prevent coagulation. Samples were immediately placed in ice-packed containers and transported to the pathology laboratory of the Federal Teaching Hospital, Ido-Ekiti. The use of a bucket centrifuge operated at 3000 rpm for 10 minutes was employed to perform the plasma separation. The separated plasma was carefully aliquoted into acid-washed polyethylene vials and stored at -20°C until laboratory analysis. Physiological parameters including systolic and diastolic blood pressure and pulse rate were measured using calibrated clinical instruments to provide baseline health information.

2.5 Sample digestion and laboratory analysis

The digestion of the plasma was done using a wet acid digestion method. The five milliliters (5 mL) of plasma was transferred into digestion vessels then followed by the addition of 20 mL of freshly prepared concentrated nitric acid (HNO₃) and hydrogen peroxide (H₂O₂) in a ratio two to one (2:1). At room temperature, the mixture was allowed to pre-digest for 10 minutes and subsequently heated at 48°C for 5 minutes. After cooling, the digest was reconstituted with 0.1 M nitric acid and diluted to a final volume of 20 mL using double-distilled water. The concentrations of Cr, Cd, As, Cu, Fe, Hg, Zn, Pb, Co, and Ni were determined using Flame Atomic Absorption Spectrometry (FAAS) (Buck Scientific Model 205) at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria. Commercially prepared standard solutions (British Drug House, BDH, England) were used for instrument calibration, and calibration curves with correlation coefficients (R²) exceeding 0.995 were achieved for all elements.

2.6 Quality assurance and quality control (QA/QC)

In order to ensure analytical accuracy and precision, quality assurance procedures were ensured which include the analysis of reagent blanks, duplicate samples, and spiked recoveries. The blank values were subtracted from sample concentrations. Spike recovery tests yielded recovery rates within the acceptable range of 90–110%, indicating good method reliability. All measurements were performed in triplicate, and results were reported as mean ± standard deviation.

2.7 Statistical analysis

The statistical analyses were performed using IBM SPSS 25. The descriptive statistics were used to summarize metal concentrations. In order to evaluate differences between exposed and non-exposed groups, independent sample t-tests and Pearson correlation were employed. One-way analysis of

variance (ANOVA) was used to assess variations across age groups, sex, and departmental units. T-test analysis was applied to determine inter-metal relationships and potential co-exposure patterns. Statistical significance was set at $p < 0.05$.

3. Results and discussion

3.1 Plasma heavy metal concentrations

Table 2

The mean concentration (ppm) of heavy metals in subjects' blood plasma for the exposed and non-exposed

Element	All (n = 64)		Exposed (n = 42)		Non exposed (n = 22)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Cr	0.215 $\pm$ 0.08	0.102–0.420	0.254 $\pm$ 0.08	0.104–0.344	0.141 $\pm$ 0.03	0.102–0.224
Cd	0.140 $\pm$ 0.05	0.056–0.219	0.174 $\pm$ 0.03	0.120–0.219	0.076 $\pm$ 0.01	0.056–0.104
As	0.064 $\pm$ 0.03	0.016–0.126	0.082 $\pm$ 0.02	0.056–0.126	0.031 $\pm$ 0.01	0.016–0.04
Cu	0.240 $\pm$ 0.15	0.08–0.48	0.308 $\pm$ 0.14	0.104–0.616	0.109 $\pm$ 0.03	0.08–0.160
Fe	0.256 $\pm$ 0.14	0.016–0.588	0.321 $\pm$ 0.13	0.120–0.588	0.132 $\pm$ 0.05	0.016–0.200
Hg	0.037 $\pm$ 0.02	0.014–0.079	0.046 $\pm$ 0.02	0.016–0.079	0.021 $\pm$ 0.01	0.014–0.032
Zn	0.167 $\pm$ 0.08	0.024–0.408	0.192 $\pm$ 0.09	0.024–0.408	0.120 $\pm$ 0.04	0.087–0.232
Pb	0.047 $\pm$ 0.02	0.022–0.136	0.056 $\pm$ 0.03	0.024–0.136	0.030 $\pm$ 0.01	0.022–0.04
Co	0.071 $\pm$ 0.03	0.024–0.128	0.08 $\pm$ 0.02	0.032–0.128	0.052 $\pm$ 0.02	0.024–0.088
Ni	0.106 $\pm$ 0.03	0.056–0.190	0.114 $\pm$ 0.04	0.056–0.190	0.090 $\pm$ 0.01	0.068–0.104

The descriptive statistics of heavy metals concentration in blood plasma was presented on Table 2. It consists of exposed and non-exposed groups across all sixty-four subjects (n = 64). Iron (Fe) exhibited the highest mean concentration (0.256 $\pm$ 0.14 mg/L), followed by copper (Cu) (0.240 $\pm$ 0.15 mg/L) and chromium (Cr) (0.215 $\pm$ 0.08 mg/L), while mercury (Hg) and lead (Pb) recorded the lowest mean concentrations. The activities of the medical waste incinerator were confirmed by significantly higher plasma metal concentrations observed in exposed workers compared to non-exposed controls (Li et al.

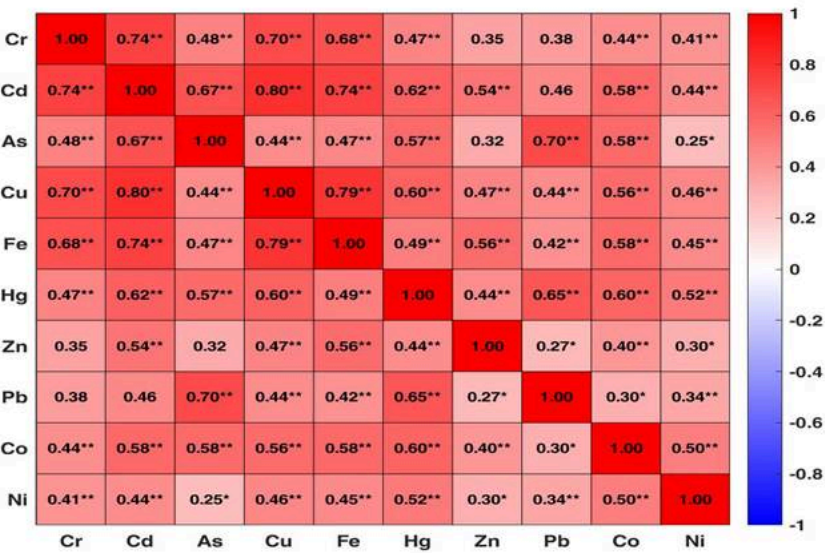
2017). The comparison shows that workers that are occupationally exposed (n = 42) to the incinerator facility had higher plasma concentrations of all measured metals compared to non-exposed controls (n = 22) (Bakoğlu et al. 2004). For all the ten metals, independent sample t-tests confirmed statistically significant differences ($p < 0.05$) between exposed and non-exposed which indicates major occupational contribution to internal metal burden (Fouad et al. 2026). The prevalence of Fe and Cu may indicate their duties as an essential trace elements or components of medical waste material (Oladejo et al. 2026; Orsini & Clarysse 2012; Oladejo et al. 2026). However, Cd, Hg, Pb, As, and Ni are found to be elevated among the exposed workers which is of greater concern due to the way accumulate and associated adverse health effects (Balali-Mood et al. 2021). These metals could have be released during incineration of medical waste components including batteries, dental materials, thermometers, electronic devices, and pharmaceutical products.

3.2 Age-dependent distribution of heavy metals

Figure 1 shows the concentration of heavy metals in blood plasma across age groups. The youngest age group (≤ 30 years) shows the highest concentrations for most metals, particularly Cd, Co, Cr, Cu, Hg, Ni, and Pb (29). A decreasing pattern with increasing age was observed for several metals which suggests age-related differences in exposure patterns or metabolic process. However, arsenic (As) shows a non-linear distribution, with peak concentrations observed in the 31- 40-year age group (Lv et al. 2021).

3.3 Inter-metal correlation analysis

Table 3: Inter-elemental correlation in subjects’ blood plasma (n = 64).



Note: **: Correlation is significant at the 0.01 level (2- tailed) *: Correlation is significant at the 0.05 level (2- tailed)

The Pearson correlation analysis which shows a strong positive correlation ($p < 0.01$) among several metals was revealed in Table 2. There exists strong positive correlation between Cd-Cu ($r = 0.80$), Cu-Fe ($r = 0.79$), Cd-Fe ($r = 0.74$), Cd-Cr ($r = 0.74$), and Cr-Cu ($r = 0.70$). There exists a moderate correlation between As-Pb ($r = 0.70$), Hg-Pb ($r = 0.65$), and Co-Ni ($r = 0.50$). The relationships suggest co-exposure pattern from a common emission source and potential concurrent accumulation pathways (Oladejo et al. 2026).

3.4 Sex-based differences in metal accumulation

Figure 2 revealed that female subjects have higher mean concentration of heavy metals in their blood plasma compared to their male counterparts with statistical significance difference ($p < 0.05$) observed for Hg, Pb, Cr, As, Co, and Ni. The concentration of Fe and Zn were comparable or slightly higher in males which suggest gender-specific variability and vulnerability to bioaccumulation of heavy metals (Huang et al. 2022; Peter et al. 2023; Vahter et al. 2007).

The differences observed across both gender in this study revealed that female is more vulnerable to heavy metal exposure than male (Liu et al., 2025). Hormonal regulation, body fat composition, metal binding protein expression (e.g., metallothioneins) among other physiological factors, may influence heavy metal absorption and retention which makes females to be more susceptible to the adverse effects of heavy metal exposure (Rebollo-Salinas et al. 2025).

3.5 Spatial Gradient and Departmental Proximity as Predictors of Exposure Intensity

A distinct spatial gradient was observed on the concentration of heavy metal in blood plasma across different departments. This highlights the effect of proximity on occupational exposure. The bioaccumulation of heavy metal in blood plasma varied consistently with distance from the incinerator site rather than working as a homogeneous exposure zone.

Workers managing the waste and those at the creche department consistently showed the highest mean concentrations of heavy metals, especially copper (Cu) and iron (Fe), with mean levels that is above 0.4 mg/L. Their fixed presence at their operational department (< 150 m to the incinerator) is attributed to the elevated profile. Moreover, they directly deal with the handling of medical wastes and they were continuously exposed to exposure to low-level ground-level emissions occurs. Arsenic (As), lead (Pb), and mercury (Hg) showed lower average levels in the downwind group compared to those who have their departments in close proximity to the source.

On the other hand, the levels of heavy metal in the blood plasma of workers at ICU, CAF, and MH departments revealed a gradual downward pattern which correspond to their greater spatial separation (150–300 m) from the emission source. The distinct, distance-dependent decline in internal biological dosage revealed strong epidemiological evidence that hospital incinerator is a source of exposure to heavy metals among health workers that are exposed to the emission from medical waste incinerator. It distinguished between the workplace pathway from environmental or nutritional factors that may

aggravate the levels of heavy metal in blood plasma of exposed group. The findings from this study shows that spatial tracking within healthcare facilities is necessary for health risk monitoring.

However, the elevated levels of Cd, Hg, Pb, As, and Ni among workers that are exposed to emission from the medical waste incinerator is of greater concern due to their toxicity and rate of at which they bioaccumulate in both environmental media and human samples through exposure pathways (Mari et al., 2012). The findings from this study indicates that heavy metal emission from medical waste incineration often co-occur and share similar exposure pathways (Li et al. 2017). The observed spatial gradient across various departments within the hospital indicate the impact of proximity of medical waste incinerator as a key factor of exposure intensity. This necessitates mitigating measures about the siting of incineration plants within hospital premises (Tait et al. 2020; Selman et al. 2021; Oyekale & Oyekale 2017).

4.1 Study Limitations and Confounder Control

Our strong structural match design rigorously limited potential confounding from external environmental backgrounds, domestic hobbies, or dietary variations, even though individual longitudinal food-frequency logs or consumer cosmetic diaries were not explicitly deployed for every participant. In order to completely shield the controls from the incinerator's atmospheric dispersion field and guarantee that baseline nutritional habits, regional crustal geology, and public water infrastructure exposures were highly uniform across both cohorts, a control cohort was chosen from an ecologically and socioeconomically parallel neighborhood 23 kilometers away.

More significantly, strong elemental co-exposure correlations (e.g., Cd–Cu tracking closely with waste incinerator fly ash profiles) and the explicit observation of a highly significant, distance-dependent spatial gradient in heavy metal accumulation across internal hospital departments ($p < 0.05$; Fig. 3) strongly suggest an occupational rather than a dietary or residential etiology. As a result, point-source occupational thermal emissions rather than unrelated background factors can be consistently blamed for the observed plasma concentration differences.

This study shows a biomonitoring evaluation of heavy metals in blood plasma of health care workers that are occupationally exposed to the emissions from medical waste incinerators while some limitations were encountered. The possible effects of environmental backgrounds to the baseline concentration of heavy metals in blood plasma cannot be completely overlooked since structured, longitudinal questionnaires tracking participant-specific dietary profiles, smoking habits, residential traffic densities, and their cosmetics were not extensively deployed. Cadmium (Cd) and lead (Pb) which are persistent elements have multiple environmental exposure pathways which include ambient air pollution and dietary intake. However,

The strict demographic and physiological matching of the 23 km control group ($p > 0.05$) and the highly substantial spatial gradient observed strictly within internal hospital departments, however, significantly reduce the impact of these external variables. Furthermore, rather than diffuse, mismatched

environmental backdrops, the high, positive inter-elemental correlations found between element pairs such as Cd-Cu ($r = 0.80$) and Pb-As ($r = 0.70$) strongly suggest a single, common thermal emission source. To further define individual exposure routes, future research should combine longitudinal biomarker collection with personal ambient air dosimetry and comprehensive lifestyle surveys.

5. Conclusion

This study reveals that health care workers that are occupationally exposed to the emission of heavy metals from medical waste incinerator has elevated levels of multiple heavy metals in their blood plasma compared to non-exposed group. Existence of strong inter-elemental correlations suggests a common emission source and possible synergistic toxic effects. This study also revealed differences in vulnerability with respect to age, sex, and proximity to medical waste incinerating plant. This study highlights incineration of hospital waste as occupational exposure pathway for heavy metals in a healthcare system with limited waste management resources like what most similar health care facilities in sub-Saharan Africa are experiencing. It is therefore necessary for medical institutions sub-Saharan Africa to encourage policy aim at monitoring healthcare worker and adequate emission control technologies in order to mitigate the pollution of hospital environments with the emission of heavy metals from medical waste incineration. Transitioning toward safer, non-incineration medical waste treatment alternatives would further reduce occupational and environmental health risks. It is necessary for subsequent studies to consider comparing the levels of heavy metals in fly ashes, particulate matter and human biological samples across many medical waste incinerators. In conclusion, this work provides important insights to inform regulatory framework for better occupational health policies and sustainable waste management practices in Nigeria and other developing countries.

Declarations

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution

Author Contributions: O.E.E. and O.P.I. conceived and designed the study. O.O.O., A.E.O., O.I.M., A.O.O., O.O.G., and I.P.O. performed the field investigations, participant recruitment, and blood sample collection. A.E.O. and K.E.A. handled data curation and statistical software analysis. O.E.E., O.O.O., and O.I.M. conducted sample digestion and atomic absorption spectrometry laboratory testing. O.E.E. wrote the original manuscript draft. O.P.I. supervised the project and critically revised the final manuscript for intellectual content. O.J.O handled data curation and statistical software analysis. All authors have read and agreed to the published version of the manuscript.

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Data Availability

All data supporting the findings of this study are available within the paper.

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Figures

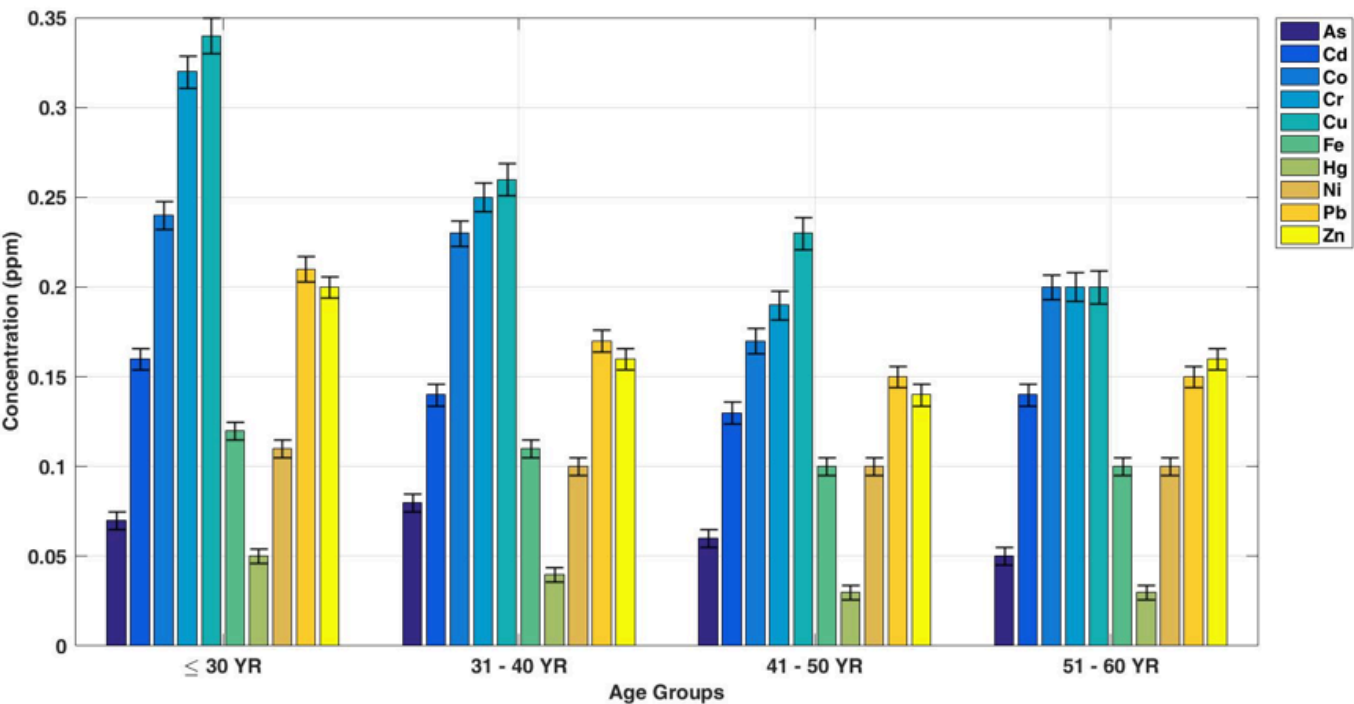


Figure 1

Elemental levels (ppm) of blood plasma according to age (year)

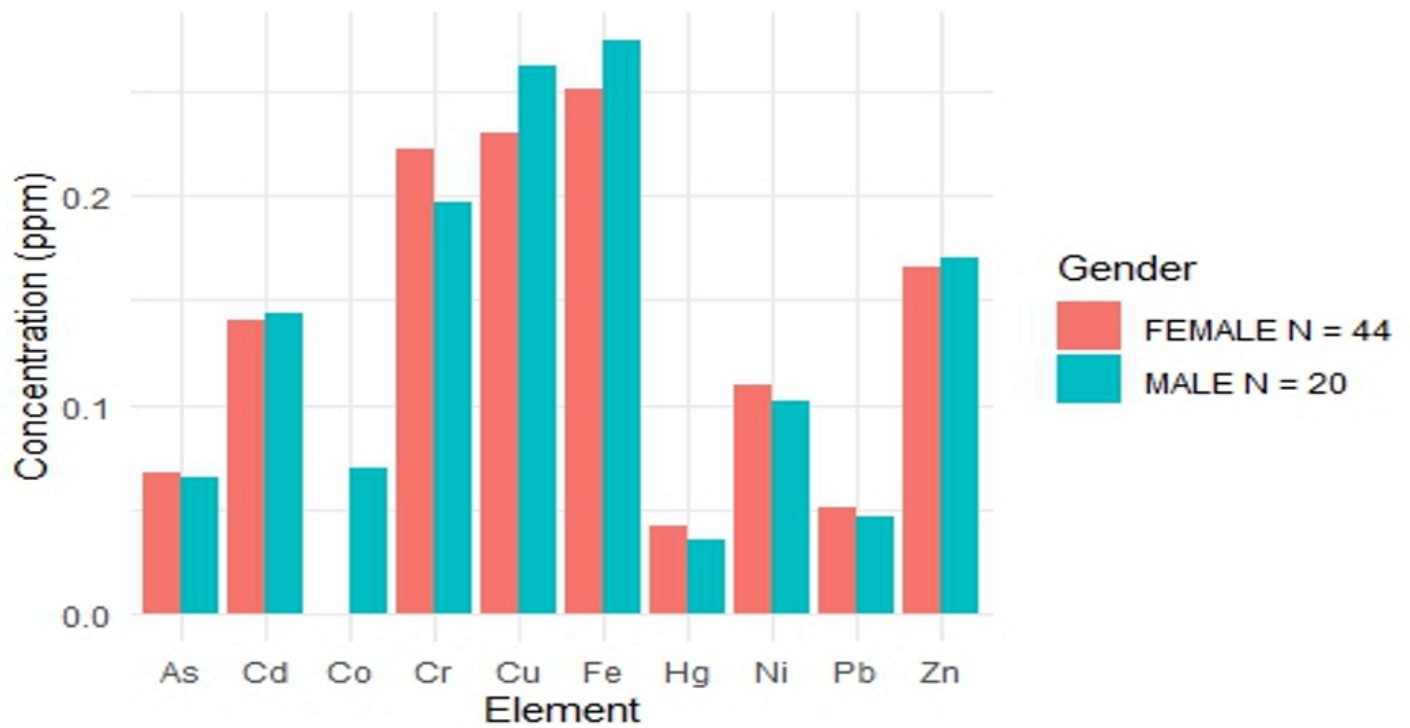


Figure 2

Elemental Levels (ppm) of Blood Plasma on the basis of sex

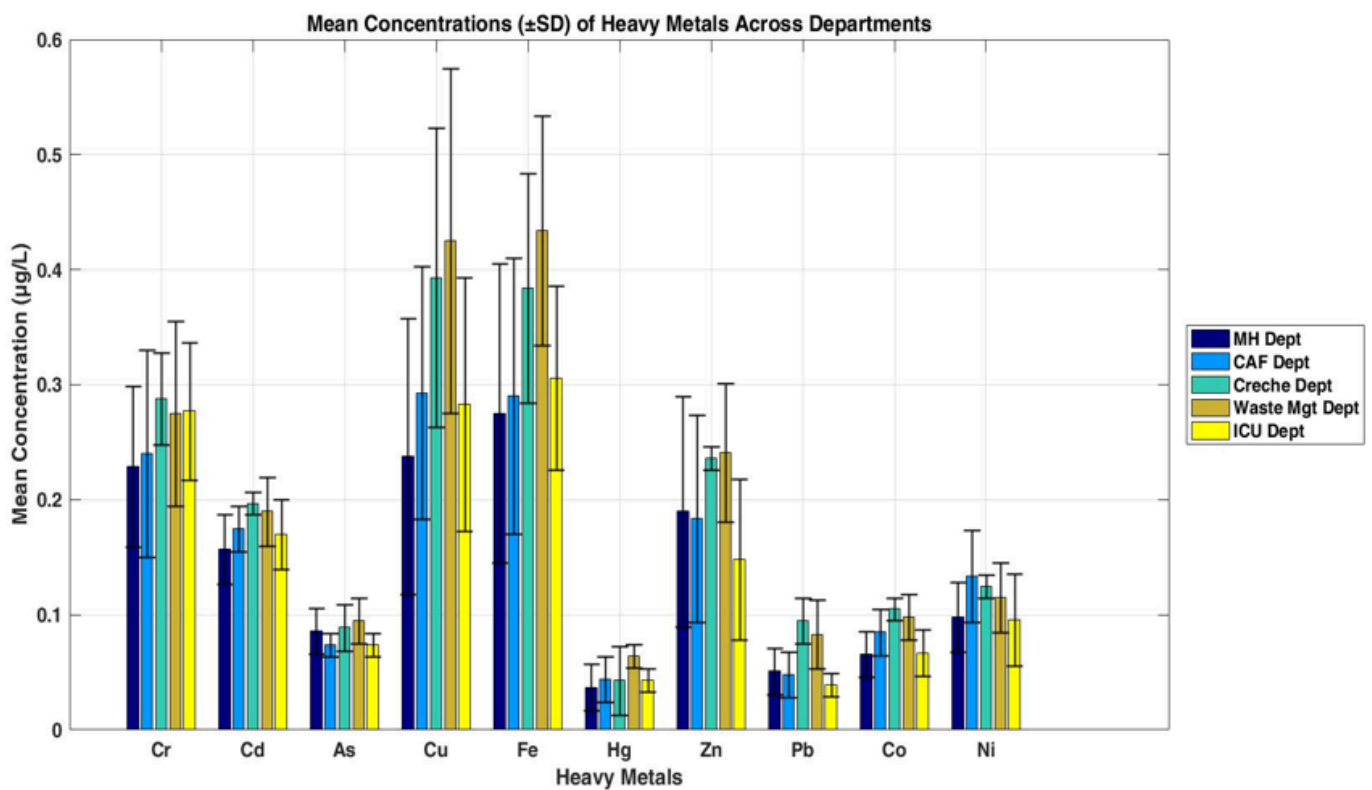


Figure 3

Mean concentration ($\pm$ SD) of heavy metals across departments