Assessment of Contamination, Risk, and Enrichment Factors of Heavy Metals in Airborne Particulate Matter Across Nigeria

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Abstract- This study evaluates the Contamination Factor (CF), Enrichment Factor (EF), and Ecological Risk (Er) of various elements in six locations across Nigeria, selected to represent the country's ecoclimatic zones: Benin, Kano, Abuja, Lagos, Enugu, and Calabar. Airborne particles were collected using the gravitational settling method, which involved the natural deposition of particles into the containers through the funnels along with rainwater. Sampling spanned nine months, from January to September 2023, with the collected sediments processed and analyzed in an air quality control laboratory using spectroscopic techniques. The analysis focused on 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), further emphasizing its potential to disrupt ecological systems. These findings underscore the urgent need to address heavy metal contamination and its ecological implications in Nigeria.

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, Contamination Factor, Risk Factor, Enrichment Factors, Heavy Metals, Airborne Particulate.

I. INTRODUCTION

Environmental contamination caused by heavy metals is a growing concern due to its adverse effects on ecosystems and human health. Various indices, such as the Contamination Factor (CF), Ecological Risk Factor (ERF), and Enrichment Factor (EF), are employed to evaluate the extent and implications of heavy metal pollution in environmental samples like air, water, and soil. These indices provide a systematic approach to quantify pollution levels, assess ecological risks, and identify anthropogenic contributions to contamination.

Contamination Factor (CF): CF evaluates the degree of pollution by comparing the concentration of a specific pollutant in an environmental sample to its natural or baseline concentration. It quantifies the contamination level, with higher CF values indicating greater pollution severity and potential environmental risk. Contamination Factor (CF): The Contamination Factor (CF) of the heavy metals measured was calculated as;

$$C_F = \frac{C_{metal}}{C_{background}} \qquad 1$$

where C_{metal} denotes the measured metal concentration of the sample (air, water, soil), and $C_{background}$ is the background reference concentration values of the individual metals. The interpretation of contamination index is based on the following intervals as proposed by Lacatusu (2000) CF = 0 – 1.0 signifies contamination; 1.1- 4.0, slight to moderate pollution; 4.1-8.0 Severe pollution; 8.1-16.0 Very severe pollution; >16.0 Extreme pollution.

Ecological Risk Factor (ERF): It measures the potential harm that pollutants, such as heavy metals, pose to ecosystems. ERF considers both the concentration of the pollutant and its toxicity, helping to evaluate the severity of environmental contamination and its ecological impacts (Lacatusa, 2000, Nwineewll et al., 2018). The terms used to interpret ecological risk is based on the suggestion of Hakanson (1980), they are: Er < Er ≤80, reasonable ecological risk; 80 < Er ≤160, significant ecological risk; 160 < Er ≤320, pronounced ecological risk; and >320, severe ecological risk;

The Ecological risk factor of heavy metals is calculated as;

$$E_r = T_r \times C_f \qquad 2$$

Where Tr is the toxic response factor (numerical values are assigned to individual elements) and CF is the contamination factor of single metals.

Enrichment Factor (EF): EF assesses the level of contamination by comparing the concentration of a pollutant in an environmental sample (e.g., soil, water) to a reference value, typically based on natural background levels or a standard element. A high EF suggests significant anthropogenic contributions to pollution impacts (Lacatusa , 2000, Nwineewll et al., 2018).

Enrichment Factor: The Enrichment Factor (EF) analysis of the measured heavy metals was calculated as;

$$\text{EF} = \frac{(C_n/C_{ref})\, sample}{(B_n/B_{ref})\, Background} \qquad 3$$

Where Cn is the concentration of metal measured in the sample, Cref is the concentration of the reference material (in this study it is Fe), Bn is the background concentration of the examined metal and Bref is the concentration of the reference element (Fe). The Enrichment factor classes were predicted on the foundation of the following categories: EF < 1 demonstrates "no enrichment", 1 < EF< 3 represents "minor enrichment" , EF= 3 – 5 demonstrates "moderate enrichment" , EF = 5-10 signifies "moderately severe enrichment" EF= 10 – 25 represents " severe enrichment" , EF = 25 – 50 signifies "very severe enrichment" and EF > 5 demonstrates "extremely severe enrichment" (Nwineewll,2018; Uwah et al., 2013). Table 1 represents description of different indices; contamination factor, Ecological risk factor, Ecological Risk factor to monitor human exposure, toxic and casinogenic elements within the environment.

Index	Category	Description
Contamination factor	CF < 1	Low contamination
	1≤ CF < 2	Low to moderate contamination
	2 ≤ CF < 3	Moderate contamination
	3 ≤ CF < 4	Moderate to high contamination
	4 ≤ CF < 5	High concentration
	5≤ CF < 6	High to very high contamination
	CF ≥ 6	Extreme contamination
Ecological Risk factor	ERI < 40	No risk or Minimal ecological risk. No significant environmental impact expected
	40 ≤ ERI < 80	Moderate risk ; some ecological concern
	80 ≤ ERI < 160	Considerable risk; Notable Ecological risk

	160 ≤ ERI < 320	High risk; significant ecological impact. Requires urgent intervention.
	ERI≥ 320	Very high risk; severe ecological threat. It requires immediate intervention.
Enrichment Factor	EF ≤ 1	No enrichment. Natural or crustal origin, no anthropogenic influence.
	1 <EF ≤ 3	Minor enrichment. Minimal anthropogenic enrichment.
	3 <EF ≤ 5	Moderate enrichment. Moderate human influence, noticeable contamination.
	5 <EF ≤ 10	Significant Enrichment. Substantial anthropogenic contribution. Clear signs of pollution.
	10 <EF ≤ 25	Very high enrichment. High level of contamination. Significant ecological concern.
	25 <EF ≤ 50	Extremely high enrichment. Severe contamination; requires intervention.
	EF > 50	Exceptionally high enrichment. Extreme anthropogenic impact; urgent remediation necessary.

Table 1 (Rostami et al., 2021; Liu et al., 2020; Wang et al., 2018; Mahabadi et al.,2020; Kang et al., 2020; Hu et al., 2013)

Recent studies highlight the critical impact of air pollution on global health. The Health Effects Institute (HEI) report on the State of Global Air (SOGA, 2020) ranks air pollution as the fourth leading cause of premature mortality worldwide, accounting for 12% of total deaths. This environmental hazard reduces life expectancy by an average of 2.2 years and contributes to nearly seven million deaths annually. In West Africa, over 80% of urban residents are exposed to air quality levels surpassing World Health Organization (WHO) guidelines (WHO, 2021). Research in Nigeria's Niger Delta by Udo and Ewona, supported by TETFund, identified significant pollution in the region, employing the gravity settling method for air sample collection (Ekah et al., 2023; Ewona et al., 2021, 2022; Udo et al., 2018, 2020).

The WHO (2021) estimates that millions of deaths and healthy life years are lost annually due to air pollution, with cardiovascular diseases—a leading global health issue—causing 17.9 million deaths in 2019, or 32% of all global fatalities. Among these deaths, 85% resulted from heart attacks and strokes. Air pollution exacerbates noncommunicable diseases (NCDs) such as cardiovascular and respiratory diseases, stroke, cancer, diabetes, and kidney diseases, alongside emerging links to neurological conditions. Studies confirm that air pollution significantly increases risks for lung cancer and dysfunction in various organ systems (Ewona et al., 2021; Udo & Ewona, 2020; Ewona et al., 2022).

II. LITERATURE REVIEW

Rushdi et al. (2013) examined air quality and enrichment factors for elemental aerosol particulate matter in Riyadh City, Saudi Arabia. Particulate matter (PM2.5 and PM10) samples were gathered using

MiniVolume air samplers installed on rooftops at heights between 15 and 25 meters above ground level over a one-year period. These samples were analyzed through X-ray fluorescence spectroscopy to detect major elements (Na, Mg, Al, K, Ca, Si, P, S, and Fe) and trace elements (Mn, Ni, Cu, Zn, and Ba). Results showed that PM10 concentrations were higher than PM2.5, indicating that local dust was the dominant source of particulate matter. Air quality assessments ranged from good to hazardous for PM2.5 and good to extremely hazardous for PM10. Enrichment factor analysis categorized elements into two groups: those with uniform spatial distribution (indicating common sources) and those with significant spatial variation (pointing to anthropogenic influences).

Maurizio (2016) reviewed the use of enrichment factors and geoaccumulation indexes in assessing soil contamination. The study highlighted how human activities such as fertilizer and pesticide use, industrial processes, waste disposal, and air pollution have led to increased concentrations of heavy metals in soils, resulting in reduced soil fertility. Enrichment factors and geoaccumulation indexes were identified as vital tools for measuring the extent of anthropogenic contamination.

Gugamsetty et al. (2012) studied ambient particulate matter of different sizes (PM10, PM2.5, and PM0.1) in Taiwan. Sampling occurred over 24-hour periods between May and November 2011 using a dichotomous sampler and a MOUDI (Micro-Orifice Uniform Deposit Impactor). Chemical analysis via ion chromatography (IC) and inductively coupled plasma mass spectrometry (ICP-MS) revealed average concentrations of 39.45 ± 11.58 μg/m³ for PM10, 21.82 ± 7.50 μg/m³ for PM2.5, and 1.42 ± 0.56 μg/m³ for PM1.1. Positive matrix factorization (PMF) identified five particulate matter sources: soil dust, vehicle emissions, sea salt, industrial emissions, and secondary aerosols. Enrichment factors calculated using Al as a reference element and conditional probability functions (CPF) indicated connections between particulate sources and wind patterns, highlighting contributions from both natural and human-made sources.

Haritash (2007) assessed seasonal variations in heavy metal enrichment within respirable suspended particulate matter (RSPM) in a suburban city in India over six months. Atomic absorption spectroscopy (AAS) analysis showed higher concentrations of metals such as Pb, As, Ni, Cu, Mn, Fe, and Mg in commercial and industrial areas. Enrichment factors indicated that Pb, As, Ni, Cu, and Mn were primarily derived from anthropogenic sources, whereas Fe and Mg were attributed to natural origins.

Yadav et al., (2022) conducted a similar study in the Singrauli Coalfield, finding enrichment factors for Co, Cu, Br, As, Zn, and H ranging between 5 and 150, confirming anthropogenic sources. High levels of N and Se in PM2.5 were linked to industrial emissions, correlations with other ions underscored biomass burning as a significant contributor.

A field study in Iraq's Al Anbar Province focused on heavy metal contamination within industrial zones. Eight soil samples were collected at depths of 0–2 cm and analyzed via X-ray fluorescence for Pb, Ni, Cd, Co, Cr, and Cu. Calculations of Enrichment Factors (EF) and Geoaccumulation Index (Igeo) quantified the impact of human activity on heavy metal distribution (Ismaeel & Kusag, 2015).

Sharma & Pervez, (2004) investigated toxic element enrichment in ambient particulate matter near a slag-based cement plant in Chhattisgarh. Toxic elements in Respirable Suspended Particulate Matter (RSPM) and Non-Respirable Suspended Particulate Matter (NRSPM) followed the order: Ca > Mg > Fe > Al > Na > K > Mn > Cr > Ni > Cu > Zn > Co > Pb > Hg > Cd. Positive correlations between RSPM and metal concentrations highlighted a strong link between particulate matter and metal enrichment factors.

Ma et al., (2015) studied seasonal variations in suspended particulate matter and sediments from the Daliao River and estuary in China. Metal concentrations were highest during the dry season, and enrichment factors revealed significant enrichment of Cd, Pb, As, and Zn. While Igeo values classified most metals as unpolluted, Cd ranged from unpolluted to moderately polluted.

Issa (2011) investigated sediment contamination in the Orogodo River, Nigeria. Heavy metals, including Cd, Mn, Fe, Cu, Ni, Pb, Zn, and Cr, were analyzed, with results indicating substantial contamination by Fe, which exceeded background standards.

In Nigeria's Ala River, Abata (2013) used Geo-accumulation Index and contamination factors to rank metal concentrations as Fe > Cr > Pb > Zn > Ni > Cu > Cd. Pearson correlation analysis linked metals like Zn, Fe, and Cr to anthropogenic sources.

Iwuoha et al., (2012) analyzed sediments from the Otamiri River, Nigeria, finding that metal concentrations correlated with organic carbon. Geo-accumulation Index results suggested that natural processes, such as erosion, were the primary sources of metals.

Ephraim & Ajayi, (2014) reported low contamination levels in sediments from the Mbat-Abbiati and Oberakkai Creeks of the Great Kwa River, where over 55% of metals were from lithogenic origins. Hasan (2012) identified significant contamination from ship-breaking activities in Bangladesh, particularly for Cr, Zn, As, and Pb. Kothai et al (2011) highlighted seasonal differences in airborne particulate concentrations in Vashi, Navi Mumbai, with EF analysis showing the highest enrichment of As, Pb, and Zn in fine particulates.

This article evaluated the concentration of heavy metals and environmental pollutants in Lagos State, Nigeria, focusing on airborne particles and rainwater contamination. The gravitational settling method was adopted to collect airborne particles over a nine-month period, using funnels and clean containers placed at various sub-locations within the state. The collected sediments were analysed in a laboratory using spectroscopic techniques. The study found that pollutants such as Nickel (Ni), manganese (Mn), and lead (Pb) were classified as Class 2, indicating moderate contamination (Ekah et al., 2024).

III. MATERIALS AND METHODS

3.1 MATERIALS

- Field data for toxic elements in Nigeria.
- MS excel was used for the statistical analysis
- The following tools were used at the field; Funnels, petri dish, sellotapes, writing markers, plastic containers.

3.2 METHOD

Six locations were selected across Nigeria to reflect the ecoclimatic zones of the country. The locations include: Benin, Kano, Abuja, Lagos, Enugu and Calabar. Gravitational settling method was adopted for data collection, allowing airborne particles to settle naturally into the container along with rainwater through the funnels.

Funnels were securely attached to clean, empty containers and the setups were placed outdoors for a duration of nine months, starting from January to September 2023 at different sample locations/ sub-locations to collect airborne particles. The samples collected were grouped to representing each city. Subsequently, the sediments collected were organized and moved to air quality control laboratory for spectroscopic analysis.

The following heavy metals. Elements and compounds were considered for the analysis: arsenic (As), cadmium (Cd), manganese (Mn), ammonia (NH_3), chromium (Cr), mercury (Hg), chloride (Cl), aluminium (Al), copper (Cu), iron (Fe), zinc (Zn), potassium (K), nitrite ($N0_2^-$), nitrate ($N0_3^-$), and fluoride (F).

The contamination factor (CF), Enrichment factor (EF), and the Ecological Risk Factor (Er) for the average concentration of the metals were computed to provide insight into the degree of environmental contamination by various elements, to highlight the extent of anthropogenic influence on the distribution of elements/compounds and to provide assessment of the potential ecological threats posed by the contaminants. The result of the estimated value is displayed in figure 1-3 below.

There was no evaluation done for the following elements; As, Cr, Hg, Cl, since it was below detection level (BDL).

IV. RESULTS AND DISCUSSION

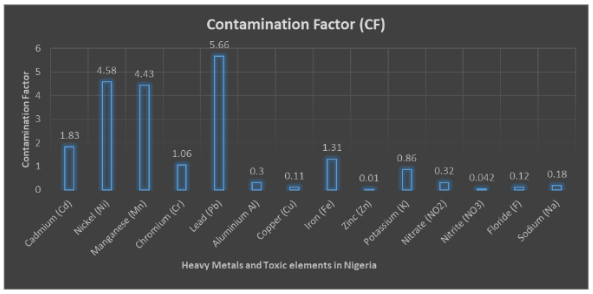

Fig 1 Contamination Factor (CF) of Heavy metals and Toxic elements in Nigeria

Figure 1 represents a bar chart displaying the Contamination Factor (CF) of Heavy metals and Toxic elements in Nigeria. The figure provides insight into the degree of environmental contamination by various elements. The results indicate that Lead (Pb) exhibits the highest contamination factor (CF = 5.66), falling into the category of considerable contamination. Similarly, Nickel (Ni) and Manganese (Mn) show CF values of 4.58 and 4.43, respectively, also indicating considerable contamination. Cadmium (Cd) exhibits a CF of 1.83, reflecting moderate contamination, while Chromium (Cr) (CF = 1.06) also falls within this range.

Conversely, elements such as Copper (Cu), Zinc (Zn), Potassium (K), and Sodium (Na) have CF values below 1, signifying low contamination. These findings suggest that the elevated contamination levels of Pb, Ni, and Mn may arise from anthropogenic sources, potentially linked to industrial discharges, vehicular emissions, or agricultural activities.

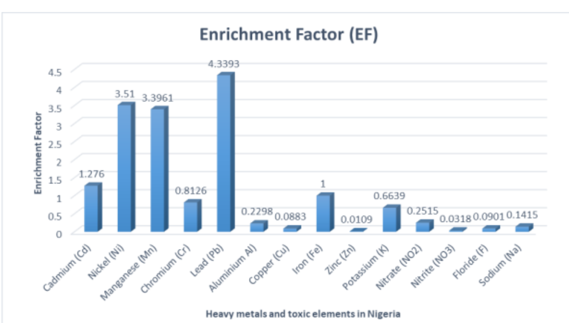

Fig 2 Enrichment Factor (EF) of Heavy metals and Toxic elements in Nigeria

Figure 2 represents a bar chart displaying the Enrichment Factor (EF) of Heavy metals and Toxic elements in Nigeria. Enrichment factor analysis highlights the extent of anthropogenic influence on the distribution of elements. Lead (Pb) (EF = 4.339), Nickel (Ni) (EF = 3.51), and Manganese (Mn) (EF = 3.396) exhibit moderate enrichment, suggesting contributions from human activities. Cadmium (Cd) (EF = 1.276) shows minimal enrichment, indicating a mixture of natural and anthropogenic sources.

Most other elements, including Copper (Cu), Zinc (Zn), and Potassium (K), have EF values below 2, signifying minimal enrichment and suggesting that their concentrations are primarily due to natural processes. The moderate EF values of Pb, Ni, and Mn underscore the need to examine anthropogenic activities contributing to their elevated levels.

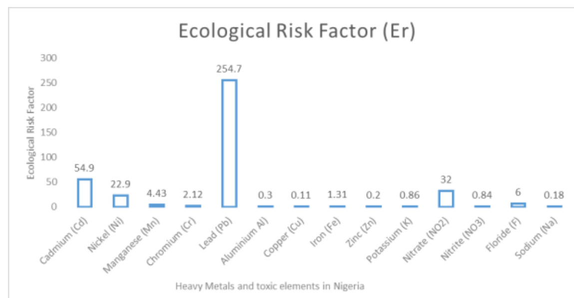

Fig 3 Ecological Risk Factor (Er) of Heavy metals and Toxic elements in Nigeria

Figure 3 displays the Ecological Risk Factor (E_r) of Heavy metals and Toxic elements in Nigeria. The ecological risk factor provides an assessment of the potential ecological threats posed by the contaminants. Lead (Pb) demonstrates a very high ecological risk (Er = 254.7), reflecting its toxic nature and significant environmental impact. Cadmium (Cd) also poses a considerable risk (Er = 54.9), highlighting its potential to disrupt ecological balance.

Other parameters, such as Nickel (Ni) (Er = 22.9), Nitrate (NO2) (Er = 32), and Nitrite (NO3) (Er = 0.84), exhibit low to moderate ecological risks. Elements such as Copper (Cu), Zinc (Zn), and Potassium (K) pose negligible risks, with Er values below 1. These results emphasize the urgent need to mitigate Pb and Cd contamination to reduce ecological threats.

4.1 Discussion

The study's methodology and findings provide critical insights into the environmental contamination and ecological risks posed by heavy metals and elements in six diverse locations across Nigeria. The adoption of the gravitational settling method ensured efficient collection of airborne particles, representing a realistic environmental sampling technique. This approach facilitated the analysis of contaminants influenced by natural and anthropogenic factors within the country's various climatic zones and geological frameworks.

The contamination factor (CF) results reveal significant contamination by Lead (Pb), Nickel (Ni), and Manganese (Mn), attributed to anthropogenic sources such as industrial discharges, vehicular emissions, and agricultural practices. The moderate CF of Cadmium (Cd) and Chromium (Cr) further highlights their potential environmental impact. Conversely, the low contamination levels of elements like Copper (Cu), Zinc (Zn), and Potassium (K) underscore the dominance of natural processes in their distribution.

The enrichment factor (EF) analysis aligns with the CF findings, identifying Pb, Ni, and Mn as moderately enriched elements, driven by human activities. Cd's minimal enrichment reinforces its mixed-source origins, while other elements exhibit minimal enrichment, confirming their natural prevalence.

The ecological risk factor (Er) assessment underscores Pb's high ecological risk, a reflection of its toxicity and widespread distribution in the environment. Cd also poses a considerable ecological threat, necessitating attention. Other elements present low to negligible ecological risks, indicating their limited environmental impact.

4.2 Summary and Conclusion

4.2.1 Summary

This study employed a nine-month field data collection across six Nigerian locations to investigate the contamination, enrichment, and ecological risks associated with various heavy metals and elements. The results highlight Pb, Ni, and Mn as elements of concern, exhibiting considerable contamination and moderate enrichment levels due to anthropogenic influences. Ecological risk analysis identified Pb and Cd as high-priority contaminants requiring immediate attention to mitigate their toxic effects on the environment. Other elements presented minimal contamination, enrichment, and ecological risks.

4.2.2 Conclusion

The findings of this study underscore the significant environmental impact of human activities on the distribution and contamination of heavy metals in Nigeria. Lead (Pb) emerges as the most critical pollutant, exhibiting the highest contamination, enrichment, and ecological risk levels. Targeted interventions are necessary to mitigate Pb and Cd contamination, particularly in industrial, urban, and agricultural areas. Continued monitoring and stricter environmental regulations are essential to safeguard ecological balance and reduce the potential health risks posed by these contaminants. This research provides a foundation for future studies and policy-making to address heavy metal pollution in Nigeria.

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REFERENCES

[1] Abata, E. O., Aiyesanmi, A. F., Adebayo, A. O., & Ajayi, O. O. (2013). Assessment of heavy metal contamination and sediment quality in the urban river: A case of Ala River in Southwestern Nigeria. *IOSR Journal of Applied Chemistry, 4*(3), 56-63. https://www.iosrjournals.org

[2] Ephraim, B. E., & Ajayi, I. O. (2014). Geoenvironmental assessments of heavy metals in surface sediments from some creeks of the Great Kwa River, Southeastern Nigeria. *Journal of Environment and Earth Science, 4*(21), 1-8.

[3] Ewona, I. O. (2020). Socioeconomic factors influencing life expectancy in rural Nigeria.

Journal of Public Health and Development, 18(1), 12-22.

[4] Ekah, B. J.; Akwagiobe, U. J., Udo, S. O., Ewona, I. O. (2023). A Review on Intergovernmental Panel on Climate Change (IPCC) 1st to 6th Report: Physical Science International Journal, 27 (1), 16- 24.

[5] Ekah, B. J.; Ekong, I. B.; Azogor W. E; Akwagiobe J. U; Ekechukwu, C. C.; Uda, C. N.; Ewona, I.O; Udo, S. O. Rabiu, B. (2024). Assessment of Heavy Metal Contamination and Rainwater Quality in Lagos State: A Geoaccumulation Index Approach, IRE journal, 8(5), ISSN: 2456 - 8880

[6] Ewona, I. O., Udo, S. O., & TET Fund. (2022). Methodological approaches in air sample collection: The gravity settling method. *International Journal of Environmental Monitoring*, *8*(2), 341- 356.

[7] Ewona, I. O., Udo, S. O., & TET Fund. (2021). Gravity settling method for air quality assessment. *Journal of Air Pollution Studies*, *5*(1), 234-245.

[8] Gugamsetty, B., Wei, H., Liu, C.-N., Awasthi, A., Hsu, S.-C., Tsai, C.-J., Roam, G.-D., Wu, Y.-C., & Chen, C.-F. (2012). Source characterization and apportionment of PM10, PM2.5 and PM0.1 by using positive matrix factorization. *Aerosol and Air Quality Research*, *12*, 476–491. https://doi.org/10.4209/aaqr.2012.04.0084

[9] Haritash, A. K., & Kaushik, C. P. (2007). Assessment of seasonal enrichment of heavy metals in respirable suspended particulate matter of a sub-urban Indian city. *Environmental Monitoring and Assessment*, *128*, 411–420. https://doi.org/10.1007/s10661-006-9335-1

[10] Hasan, A. B., Kabir, S., Reza, S. A., Zaman, M. N., Ahsan, A., and Rashid, M. (2012). Enrichment factor and geo-accumulation index of trace metals in sediments of the ship breaking area of Sitakund Upazilla (Bhatiary- Kumira), Chittagong, Bangladesh, Journal of Geochemical Exploration,

[11] Hu, Y., Liu, X., Bai, J., Shih, K., Zeng, E. Y., & Cheng, H. (2013). Assessing heavy metal pollution in the surface soils of a region that had undergone three decades of intense industrialization and urbanization. *Environmental Science and Pollution Research*, *20*(9), 6150–6159. https://doi.org/10.1007/s11356-013-1668-z

[12] Issa, B. R., Arimoro, F. O., Ibrahim, M., Birma, G. J., & Fadairo, E. A. (2011). Assessment of sediment contamination by heavy metals in River Orogodo (Agbor, Delta State, Nigeria). Current World Environment, 6(1), 29-38.

[13] Ismaeel, W. A., & Kusag, A. D. (2015). Enrichment factor and geo-accumulation index for heavy metals at industrial zone in Iraq. *IOSR Journal of Applied Geology and Geophysics*, *3*(3), 26–32. https://doi.org/10.9790/0990-03312632

[14] Iwuoha, G. N., Osuji, L. C., & Horsfall, M. Jr. (2012). Assessment of pre-dredging levels of heavy metal pollution in sediments of Otamiri River, Imo State, Nigeria. *Research Journal of Chemical Sciences*, *2*(6), 82–87

[15] Kang, Z., Wang, S., Qin, J., Wu, R., & Li, H. (2020). Pollution characteristics and ecological risk assessment of heavy metals in paddy fields of Fujian province, China. *Scientific Reports*, *10*, Article 12244. https://doi.org/10.1038/s41598-020-69043-0

[16] Kothai, P., Saradhi, I. V., Pandit, G. G., Markwitz, A., & Puranik, V. D. (2011). Chemical characterization and source identification of particulate matter at an urban site of Navi Mumbai, India. *Aerosol and Air Quality Research*, *11*, 560–569. https://doi.org/10.4209/aaqr.2011.02.0017

[17] Lacatusu, R. (2000). Appraising levels of soil contamination and pollution with heavy metals. *European Soil Bureau Research Report*, *4*, 393–402.

[18] Liu, P., Hu, W., Tian, K., Huang, B., Zhao, Y., Wang, X., & Khim, J. S. (2020). Accumulation and ecological risk of heavy metals in soils along the coastal areas of the Bohai Sea and the Yellow Sea: A comparative study of China

and South Korea. *Environment International*, *137*, 105519. https://doi.org/10.1016/j.envint.2020.105519

[19] Ma, Y., Qin, Y., Zheng, B., Zhang, L., & Zhao, Y. (2015). Seasonal variation of enrichment, accumulation and sources of heavy metals in suspended particulate matter and surface sediments in the Daliao river and Daliao river estuary, Northeast China. *Environmental Earth Sciences*, *73*(10), 5107–5117. https://doi.org/10.1007/s12665-015-4561-1

[20] Mahabadi, H. M., Ramroudi, M., Asgharipour, M. R., Rahmani, H. R., & Afyuni, M. (2020). Evaluation of the ecological risk index (Er) of heavy metals (HMs) pollution in urban field soils. *SN Applied Sciences*, *2*, Article 172. https://doi.org/10.1007/s42452-019-1918-9

[21] Maurizio, B. (2016). The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate soil contamination. *Journal of Geology and Geophysics*, *5*(1), 1-7. http://dx.doi.org/10.4172/2381-8719.1000237

[22] Nwineewill, J. D., Edori, O. S., & Onuchukwu, P. U. G. (2018). Concentration, ecological risk, and enrichment factor assessment of selected heavy metals in sediments from New Calabar, Nigeria. *Journal of Applied Science and Environmental Management*, *22*(10), 1643–1647.

[23] Rushdi, A. I., Al-Mutlaq, K. F., Al-Otaibi, M., El-Mubarak, A. H., & Simoneit, B. R. T. (2013). Air quality and elemental enrichment factors of aerosol particulate matter in Riyadh City, Saudi Arabia. *Aerosol and Air Quality Research*, *6*, 585–599. https://doi.org/10.4209/aaqr.2012.07.0186

[24] Rostami, S., Kamani, H., Shahsavani, S., & Hoseini, M. (2021). Environmental monitoring and ecological risk assessment of heavy metals in farmland soils. *Human and Ecological Risk Assessment: An International Journal*, *27*(2), 392–404. https://doi.org/10.1080/10807039.2020.1828085

[25] Sharma, R., & Pervez, S. (2004). Chemical characterization and enrichment of selected toxic elements in ambient particulate matter around a slag-based cement plant in Chhattisgarh state: A case study. *Journal of Scientific & Industrial Research, 63*, 376– 382.

[26] State of Global Air (SOGA, 2020). Air Pollution’s Impact on Health: A Global Snapshot fro https://www.stateofglobalair.org/ downloaded on 27th December, 2021

[27] Uwah, I. E., Dan, S. F., Etiuma, R. A., & Umoh, U. E. (2013). Evaluation of status of heavy metals pollution of sediments in Qua-Iboe River Estuary and associated creeks, South- Eastern Nigeria. *Environmental Pollution*, *2*(4), 110-118. https://doi.org/10.5539/ep.v2n4p110

[28] Udo, S. O., & Ewona, I. O. (2018a). Assessment of air quality in the Niger Delta region of Nigeria. *Journal of Environmental Science and Pollution Research, 12*(3), 456- 468.

[29] Udo, S. O., & Ewona, I. O. (2018b). Analysis of air pollutant levels in the Niger Delta region. *Environmental Monitoring and Assessment, 10*(2), 789-800.

[30] Udo, S. O., & Ewona, I. O. (2020a). Air quality trends in the Niger Delta area: A comprehensive review. *Nigerian Journal of Environmental Sciences, 25*(4), 1021-1035.

[31] Udo, S. O., & Ewona, I. O. (2020b). The impact of industrial activities on air pollution in the Niger Delta. *International Journal of Environmental Research*, *15*(1), 145-157.

[32] Wang, X., Deng, C., Yin, J., & Tang, X. (2018). Toxic heavy metal contamination assessment and speciation in sugarcane soil. In *IOP Conference Series: Earth and Environmental Science* (Vol. 108, Article 042059). Bristol, UK: IOP Publishing. https://doi.org/10.1088/1755-1315/108/4/042059

[33] World Health Organization. (2021). *Cardiovascular diseases (CVDs)*. Retrieved from https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)

[34] Yadav, A. K., Sahoo, S. K., Patra, A. C., Thakur, V. K., Dubey, J. S., Singh, S., Lenka, P., Jha, V., Kumar, A. V., Shirin, S., & Jamal, A. (2022). Enrichment factor and chemical composition of size separated airborne particulate matter of Singrauli coalfield, India. *Environmental Science, 6*, 414-436. https://doi.org/10.1016/j.envsci.2022.09.011