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SPATIAL DISTRIBUTION AND HEALTH RISK IMPLICATIONS OF ELEMENTAL HAZARD QUOTIENTS IN SELECTED NIGERIAN CITIES

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ABSTRACT

The disease burden associated with air pollution is now comparable to that of other major global health threats, including poor nutrition and tobacco use. This study employed the gravitational settling method to collect airborne particles in selected Nigerian cities. The cities include; Benin, Kano, Abuja, Lagos, Enugu, and Calabar. Airborne particles were allowed to settle naturally into containers fitted with funnels and placed outdoors at various sub-locations within each State. Sampling was conducted over a nine-month period from January to September 2023. The collected sediments were analyzed spectroscopically using a UV Visible (UV-VIS) Spectrophotometer CE 1101 to determine concentrations of cadmium (Cd), nickel (Ni), lead (Pb), and manganese (Mn). Results revealed that hazard quotient (HQ) values for all analyzed metals exceeded the recommended safe limit of 1 across all locations. In Benin City, nickel and lead recorded HQ values of 5.5 and 4.0, respectively. Enugu showed particularly elevated levels, with manganese (Mn) at HQ 16 and lead (Pb) at HQ 5, attributed to industrialization and vehicular activities. In Kano, HQ values for lead (Pb) and nickel (Ni) were 8.0 and 4.9, respectively. Abuja recorded HQ values of 6.0 for lead (Pb) and 4.9 for nickel (Ni), likely linked to recycling and agricultural activities. Lagos and Calabar also exhibited elevated HQ values, particularly for lead and nickel. Elevated exposure to these toxic elements can pose potential health risks, including neurological, respiratory, and allergic effects, to exposed populations.

KEYWORDS: Particulate matters PM, Toxic elements and metals, carcinogenic elements, Hazard Quotient.

INTRODUCTION

The Health Effects Institute (HEI) report on the State of Global Air (SOGA, 2020) identifies air pollution as the fourth most significant cause of premature mortality, accounting for about 12% of deaths worldwide. It reduces average life expectancy by 2.2 years and contributes to nearly seven million deaths each year. In West Africa, over 80% of urban dwellers face air quality levels that surpass World Health Organization (WHO) standards (WHO, 2016). Research conducted by Udo and Ewona, (2022) in Nigeria's Niger Delta, supported by TET Fund, uncovered substantial pollution levels in the area using gravity settling method for air sampling.

Air pollution stems from both natural processes and human actions, with combustion being a leading cause. Energy production from fossil fuels and biomass significantly affects both indoor and outdoor air quality. Indoor sources include burning coal, wood, or dung for cooking and heating, unventilated stoves, tobacco smoke, and incense. Everyday household items like detergents, insecticides, and emissions from appliances such as printers also contribute. Outdoor sources range from transportation and industrial activities to construction and biomass burning. Pollutants can be directly emitted (primary pollutants) or formed through atmospheric chemical reactions (secondary pollutants) like sulfates and nitrates (WHO, 2023).

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According to WHO (2021), air pollution leads to millions of deaths and significant reductions in healthy life years annually. Cardiovascular diseases responsible for 17.9 million deaths in 2019, or 32% of global fatalities are closely linked to air pollution. Most of these deaths (85%) result from heart attacks and strokes. Air pollution is now regarded as the most critical environmental health threat, significantly contributing to the rise of noncommunicable diseases (NCDs). These conditions, which are not contagious, include illnesses such as Parkinson's disease, stroke, heart disease, cancer, diabetes, chronic kidney disease, and osteoarthritis. They impact various organ systems, including the cardiovascular, respiratory, and neurological systems. Air pollution is known to worsen respiratory and cardiovascular conditions, elevate the risk of lung cancer, and increasingly appears to affect other organ functions (Ewona et al., 2021; Udo, 2020; Ewona et al., 2022).

Sources of Emissions and Exposure

Air pollution originates from both natural and human-induced activities, with industrialization playing a significant role. The World Health Organization (WHO) identifies energy combustion as the leading contributor, encompassing fossil fuel burning, unvented stoves, tobacco use, and practices tied to cultural or religious traditions. Outdoor pollution sources include transportation, industrial processes, power generation, forest fires, and the burning of agricultural waste.

On a global scale, particulate matter ($PM_{2.5}$) has been associated with health conditions such as asthma, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, cancer, type 2 diabetes, and neurodegenerative diseases. While developed nations have advanced in reducing pollution through better access to environmental data, developing countries often face challenges due to insufficient records (Abulude et al., 2022; Ekah, 2023). Air pollution is a significant contributor to premature deaths and illnesses, including coronary heart disease, diabetes, and cancer (Slezakova et al., 2018).

To mitigate greenhouse gas emissions, strategies include improving public transportation systems, encouraging walking and cycling, increasing tree planting to absorb pollutants, and discouraging the use of outdated, high-emission vehicles (Tunde et al., 2022).

LITERATURE REVIEW

Akhilesh et al. (2022) explored the enrichment factors and chemical composition of size-fractionated airborne particulate matter in the Singrauli Coalfield region of India. Elevated enrichment factors for N and Se in $PM_{2.5}$ were linked to industrial activities, particularly coal-related industries and storage facilities near the monitoring site. Enrichment factors for Co, Cu, Br, As, Zn, and H ranged between 5 and 150, pointing to anthropogenic emissions as primary sources. Biomass burning was suggested as a significant contributor due to correlations of NO_3^- with Cl−, F−, NO_2^-, $SO_4^{2-}$and Mg^{2+}.

Rushdi et al. (2013) investigated air quality and enrichment factors of elemental aerosol particulate matter in Riyadh City, Saudi Arabia. Samples of $PM_{2.5}$ and PM_{10} collected from rooftops were analyzed using X-ray fluorescence spectroscopy, identifying major and trace elements. The study highlighted that PM_{10} concentrations exceeded $PM_{2.5}$ levels, indicating local dust as the predominant source. Enrichment factors categorized elements into groups based on their spatial variations, reflecting common and anthropogenic sources.

Maurizio (2016) reviewed the application of enrichment factors and geo-accumulation indexes in soil contamination assessment. Human activities, including industrial operations, fertilizer and pesticide use, waste disposal, and air pollution, were identified as key contributors to heavy metal accumulation in soils, which degraded fertility. The study emphasized the importance of enrichment factors and geo-accumulation indexes in quantifying anthropogenic contamination.

Haritash (2006) evaluated seasonal enrichment of heavy metals in respirable suspended particulate matter (RSPM) in a suburban Indian city. Heavy metals such as Pb, As, Ni, Cu, Mn, Fe, and Mg were analyzed, with enrichment factors indicating human activities as the dominant sources for Pb, As, Ni, Cu, and Mn. Conversely, Fe and Mg were linked to natural sources.

Gugamsetty et al. (2012) analyzed ambient particulate matter in Taiwan, focusing on PM_{10}, $PM_{2.5}$, and PM0.1. Chemical analysis revealed five sources of particulate matter: soil dust, vehicle emissions, sea salt, industrial emissions, and secondary aerosols. Enrichment factors, with Al as a reference, underscored competitive contributions from both natural and anthropogenic origins.

In a field study, Gao (2023) investigated particle-size-dependent selectivity of heavy metals in dust aerosols, with findings showing high enrichment of Mn, Cd, Pb, and other heavy metals in fine-dust ($PM_{2.5}$) aerosols. Outdoor air samples collected in New Delhi emphasized anthropogenic contributions, with enrichment factors confirming human-induced sources for Cr, Fe, Cu, Ni, Zn, and Pb.

Sharma (2004) analyzed toxic element enrichment in particulate matter near a slag-based cement plant in Chhattisgarh, India. Samples revealed significant enrichment of elements such as Ca, Mg, Fe, and Al. Positive correlations between particulate matter and metal concentrations highlighted strong anthropogenic influences on air pollution.

Kothai (2011) conducted air quality monitoring in Navi Mumbai, India, using a dichotomous sampler. Seasonal variation analysis showed higher particulate matter concentrations in winter. Enrichment factors using Fe as a reference revealed the presence of Cu, Cr, and Mn from anthropogenic sources, with the highest EF values for As, Pb, and Zn in fine particulates.

Ismaeel (2015) assessed heavy metal contamination in industrial zones of Al Anbar Province, Iraq. Using X-ray fluorescence, six metals were analyzed, with Cd showing extreme enrichment (EF = 40.3). Geo-accumulation index calculations classified contamination levels as high to very high, indicating significant anthropogenic impacts.

Yadav (2022) confirmed industrial emissions as the source of high enrichment factors for Co, Cu, Br, As, Zn, and H in $PM_{2.5}$ samples from the Singrauli Coalfield. The study also linked correlations of nitrate ions with other chemical species to biomass burning, emphasizing multiple anthropogenic influences.

Issa (2011) conducted a study on sediments from the Orogodo River in Agbor, Delta State, Nigeria, over four months (May to August). Atomic absorption spectroscopy revealed concentrations of metals like Cd, Mn, Fe, Cu, Ni, Pb, Zn, and Cr. Physicochemical parameters such as pH, conductivity, and organic matter content were also analyzed, revealing significant metal interactions within sediments. Fe levels exceeded background and DPR standards, indicating notable contamination.

Abdelbagi (2018) explored anthropogenic contributions to ambient air pollution in New Delhi, India, through the analysis of Cr, Mn, Fe, Cu, Ni, Zn, and Pb in outdoor air samples. Using atomic absorption spectroscopy, enrichment factors highlighted human-induced sources for these metals. The study further emphasized the role of fine-dust aerosols in particulate matter pollution.

Ma (2015) assessed metal concentrations, enrichment factors, and geo-accumulation indexes in suspended particulate matter (SPM) and sediments from the Daliao River and estuary in China. The dry season showed the highest metal concentrations in sediments. Cd was identified as significantly enriched, with geo-accumulation index results revealing varying pollution levels.

In Chhattisgarh, India, toxic element enrichment in particulate matter was investigated near a slag-based cement plant (Sharma, 2004). RSPM and NRSPM samples were analyzed, showing significant enrichment of toxic metals in the order of Ca > Mg > Fe > Al > Na > K > Mn > Cr > Ni > Cu > Zn > Co > Pb > Hg > Cd. The study demonstrated strong links between particulate matter and metal enrichment factors.

Andem (2015) evaluated sediment contamination in the Ona River over six months using indices such as Pollution Load Index (PLI) and Geo-accumulation Index (Igeo). Lead concentrations ranged from 0.004 to 0.330 mg/kg, with moderate to heavy pollution levels indicated by Igeo values for lead and copper. Localized contamination was evident, despite the sediments being generally unpolluted.

Abata (2013) investigated heavy metal distribution in Ala River sediments in Nigeria during the rainy season. Using Geo-accumulation Index and contamination factor methods, Pb > Cd > Cr > Cu > Zn > Ni > Fe was the identified enrichment sequence. Anthropogenic sources significantly influenced metal concentrations, particularly at heavily contaminated sites.

Uwah (2013) analyzed sediments from Qua Iboe River estuary, identifying significant enrichment of Cd, Zn, Cu, and Pb. Geo-accumulation index results showed strong to extreme pollution by Cd and Ni. Anthropogenic contributions, such as oil-related waste, were highlighted as major pollution sources.

Iwuoha (2012) studied sediments from the Otamiri River in Owerri, Nigeria, to evaluate heavy metal concentrations, pH, and Total Organic Carbon (TOC%). Results linked higher metal concentrations to seasonal variations, with natural processes like weathering and erosion identified as primary contributors to sediment quality.

Justina et al. (2015) investigated seasonal variations of heavy metal pollution in Qua Iboe River estuary sediments. Concentrations of Fe > Mn > Zn > Cu > Cr > Cd > Pb > Ni > V were significantly above benchmarks. Point and diffuse pollution sources contributed to contamination, particularly from anthropogenic activities.

Ji (2007) used geo-accumulation indices to evaluate soil dust contamination in 15 Chinese cities. Severe contamination by elements such as Ca, Cr, Ni, and Cu was observed, with urbanization identified as a primary driver of moderate to severe Zn and Pb pollution.

Ogbeibu (2014) assessed sediment quality along the Benin River in Niger Delta, focusing on heavy metals and physicochemical properties. While sediments were slightly acidic, pollution indices indicated they were largely uncontaminated, reflecting minimal anthropogenic influence.

Hasan et al. (2012) examined trace metal pollution in sediments from a ship-breaking area in Bangladesh. Enrichment factors revealed slight to severe enrichment of Cr, Zn, As, and Pb. Anthropogenic activities, particularly ship-breaking, were the primary contributors to contamination.

Ephraim (2014) analyzed heavy metal distribution in sediments from Mbat-Abbiati and Oberakkai Creeks of the Great Kwa River. Pollution indices suggested over 55% of metals were of lithogenic origin, with mining and quarrying identified as key sources of contamination.

Ochiagha (2020) investigated soil pollution in Onitsha South Local Government Area. Geo-accumulation indices revealed significant pollution by Mn, Cr, Zn, and Ni across seasons, while Cd, Pb, and Fe remained within acceptable limits. Industrial discharges were the primary anthropogenic contributors.

MATERIALS AND METHODS

Hazard Quotient index method was employed in selected Nigerian cities to collect airborne particles (sediments), which were allowed to settle naturally into containers along with rainwater.

Funnels were securely attached to clean, empty plastic containers using sellotape, properly labelled with writing markers, and placed outdoors at various sub-locations within different cities (Benin, Kano, Abuja, Lagos, Enugu and Calabar) for the collection of atmospheric deposits. The selected sampling points considered were densely populated and rapidly urbanizing areas characterized by intense anthropogenic activities. These areas experience heavy vehicular traffic, commercial operations, industrial activities, frequent use of power generators, and ongoing construction works, all of which are recognized sources of atmospheric pollutants and heavy metal emissions. The sampling setups were strategically positioned in open environments to ensure adequate exposure to atmospheric deposition. Sample collection was conducted over a nine-month period, spanning from January to September 2023, after which the setups were retrieved from the respective locations for laboratory analysis.

After collection, the airborne particles (sediments) collected were arranged accordingly and transported to the air quality control laboratory for spectroscopic analysis in waterboard Calabar. The UV- VIS Spectrometer CE 1101 was used for the analysis. This is essential in determining the concentration of substances (e.g., metals, pollutants, organic compounds). This is due to the fact that the instrument has; Advanced analytical capacity, non-destructive testing capacity, Speed and efficiency.

During the analysis, sediments extracted from the liquid samples were dried through heating. The study focused on the following elements: cadmium (Cd), Nickel (Ni) , Lead (Pb), manganese (Mn).

HAZARD QUOTIENT

BRIEF EXPLANATION ABOUT HAZARD QUOTIENT

The Hazard Quotient (HQ) is a numerical metric employed in risk assessment to evaluate the potential health risks associated with exposure to hazardous substances. It is a dimensionless ratio that compares the estimated exposure level to a reference dose or concentration, representing the threshold below which no adverse health effects are anticipated. HQ is widely used in environmental health to assess the likelihood of non-carcinogenic effects resulting from chemical exposures (U.S. Environmental Protection Agency, 2014).

Interpretation of Hazard Quotient

- HQ < 1: Indicates that the exposure level is less than the reference dose, suggesting that adverse health effects are unlikely.
- HQ = 1: Indicates that the exposure level is equal to the reference dose, which is considered a threshold level where no adverse health effects are expected.
- HQ > 1: Indicates that the exposure level exceeds the reference dose, suggesting a potential for adverse health effects and the need for further investigation or mitigation.

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CALCULATION OF HAZARD QUOTIENT

$$\text{HQ} = \frac{\textit{Air concentration exposure measured at the field}\ \ EC}{\textit{Reference concentration as recommended by regulatory bodies}\ \ (RFC)} \qquad 1$$

Where

HQ = Hazard Quotient is dimensionless

EC = Exposure air concentration (μg/m^3)

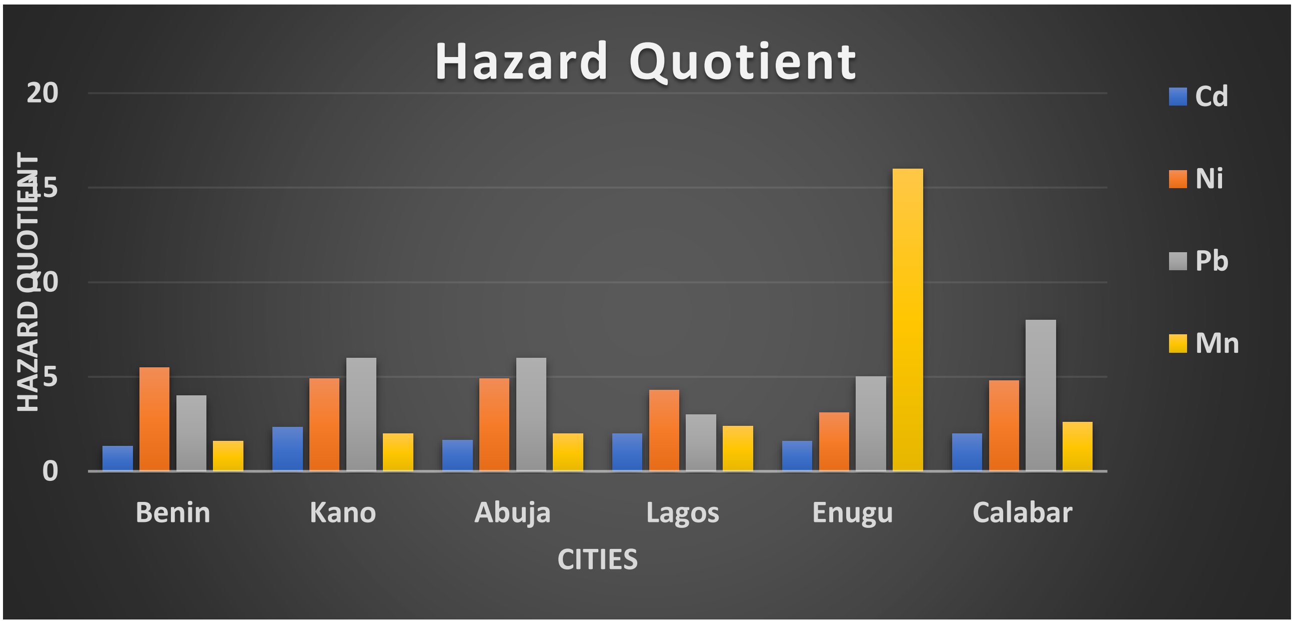
RfC = Reference concentration (μg/m^3)

Application of Hazard Quotient

Hazard Quotient is used in the following;

- Environmental Risk Assessment: HQ is used to evaluate the risk of non-carcinogenic effects from exposure to environmental contaminants, such as heavy metals in soil, water, or air.
- Human Health Risk Assessment: HQ helps determine the risk associated with exposure to chemicals in consumer products, occupational settings, or contaminated sites.
- Regulatory Standards: HQ is used by regulatory agencies to establish safety standards and guidelines for allowable exposure levels to various substances.

RESULT OF ANALYSIS



INTERPRETATION:
Across all locations investigated in this study, the hazard quotient (HQ) values for Cd, Ni, Pb, and Mn exceeded the recommended safe limit of 1, indicating potential non-carcinogenic health risks to exposed populations.

In Benin City, nickel (Ni) recorded the highest HQ value of 5.5, which is more than five times the recommended threshold. Lead (Pb) followed with an HQ of 4.0, while cadmium (Cd) and manganese (Mn) recorded HQ values of 1.33 and 1.6, respectively. Elevated exposure to Ni and Pb is associated with respiratory disorders, kidney dysfunction, neurological impairment, and developmental effects, particularly in children. activities such as rubber and plastic manufacturing, paint production, battery recycling, and agricultural practices are likely contributors.

The hazard quotient of Manganese (Mn) was observed to be the highest in Enugu with HQ of 16, which could be attributed to inadequate management of pollutants from various sources, including bottling industries, lead mining in Abakaliki, coal mining activities in Enugu, metalworking, ceramic and pottery production, plastic manufacturing, chemical production facilities, vehicular emissions, and agricultural practices.

In Kano, lead exhibited the highest HQ value of 8.0, followed by nickel (HQ = 4.9). Cadmium and manganese recorded HQ values of 2.33 and 2.0, respectively. These elevated levels suggest significant health concerns, as high Pb exposure can result in neurotoxicity, reduced cognitive function, and cardiovascular problems, while Cd exposure is linked to renal damage and bone demineralization. The combined presence of these elements poses increased health risks to residents, especially in densely populated areas of Kano. Potential sources include tanneries and textile industries, metalworking and electroplating, battery production and recycling, and the use of agricultural inputs.

In Abuja, lead again showed the highest HQ value of 6.0, followed by nickel with an HQ of 4.9. Manganese and cadmium recorded HQ values of 2.0 and 1.66, respectively. Prolonged exposure to these elements may result in neurological disorders, impaired motor function, and kidney-related diseases. The primary sources contributing to elevated element concentrations include construction activities, mining and quarrying, metal fabrication, and waste management practices.

In Lagos State, nickel had the highest HQ value of 4.3, while lead recorded an HQ of 3.0. Manganese and cadmium showed HQ values of 2.4 and 2.0, respectively. Elevated Mn exposure is known to affect the central nervous system and may lead to symptoms similar to Parkinson's disease, while chronic Ni exposure can cause respiratory irritation and allergic reactions. The high emissions of these elements can be attributed to activities such as metal recycling and refining, battery manufacturing, paint and coating industries, and electroplating processes.

In Enugu, manganese recorded an exceptionally high HQ value of 16, which is sixteen times greater than the recommended limit. This was followed by lead (HQ = 5.0), nickel (HQ = 3.1), and cadmium (HQ = 1.66). Such extreme Mn exposure presents serious health risks, including neurobehavioral changes, impaired cognitive development, and motor dysfunction, thereby posing significant threats to residents.

In Calabar, lead recorded an HQ value of 8.0, followed by nickel (HQ = 4.8), manganese (HQ = 2.6), and cadmium (HQ = 2.0).

These elevated HQ values indicate potential adverse health effects, including neurological damage, kidney impairment, and increased risk of cardiovascular diseases among exposed populations. This elevated level could result from vehicular emissions, industrial activities within the Export Processing Zone (EPZ), operations at the UNICEM cement production facility, construction material manufacturing, paint production, and maritime activities.

DISCUSSION

The study evaluated the spatial distribution of hazard quotients (HQs) for Cd, Ni, Pb, and Mn across selected cities in Nigeria to assess potential non-carcinogenic health risks associated with human exposure to these elements. The findings reveal that HQ values for all analyzed elements exceeded the recommended threshold of 1 in all locations, indicating varying degrees of potential health concern across the study area.

The consistently elevated HQ values observed for lead and nickel across most cities suggest widespread anthropogenic influence, likely linked to urbanization, traffic emissions, industrial activities, waste disposal practices, and the combustion of fossil fuels. Lead, which recorded particularly high HQ values in Kano, Calabar, Abuja, Enugu, Benin and Lagos is well known for its persistence in the environment and its ability to accumulate in biological systems. Chronic exposure to Pb has been associated with neurological impairment, reduced cognitive performance in children, cardiovascular disorders, and renal dysfunction, making its high HQ values a major public health concern.

Nickel also exhibited significantly elevated HQ values in all cities, with the highest values recorded in Benin, Kano, Abuja, Calabar and Lagos. This may be attributed to emissions from vehicular exhausts, industrial processes, metal processing activities, and oil-related operations, especially in urban and industrial centers. Prolonged exposure to Ni has been linked to respiratory diseases, skin allergies, and potential carcinogenic effects, further emphasizing the need for monitoring and mitigation.

Cadmium, although generally recording lower HQ values relative to Pb and Ni, still exceeded the safe limit in all locations, indicating chronic exposure risks. Cd contamination is commonly associated with improper waste disposal, battery waste, fertilizers, and industrial effluents. Long-term exposure to cadmium could lead to kidney damage, skeletal disorders, and weakened immune responses.

Manganese showed notable spatial variability, with extremely high HQ values recorded in Enugu. While Mn is an essential trace element, excessive exposure is known to cause neurotoxicity, leading to cognitive impairment, behavioral changes, and motor dysfunction.

The exceptionally high HQ value observed in Enugu suggests a localized source of Mn contamination, potentially linked to geological background, mining activities, or industrial emissions, warranting further investigation.

Overall, the spatial variation in HQ values across the studied cities reflects differences in land use patterns, population density, industrial intensity, traffic volume, and environmental management practices. The simultaneous elevation of multiple elements in several locations highlights the potential for synergistic health effects, which may further increase the risk to exposed populations.

SUMMARY AND CONCLUSION

This study assessed the spatial distribution of hazard quotients of Cd, Ni, Pb, and Mn in selected Nigerian cities to evaluate potential non-carcinogenic health risks to residents. The results indicate that HQ values for all analyzed elements exceeded the recommended safety limit of 1 in all locations, suggesting that populations in these cities may be exposed to harmful levels of these elements.

Lead and nickel were identified as the dominant contributors to health risk in most locations, while manganese posed a particularly severe risk in Enugu due to its exceptionally high HQ value. Although cadmium recorded comparatively lower HQ values, its persistent exceedance of safe limits remains a cause for concern due to its cumulative toxicity.

The findings highlight the significant influence of anthropogenic activities on environmental contamination in urban centers and emphasize the need for continuous environmental monitoring, improved waste management practices, and strengthened enforcement of environmental regulations. Public health awareness programs are recommended to reduce exposure risks, particularly in high-risk locations.

In conclusion, the elevated hazard quotients observed in this study indicate potential non-carcinogenic health risks associated with elemental exposure in the selected Nigerian cities. The study provides valuable baseline data that can inform policymakers, environmental managers, and public health authorities in developing effective strategies to mitigate exposure and protect human health.

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