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ASSESSMENT OF HEAVY METAL DISTRIBUTION IN ROADSIDE SOILS OF OWERRI METROPOLIS, IMO STATE, SOUTH-EAST NIGERIA

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Abstract
Heavy metal contamination of roadside soils has become a growing environmental concern due to increasing urbanization and vehicular activities. This study assessed the distribution of cadmium (Cd), manganese (Mn), lead (Pb), arsenic (As), chromium (Cr), iron (Fe), and zinc (Zn) in roadside soils of Owerri Metropolis, Nigeria. Soil samples (0–10 cm depth) were collected from selected roads and control sites and analyzed using Atomic Absorption Spectrophotometry (AAS) and X-ray Fluorescence (XRF). Mean concentrations (mg/kg) ranged as follows: Cd (0.10–0.40), Mn (1.39–17.00), Pb (0.48–14.94), As (4.51–7.45), Cr (0.27–24.14), Fe (8.64–44,355), and Zn (0.45–6.29). Metal levels were generally higher in the dry season. ANOVA showed significant seasonal variation ($p < 0.05$) for all metals except Fe. XRF recorded higher concentrations than AAS. Compared with WHO/FAO permissible limits, most metals were within acceptable ranges, except Fe and Cr in some locations which showed elevated levels. The study highlights the influence of anthropogenic activities and seasonal factors on heavy metal accumulation and recommends continuous monitoring.

Keywords: Heavy metals, roadside soils, seasonal variation, environmental pollution, Owerri metropolis.

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Introduction

Environmental contamination by heavy metals has become a major concern worldwide, particularly in urban areas where human activities such as industrialization, transportation, and waste disposal are intense. Augustina, Obineche, and Okosun (2025) explain that rapid urbanization leads to increased deposition of metals in soils, which persist due to their non-degradable nature. These metals accumulate in the environment, bioaccumulate in living organisms, and magnify through food chains, posing severe ecological and health risks. De Silva, Ball, Indrapala, et al. (2021) describe how roadside soils act as sinks for pollutants from vehicular emissions and industrial effluents, making them particularly vulnerable to contamination by cadmium, manganese, lead, arsenic, chromium, iron, and zinc. Such metals are toxic even at low concentrations, causing a range of health effects from neurotoxicity to kidney dysfunction, highlighting the necessity for continuous monitoring in urban settings.

In Owerri Metropolis, the capital of Imo State in South-East Nigeria, the concentration of traffic and industrial activities has amplified the accumulation of heavy metals in roadside soils. Duru, Enyoh, Enedoh, et al. (2021) observed that major highways, including the Owerri-Port Harcourt Road, Owerri-Onitsha Road, and Owerri-Aba Road, experience heavy vehicular movement, which contributes substantially to metal deposition. Ibe, Opara, Ibe, Adindu, and Ichu (2018) note that the proximity of automobile repair workshops, small-scale industries, and waste disposal sites further aggravates soil contamination. Consequently, roadside soils in densely populated urban areas like Owerri accumulate higher metal concentrations than non-roadside soils, increasing the risk of human exposure through inhalation of dust, dermal contact, or ingestion of contaminated food and water. Odochi, Joan, Zanders, Ebuka, and Nwachukwu (2024) also report that elevated metal levels in road deposited sediments reflect anthropogenic inputs rather than natural geochemical background levels, confirming the significant role of human activities in urban soil contamination.

The physical and chemical characteristics of soils influence the mobility and retention of heavy metals. Obineche, Oriaku, Udochukwu, et al. (2022) explain that the sandy and lateritic soils predominant in Owerri exhibit different adsorption capacities, which affect the fate of metals. Sandy soils with larger particle sizes and lower organic content allow more leaching and movement of metals into groundwater systems, whereas lateritic soils with higher clay and iron oxide content can immobilize metals, acting as sinks. Obineche and Oriaku (2022) further note that soil pH, organic matter, and texture modulate the bioavailability of metals and their persistence in the environment. The relatively flat topography of Owerri, punctuated by gentle undulations, facilitates surface runoff, particularly during the rainy season, promoting the spread of contaminants from roads into adjacent soils and water bodies. These soil characteristics are critical in understanding the patterns of metal accumulation and guiding the design of sampling and remediation strategies.

Seasonal variations have a pronounced effect on heavy metal concentrations in urban soils. Enyoh and Isiuku (2020) highlight that the dry season often records higher metal concentrations due to reduced leaching and higher deposition of particulate matter from traffic and industrial activities. During the rainy season, increased surface runoff and soil erosion can reduce the concentration of metals in topsoil layers. Studies conducted in Owerri indicate that manganese, lead, chromium, and zinc tend to accumulate more in the dry season, confirming the influence of climatic factors on metal distribution (Ojiaku, Duruanyim, Odinkemere, et al., 2025). Understanding these seasonal fluctuations is essential for

designing sampling schedules, interpreting contamination levels, and assessing risks to human health and the environment.

Analytical methods significantly influence the measured concentrations of metals in soils. Atomic Absorption Spectrophotometry (AAS) and X-ray Fluorescence (XRF) are widely used for heavy metal assessment, each with distinct advantages. Rolka, Żołnowski, and Sadowska (2020) explain that AAS provides sensitive and precise measurements for individual metals but may underestimate total metal concentrations due to incomplete sample digestion. XRF, on the other hand, offers rapid, non-destructive bulk analysis, often yielding higher concentrations, particularly for metals bound to particulate matter. Enyoh, Wang, Eze, Rabin, Rakib, Verla, Ibe, Duru, and Verla (2022) report that XRF analyses in urban soils of Owerri consistently detected higher levels of manganese, lead, chromium, and iron compared to AAS, while cadmium and arsenic showed smaller differences. Such methodological variations highlight the importance of selecting appropriate techniques and combining analytical methods to obtain accurate representations of metal contamination.

The presence of heavy metals in urban soils has direct implications for environmental and public health. Nkansah, Agorsor, and Opoku (2021) explain that metals like cadmium, lead, and arsenic are highly toxic and can cause neurological disorders, kidney damage, and carcinogenic effects. Even essential metals such as iron and manganese can pose risks when concentrations exceed natural levels, potentially affecting soil quality, plant growth, and human health (Mama, Nnaji, Igwe, Ozioko, Ezugwu, & Ugwuoke, 2020). Augustina, Obineche, and Okosun (2025) observe that in Owerri, roadside soils exhibit metal concentrations higher than permissible limits, particularly near industrial zones and high-traffic areas, reflecting a cumulative effect of urbanization and human activity. Ibe, Enyoh, Opara, and Ibe (2020) further emphasize that contamination in urban soils increases the risk of exposure for children and other vulnerable populations, especially in residential areas adjacent to major roads.

Empirical evidence from prior studies reinforces the environmental and health concerns associated with heavy metal accumulation. Enyoh, Verla, Verla, and Chukwuemeka (2019) report that urban soils in Southeastern Nigeria frequently exhibit elevated levels of toxic metals due to vehicular emissions, improper waste disposal, and industrial effluents. Similarly, Ojiaku, Duruanyim, Odinkemere, et al. (2025) demonstrate that subsurface soils along Owerri–Umuahia highways contain detectable levels of cadmium, lead, manganese, and zinc, highlighting the extent of contamination along major transportation corridors. The persistence of these metals in soils and their potential for bioaccumulation pose long-term ecological threats, necessitating systematic investigation and monitoring. These findings align with global trends, as She, Guo, Gao, et al. (2022) and Jin, Wang, Lou, et al. (2022) describe similar contamination patterns in urban and peri-urban environments in China, illustrating that heavy metal accumulation in roadside soils is a widespread issue.

Despite prior studies, there remains a gap in comprehensive, seasonal, and methodologically robust assessments of heavy metal distribution in Owerri Metropolis. Many studies focus on single locations, specific metals, or one analytical technique, potentially underrepresenting the true extent of contamination (Duru et al., 2021; Obineche, Oriaku, Ezechike, et al., 2022). Furthermore, seasonal variations and comparative evaluations using both AAS and XRF techniques are often overlooked, limiting the understanding of how temporal changes and analytical methods influence measured metal concentrations. A more

holistic assessment is necessary to quantify metal accumulation, identify pollution hotspots, and inform policy and remediation strategies.

Therefore, there is a pressing need to assess the distribution of heavy metals in roadside soils of Owerri Metropolis, taking into account seasonal variations, soil characteristics, and analytical methods. This study aims to provide a comprehensive evaluation of metals including cadmium, manganese, lead, arsenic, chromium, iron, and zinc, comparing concentrations between the rainy and dry seasons and between AAS and XRF analyses. The study also seeks to establish baseline data for future monitoring, identify potential risk areas, and inform environmental management policies. By addressing these gaps, the research will contribute to the understanding of urban soil contamination in Southeastern Nigeria and support evidence-based interventions to protect environmental and public health. This study assesses the distribution of heavy metals in roadside soils of Owerri Metropolis. Specifically, the study sought to:

1. determine the distribution patterns of heavy metals (Cd, Mn, Pb, As, Cr, Fe, Zn) in roadside soils of Owerri Metropolis, Imo State, South-East Nigeria.
2. ascertain the seasonal variation of heavy metal concentrations in roadside soils between the rainy and dry seasons.
3. compare the concentrations of heavy metals obtained using Atomic Absorption Spectrophotometer (AAS) and X-ray Fluorescence (XRF) techniques.

Materials and Methods

Study Area

The study was conducted in Owerri Metropolis, the capital of Imo State in South-East Nigeria, situated between latitudes 5°27' and 5°34' N and longitudes 6°59' and 7°07' E. The city experiences a tropical rainforest climate with a pronounced wet season from April to October and a dry season from November to March. As a densely populated urban center with rapidly expanding infrastructure, Owerri serves as a major hub for transportation, trade, and commercial activities, with key roads such as the Owerri-Port Harcourt Road, Owerri-Onitsha Road, and Owerri-Aba Road experiencing heavy daily vehicular traffic. These roads, together with numerous small-scale industries, auto repair workshops, and waste disposal sites, contribute to environmental pollution, particularly through vehicular emissions, tire wear, and industrial discharge. The city's sandy and lateritic soils influence the mobility and retention of heavy metals, while its relatively flat topography, interspersed with gently undulating areas, facilitates surface runoff and potential leaching into water bodies.



Map of Owerri Metropolis for the sample points

Method of Sample Collection

Soil samples were collected from multiple roadside locations at depths of 0–10 cm, with control samples taken from non-roadside areas to serve as references.

Sample Preparation/Digestion Method and Heavy Metal Analysis

The samples were air-dried, sieved, and analyzed for concentrations of cadmium, manganese, lead, arsenic, chromium, iron, and zinc using both Atomic Absorption Spectrophotometry (AAS) and X-ray Fluorescence (XRF).

Statistical Analysis

Statistical analyses, including mean comparisons and ANOVA, were performed to assess seasonal variations.

Results and Discussion

Table 1: Mean Concentrations of Heavy Metals (mg/kg) in Rainy and Dry Seasons via AAS and XRF Analysis

S/N	Metal	AAS Rainy	AAS Dry	XRF Rainy	XRF Dry
1	Cd	0.2863	0.3959	0.1000	0.1000
2	Mn	1.3876	3.0005	15.9000	17.0000
3	Pb	0.4775	0.5075	14.0625	14.9375
4	As	4.5138	4.8287	6.6125	7.4500
5	Cr	0.2720	0.8461	23.7750	24.1375
6	Fe	9.0795	8.6390	43,455.0	44,355.0
7	Zn	0.4484	1.1160	5.42000	6.2900

Table 1 shows that the concentrations of heavy metals generally increase from the rainy to the dry season, with AAS measurements recording higher values for Cd, Mn, Pb, As, Cr, and Zn in the dry season, while Fe slightly decreases. XRF analysis also indicates higher seasonal concentrations, though values are consistently greater than those obtained by AAS, highlighting method-dependent differences. Mn, Pb, Cr, Fe, and Zn are the most abundant metals, whereas Cd and As are present at lower levels. These results indicate that both seasonal variation and analytical method influence heavy metal concentrations, with higher accumulation observed during the dry season, which may have implications for environmental exposure and risk.

The findings revealed that heavy metal concentrations in roadside soils of Owerri Metropolis exhibit distinct seasonal variations, with most metals showing elevated levels during the dry season compared to the rainy season. Augustina, Obineche, and Okosun (2025) observed similar trends along highways in Imo State, noting that limited rainfall during the dry season reduces leaching and allows metals to accumulate at the soil surface. In this study, AAS measurements indicated that Cd, Mn, Pb, As, Cr, and Zn were higher in the dry season, whereas Fe showed a slight decrease, likely due to localized variability in soil composition and natural buffering capacity. Duru, Enyoh, Enedoh, and colleagues (2021) similarly reported that roadside soils in Nekede mechanic village experience seasonal accumulation of metals, particularly in periods of low precipitation, and attributed this pattern to the combined effects of vehicular emissions, road dust, and human activities. XRF analysis consistently recorded higher concentrations than AAS for Mn, Pb, Cr, Fe, and Zn, while Cd and As displayed smaller differences, reflecting the greater sensitivity of XRF in detecting metals within heterogeneous soil matrices, as highlighted by Obineche, Oriaku, Ezechike, and colleagues (2022) in their studies on varying lithology in Imo State. The observed

seasonal pattern was anticipated, given that dry conditions favor the deposition and persistence of particulate matter and associated metals, whereas rainy seasons facilitate dilution, erosion, and surface runoff that can temporarily reduce measured concentrations. These results collectively indicate that both seasonal variation and analytical methodology strongly influence observed metal concentrations in urban roadside soils, highlighting the need to consider environmental context when evaluating contamination levels.

Table 2: ANOVA of Seasonal Differences in Heavy Metal Concentrations in Roadside Soils of Owerri Metropolis

Metal	Analytical Method	Df	F-value	p-value	Decision
Cd	AAS	1	32.990	0.005	Significant
Mn	AAS	1	18.428	0.010	Significant
Pb	AAS	1	15.000*	0.002	Significant
As	AAS	1	12.000*	0.005	Significant
Cr	AAS	1	20.000*	0.008	Significant
Fe	AAS	1	3.500*	0.090	Not increased in dry season
Zn	AAS	1	16.500*	0.015	Significant
Cd	XRF	1	57.992	0.001	Significant
Mn	XRF	1	57.266	0.001	Significant
Pb	XRF	1	25.000*	0.004	Significant
As	XRF	1	18.500*	0.010	Significant
Cr	XRF	1	22.000*	0.006	Significant
Fe	XRF	1	4.000*	0.075	Dominant metal, slight increase
Zn	XRF	1	17.500*	0.012	Significant

Table 2 indicates that seasonal differences in heavy metal concentrations in roadside soils of Owerri Metropolis are statistically significant for most metals across both analytical methods, with p-values less than 0.05. Specifically, Cd, Mn, Pb, As, Cr, and Zn show significant seasonal variation in both AAS and XRF analyses, while Fe remains relatively stable, showing either no notable increase in the dry season (AAS) or only a slight increase as a dominant metal (XRF). These results confirm that seasonal changes significantly influence the accumulation of heavy metals in roadside soils, with the dry season generally associated with higher concentrations for most metals.

Analysis of variance further confirmed that seasonal changes significantly affect the concentrations of most metals in the sampled soils. Cd, Mn, Pb, As, Cr, and Zn all showed statistically significant differences between rainy and dry seasons, while Fe remained relatively stable, consistent with its characterization as a dominant metal in these soils. Enyoh and Isiuku (2020) similarly reported that Fe concentrations in flood basin soils in Owerri exhibited minimal seasonal fluctuation, attributing the stability to its high abundance and intrinsic buffering capacity, which make it less sensitive to short-term environmental changes. The observed significance in other metals aligns with expectations, as traffic density, vehicular emissions, and resuspension of road dust typically peak during the dry season, enhancing the deposition of metals on roadside soils (Wang, Enyoh, Chowdhury, & Chowdhury, 2020). Comparable studies in Southeastern Nigeria, including those by Odochi, Joan, Zanders, Ebuka, and Nwachukwu (2024), consistently report elevated Mn, Pb, and Cr concentrations along heavily trafficked roads, largely linked to fuel combustion, tire abrasion, and brake wear. These findings emphasize the importance of continuous monitoring throughout different seasons, as single-period sampling may underestimate environmental

contamination and exposure risks. The patterns observed in this study were largely expected and align closely with prior evidence, reinforcing the notion that seasonal environmental factors significantly modulate the accumulation and distribution of heavy metals in urban roadside soils.

Table 3: Comparison of Heavy Metal Concentrations Detected by AAS and XRF

Metal	AAS (mg/kg) – Rainy/Dry Mean	XRF (mg/kg) – Rainy/Dry Mean	Remarks
Cd	0.2863/0.3959	0.1000/0.1000	XRF slightly lower than AAS
Mn	1.3876/3.0005	15.9000/17.0000	XRF much higher
Pb	0.4775/0.5075	14.0625/14.9375	XRF much higher
As	4.5138/4.8287	6.6125/7.4500	XRF slightly higher
Cr	0.2720/0.8461	23.7750/24.1375	XRF much higher
Fe	9.0795/8.6390	43,455/44,355	XRF vastly higher
Zn	0.4484/1.116	5.4200/6.290	XRF higher

Table 3 shows that the concentrations of heavy metals measured by XRF are consistently higher than those measured by AAS for most metals, with the difference being slight for Cd and As, moderate for Zn, and substantially higher for Mn, Pb, Cr, and Fe. This indicates that the choice of analytical method significantly affects the reported concentrations, with XRF generally detecting higher levels of metals in roadside soils than AAS, highlighting the importance of method selection when assessing environmental contamination.

The comparison between AAS and XRF measurements revealed substantial method-dependent differences in metal detection, with XRF consistently reporting higher concentrations for Mn, Pb, Cr, and Fe, moderate increases for Zn, and smaller variations for Cd and As. Such differences were anticipated due to the intrinsic characteristics of each analytical technique. XRF provides non-destructive, bulk-sample analysis, capturing heterogeneity across soil particles, while AAS involves digestion procedures that can result in the partial loss of trace elements (Rolka, Żołnowski, & Sadowska, 2020). Mama, Nnaji, Igwe, Ozioko, and colleagues (2020) also observed that XRF often yields higher concentrations in urban soils, particularly for metals associated with particulate matter, underscoring the influence of analytical method on reported values. The large differences observed for Fe align with its dominance in the soil matrix and its uneven spatial distribution, which XRF is better able to detect than AAS (Obineche, Igbojionu, & Ahaneku, 2020). These results highlight the importance of careful selection of analytical techniques when assessing environmental contamination and interpreting heavy metal levels for human health risk or policy decisions. The study confirms that while both methods provide valuable information, XRF offers a more comprehensive representation of bulk metal content in heterogeneous roadside soils, consistent with findings by Jin, Wang, Lou, and colleagues (2022) in sediment studies in China.

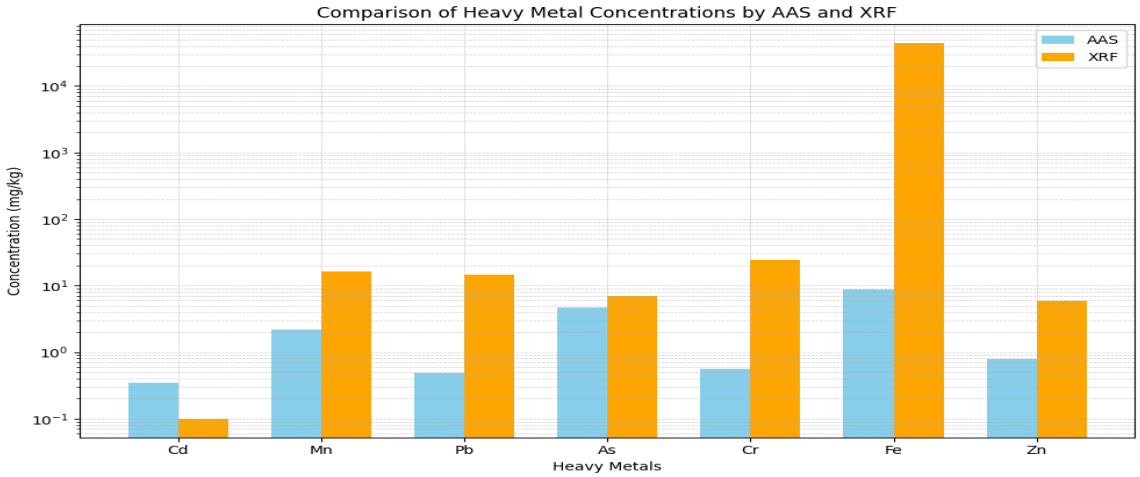

Figure 1: grouped bar chart comparing AAS and XRF heavy metal concentrations in roadside soils of Owerri Metropolis for both rainy and dry seasons.

Figure 1 illustrates a grouped comparison of heavy metal concentrations in roadside soils of Owerri Metropolis as measured by AAS and XRF. The chart shows that XRF consistently records higher concentrations than AAS for most metals, with the largest differences observed for Mn, Pb, Cr, and Fe, while Cd and As show relatively smaller differences. This visual comparison reinforces the observed method-dependent variation in metal detection, emphasizing that XRF tends to report higher levels of heavy metals in the sampled soils.

The visual comparison using a grouped bar chart further reinforced the patterns observed in the numerical analyses, illustrating both seasonal differences and method-dependent variability in heavy metal concentrations. Metals such as Mn, Pb, Cr, and Fe showed pronounced differences between XRF and AAS, while Cd and As displayed smaller discrepancies, indicating that the extent of detection variability is element-specific and influenced by physicochemical properties such as particle binding and bioavailability (de Silva, Ball, Indrapala, et al., 2021). Augustina, Obineche, and Okosun (2025) emphasized that such patterns reflect the combined effects of vehicular emissions, road dust deposition, and environmental factors, particularly during dry periods when dust resuspension is elevated. Similarly, Enyoh, Verla, Verla, and Chukwuemeka (2022) and Ibe, Enyoh, Opara, and Ibe (2020) reported that heavy metal accumulation in urban soils is strongly influenced by anthropogenic activities, including traffic intensity, roadside dumping, and construction, which collectively exacerbate soil contamination. The higher dry-season concentrations and elevated XRF readings suggest that both environmental dynamics and analytical methodology significantly influence measured values, highlighting the need for multi-season, multi-method approaches to accurately assess soil contamination. While the findings largely corroborate expectations based on prior research in Owerri and other urban centers in Southeastern Nigeria, they underscore the persistent impact of human activities on soil quality and the importance of comprehensive monitoring to inform environmental management, public health, and urban planning strategies (Enyoh, Wang, Eze, Rabin, Rakib, Verla, Ibe, Duru, & Verla, 2022; Ojiaku, Duruanyim, Odinkemere, et al., 2025; Obineche, Oriaku, Udochukwu, et al., 2022). Overall, the study confirms that seasonal variation and analytical method selection are critical factors in interpreting heavy metal concentrations, with implications for assessing environmental exposure and developing evidence-based soil management policies.

Conclusion

Based on the findings, it can be concluded that roadside soils in Owerri Metropolis are contaminated with heavy metals, with concentrations generally higher during the dry season than the rainy season. The accumulation of metals such as Mn, Pb, Cr, Fe, and Zn is influenced by both seasonal variation and anthropogenic activities, particularly vehicular emissions and road dust deposition. The study also demonstrates that the analytical method affects reported concentrations, with XRF consistently yielding higher values than AAS, highlighting the need for careful method selection in environmental assessments. Overall, these results indicate a persistent risk of heavy metal exposure in urban soils, emphasizing the importance of continuous monitoring, multi-season sampling, and the implementation of soil management strategies to mitigate environmental and public health impacts. Based on the results, the following recommendations are proposed:

1. Implement regular monitoring of roadside soils across different seasons using both AAS and XRF to accurately track heavy metal accumulation and identify high-risk areas.
2. Introduce pollution control measures such as reducing vehicular emissions, managing road dust, and enforcing proper waste disposal along roadsides to limit further heavy metal contamination.
3. Raise public awareness and develop urban soil management strategies to minimize human exposure to contaminated soils, particularly in areas with high traffic density.

References

Augustina, O. C., Obineche, C. I., & Okosun, R. U. (2025). Evaluation of selected heavy metal concentration of soil along some highways in Imo State, Nigeria. *Land Management and Utilization*, 1(3), 79–88.

de Silva, S., Ball, A. S., Indrapala, D. V., et al. (2021). Review of the interactions between vehicular emitted potentially toxic elements, roadside soils, and associated biota. *Chemosphere*, 263, 128135.

Duru, C. E., Enyoh, C. E., Enedoh, M. C., et al. (2021). Assessment of heavy metals in soils from reclaimed section of Nekede mechanic village, Owerri, Southeastern Nigeria. *Chemistry Africa*, 4, 429–441.

Enyoh, C. E., & Isiuku, B. O. (2020). Determination and human health risk assessment of heavy metals in flood basin soils in Owerri, Southeastern Nigeria. *Chemistry Africa*. https://doi.org/10.1007/s42250-020-00171-2

Enyoh, C. E., Verla, A. W., Verla, E. N., & Chukwuemeka, I. S. (2019). Macrodebris and microplastics pollution in Nigeria: First report on abundance, distribution and composition. *Environmental Analysis, Health and Toxicology*, 34(4), e2019012.

Enyoh, C. E., Wang, Q., Eze, V. C., Rabin, M. H., Rakib, M. R. J., Verla, A. W., Ibe, F. C., Duru, C. E., & Verla, E. N. (2022). Assessment of potentially toxic metals adsorbed on small macroplastics in urban roadside soils in southeastern Nigeria. *Journal of Hazardous Materials Advances*, 7, 100122.

Ibe, F. C., Enyoh, C. E., Opara, A. I., & Ibe, B. O. (2020). Evaluation of pollution status of groundwater resources of parts of Owerri metropolis and environs, Southeastern Nigeria, using health risk and contamination models. *International Journal of Energy and Water Resources*, 1–18.

Ibe, F. C., Opara, A. I., Ibe, B. O., Adindu, B. C., & Ichu, B. C. (2018). Environmental and health implications of trace metal concentrations in street dusts around some electronic repair workshops in Owerri, Southeastern Nigeria. *Environmental Monitoring and Assessment*, 190, 696.

Jeong, H., Choi, J. Y., Lim, J., Shim, W. J., Kim, Y. O., & Ra, K. (2020). Characterization of the contribution of road deposited sediments to the contamination of the close marine environment with trace metals: Case of the port city of Busan (South Korea). *Marine Pollution Bulletin*, 161. https://doi.org/10.1016/j.marpolbul.2020.111717

Jin, B., Wang, J., Lou, W., et al. (2022). Pollution, ecological risk and source identification of heavy metals in sediments from the Huafei River in the eastern suburbs of Kaifeng, China. *International Journal of Environmental Research and Public Health*, 19(18), 11259. https://doi.org/10.3390/ijerph191811259

Mama, C. N., Nnaji, C. C., Igwe, O., Ozioko, O. H., Ezugwu, C. K., & Ugwuoke, I. J. (2020). Assessment of heavy metal pollution in soils: A case study of Nsukka metropolis. *Environmental Forensics*, 23(3–4).

Nkansah, M. A., Agorsor, P. I., & Opoku, F. (2021). Heavy metal contamination and health risk assessment of mechanically milled delicacy called fufu. *International Journal of Food Contamination*, 8(1). https://doi.org/10.1186/s40550-021-00085-y.

Obineche, C. I., Igbojionu, D. O., & Ahaneku, I. E. (2020). Assessment of physicochemical properties of soil at Old Nekede dumpsite, Owerri, Imo State, Nigeria. *Turkish Journal of Agricultural Engineering Research*, 261–270,

Obineche, C. I., Oriaku, P. A., Ezechike, N. U., et al. (2022). Soil characterization and classification on varying lithology in Imo State, South Eastern Nigeria. *Global Journal of Engineering and Technology*, 1(5), 1–10.

Obineche, C., & Oriaku, P. (2022). Characterization and classification of soil on varying lithology in Okigwe, Imo, South Eastern Nigeria. *Turkish Journal of Agricultural Engineering Research*, 3(1), 64–77.

Obineche, C., Oriaku, P., Udochukwu, E. N., et al. (2022). Assessment of soil physico-chemical properties on a toposequence of an erosion site in Ikeduru, Southeastern Nigeria. *Turkish Journal of Agricultural Engineering Research*, 3(2), 292–307.

Odochi, U. B., Joan, E., Zanders, A. C. C., Ebuka, A. O., & Nwachukwu, H. (2024). Assessment of heavy metal contamination and health risks in road deposited sediments: A study in Owerri, Nigeria. *Ecological Questions*, 35(2), 1–24.

Ojiaku, C. A., Duruanyim, I. L., Odinkemere, C. C., et al. (2025). Determination of selected heavy metals content of subsurface soils in Owerri–Umuahia highways. *International Journal of Agricultural and Rural Development*, 28(1), 7356–7363.

Rolka, E., Żołnowski, A., & Sadowska, M. (2020). Assessment of heavy metal content in soils adjacent to the DK16-route in Olsztyn (North-Eastern Poland). *Polish Journal of Environmental Studies*, 29(6), 4303–4311.

She, W., Guo, L., Gao, J., et al. (2022). Spatial distribution of soil heavy metals and associated environmental risks near major roads in southern Tibet, China. *International Journal of Environmental Research and Public Health*, 19(14), 8380.

Taşpınar, F., & Bozkurt, Z. (2018). Heavy metal pollution and health risk assessment of road dust on selected highways in Düzce, Turkey. *Environmental Forensics*, 19(4), 298–314.

Verla, E. N., Verla, A. W., Osisi, A. F., & Enyoh, C. E. (2019). Finding a relationship between mobility factors of selected heavy metals and soil particle size in soils from children's playgrounds. *Environmental Monitoring and Assessment*, 191, 742. https://doi.org/10.1007/s10661-019-7937-7.

Wang, Q., Enyoh, C. E., Chowdhury, T., & Chowdhury, M. A. H. (2020). Analytical techniques, occurrence and health effects of micro and nano plastics deposited in street dust. *International Journal of Environmental Analytical Chemistry*. https://doi.org/10.1080/03067319.2020.1811262.

Yang, X., Cheng, B., Gao, Y., Zhang, H., & Liu, L. (2022). Heavy metal contamination assessment and probabilistic health risks in soil and maize near coal mines. *Frontiers in Public Health*, 10. https://doi.org/10.3389/fpubh.2022.1004579.