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Assessment of air pollution in Calabar using geo-accumulation index

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Abstract

This study investigates the levels of airborne toxic substances in Calabar, Nigeria, using the gravitational settling method to collect airborne particles along with rainwater over a nine-month period, from January to September 2023. The collected sediments underwent spectroscopic analysis to determine concentrations of heavy metals and other toxic substances. The salinity and conductivity of the rainwater samples were also measured. The results were averaged across sub-locations and generalized to represent Calabar, with the geoaccumulation index calculated to assess the degree of contamination. Statistical analysis was performed using MS Excel for computation and graphical presentation of results. The findings revealed that most of the elements, including cadmium, chromium, aluminum, cobalt, copper, iron, zinc, potassium, nitrite, nitrate, fluoride, and sodium, showed no contamination (Class 0), while nickel (Ni) exhibited extremely polluted contamination (Class 6). Lead (Pb) showed moderately to heavily polluted contamination (Class 3), and manganese was heavily contaminated (Class 4). The rainwater samples showed extremely polluted salinity and low conductivity, indicating the presence of dissolved salts and minimal ionization, respectively. These results provide insight into the contamination levels of toxic metals in the environment and the impact of anthropogenic activities in Calabar.

Keywords: Particulate matters; Sources of PM; Effects of PM; Healthy life expectancy; Life expectancy; Air Quality Index; Toxic elements and metals; Casinogenic elements; Enrichment factor; Hazard Quotient; Geoaccumulation index

1. Introduction

The 2024 Health Effects Institute (HEI) report on the State of Global Air (SOGA, 2024) identifies air pollution as the second leading cause of premature death, responsible for approximately 12% of global fatalities. It is linked to a reduction in average life expectancy by 2.2 years and contributes to nearly eight million deaths annually. The 2020 report reveals that in West Africa, more than 80% of urban populations experience air quality levels exceeding the standards set by the World Health Organization (WHO, 2016). Research by Udo and Ewona in Nigeria's Niger Delta, funded by TETFund, revealed significant pollution levels in the region, employing the gravity settling method for air sampling as outlined in studies by Ewona et al. (2021, 2022) and Udo et al. (2018, 2020).

Air pollution arises from both natural sources and human activities, with combustion being a major contributor. Energy production from fossil fuels and biomass notably impacts both indoor and outdoor air quality. Indoor pollution sources include the burning of coal, wood, or dung for cooking and heating, poorly ventilated stoves, tobacco smoke, and incense, as well as emissions from household items such as detergents, insecticides, and appliances like printers. Outdoor pollution stems from transportation, industrial activities, construction, and biomass burning. Pollutants can either be directly emitted (primary pollutants) or form through chemical reactions in the atmosphere (secondary pollutants), such as sulfates and nitrates.

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Pollutants like particulate matter ($PM_{2.5}$ and PM_{10}) and gases, including ammonia (NH_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and organic compounds, present significant health and environmental threats. In Rivers State, Nigeria, research by Tamuno et al. (2022) has linked visible soot to an increase in respiratory infections. Air pollution is a growing contributor to health issues and mortality, particularly in oil-rich areas like Rivers State, which produces 60% of Nigeria's crude oil (Whyte et al., 2020). Identifying sources of soot, implementing control measures, and raising public awareness about the health risks are crucial. The size of particulate matter determines its behavior in the atmosphere and its ability to penetrate the respiratory system. Solid fuel combustion, including burning coal and biomass, remains a key source of these pollutants.

Even at low concentrations, chlorine gas is highly toxic, causing conditions such as pulmonary edema, pneumonitis, and bronchitis, along with irritation to the eyes, throat, and nose. Particulate matter also plays a significant role in climate change by affecting the earth's radiation balance, cloud formation in the upper atmosphere, and visibility, while also influencing biogeochemical cycles in the lower atmosphere. Its presence in ambient air continues to pose a serious threat to public health (Mukherjee, 2017).

According to the World Health Organization (2021), air pollution is responsible for millions of deaths and a substantial loss of healthy life years each year. Cardiovascular diseases, which caused 17.9 million deaths in 2019 (32% of global deaths), are strongly associated with air pollution. Most of these deaths (85%) are due to heart attacks and strokes. Air pollution has become the most pressing environmental health issue, significantly contributing to the rise of non-communicable diseases (NCDs). These diseases, which are not contagious, include conditions like Parkinson's disease, stroke, heart disease, cancer, diabetes, chronic kidney disease, and osteoarthritis. They affect various organ systems, such as the cardiovascular, respiratory, and neurological systems. Air pollution is known to exacerbate respiratory and cardiovascular conditions, increase the risk of lung cancer, and appears to have growing impacts on other organ functions (Ewona et al., 2021; Udo, 2020; Ewona et al., 2022).

Air pollution arises from both natural and human activities, with industrialization playing a major role. The World Health Organization (WHO) highlights energy combustion as the primary cause, which includes the burning of fossil fuels, the use of unventilated stoves, tobacco consumption, and certain cultural or religious practices. Outdoor sources of pollution include transportation, industrial activities, power generation, forest fires, and the burning of agricultural waste.

Globally, particulate matter ($PM_{2.5}$) has been linked to various health issues such as asthma, chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, cancer, type 2 diabetes, and neurodegenerative diseases. While developed countries have made progress in reducing pollution through improved access to environmental data, developing nations often struggle with inadequate records (Abulude et al., 2022; Ekah, 2023). Air pollution is a major contributor to premature mortality and illnesses, including coronary heart disease, diabetes, and cancer (Slezakova et al., 2018).

To reduce greenhouse gas emissions, several strategies are proposed, including enhancing public transportation systems, promoting walking and cycling, increasing tree planting to absorb pollutants, and discouraging the use of outdated, high-emission vehicles (Tunde et al., 2022).

1.1. The Geo-Accumulation Index (IGEO)

The IGEO is used to evaluate the pollution status of heavy metals in sediments or soil. The equation is as follows:

$$\text{Igeo} = Log_2\left(\frac{C_n}{1.5 \times B_n}\right) \ldots\ldots\ldots\ldots\ldots 1$$

Where:
C_n: Measured concentration of elements in the collected sample
B_n: Geochemical background value of the element n in a reference material (e.g regional baseline)
1.5: A constant factor to account for natural variability and minor anthropogenic influences.

1.2. Igeo Classification

The geoaccumulated index (Igeo) is typically classified into seven categories to indicate pollution levels. The index helps in identifying areas requiring remediation and environmental management.

Table 1 The Igeo range, pollution level and description

Igeo Range	Pollution Level	Description
≤0	0	Unpolluted/contaminated
0< Igeo ≤ 1	1	Unpolluted/uncontaminated to moderately polluted/contaminated
1< Igeo ≤ 2	2	Moderately polluted/contaminated
2< Igeo ≤ 3	3	Moderately to heavily polluted/contaminated
3< Igeo ≤ 4	4	Heavily polluted/contaminated
4< Igeo ≤ 5	5	Heavily to extremely polluted/contaminated
Igeo > 5	6	Extremely polluted/contaminated

(JI,2007)

2. Literature review

Ekah et al. (2024a) assessed the concentration of heavy metals and environmental pollutants in Lagos State, Nigeria, focusing on airborne particles and rainwater contamination using gravitational settling method. Airborne particles were collected over a nine-month period, from January to September 2023, using funnels and clean containers placed at various sub-locations within the state. The collected sediments were analyzed in a laboratory using spectroscopic techniques. The following compounds were examined: arsenic (As), cadmium (Cd), manganese (Mn), ammonia (NH_3), chromium (Cr), mercury (Hg), chloride (Cl), aluminum (Al), cobalt (Co), copper (Cu), iron (Fe), zinc (Zn), potassium (K), nitrite (NO_2^-), nitrate NO_3^-, and fluoride (F). In addition, salinity and conductivity of the rainwater samples were analyzed. The sediments were collected and averaged across the sub-locations, and generalized for the entire state, with a geoaccumulation index computed to assess contamination levels. The study found that pollutants such as cadmium (Cd), chromium (Cr), aluminum (Al), cobalt (Co), copper (Cu), iron (Fe), zinc (Zn), potassium (K), nitrite (NO_2^-), nitrate (NO_3^-), and fluoride (F) reflected a clean or natural environment (Class 0) in terms of contamination. However, salinity levels were found to be a concern, indicating moderate to heavy contamination, which could affect environmental and ecological health. Nickel (Ni), manganese (Mn), and lead (Pb) were classified as Class 2, indicating moderate contamination.

Akhilesh et al. (2022) investigated the chemical composition and enrichment factors of size-fractionated airborne particulate matter in India's Singrauli Coalfield region. 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. Similarly, 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, emphasizing biomass burning as another significant contributor due to correlations with various chemical species.

The following compounds were analyzed; arsenic (As), cadmium (Cd), manganese (Mn), ammonia (NH_3), chromium (Cr), mercury (Hg), chloride (Cl), aluminum (Al), cobalt (Co), copper (Cu), iron (Fe), zinc (Zn), potassium (K), nitrite (NO_2^-), nitrate (NO_3^-), and fluoride (F). Results revealed that Lead (Pb) exhibited the highest CF (5.66), indicating considerable contamination, followed by Nickel (Ni) (CF = 4.58) and Manganese (Mn) (CF = 4.43). Cadmium (Cd) and Chromium (Cr) demonstrated moderate contamination, with CF values of (1.83 and 1.06), respectively. The EF results suggest moderate enrichment for Pb (4.339), Ni (3.51), and Mn (3.396), pointing to significant anthropogenic contributions, while Cd (1.276) reflected minimal enrichment, indicating a blend of natural and human sources. Ecological risk assessment revealed that Lead (Pb) posed a very high ecological risk (Er = 254.7), reflecting its toxicity and substantial environmental impact. Cadmium (Cd) presented a considerable risk (Er = 54.9) (Ekah et al. 2024b).

Gugamsetty et al. (2012) analyzed ambient particulate matter in Taiwan, focusing on PM_{10} , $PM_{2.5}$, and $PM_{0.1}$. Chemical analysis revealed five sources of particulate matter: soil dust, vehicle emissions, sea salt, industrial emissions, and secondary aerosols. Enrichment factors, using Al as a reference, underscored the competitive contributions of both natural and anthropogenic sources. In contrast, a study by Gao (2023) on particle-size-dependent selectivity of heavy metals in dust aerosols in New Delhi emphasized the human-induced sources for heavy metals like Cr, Fe, Cu, Ni, Zn, and Pb.

Rushdi et al. (2013) conducted a study on the air quality and enrichment factors of elemental aerosol particulate matter in Riyadh City, Saudi Arabia. Using X-ray fluorescence spectroscopy, they identified major and trace elements in $PM_{2.5}$ and PM_{10} samples collected from rooftops. The study found that PM_{10} concentrations exceeded $PM_{2.5}$ levels, indicating local dust as the primary source. Enrichment factors categorized elements based on their spatial variations, reflecting both natural and anthropogenic sources.

Haritash (2006) evaluated seasonal enrichment of heavy metals in respirable suspended particulate matter (RSPM) in a suburban Indian city. The study revealed that human activities were the dominant sources of metals like Pb, As, Ni, Cu, and Mn, while metals like Fe and Mg were linked to natural sources. Similarly, in a study of toxic element enrichment near a slag-based cement plant in Chhattisgarh, India, Sharma (2004) found significant metal enrichment, particularly for Ca, Mg, Fe, and Al, highlighting anthropogenic influences on air pollution.

In Nigeria, Issa (2011) studied sediments from the Orogodo River in Agbor over a period of four months. Atomic absorption spectroscopy revealed high concentrations of metals like Cd, Mn, Fe, Cu, Ni, Pb, Zn, and Cr. These were linked to anthropogenic activities, with Fe levels exceeding background and DPR standards, indicating notable contamination. Likewise, Andem (2015) evaluated sediment contamination in the Ona River, using Pollution Load Index (PLI) and Geo-accumulation Index (Igeo), finding moderate to heavy pollution levels due to local anthropogenic sources.

Ma (2015) assessed metal concentrations, enrichment factors, and geo-accumulation indexes in suspended particulate matter (SPM) and sediments from China's Daliao River. The dry season revealed the highest metal concentrations in sediments, with Cd being notably enriched. Geo-accumulation index results highlighted varying pollution levels, with some areas exhibiting high contamination. Similarly, Uwah (2013) analyzed sediments from the Qua Iboe River estuary, identifying significant enrichment of Cd, Zn, Cu, and Pb, with oil-related waste as a major pollution source.

In a study by Ismaeel (2015), heavy metal contamination in industrial zones of Al Anbar Province, Iraq was assessed, revealing extreme enrichment of Cd (EF = 40.3). This significant anthropogenic impact was corroborated by geo-accumulation index calculations, which indicated high levels of contamination. Meanwhile, Abdelbagi (2018) explored anthropogenic contributions to ambient air pollution in New Delhi, finding human-induced sources for Cr, Mn, Fe, Cu, Ni, Zn, and Pb, with fine-dust aerosols playing a significant role in particulate matter pollution.

Finally, Ochiagha (2020) investigated soil pollution in Onitsha South Local Government Area, where geo-accumulation indices revealed significant pollution by Mn, Cr, Zn, and Ni. Industrial discharges were identified as the primary anthropogenic contributors, while Cd, Pb, and Fe remained within acceptable limits. This finding was similar to that of Ji (2007), who used geo-accumulation indices to evaluate soil dust contamination in 15 Chinese cities, observing severe contamination by Ca, Cr, Ni, and Cu, driven by urbanization and industrial activities.

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.

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.

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.

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.

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.

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 (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.

3. Materials and methods

3.1. Materials

- Field data for toxic elements.
- Funnels, petri dishes, sellotapes, writing markers, and plastic containers were used in the field for sample collection.
- Statistical analysis was conducted using MS Excel for calculations and graphical representation.

3.2. Method

The gravitational settling method was used in Calabar to collect airborne particles, allowing them to naturally settle into containers along with rainwater. Funnels were securely attached to clean, empty containers, which were placed outdoors at various sub-locations across the state. The collection period lasted nine months, from January to September 2023.

After collection, the sediments were treated and transported, in sealed containers, to the air quality control laboratory for spectroscopic analysis. The sediments extracted from the liquid samples were dried by heating. The analysis focused on the following metals and other substances: arsenic (As), cadmium (Cd), manganese (Mn), ammonia (NH_3), chromium (Cr), mercury (Hg), chloride (Cl), aluminum (Al), cobalt (Co), copper (Cu), iron (Fe), zinc (Zn), potassium (K), nitrite

(NO_2^-), nitrate (NO_3^-), and fluoride (F). Additionally, the salinity and conductivity of the collected rainwater samples were analyzed.

The results were compiled, organized, and averaged for all sub-locations to determine the overall concentration across Calabar. These findings were then generalized to represent Calabar. The geoaccumulation index for the average concentrations of the metals was calculated to assess the degree of heavy metal contamination in Calabar, Nigeria, using Equation (1). The computed results are presented in Figure 1 below.

4. Result of analysis

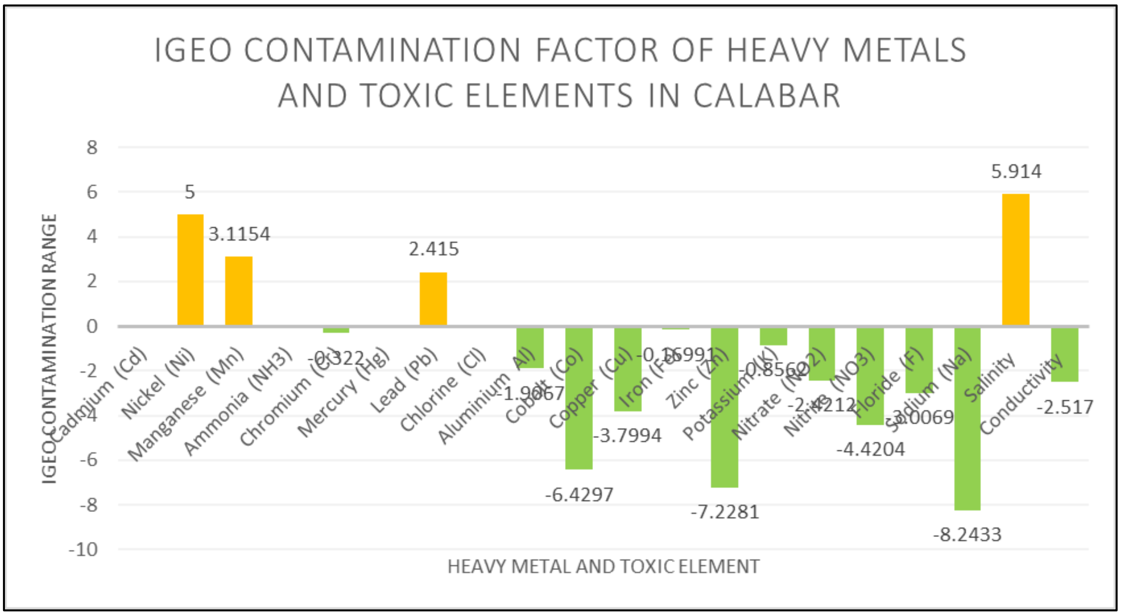

Figure 1 IGEO value of heavy metals in Calabar, Nigeria

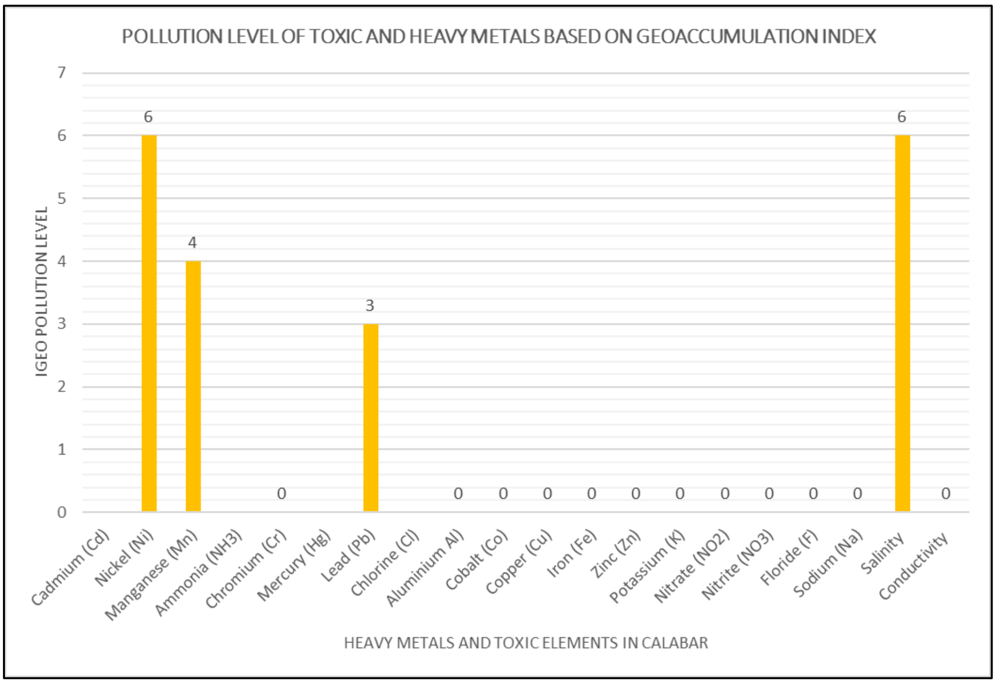

Figure 2 Pollution level of heavy metals and elements in rainwater based on geo-accumulation index

Figure 1 presents the geoaccumulation index derived from the concentration of heavy metals and elements analyzed during the study, which included As, Cd, Ni, Mn, NH_3, Cr, Hg, Pb, Cl, Al, Co, Cu, Fe, Zn, K, NO_2^-,NO_3^-, F, and Na, as well as the salinity and conductivity of rainwater samples collected from Calabar. The geoaccumulation index pollution range was then used to generate Figure 2, which represents the contamination levels and the state of contamination of heavy metals in Lagos.

4.1. Interpretation

The geoaccumulation index results for Calabar show that most compounds, including cadmium, chromium, aluminum, cobalt, copper, iron, zinc, potassium, nitrite, nitrate, fluoride, and sodium, fall under Class 0 (No contamination), indicating natural concentrations. Nickel (Ni) falls under (Class 6), indicating an extremely polluted environment, lead (Pb) falls under (Class 3) (Moderately to heavily polluted contamination), and manganese falls under (Class 4) Indicating a very strong contamination, suggesting varying degrees of anthropogenic influence. Additionally, Salinity falls under (Class 6), indicating an extremely polluted environment. The rainwater samples low conductivity, indicates the presence of dissolved salts and minimal ionization, respectively.

Geo-accumulation index for; As, Hg, NH_3 and Cl were not computed due to the fact that they are below detection level for the spectroscopic analyses.

These results are expected to serve as a guide to Cross River State Environmental Monitoring organizations, particularly focusing on effects and health implications on human health that may arise from the following elements; manganese (Mn), nickel (Ni), lead (Pb) and Salinity (concentration of dissolved salt in water).

5. Discussion

The results of this study highlight varying degrees of contamination in Calabar, Nigeria, with a significant focus on airborne toxic elements. The geoaccumulation index revealed that most of the elements measured, including cadmium, chromium, aluminum, cobalt, copper, iron, zinc, potassium, nitrite, nitrate, fluoride, and sodium, displayed natural concentrations, indicating no significant pollution. However, certain metals, such as nickel, mercury, and lead, showed elevated levels, pointing to anthropogenic influences.

Nickel and salinity showed igeo pollution of (Class 6), indicating extremely polluted contamination) classification, suggests a high level of contamination, likely from industrial activities or vehicular emissions. The strong presence of nickel in the environment calls for increased attention to potential sources of pollution and their long-term effects on both human health and the ecosystem. Similarly, lead (Pb), classified under Class 3 (Moderately to heavily contamination), point to anthropogenic contributions such as, industrial emissions and urbanization, both of which are prevalent in populated regions.

Manganese, classified under Class 4 (Strong contamination), indicates a more significant level of contamination, which may stem from activities such as mining and industrial processing.

The rainwater analysis also provided valuable insights. The moderate salinity levels observed in the rainwater samples reflect the influence of natural sources, such as sea spray, as well as possible anthropogenic contributions from road runoff or industrial activities. The low conductivity indicates that the rainwater is not significantly ionized, meaning that dissolved ions are minimal, further suggesting that the contamination in the region is not extreme.

6. Conclusion

This study investigated the levels of airborne toxic elements in Calabar, Nigeria, using the gravitational settling method for sample collection over a period of nine months from January to September 2023. The analysis focused on several heavy metals and other toxic substances, including cadmium, chromium, manganese, mercury, lead, aluminum, cobalt, copper, iron, zinc, potassium, nitrite, nitrate, fluoride, and sodium, as well as the salinity and conductivity of the collected rainwater. The results indicated that most of the elements, including cadmium, chromium, aluminum, cobalt, copper, iron, zinc, potassium, nitrite, nitrate, fluoride, and sodium, showed no significant contamination, falling under Class 0 (No contamination). However, certain metals such as nickel, manganese, and lead exhibited higher contamination levels, with nickel falling under Class 6 (extremely contaminated), manganese and lead under Class 4 (Heavily contaminated), and Class 3 (Moderate to strong contamination). The rainwater analysis showed extremely contaminated salinity and low conductivity, indicating dissolved salts and minimal ionization, respectively.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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