

Assessment of Heavy Metals in Airborne Particulates from Industrial Areas of Kaduna Metropolis, Nigeria: Emphasis on Concentrations and Toxicity Potential

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ABSTRACT

Industrialization contributes significantly to the release of toxic pollutants, particularly heavy metals, into the environment. Unlike organic contaminants, heavy metals are non-biodegradable and persist in air, soil, and water, posing long-term health and ecological risks. This study assessed the concentrations of selected heavy metals (Ni, Co, Cu, Pb, Cd, Cr, Mn, Zn) in airborne particulates collected from five major industrial locations in Kaduna Metropolis, Nigeria: Kaduna Refinery (10.4896° N, 7.4119° E), Indomie Factory (10.5015° N, 7.4408° E), Hikman Gas Plant (10.6446° N, 7.5439° E), PZ Cussons Factory (10.5864° N, 7.4658° E), and A.A. Rano Diesel Plant (10.5516° N, 7.4547° E). Air samples were collected using high-volume samplers fitted with membrane filters, and the captured particulates were digested and analyzed for heavy metal content using Atomic Absorption Spectrophotometry (AAS). Results revealed the consistent presence of zinc and copper across all sites, with zinc recording the highest concentrations (1.97–2.44 mg/m³), followed by copper (0.79–0.97 mg/m³), while cobalt and cadmium showed the lowest concentrations (0.0002–0.0018 mg/m³). Comparisons with WHO/EU limits indicated that all detected heavy metals remained within permissible safety thresholds. Toxicity Potential Values (TPVs) ranged from 0.18 to 1 across the study sites, signifying low toxicity potential. Copper exhibited the highest TPVs (0.79–0.97), while cadmium recorded the lowest (0.28–0.36). Although the measured concentrations fall within international safety limits, the findings highlight potential long-term risks of continuous exposure, especially for factory workers and nearby residents. Preventive measures such as the consistent use of protective gear (e.g., facemasks), stricter enforcement of emission control policies, and continuous environmental monitoring are strongly recommended. This study provides baseline data on airborne heavy metal pollution in Kaduna industrial

Keywords:

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Heavy metals,
Toxicity potential,
Kaduna Metropolis,
Industrial emissions,
Environmental health,
WHO/EU standards.

zones and underscores the need for sustainable industrial practices to safeguard public health and the environment.

INTRODUCTION

Heavy metals are a class of toxic, non-biodegradable elements that persist in the environment for decades. Unlike organic pollutants that degrade over time, heavy metals accumulate in soils, sediments, water bodies, and biota, where they are biomagnified through the food chain (Odipe *et al.*, 2018; Sawyerr *et al.*, 2018; Akan *et al.*, 2009). Their persistence makes them a global environmental concern, with serious implications for ecological health and human well-being. Globally, heavy metal pollution is primarily associated with anthropogenic activities such as mining, industrial manufacturing, petroleum refining, agricultural practices, and urbanization (Olalekan *et al.*, 2018; Raimi and Sabinus, 2017). In developing countries such as Nigeria, the situation is further compounded by weak environmental regulations, rapid industrialization, and population growth, which have collectively accelerated environmental contamination (Olalekan *et al.*, 2020).

Heavy metals such as lead (Pb), cadmium (Cd), nickel (Ni), chromium (Cr), arsenic (As), and mercury (Hg) are of particular concern because of their well-documented toxicity and ability to accumulate in body tissues (Zukowska and Biziuk, 2008; Anita *et al.*, 2010). Even at trace levels, these metals can pose significant health risks. Prolonged exposure has been associated with liver dysfunction, renal failure, neurotoxicity, cardiovascular disease, and various forms of cancer (Irwandi and Farida, 2015; Babalola *et al.*, 2007; Ademuyiwa *et al.*, 2003; Adekunle *et al.*, 2006; Ayodele & Bayero, 2003). For example, cadmium inhalation may cause lung irritation and kidney damage, while lead exposure is linked to developmental and neurological disorders in children (Adekunle *et al.*, 2006). Chronic exposure to nickel and chromium has been associated with increased risk of respiratory diseases and carcinogenic effects (Luckey and Venugopal, 1976).

In Nigeria, several studies have reported elevated concentrations of heavy metals in water, soil, and food items, underscoring the widespread nature of the problem. For instance, effluents discharged from textile industries in Zaria and Funtua were found to contain levels of heavy metals that exceeded permissible standards (Odipe *et al.*, 2018). Similarly, studies conducted in Kano and Rivers State have demonstrated that vegetables and groundwater sourced near industrial facilities were contaminated with cadmium, lead, and nickel above safe thresholds (Akan *et al.*, 2009; Olalekan *et al.*, 2020). These findings highlight the pressing need for environmental monitoring in regions with high industrial activity.

Kaduna State, located in northwestern Nigeria, is one of the country's oldest and largest industrial centers. It hosts a wide range of industries, including oil refineries, textile mills, petrochemical plants, food processing companies, and metal works (Mohammed & Folorunsho, 2015; Sulyman *et al.*, 2015). These industries release a mixture of gaseous and particulate pollutants into the atmosphere, often without adequate treatment. The emissions, effluents, and solid wastes generated may contaminate the surrounding environment and increase the levels of toxic substances, particularly heavy metals, in the air, soil, and water. Previous studies within Kaduna and similar industrial regions in Nigeria have consistently shown elevated concentrations of lead, cadmium, chromium, and nickel that surpass the limits set by international regulatory agencies (Akan *et al.*, 2009; Mohammed & Folorunsho, 2015; Sulyman *et al.*, 2015; Adepoju *et al.*, 2018).

Airborne particulates are of particular concern, as they provide a medium for heavy metals to attach, disperse, and be inhaled directly by populations living or working near industrial facilities. Inhalation of particulate-bound metals represents a significant exposure pathway for urban and industrial populations (World Health Organization [WHO], 2009). Residents, factory workers, and commuters in Kaduna metropolis are therefore at risk of chronic exposure to these toxicants, which may contribute to respiratory illnesses, oxidative stress, and systemic toxicity. Beyond human health, heavy metal contamination can also degrade air quality, reduce agricultural productivity, and compromise ecosystem sustainability (WHO, 2015).

Despite the clear evidence of heavy metal contamination in industrialized Nigerian cities, there is still limited data on the toxicity potential of heavy metals in air particulates within Kaduna. Most prior studies in Nigeria have focused on water, soil, and food pathways (Odipe *et al.*, 2018; Akan *et al.*, 2009; Olalekan *et al.*, 2020), with fewer investigations directed at airborne particulates, which represent a more direct and continuous source of exposure. Assessing airborne heavy metals is critical, as it provides insight into not only environmental pollution but also potential occupational and public health hazards. Therefore, this study aims to address this gap by analyzing the concentrations of selected heavy metals (Ni, Co, Cu, Pb, Cd, Cr, Mn, and Zn) in air samples collected from major industrial areas of Kaduna metropolis. Specifically, the objectives are to: (i) measure the concentrations of heavy metals in airborne particulates collected from five industrial locations; (ii) compare these concentrations against permissible limits set by the World Health Organization (WHO) and

European Union (EU) (WHO, 2009, 2015); and (iii) evaluate the toxicity potential of the detected metals using established indices. The findings from this research will provide essential data for environmental regulators, policymakers, and public health authorities in Nigeria to design strategies for pollution control, occupational safety, and community health protection.

MATERIALS AND METHODS

Materials

The materials and instruments used in this study included a High Volume Respirable Dust Sampler (APM 460 NL), an Atomic Absorption Spectrophotometer (AAS), Altair Pro single-gas detectors, a HAT 200 detector for particulate matter, a GC310 gas detector, and a Global Positioning System (GPS). The High Volume Respirable Dust Sampler was employed to simultaneously collect fine and coarse particulate matter, with provisions for gaseous attachment. The Atomic Absorption Spectrophotometer was used in the laboratory for the analysis of heavy metal concentrations in the collected samples. The Altair Pro single-gas detectors, which are handheld devices designed for monitoring gases such as CO, CO₂, SO₂, NO, NO₂, and H₂S, were deployed to monitor gaseous pollutants. In addition, the HAT 200, a Class-1 laser-based device, was used to measure particulate matter fractions including PM_{1.0}, PM_{2.5}, and PM₁₀, while the GC310 gas detector was employed as a flexible portable multi-gas detector for monitoring toxic and combustible gases. The Global Positioning System (GPS) was used to provide accurate location data for sampling sites.

Study Area

The study was conducted in Kaduna State, located in the northwestern geopolitical zone of Nigeria. Kaduna is the eighth largest city in the country according to the 2006 census, and it serves as a major industrial hub, hosting a concentration of cement factories, textile industries, petrochemical plants, and food-processing companies. The state has a total land area of 46,053 km² and a population of approximately 6.1 million. Geographically, Kaduna lies between latitude 10°38'58" N and longitude 7°22'14" E (Sulyman *et al.*, 2015). The climate of Kaduna is characterized by two distinct seasons: a rainy season lasting from April to October and a dry season that extends from November to March. Temperatures range from about 10°C to 39°C throughout the year (Sulyman *et al.*, 2015). High vehicular traffic and numerous industrial activities contribute to the release of emissions that degrade air quality across the metropolis.

Study Sites

Five industrial sites were selected for this research based on their high potential for emissions. These included the Kaduna Refinery located in Kaduna South, the Indomie Factory situated at Maraban Rido also in Kaduna South, the Hikman Gas Plant along Zaria Road in Kaduna North, the PZ Cussons Factory in Kaduna North, and the A.A. Rano Diesel Plant likewise in Kaduna North. The exact coordinates of these study sites are presented in Table 1, while Figure 1 provides a map of Kaduna metropolis showing their spatial distribution.

Table 1: The Study Area/Sites and Their GPS Coordinates

Study site	Latitude	Longitude
Kaduna Refinery	10.4896 ° N	7.4119 ° E
Indomie Factory	10.5015 ° N	7.4408 ° E
Hikman Gas Plant	10.6446 ° N	7.5439 ° E
PZ Cussons Factory	10.5864 ° N	7.4658 ° E
A. A Rano Diesel Plant	10.5516 ° N	7.4547 ° E

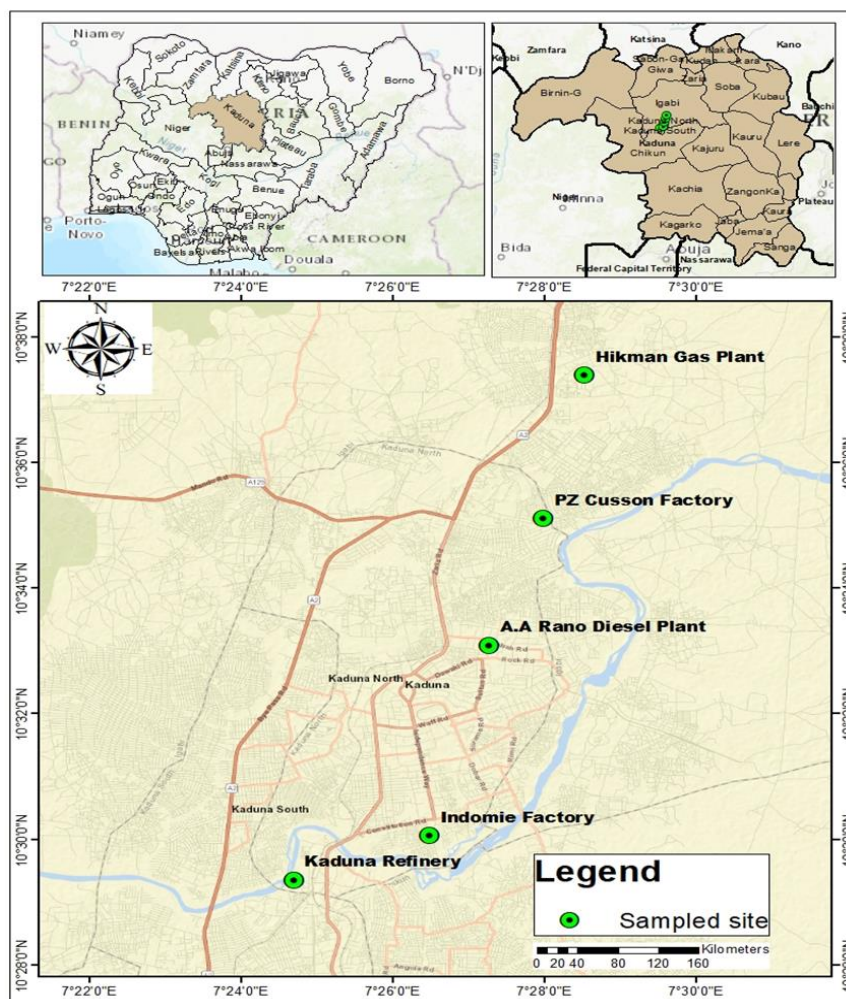


Figure 1: Map of Kaduna State, Nigeria showing the study locations

RESULTS AND DISCUSSION

Heavy Metals Concentration Analysis in Air Samples Collected from Study Sites and their Toxicity Potential to Human Health

Airborne dust samples were collected using Whatman glass fiber filter paper (GF/A) 8 by 10 inches using the high volume reparable dust sampler (APM 460 NL Model). The filter papers were stored in desiccators and removed as needed and digested in concentrated nitric acid and hydrofluoric acid and placed in fume cardboard at a temperature of 150 °C. The content was then filtered through Whatman filter paper number 42 and standard volume made up to 100 ml with distilled water along with a blank also prepared in the same way. The filtrates were tested for the concentration of eight heavy metals [Nickel (Ni), Cobalt (Co), Copper (Cu), Lead (Pb), Cadmium (Cd), Chromium (Cr), Manganese (Mn) and Zinc (Zn)] using Atomic Absorption (Spectrometer serial number

AA0904M046) flame test from Multi-User Scientific Research Laboratory, Ahmadu Bello University, Zaria following the user manual. The results of heavy metals reported by AAS in ppm and was converted to mg/m³ using equation (1).

$$1 \text{ mg/m}^3 = \frac{\text{ppm} \times m_i}{24.45} \quad (1)$$

This implies that;

$$1 \mu\text{g/m}^3 = \frac{\text{ppb} \times m_i}{24.45} \quad (2)$$

Where m_i is the molecular weight of the i^{th} metal in g/mol and 24.45 is the quotient of mean mass of air by its density at 25 °C (Tyovenda *et al.*, 2016).

Toxicity potential (Tp) was computed using equation (3):

$$Tp = \frac{\text{Observed concentration of } i^{\text{th}} \text{ metal}}{\text{Permissible limit set by WHO/EU}} \quad (3)$$

The results of the heavy metal concentration in air samples are presented in Table 2 and Figures 2 – 6

Table 2: Mean Concentration of Heavy Metals from Study Sites

Metals (M _i)	Mean concentration in (mg/m ³) /Tp at the selected point sources					Permissible limit set by WHO/EU (mg/m ³)
	Kaduna Refinery	Indomie Factory	Hikman Gas Plant	PZ Cusson Factory	A. A Rano Diesel Plant	
Nickel (Ni)	0.0341	0.0393	0.03673	0.03385	N.D	0.050
Cobalt (Co)	0.0005	0.0007	0.0002	0.0005	0.0005	0.001
Copper (Cu)	0.8271	0.9670	0.8890	0.7994	N.D	1.000
Lead (Pb)	0.0339	0.0424	0.0169	0.02542	N.D	0.050
Cadmium (Cd)	0.0009	0.0018	0.0014	0.0009	0.0014	0.005
Chromium (Cr)	0.2594	0.2786	0.2361	0.2594	N.D	0.500
Manganese (Mn)	0.0615	0.0721	0.0697	0.0663	N.D	0.150
Zinc (Zn)	1.9714	2.4377	2.4377	2.4403	N.D	5.000

N.D = Not Detectable

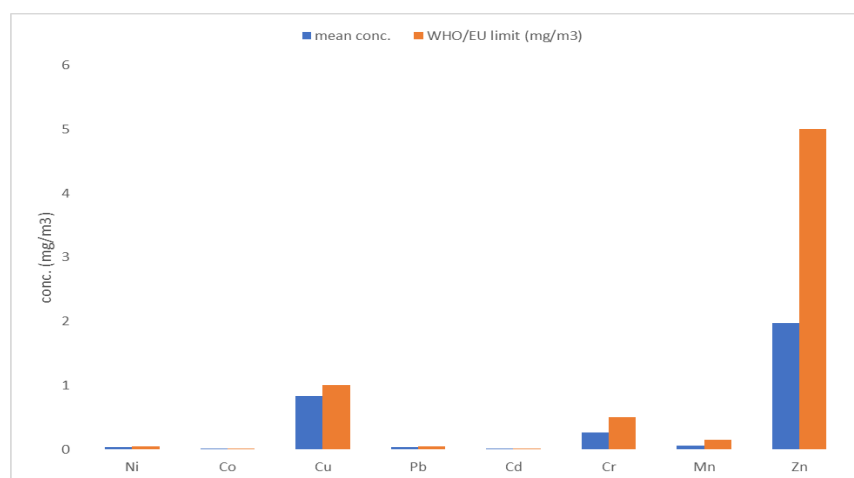


Figure 2: Comparison of Concentration of heavy metals in the particulates with WHO/EU limit at the Kaduna Refinery

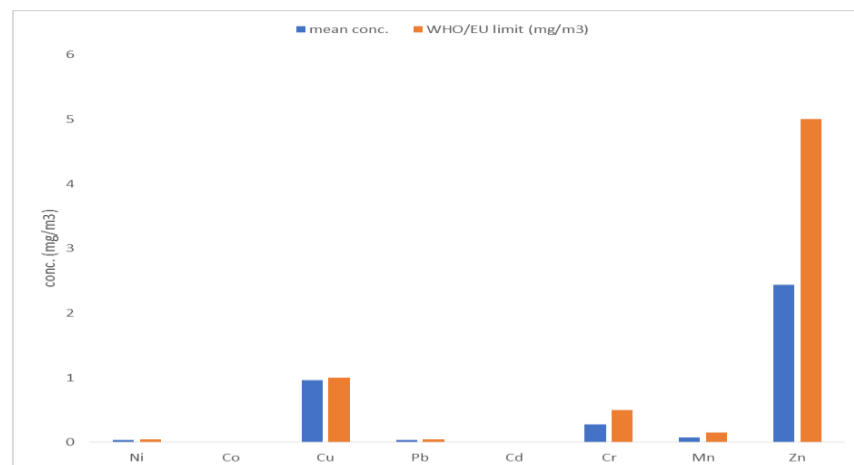


Figure 3: Comparison of Concentration of heavy metals in the particulates with WHO/EU limit at the Indomie factory Marabanrido, Kaduna

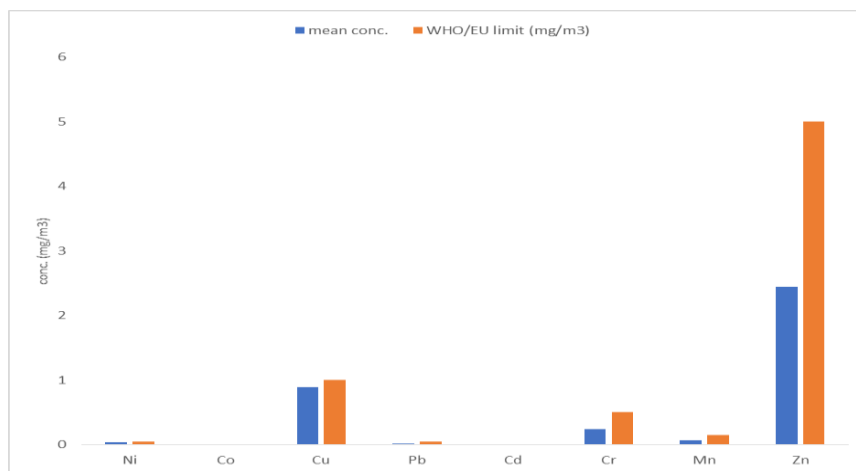


Figure 4: Comparison of Concentration of heavy metals in the particulates with WHO/EU limit at the Hikman Gas Plant, Zaria Road, Kaduna

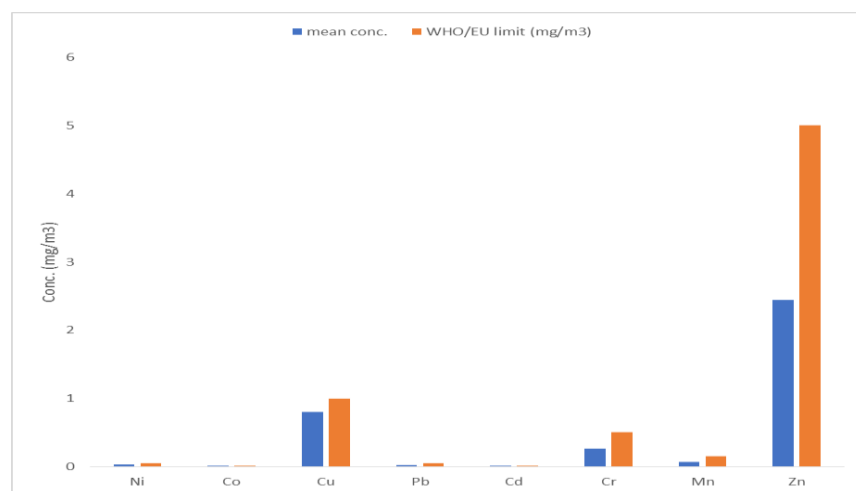


Figure 5: Comparison of Concentration of heavy metals in the particulates with WHO/EU limit PZ Cussons factory, Kaduna

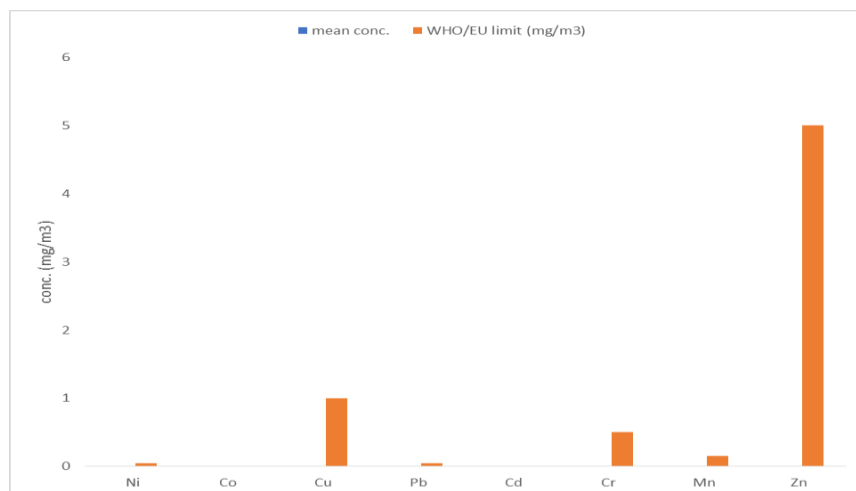


Figure 6: Comparison of Concentration of heavy metals in the particulates with WHO/EU limit at the A.A. Rano Diesel Plant, Kaduna

Toxicity Potential of Heavy Metals in Filtered Air Samples

samples of the pollutants from the five sampled locations in Kaduna metropolis.

The results displayed in Tables 3 - 7 shows the toxicity potentials of the heavy metals detected in the filtered air

Table 3: Toxicity Potentials of the Heavy Metals in the Pollutants Measured at the Kaduna Refinery

Heavy metals	Toxicity Potential (T.P)
Nickel (Ni)	0.682
Cobalt (Co)	0.500
Copper (Cu)	0.827
Lead (Pb)	0.678
Cadmium (Cd)	0.180
Chromium (Cr)	0.519
Manganese (Mn)	0.410
Zinc (Zn)	0.394

Table 4: Toxicity Potentials of the Heavy Metals in the Pollutants Measured At the Indomie Factory Marabanrido, Kaduna

Heavy metals	Toxicity Potential (T.P)
Nickel (Ni)	0.786
Cobalt (Co)	0.700
Copper (Cu)	0.967
Lead (Pb)	0.848
Cadmium (Cd)	0.360
Chromium (Cr)	0.557
Manganese (Mn)	0.481
Zinc (Zn)	0.488

Table 5: Toxicity Potentials of the Heavy Metals in the Pollutants Measured at Hikman Gas Plant, Kaduna

Heavy metals	Toxicity Potential (T.P)
Nickel (Ni)	0.735
Cobalt (Co)	0.200
Copper (Cu)	0.889
Lead (Pb)	0.338
Cadmium (Cd)	0.280
Chromium (Cr)	0.472
Manganese (Mn)	0.465
Zinc (Zn)	0.488

Table 6: Toxicity Potentials of the Heavy Metals in the Pollutants Measured at the PZ Cussons Factory Zaria Road, Kaduna

Heavy metals	Toxicity Potential (T.P)
Nickel (Ni)	0.677
Cobalt (Co)	0.500
Copper (Cu)	0.799
Lead (Pb)	0.508
Cadmium (Cd)	0.180
Chromium (Cr)	0.519
Manganese (Mn)	0.442
Zinc (Zn)	0.488

Table 7: Toxicity Potentials of the Heavy Metals in the Pollutants Measured at the A.A. Rano Diesel Plant, Kaduna

Heavy Metals	Toxicity Potential (T.P)
Nickel (Ni)	N.A
Cobalt (Co)	0.50
Copper (Cu)	N.A
Lead (Pb)	N.A
Cadmium (Cd)	0.28
Chromium (Cr)	N.A
Manganese (Mn)	N.A
Zinc (Zn)	N.A

N.A = Not Available

Discussion

Heavy Metals Concentration Analysis of Filtered Air Samples and Comparison with WHO/EU Limits

The analysis of heavy metals in the filtered air samples revealed the presence of nickel (Ni), cobalt (Co), copper (Cu), lead (Pb), cadmium (Cd), chromium (Cr), manganese (Mn), and zinc (Zn). Their concentrations across the five industrial locations in Kaduna metropolis are presented in Figures 3 - 7 and Table 2.

At the Kaduna Refinery, all heavy metal concentrations fell below the permissible limits set by WHO and the EU. Zinc was the most abundant, with a concentration of 1.9714 mg/m³, followed by copper (0.8271 mg/m³). The lowest concentrations were recorded for cobalt (0.0005 mg/m³) and cadmium (0.0009 mg/m³) (Figure 2).

Similarly, at the Indomie Factory, zinc again dominated with a concentration of 2.4372 mg/m³, followed by copper at 0.9670 mg/m³, while cobalt (0.0005 mg/m³) and cadmium (0.0018 mg/m³) were the least abundant (Figure 3).

At the Hikman Gas Plant, the same trend was observed, with zinc at the highest level (2.4377 mg/m³), followed by copper (0.8890 mg/m³), while cobalt (0.0002 mg/m³) and cadmium (0.0018 mg/m³) remained the lowest (Figure 4).

For the PZ Cussons Factory, zinc remained the dominant heavy metal (2.4403 mg/m³), followed by copper (0.7994 mg/m³), while cobalt and cadmium maintained the lowest concentrations at 0.0005 mg/m³ and 0.0009 mg/m³ respectively (Figure 5).

In contrast, the A.A. Rano Diesel Plant exhibited the least diversity of heavy metals. Only cobalt (0.0005 mg/m³) and cadmium (0.0009 mg/m³) were detected, and both were within WHO/EU limits (Figure 6).

Although the concentrations of these heavy metals were within international safety limits, their presence remains of concern because of their cumulative effects on human health. Zinc, released into the atmosphere through mining activities, industrial smelting, and waste burning, can

cause *metal fume fever*, *excessive sweating*, and *body weakness* upon excessive inhalation. Copper, introduced largely through waste burning and sewage disposal, can cause *liver and kidney diseases* at elevated concentrations. Cadmium, mostly released from electronic waste burning, is associated with *respiratory tract irritation* and lung damage. Cobalt, often derived from smelting activities and catalytic converters in vehicles, may exacerbate *asthma and respiratory illnesses* when inhaled in excess (Salazar, 2025).

These findings emphasize that, while short-term risks appear minimal, chronic exposure to even sub-threshold concentrations of heavy metals in industrial areas poses a public health concern, especially for workers and residents within close proximity to emission sources.

Toxicity Potential of Heavy Metals in Filtered Air Samples

To quantify the risk associated with exposure, the toxicity potential (TPV) of heavy metals was evaluated as the ratio of their measured concentrations to WHO/EU permissible limits. The results, presented in Tables 3–7, show TPV values in the range of 0.18–1.0, indicating low toxicity potential.

According to Chao et al. (2023), TPV values less than 0.1 suggest negligible toxicity, values between 0.1 and 1 indicate low toxicity, and values greater than 1 suggest moderate to severe risk. In this study, the highest TPV values were consistently associated with copper, ranging from 0.79–0.97 across four of the industrial sites. This suggests that, although copper concentrations were below WHO/EU limits, its potential for harm was greater relative to the other heavy metals detected.

Cadmium consistently recorded the lowest TPV values (0.28–0.36), followed by cobalt, indicating a relatively lower potential for immediate health risks. However, cadmium is particularly worrisome due to its persistence in the human body and its long-term carcinogenic effects when inhaled regularly.

The A.A. Rano Diesel Plant had the lowest overall TPV values since only cobalt and cadmium were detected, while the other four sites presented higher TPVs due to the additional presence of zinc and copper.

Despite the low toxicity classification, the chronic exposure to these metals particularly for factory workers, roadside traders, and commuters regularly passing near these industrial plants can still pose health risks over time. It is therefore recommended that preventive measures such as the consistent use of facemasks, installation of efficient emission control technologies, and strict environmental monitoring policies be enforced. These findings corroborate earlier reports (Holmes & Morawska, 2006; Abioye et al., 2016) which emphasize that even low concentrations of airborne toxicants can accumulate and exert significant public health burdens if not mitigated.

CONCLUSION

This study assessed the concentration of gaseous pollutants, particulate matter, and heavy metals in selected industrial areas of Kaduna metropolis, Nigeria, and evaluated their compliance with the permissible limits set by WHO and EU. The findings revealed that: Gaseous pollutants (CO, NO, NO₂, SO₂, H₂S, and NH₃) as well as particulate matter (PM_{1.0}, PM_{2.5}, and PM₁₀) generally decreased with increasing distance from emission sources across all the sampled industrial sites. However, their concentrations at short distances (10–40 m) were significantly above WHO guideline limits, posing a potential health risk to workers and nearby residents.

Heavy metals (Ni, Co, Cu, Pb, Cd, Cr, Mn, and Zn) were detected in the filtered air samples. Although all concentrations fell within WHO/EU permissible safety limits, zinc and copper consistently recorded the highest concentrations, while cobalt and cadmium were present at trace levels.

The toxicity potential values (TPVs) of the heavy metals across all sites ranged from 0.18–1.0, indicating low toxicity potential. Despite this classification, the cumulative and long-term exposure to these metals, particularly copper and cadmium, may still result in chronic health problems.

Overall, the results highlight that while the pollutant levels in Kaduna's industrial areas may not pose an immediate severe health hazard according to international standards, the continuous release and exposure to these pollutants is a matter of concern. Sustained inhalation of particulate matter and heavy metals, even at low levels, is associated with cardiovascular, respiratory, and systemic health risks.

Strengthen Emission Control and Monitoring

Industries should adopt modern pollution control technologies (e.g., scrubbers, electrostatic precipitators) while government agencies like NESREA must enforce strict compliance through continuous air quality monitoring.

Protect Public and Worker Health

Workers and nearby residents should be encouraged to use protective gear such as facemasks, while buffer zones and green belts should be established between industrial areas and residential communities to minimize exposure.

Policy Enforcement and Awareness

Stronger enforcement of environmental regulations is needed, alongside public awareness campaigns on the health risks of long-term exposure to air pollutants and heavy metals, especially for vulnerable populations.

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