FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 8, August, 2025, pp 165 – 171
DOI: https://doi.org/10.33003/fjs-2025-0908-3900

ASSESSMENT OF HEAVY METAL CONTAMINATION IN SOILS AND VEGETABLE CROPS FROM SHARADA INDUSTRIAL ZONE, KANO STATE, NIGERIA

***[1]Kabiru Suleiman and [2]Abdullateef Abdullahi Ibrahim**

[1]Department of Biological Sciences, Bayero University, Kano, Kano State, Nigeria
[2]Department of Environmental Biology, University of Maiduguri, Borno State, Nigeria

*Corresponding authors' email: suleimank098@gmail.com Phone: +2348037052928

ABSTRACT

Heavy metal accumulation in agricultural soils and vegetables near industrial zones poses a significant threat to food safety and public health. This study assessed the concentrations of Fe, Zn, Cu, Cd, Ni, Pb, and Cr in soils and edible parts of onion (Allium cepa), carrot (Daucus carota), and spinach (Spinacia oleracea) collected from three irrigation farms in the Sharada industrial area, Kano State, Nigeria. A total of 36 composite samples were analysed using atomic absorption spectroscopy (AAS). Results revealed that cadmium levels in spinach reached 0.44 mg/kg, exceeding the WHO/FAO limit (0.1 mg/kg) by 340%. Lead concentrations in carrots (0.33 mg/kg) and spinach (0.49 mg/kg) also surpassed the permissible threshold of 0.3 mg/kg, while Pb in soil peaked at 1.05 mg/kg, more than three times the allowable limit. Chromium levels in soil were similarly elevated (1.05 mg/kg), though plant uptake remained low. Strong positive correlations between Pb and Zn ($r > 0.90$) and between Cr and Zn ($r > 0.90$) indicate likely shared sources, such as industrial effluents and vehicular emissions. The findings recommend strict regulatory enforcement, continuous environmental monitoring, and remediation strategies, such as soil amendments and safer irrigation practices, to reduce human health risks and ensure sustainable crop production.

Keywords: Heavy Metals, Food Safety, Industrial Effluent, Spinach, Soil Contamination, Kano State

INTRODUCTION

Heavy metal contamination in agricultural soils and food crops is a growing global concern due to its potential to harm environmental quality and human health (Mai *et al.,* 2024; Jahandari & Abbasnejad, 2024; Wang *et al.,* 2023). In agricultural systems, the overuse of fertilizers, pesticides, and herbicides contributes to chemical runoff and groundwater infiltration (Sarkar *et al.,* 2024; Kumari *et al.,* 2024; Schwartz & Zhang, 2024), leading to contaminated water sources that affect crop safety (Singh *et al.,* 2023).

Toxic metals such as cadmium (Cd), lead (Pb), and chromium (Cr) are persistent in the environment and can accumulate in soils and plants (Madhogaria *et al.,* 2024; Xu *et al.,* 2024). Consumption of crops grown in contaminated soils has been linked to adverse health effects, including kidney dysfunction, neurological disorders, and increased cancer risk (Neisi *et al.,* 2024; Jolly *et al.,* 2024; Sanga *et al.,* 2024).

In Nigeria, particularly in industrial areas, heavy metal levels often exceed international safety thresholds (Ibrahim *et al.,* 2021). Poor effluent regulation, ineffective waste management, and the use of polluted water for irrigation exacerbate the issue. For example, studies in Challawa, Kano, have reported elevated levels of Pb and Cd in irrigated vegetables due to industrial discharge and untreated wastewater (Edogbo *et al.,* 2020).

The Sharada industrial zone in Kano State, characterized by high industrial density, is a potential hotspot for heavy metal pollution. Yet, limited data exist on the extent of contamination in its agricultural soils and vegetables. This knowledge gap limits the ability of local authorities to implement effective control measures. Although some Nigerian studies have assessed contamination generally, few have focused on site-specific uptake of metals in staple crops in Sharada.

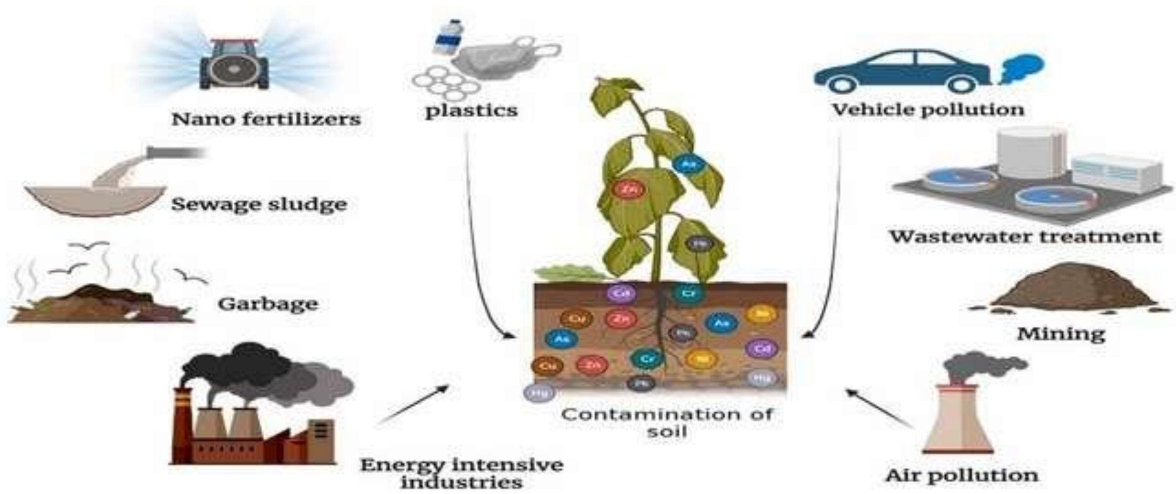

Figure 1: Sources of Heavy Metals, Source: (Angon *et al.,* 2024)

Figure 1 illustrates the key anthropogenic sources of heavy metals, including industrial effluent, vehicular emissions, and atmospheric deposition (Angon *et al.,* 2024). For example, metals like Pb and Zn are emitted from vehicle exhaust and tire wear (Luo *et al.,* 2024; Laskowski *et al.,* 2024), while improperly disposed urban waste contributes additional loads. These pollutants are deposited into the soil either directly or through air and water pathways, posing long-term risks to the food chain.

Human exposure to heavy metals typically occurs through a soil–plant–consumer pathway. Crops absorb metals from soil and irrigation water, especially leafy vegetables like spinach, which tend to accumulate high levels of toxic elements due to their large surface area and rapid growth (Bambhaneeya *et al.,* 2024).

Despite the industrial legacy of the Sharada area, no recent study has quantitatively assessed heavy metal transfer from soil to commonly consumed vegetables. This study aims to fill that gap by evaluating the levels of Fe, Zn, Cu, Cd, Ni, Pb, and Cr in soils and three vegetables (*Allium cepa*, *Daucus carota*, and *Spinacia oleracea*) cultivated in Sharada.

It was hypothesized that metal concentrations in soils and vegetables from Sharada exceed WHO/FAO safety limits due to cumulative industrial discharge and poor environmental regulation.

MATERIALS AND METHODS

Study Area

The study area is located in the Kano Municipal Local Government Area (LGA), which is a well-known industrial area in Kano State. It is located between longitude 8030’50’’E and latitude 110 57’30” N (Figure 2). The Sharada area has a diverse range of industries, including light, heavy, dry, wet, food, and plastic, among others (Ekpa, 2022). There is also commercial irrigation farming taking place in the area. The annual mean rainfall ranges from 800 mm to 900 mm, with variations of up to ± 30%. The typical annual temperature is around 26˚C.

Figure 2: Satellite Image of the Study Area

Sample Collection

The samples of soil and fresh vegetables (onion (*Alium cepa*), carrot (*Daucus carota*) and spinach (*Spinacia oleracea*)) were randomly handpicked from the irrigation sites.

Plate 1: Illustration the Sampling Collection

Samples of soil and irrigated vegetables from Sharada for commercial purposes were randomly collected as shown in Plate 1.
We randomly collected five soil (0-15 cm depth) samples from the farm and mixed them to create a composite sample from each plant collection site (Bouida *et al.,* 2024; Nepal *et al.,* 2024). We packaged these samples in well-labeled polythene bags and transported them to the laboratory for further treatment and analysis. We obtained three (3) replicates from each composite for analysis. We wrapped the samples in a large brown envelope, labeled them, and transported them to the laboratory (Aluko *et al.,* 2024).

Preparation of Soil and Vegetable Samples
The plant samples were washed with tap water and carefully rinsed with deionized water. The edible portions of the samples were then cut into small pieces, air dried for 24 hours to reduce moisture content, and then dried in an oven at 65°C - 70°C until totally dry. Each dry sample was ground into a fine powder using a blender before being sieved through a 2 mm mesh. Before analysis, the powdered materials were stored in properly labelled plastic containers (Hussaini *et al.,* 2021). The soil samples were air dried, grinded and sieved to obtain a less than 2 mm fraction of the soil. All samples were kept at room temperature until utilized for acid digestion (Nazir *et al.,* 2015). The study was conducted using analytical reagent (AnalaR) grade chemicals and distilled water. All glassware and plastic containers were washed with detergent solution, followed by 20% nitric acid, rinsed with tap water, and finally distilled water (Hussaini *et al.,* 2021; Alkali *et al.,* 2022).

Determination of the Concentration of Heavy Metals
The concentrations of metals (nickel, zinc, iron, chromium, copper, lead and cadmium) will be determined using atomic absorption spectrophotometer AAS (Agilent 240FS AA model, Agilent Lab, USA).

Statistical Analysis
The study used Principal Component Analysis with SPSS 29, 2022 software to compare the relationship between heavy metals. We assessed the level of significance of differences in the parameter values, considering values of P 0.05 as significant differences, and plotted the tables using Microsoft Excel 2007 (Ogundiran, 2014).

RESULTS AND DISCUSSION

Table 1: Mean Values ± Standard Error of Heavy Metals Concentrations in Some Vegetables and Soil from Sharada Industrial Area

Metals/Vegetable/Soil	*Alium cepa*	*Daucus carota*	*Spinacia oleracea*	Farm Soil
Fe (mg/l)	137.990 ± 0.56	42.815 ± 1.15	103.605 ± 1.73	3010 ± 1154.71
Zn (mg/kg)	32.080 ± 0.56	40.525 ± 0.56	35.975 ± 1.15	66.47 ± 11.55
Cu (mg/kg)	37.660 ± 0.56	115.350 ± 1.15	23.385 ± 0.56	72.71 ± 5.77
Cd (mg/kg)	0.285 ± 0.06	0.280 ± 0.58	0.440 ± 0.13	0.095 ± 0
Ni (mg/kg)	ND	0.085 ± 0.01	3.010 ± 0.58	2.74 ± 0.58
Pb (mg/kg)	0.294 ± 0.06	0.328 ± 0.06	0.490 ± 0.06	1.054 ± 0.58
Cr (mg/kg)	0.230 ± 0.06	0.227 ± 0.06	0.075 ± 0.01	1.052 ± 0.57

ND = Not Detected

Table 1 above shows the mean values of heavy metal concentrations in some vegetables and soil from the Sharada Industrial Area. Lead (Pb) levels exceeded safe limits in all the vegetables except onions, indicating a widespread issue with lead contamination in crops (Hettiarachchi *et al.,* 2024), likely due to industrial pollution. The levels of Cadmium (Cd) in the vegetables are exceeding permissible limits in all tested samples, which is a significant concern. It is widely recognized that cadmium has severe toxicity (Sable *et al.,* 2024; Kuna *et al.,* 2024; Huang *et al.,* 2024; Goel *et al.,* 2024; Daliyev *et al.,* 2024; Jiang *et al.,* 2024; Budi *et al.,* 2024), even in small quantities, and it can cause significant health threats to people if ingested through contaminated food.
We discovered that the amount of iron (Fe) is high in farm soils in contrast to the results of Chandrasekara *et al.,* 2024. This suggests that while iron may naturally exist in greater amounts here, industrial activities may have further increased its levels in some areas.
The results of this study reveal a concerning level of heavy metal contamination in both soils and vegetables cultivated within the Sharada industrial zone. Cadmium (Cd) and lead (Pb) concentrations in all vegetable samples exceeded WHO/FAO permissible limits, with spinach (*Spinacia oleracea*) recording a cadmium level of 0.44 mg/kg, which is 340% above the recommended maximum of 0.1 mg/kg. These exceedances are clearly presented in Table 2, which compares the measured concentrations in vegetables and soils with WHO/FAO recommended safety limits.

Table 2: Mean Concentrations of Heavy Metals (mg/kg) in Vegetables and Farm Soils from Sharada Compared with WHO/FAO Safety Limits

Vegetables/Soil /Standard	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Cd (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Cr (mg/kg)
Alium cepa	138 ± 0.56	32.08 ± 0.56	37.66 ± 0.56	0.285 ± 0.06	ND	0.294± 0.06	0.23 ± 0.06
Daucus carota	42.8 ± 1.15	40.53 ± 0.56	115.35 ± 1.15	0.28 ± 0.58	0.085 ± 0.01	0.328 ± 0.06	0.227 ± 0.06
Spinacia oleracea	104 ± 1.73	35.98 ± 1.15	23.385 ± 0.56	0.44 ± 0.13	3.01 ± 0.58	0.49 ± 0.06	0.075 ± 0.01
Farm Soil	3010±1154.71	66.47 ± 11.55	72.71 ± 5.77	0.095 ± 0	2.74 ± 0.58	1.054 ± 0.58	1.052 ± 0.57
WHO/FAO (2011)	426	100	73	0.1	10	0.3	1.36

The elevated accumulation of Cd in spinach is likely attributable to the plant's physiological properties, including its broad leaf surface area and highly absorptive root structure, which facilitate efficient metal uptake and translocation. In contrast, carrots (*Daucus carota*) exhibited the highest levels of copper (Cu), reaching 115.35 mg/kg, suggesting that root morphology and direct contact with soil may enhance copper accumulation in root vegetables.

The data confirm that Cd and Pb levels in all vegetable samples exceeded safe limits, particularly in spinach and carrot. Chromium levels in soil were also close to the permissible threshold of 1.36 mg/kg but remained low in plant tissues, suggesting limited uptake due to its chemical form or low mobility. This reinforces the influence of species-specific uptake mechanisms and the bioavailability of metals under field conditions.

The observed disparities in metal accumulation among plant species emphasize the role of plant-specific uptake mechanisms and bioaccumulation potential. These patterns are consistent with previous findings indicating that leafy vegetables tend to accumulate higher levels of mobile heavy metals, while root vegetables are more prone to accumulating elements like Cu and Ni due to prolonged contact with soil particles and lower translocation barriers. The limited uptake of chromium (Cr) by vegetables, despite its high concentrations in soil (1.052 mg/kg), may be explained by its low bioavailability in oxidized or less mobile forms, which reduces its transfer from soil to plant tissues.

The correlation analysis further supports the presence of common anthropogenic sources of contamination. Strong positive correlations were observed between Zn and Pb (r = 0.918) and between Zn and Cr (r = 0.903), suggesting that these metals likely originate from shared sources such as industrial effluent discharges, vehicular emissions, and atmospheric deposition. These relationships are quantitatively detailed in Table 3, which shows significant correlations between several heavy metals across plant and soil matrices.

Table 3: Pearson Correlation Matrix of Heavy Metals in Vegetable and Soil Samples. Correlations Significant at the 0.01 and 0.05 Levels are Noted

	Samples	Fe	Zn	Cu	Cd	Ni	Pb	Cr
Samples	1	0.888*	0.731	-0.071	-0.605	0.717	0.903*	0.563
Fe		1	0.718	-0.063	-0.862	0.409	0.868	0.644
Zn			1	0.404	-0.415	0.514	0.918*	0.959**
Cu				1	-0.043	-0.333	0.039	0.373
Cd					1	.085	-0.516	-.0368
Ni						1	0.704	0.389
Pb							1	0.848
Cr								1

**Correlation is significant at the 0.01 level. *Correlation is significant at the 0.05 level.

These findings align with those of Aksouh et al. (2024) and Hassan et al. (2024), who reported similar contamination patterns in urban-industrial regions. The consistent co-occurrence of these metals across soil and plant matrices reinforces the role of persistent industrial activities in shaping the contamination profile observed in this study.

Despite identifying high concentrations of toxic metals in soil and crops, the health implications of long-term dietary exposure warrant further emphasis. Chronic intake of cadmium has been associated with renal dysfunction, skeletal demineralization, and carcinogenic effects, while lead exposure is linked to neurological impairments, developmental delays, and cardiovascular diseases. The consumption of vegetables such as spinach and carrot, which significantly exceeded established safety thresholds, poses a credible risk to public health, particularly among vulnerable groups such as children and pregnant women. These risks underscore the importance of integrating environmental monitoring with food safety regulations and public health surveillance in industrial zones like Sharada.

When compared with other industrial regions in Nigeria and West Africa, the metal concentrations recorded in Sharada are consistent with, and in some cases exceed, those reported in similar zones. For instance, Pb levels in soil (1.054 mg/kg) were comparable to or higher than those reported in the Challawa industrial area of Kano (Edogbo *et al.,* 2020) and Boumerdes in Algeria (Aksouh *et al.,* 2024). These cross-regional comparisons validate the findings and indicate a persistent trend of heavy metal pollution in rapidly industrializing urban zones, where environmental regulations may be insufficiently enforced.

In addition to industrial discharges, local agronomic practices may influence the levels of metal accumulation in crops. The use of untreated groundwater for irrigation, lack of crop rotation, and minimal application of soil amendments contribute to the persistence and bioavailability of toxic metals in the farming systems of the Sharada area. These factors create conditions conducive to continuous metal cycling within the agro-ecosystem, thereby increasing the risk of chronic exposure through food consumption.

While the abstract highlights the need for mitigation, the discussion extends this recommendation by suggesting context-specific intervention strategies. These include the application of soil amendments such as lime or biochar to immobilize metals, the use of constructed wetlands to treat wastewater before reuse in irrigation, and the implementation of regular soil and crop monitoring programs to detect early signs of contamination. Encouraging the cultivation of low-accumulating crops and the introduction of phytoremediation trials could further reduce the transfer of metals into the food chain. Strengthening local enforcement of industrial waste management policies is also essential to curb the primary sources of contamination.

This study acknowledges several limitations. The research was confined to three farms within the Sharada industrial area, limiting its spatial coverage. Seasonal variation, which can influence metal mobility and uptake, was not assessed, and no human biomonitoring data were collected to directly quantify exposure risks. These limitations, while not undermining the validity of the findings, suggest the need for further studies with expanded geographic coverage, seasonal sampling, and integration of human health metrics.

Future research should include quantitative health risk assessments such as hazard quotient (HQ) and hazard index (HI) calculations, as well as metal speciation studies to determine the chemical forms and bioavailability of contaminants. Longitudinal monitoring would also provide insight into temporal trends and the effectiveness of mitigation strategies. Such approaches will better inform environmental policy and public health planning in industrial regions vulnerable to heavy metal pollution.

CONCLUSION

The presence of elevated heavy metal concentrations in both vegetables and irrigation soils within the Sharada industrial area presents a significant environmental and public health concern. Cadmium and lead levels in all tested vegetables, especially *Spinacia oleracea* and *Daucus carota,* substantially exceeded WHO/FAO safety thresholds. Similarly, chromium concentrations were high in soils, while iron levels surpassed permissible limits, indicating sustained anthropogenic input, most likely from industrial effluents.

These findings point out the urgent need for targeted mitigation measures and informed policy intervention. It is imperative that regulatory authorities strengthen enforcement of effluent discharge standards, implement regular monitoring of soil and crop metal levels, and promote the adoption of phytoremediation techniques and soil amendments to reduce metal bioavailability. Furthermore, agricultural extension services should prioritise farmer education on best practices, including safer irrigation sources, crop rotation, and heavymetal-tolerant plant varieties.

To ensure long-term food security and ecological health, a robust, cross-sectoral policy response is essential. Government agencies must commit to implementing environmental protection strategies tailored to industrial-agricultural interfaces such as Sharada. Without decisive action, the continued contamination of edible crops poses a growing threat to both human health and sustainable urban agriculture.

ACKNOWLEDGMENTS

The authors sincerely express their profound gratitude to Prof. Bukar A. Abdullah for his exceptional mentorship, insightful supervision, and unwavering academic guidance throughout the course of this study.

REFERENCES

Aksouh, M. Y., Boudieb, N., Benosmane, N., Moussaoui, Y., Michalski, R., Klyta, J., & Kończyk, J. (2024). Presence of Heavy Metals in Irrigation Water, Soils, Fruits, and Vegetables: Health Risk Assessment in Peri-Urban Boumerdes City, Algeria. Molecules, 29(17), 4187.

Alkali, I., Audu, A. A., Bello, U., Darma, S. M., Ahmad, A. T. (2022) Heavy Metals Accumulation and Phytoremediation Ability of Onion (Allium cepa) and Garlic (Allium sativum) Grown on Contaminated Soils from Challawa Industrial Estate, Kano, Nigeria, Journal of Applied Sciences and Environmental Management, 26(2): 1887-1894

Aluko, A. O. T., Obaseki, O. O. O., & Ibikunle, I. O. S. (2024). Impacts of dumpsites on heavy metal concentration in soil and vegetation in four dumpsites in Akure North, Ondo State.

Amarasena, M. D. M. C. K., & Wijeyaratne, W. M. D. N. (2024). Bioaccumulation and health risks of chromium and cadmium in Basella alba with emphasis on Urea, muriate of potash and triple super phosphate mixtures. Journal of the National Science Foundation of Sri Lanka, 52(3).

Anggraeni, D., Oginawati, K., Fahimah, N., Salami, I. R. S., Absari, H. R., Mukhaiyar, U., ... & Adiyani, L. (2024). Analysis of heavy metals (Pb and Cd) in soil layers of Indonesia: Spatial distribution, potential source, and groundwater effect. Case Studies in Chemical and Environmental Engineering, 9, 100652.

Angon, P. B., Islam, M. S., Kc, S., Das, A., Anjum, N., Poudel, A., & Suchi, S. A. (2024). Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain. Heliyon.

Azhdarpoor, A., Moeini, Z., Ranjbar, F., Samaei, M., & Hashemi, H. (2024). Risk assessment of heavy metals in soil and simultaneous monitoring in wheat irrigated with groundwater and treated wastewater and its long-term effects for residents of adjacent regions. *Environmental Science: Water Research & Technology*, *10*(5), 1135-1146.

Bambhaneeya, S., Garaniya, N. H., Surve, V., Deshmukh, S. P., & Patel, K. H. (2024) Investigation of Heavy Metal Accumulation and Nutritious Status Changes in Leafy Vegetables Grown on Contaminated and Non-Contaminated Soils Collected from Industrial Area of Bharuch District, Gujarat, India. 24 (2): 247-254

Bernard, E. & Ayandeji, O. M. (2020) Impact of industrial effluents, domestic wastewater and natural dams on heavy metals concentrations in vegetables cultivated in Northern Nigeria *Journal of Environmental Chemistry and Ecotoxicology,* 12(**1**):1-7

Bouida, L., Ya'acob, F., Jaafar, M. H., Abdullah, H., & Fadhullah, W. (2024). Human and Ecological Risk Assessment of Soil and Plants Metal Contamination in a Tropical Municipal Solid Waste Dumping Site. Soil and Sediment Contamination: An International Journal, 1-37.

Budi, H. S., Catalan Opulencia, M. J., Afra, A., Abdelbasset, W. K., Abdullaev, D., Majdi, A., ... & Mohammadi, M. J. (2024). Source, toxicity and carcinogenic health risk assessment of heavy metals. Reviews on Environmental Health, 39(1), 77-90.

Chandrasekara, C., Rajapaksha, I., Dissanayake, S., Kadupitiya, H., Sirisena, D., Chandrajith, R., ... & Suriyagoda, L. (2024). Effects of climate, soil and water source on the distribution of bioavailable iron in low-land paddy soils of Sri Lanka. Applied Geochemistry, 160, 105875.

Cui, Y., Fan, C., Zhou, X., & Yu, P. (2024). Impact of urbanization on heavy metals in outdoor air and risk assessment: A case study in severe cold regions. *Sustainable Cities and Society*, *114*, 105713.

Daliyev, M. (2024). Dangerous Effects of Toxic Substances. Journal of new century innovations, 51(2), 70-73.

Edogbo, B., Okolocha, E., Maikai, B., Aluwong, T., & Uchendu, C. (2020). Risk analysis of heavy metal contamination in soil, vegetables and fish around Challawa area in Kano State, Nigeria. *Scientific African*, *7*, e00281.

Ekpa (2022) Impact of Environmental Pollution on the Residents of Sharada from Tannery Industries, Kano, Northwestern Nigeria, *Journal of Environmental and Occupational Health*, JENVOH-22-80701(R).

Goel, S. (2024). Phytoremediation of Cadmium Toxicity in Water and Soil: A Sustainable, Multidisciplinary and Eco-Friendly Approach. In Cadmium Toxicity: Challenges and Solutions (pp. 181-207). Cham: Springer Nature Switzerland.

Guerrieri, N., Mazzini, S., & Borgonovo, G. (2024). Food Plants and Environmental Contamination: An Update. Toxics, 12(5), 365.

Guo, J., Liu, L., Feng, Q., Okonkwo, C. U., Zhang, X., Chen, J., ... & Yang, C. (2024). Heavy metal pollution near an abandoned mercury-bearing waste recovery enterprise in southwestern China: Spatial distribution and its sources in soil and plants. Environmental Research, 252, 118694.

Hassan, J., Rajib, M. M. R., Khan, M. N. E. A., Khandaker, S., Zubayer, M., Ashab, K. R., ... & Awual, M. R. (2024). Assessment of heavy metals accumulation by vegetables irrigated with different stages of textile wastewater for evaluation of food and health risk. Journal of Environmental Management, 353, 120206.

He, Y., Wang, W., Chen, Y., Hua, J., Deng, C., & Li, H. (2024). Source-sink response analysis of heavy metals and soil pollution assessment in non-ferrous metal industrial agglomeration areas based on decision unit. Science of The Total Environment, 906, 167437.

Hettiarachchi, G. M., Betts, A. R., Wekumbura, W. C., Lake, L., Mayer, M. M., Scheckel, K. G., & Basta, N. T. (2024). Lead: The most extensively spread toxic environmental contaminant. In Inorganic contaminants and radionuclides (pp. 113-150). Elsevier.

Huang, N., Wang, B., Liu, S., Wang, K., Wang, R., Liu, F., & Chen, C. (2024). Cadmium exposure in infants and children: Toxicity, health effects, dietary risk assessment and mitigation strategies. Critical Reviews in Food Science and Nutrition, 1-23.

Hussaini, A., Ali, A. F. & Abdullahi, B. A. (2021) Effects of Using Industrial Wastewater for Irrigation on Heavy Metals in Soils and Crops: A Case of Kano Metropolis, Nigeria, J. Chem. Soc. Nigeria, 46(6) 0931 – 0939.

Ibrahim, A. A., Yusuf, A. G., Ismail, G., Ibrahim, M. A., Musa, A. R., & Sulaiman, M. S. (2021). Conceptual Background of Bioaccumulation in Environmental Science. World Journal of Advanced Pharmaceutical and Life Sciences, 01(01), 035–041.

Isukuru, E. J., Opha, J. O., Isaiah, O. W., Orovwighose, B., & Emmanuel, S. S. (2024). Nigeria's water crisis: Abundant water, polluted reality. Cleaner Water, 100026.

Jahandari, A., & Abbasnejad, B. (2024). Environmental pollution status and health risk assessment of selective heavy metal (oid) s in Iran's agricultural soils: A review. Journal of Geochemical Exploration, 256, 107330.

Jangirh, R., Mondal, A., Yadav, P., Yadav, L., Datta, A., Saxena, P., & Mandal, T. K. (2024). Characterization of Road Dust in Delhi: Heavy Metal Analysis, Health Risks, and Sustainability Implications. Aerosol Science and Engineering, 1-12.

Jiang, H., Li, R., Zhao, M., Peng, X., Sun, M., Liu, C., ... & Xue, H. (2024). Toxic effects of combined exposure to cadmium and diclofenac on freshwater crayfish (Procambarus clarkii): Insights from antioxidant enzyme activity, histopathology, and gut microbiome. Aquatic Toxicology, 106844.

Jolly, Y. N., Akter, S., Kabir, M. J., Mamun, K. M., Abedin, M. J., Fahad, S. M., & Rahman, A. (2024). Heavy metals accumulation in vegetables and its consequences on human health in the areas influenced by industrial activities. Biological Trace Element Research, 202(7), 3362-3376.

Kumari, D., Thakur, A., Tiwari, A. K., & Singh, R. (2024). Types and Sources of Agricultural Pollution: Identifying the different pollutants generated by farming practices and their origins. Compreh Explor Soil. A Comprehensive Exploration of Soil, Water, and Air Pollution in Agriculture, 71.

Kuna, G., Gullipalli, S., & Chintada, V. (2024). Health Risks Associated with Cadmium Toxicity. In Cadmium Toxicity in Water: Challenges and Solutions (pp. 47-60). Cham: Springer Nature Switzerland.

Laskowski, P., & Zimakowska-Laskowska, M. (2024). The problem of emission of total particulate matter and heavy metals from tribological systems in vehicles. Combustion Engines.

Liu, H., Anwar, S., Fang, L., Chen, L., Xu, W., Xiao, L., ... & Liu, D. (2024). Source apportionment of agricultural soil heavy metals based on PMF model and multivariate statistical analysis. *Environmental Forensics*, *25*(1-2), 40-48.

Liu, T., Ni, S. Y., & Wang, Z. (2024). Contamination and health risk assessment of heavy metals in soil surrounding an automobile industry factory in Jiaxing, China. Frontiers in Environmental Science, 12, 1362366.

Luo, Z., Wang, H., Wang, Z., Zhang, X., Yan, C., Yu, R., ... & Xing, B. (2024). Tire and road wear particles contribute highly to N-(1, 3-dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD) and heavy metals in road dust on driving school grounds and their risk implications in China. Environmental Technology & Innovation, 36, 103816.

Madhogaria, B., Banerjee, S., Chakraborty, S., Dhak, P., & Kundu, A. (2024). Alleviation of heavy metals chromium, cadmium and lead and plant growth promotion in Vigna radiata L. plant using isolated Pseudomonas geniculata. International Microbiology, 1-17.

Mai, X., Tang, J., Tang, J., Zhu, X., Yang, Z., Liu, X., ... & Tang, L. (2024). Research progress on the environmental risk assessment and remediation technologies of heavy metal pollution in agricultural soil. Journal of Environmental Sciences.

Mitran, T., Gunnam, J. R. S., Gourigari, S., & Kandrika, S. (2024). Assessment of depth wise distribution, enrichment, contamination, ecological risk and sources of soil heavy metals over an Industrial area in Southern India. Journal of Geochemical Exploration, 257, 107379.

Mitryasova, O., Smyrnov, V., Koszelnik, P., Salamon, I., Smyrnova, S., & Mats, A. (2024). Geochemical Anomalies of the Heavy Metals in the Industrial and Urban Agglomeration Soils. Ecological Engineering & Environmental Technology, 25.

Nazir, R., Khan, M., Masab, M., Rehman, H. U. R., & Rauf, N. U. R. (2015). Accumulation of Heavy Metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water and plants and analysis of physico-chemical parameters of soil and water Collected from Tanda Dam kohat. 7(3), 89–97.

Neisi, A., Farhadi, M., Angali, K. A., & Sepahvand, A. (2024). Health risk assessment for consuming rice, bread, and vegetables in Hoveyzeh city. Toxicology Reports, 12, 260-265.

Nepal, A., Antonious, G. F., Gyawali, B. R., Webster, T. C., & Bebe, F. (2024). Assessing the bioaccumulation of heavy metals in cabbage grown under five soil amendments. *Pollutants*, *4*(1), 58-71.

Noor, A. E., Fatima, R., Aslam, S., Hussain, A., un Nisa, Z., Khan, M., ... & Sillanpaa, M. (2024). Health risks assessment and source admeasurement of potentially dangerous heavy metals (Cu, Fe, and Ni) in rapidly growing urban settlement. Environmental Research, 242, 117736.

Obiri-Nyarko, F., Quansah, J. O., Asare, S. V., Fynn, O. F., Okrah, C., Debrah, S. K., & Karikari, A. Y. (2024). Determination of threshold values and heavy metal pollution assessment of soils in an industrial area in Ghana. *Environmental Monitoring and Assessment*, *196*(6), 546.

Ogundiran, M. A. and Fawole, O. O. (2014). Assessment of the Impacts of Industrial Effluent Discharges on the Water Quality of Asa River, Ilorin, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT),* 8 (1): 80-98.

Qi, C., Xu, M., Liu, J., Li, C., Yang, B., Jin, Z., ... & Guo, B. (2024). Source analysis and contribution estimation of heavy metal contamination in agricultural soils in an industrial town in the Yangtze River Delta, China. Minerals, 14(3), 279.

Sable, H., Singh, V., Kumar, V., Roy, A., Pandit, S., Kaur, K., ... & Malik, S. (2024). Toxicological and bioremediation profiling of nonessential heavy metals (mercury, chromium, cadmium, aluminium) and their impact on human health: A review. Toxicologie Analytique et Clinique.

Sanga, V. F., & Pius, C. F. (2024). Heavy metal contamination in soil and food crops and associated human health risks in the vicinity of Iringa Municipal dumpsite, Tanzania. Discover Environment, 2(1), 104.

Sarkar, S., Jaswal, A., & Singh, A. (2024). Sources of inorganic nonmetallic contaminants (synthetic fertilizers, pesticides) in agricultural soil and their impacts on the adjacent ecosystems. In Bioremediation of Emerging Contaminants from Soils (pp. 135-161). Elsevier.

Schwartz, F. W., & Zhang, H. (2024). Fundamentals of groundwater. John Wiley & Sons.

Selvam, R., Kalaiyarasi, G., & Saritha, B. (2024). Heavy Metal Contamination in Soils: Risks and Remediation. Soil Fertility and Plant Nutrition, 141.

Singh, N. K., Sanghvi, G., Yadav, M., Padhiyar, H., Christian, J., & Singh, V. (2023). Fate of pesticides in agricultural runoff treatment systems: Occurrence, impacts and technological progress. Environmental Research, 117100.

Singh, P. K., Kumar, U., Kumar, I., Dwivedi, A., Singh, P., Mishra, S., ... & Sharma, R. K. (2024). Critical review on toxic contaminants in surface water ecosystem: sources, monitoring, and its impact on human health. Environmental Science and Pollution Research, 1-35.

Srivastav, A. L., Patel, N., Rani, L., Kumar, P., Dutt, I., Maddodi, B. S., & Chaudhary, V. K. (2024). Sustainable options for fertilizer management in agriculture to prevent water contamination: a review. Environment, Development and Sustainability, 26(4), 8303-8327.

Suljević, D., Fočak, M., & Alijagic, A. (2024). Assessing chromium toxicity across aquatic and terrestrial environments: a cross-species review. Drug and Chemical Toxicology, 1-13.

Tang, S., Wang, C., Song, J., Ihenetu, S. C., & Li, G. (2024). Advances in Studies on Heavy Metals in Urban Soil: A Bibliometric Analysis. *Sustainability*, *16*(2), 860.

Upadhyay, V., Kumari, A., & Kumar, S. (2024). From soil to health hazards: Heavy metals contamination in northern India and health risk assessment. Chemosphere, 354, 141697.

Wang, W., Chen, Y., Wang, W., Zhu, C., Chen, Y., Liu, X., & Zhang, T. (2023). Water quality and interaction between groundwater and surface water impacted by agricultural activities in an oasis-desert region. Journal of Hydrology, 617, 128937.

Xiang, M., Li, Y., Yang, J., Lei, K., Li, Y., Li, F., Zheng, D., Fang, X. & Cao, Y. (2021) Heavy metal contamination risk assessment and correlation analysis of heavy metal contents in soil and crops, *Environmental Pollution,* 278: 116911.

Xiang, Z., Wu, S., Zhu, L., Yang, K., & Lin, D. (2024). Pollution characteristics and source apportionment of heavy metal (loid) s in soil and groundwater of a retired industrial park. Journal of Environmental Sciences, 143, 23-34.

Xu, W., Jin, Y., & Zeng, G. (2024). Introduction of heavy metals contamination in the water and soil: a review on source, toxicity and remediation methods. Green Chemistry Letters and Reviews, 17(1), 2404235.

Yao, C., Yang, Y., Li, C., Shen, Z., Li, J., Mei, N., ... & Wang, D. (2024). Heavy metal pollution in agricultural soils from surrounding industries with low emissions: Assessing contamination levels and sources. Science of The Total Environment, 917, 170610.

Zhang, Q., Charles, P. D., Bendif, E. M., Hester, S. S., Mohammad, S., & Rickaby, R. E. (2024). Stimulating and toxic effect of chromium on growth and photosynthesis of a marine chlorophyte. New Phytologist, 241(2), 676-686.