Assessment of Heavy Metal Contamination and Rainwater Quality in Lagos State: A Geoaccumulation Index Approach

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Abstract- This study assessed the concentration of heavy metals and environmental pollutants in Lagos State, Nigeria, focusing on airborne particles and rainwater contamination. The gravitational settling method was employed to collect airborne particles 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 heavy metals and elements were examined: arsenic (As), cadmium (Cd), manganese (Mn), ammonia (NH3), 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 results were compiled, 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. The geoaccumulation index for arsenic (As), mercury (Hg), ammonia (NH3), and chloride (Cl) could not be computed due to low detection limits. These findings emphasize the importance of continued environmental monitoring in Lagos, particularly with regard to manganese, nickel, lead, and salinity, to ensure the protection of public and ecological health.

Indexed Terms- 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.

I. 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 in Nigeria's Niger Delta, supported by TET Fund, uncovered substantial pollution levels in the area. This research utilized the gravity settling method for air sampling, as reported in studies by Ewona et al. (2021, 2022) and Udo et al. (2018, 2020).

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.

Key pollutants, such as particulate matter ($PM_{2.5}$ and PM_{10}) and gases like ammonia (NH_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and organic compounds, pose substantial health and environmental risks. In Rivers State, Nigeria, research by Tamuno et al. (2022) associated visible soot with a rise in respiratory infections. Air pollution increasingly contributes to health problems and mortality in Nigeria, especially in oil-producing regions like Rivers State, which accounts for 60% of the country's crude oil output (Whyte et al., 2020). Efforts to identify soot sources, implement control measures, and raise public awareness of associated health hazards are essential. The size of particulate matter determines its behavior in the atmosphere and its capacity to penetrate the respiratory system. Solid fuel combustion, such as burning coal and biomass, remains a primary source of these pollutants.

Chlorine gas, even at low concentrations, is extremely hazardous, causing conditions such as pulmonary edema, pneumonitis, and bronchitis, alongside eye, throat, and nasal irritation. Particulate matter also significantly affects climate change by influencing the earth's radiation balance and cloud formation in the upper atmosphere while reducing visibility and impacting biogeochemical cycles in the lower atmosphere. Its presence in ambient air continues to pose a serious risk to public health (Mukherjee, 2017). 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).

1.1 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).

1.2 The Geo-Accumulation Index (IGEO)

The Geo-Accumulation Index is a quantitative measure used in environmental studies to assess the degree of contamination in soils or sediments by comparing current concentrations of a particular element to its natural background levels. The IGEO is used to evaluate the pollution status of heavy metals in sediments or soil. The equation is as follows:

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

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.

1.3 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 represents the Igeo range, pollution level and description of the Igeo index.

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)

II. 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 (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.

III. 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.

3.2 METHOD

Gravitational settling method was employed in Lagos State to collect airborne particles, which were allowed to settle naturally into containers along with rainwater. Funnels were securely attached to clean, empty containers, and the setups were placed outdoors at various sub-locations within the state. The collection period spanned nine months, from January to September 2023.

After collection, the sediments were treated and transported to the air quality control laboratory for spectroscopic analysis.

During the analysis, sediments extracted from the liquid samples were dried through heating. The study focused on the following heavy metals, elements and compounds: 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, 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 Lagos State. These findings were subsequently generalized to represent the entire country.

The geoaccumulation index for the average concentrations of the metals was computed to assess the degree of contamination of heavy metals in Lagos State, Nigeria, using Equation (1). The computed results are presented in Figure 1 below.

IV. RESULT OF ANALYSIS

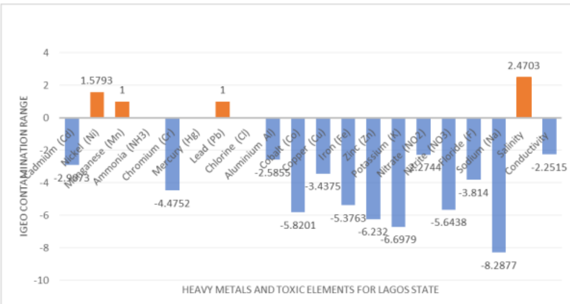

FIGURE 1 IGEO VALUE OF HEAVY METALS IN NIGERIA

Figure 1 presents the geoaccumulation index derived from the concentration of heavy metals, elements and compounds 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 Lagos. 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.

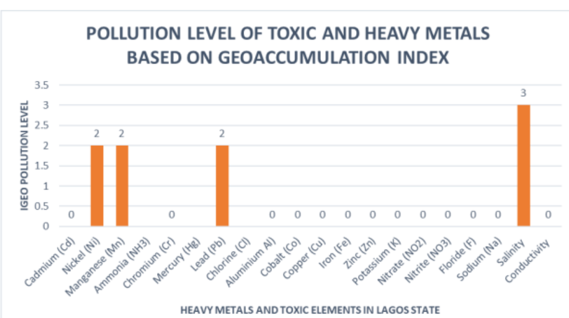

FIGURE 2 POLLUTION LEVEL OF HEAVY METALS AND ELEMENTS IN RAINWATER BASED ON GEO-ACCUMULATION INDEX

Interpretation:
The contamination levels for the following pollutants; Cd, Cr, Al, Co, Cu, Fe, Zn, K, NO_2^-, NO_3^-, F, and Na, indicated a clean or natural environment (Class 0).

In Lagos state, Salinity (concentration of dissolved salt in water) is an area of concern, indicating moderate to heavy contamination, which could affect environmental and ecological health.

Nickel (Ni), Manganese (Mn) and lead (Pb) are moderately polluted, suggesting varying degrees of anthropogenic influence.

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 Lagos State environmental monitoring organizations, such as Lagos State Environmental Protection agencies (LASEPA), Lagos State Waste Management Authority (LAWMA), particularly focusing on the excessive intake of the following; manganese (Mn), nickel (Ni), lead (Pb) and Salinity.

4.1 Discussion

The study aimed to assess the concentration of heavy metals and environmental pollutants in Lagos State, Nigeria, focusing on airborne particles and rainwater contamination over a nine-month period. The results revealed a varied range of contamination across the pollutants measured. Most of the heavy metals and elements analyzed, including 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), fell under Class 0 (clean or natural environment). This indicates that these pollutants have not contributed significantly to contamination levels in Lagos State. The absence of major contamination in these pollutants is a positive sign for air quality and environmental health.

However, the findings highlight concerns about certain pollutants, specifically nickel (Ni), manganese (Mn), lead (Pb). Salinity levels in the collected rainwater samples reflected moderate to heavy contamination, suggesting potential ecological risks. The presence of salinity at higher levels may have implications for water quality and the broader ecosystem in Lagos State, as excessive salinity can harm aquatic life and disrupt natural processes in the environment by affecting the soil, plants and animals.

Nickel (Ni), manganese (Mn), and lead (Pb) were classified under Class 2, indicating moderate contamination. Their presence could pose risks to human health and the environment if not properly monitored. Nickel and manganese are often associated with industrial activities, while lead is known for its toxicity, particularly concerning its impact on human health, especially in children.

Interestingly, certain pollutants such as arsenic (As), mercury (Hg), ammonia (NH_3), and chloride (Cl) were below detection levels, meaning they did not contribute significantly to contamination during the study period. This may suggest either the natural absence of these elements in the study area or limitations in the detection method, which should be addressed in future studies to ensure comprehensive monitoring.

The geoaccumulation index used in this study was effective in identifying the degree of contamination for each pollutant and provides a valuable tool for assessing the environmental quality of Lagos State. This information is critical for policymakers and environmental agencies to prioritize areas for remediation and improve air and water quality standards.

4.2 Summary and Conclusion

4.2.1 Summary

This study focused on the collection and analysis of airborne particles and rainwater samples from Lagos State, Nigeria, to assess the concentration of heavy metals and environmental pollutants. The gravitational settling method was employed to collect airborne particles over a nine-month period, from January to September 2023. The collected samples were analyzed for a range of pollutants, including 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). The study found that most pollutants were within acceptable environmental levels, with the exception of salinity (concentration of dissolved salt in water), nickel (Ni), manganese (Mn), and lead (Pb), which were classified as moderately polluted and moderately to heavily polluted. The geoaccumulation index further confirmed the environmental quality status of the pollutants in the state.

4.2.2 Conclusion

The results of this study indicate that Lagos State's environment is relatively free from significant contamination by most heavy metals and pollutants, as evidenced by the Class 0 classification for many elements. However, attention should be given to certain pollutants such as; nickel (Ni), manganese (Mn), and lead (Pb), which were found to be moderately contaminated (Class 2). Salinity, in particular, poses an environmental concern that could impact local ecosystems and water quality.

The geoaccumulation index provides valuable insights into the extent of contamination, and its application can guide future environmental monitoring and decision-making in Lagos State. Further studies should focus on improving detection methods and expanding the geographical scope of the analysis to enhance our understanding of environmental pollutants across the state.

Overall, the study underscores the importance of regular environmental monitoring and proactive measures to maintain and improve air and water quality in Lagos State and Nigeria at large. Environmental agencies and policymakers should focus on the pollutants identified in this study to prevent potential ecological and health risks in the future.

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