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ORIGINAL RESEARCH ARTICLE

Impact of Climate Change on Heavy Metal Dispersion in Rice Farms: A Case Study of Hadejia, Jigawa State

J. Simon[1]*, E.A. Ibanga[1], E.P. Inyang[1], H.G. Kama[2], K.O. Momoh[1], S. Bello[4], A.G. Yisa[3] and D.S. Balami[5]

[1]Department of Physics, National Open University of Nigeria, Jabi, Abuja, Nigeria
[2]Department of Environmental Science, National Open University of Nigeria, Jabi, Abuja, Nigeria
[3]Department of Biological Sciences, National Open University of Nigeria, Jabi, Abuja, Nigeria
[4]Department of Physics, Umaru Musa Yar'adua University, Katsina, Katsina State, Nigeria
[5]Department of Physics, University of Maiduguri, Borno State, Nigeria

ABSTRACT
The study employed the Agilent/MP-AES model MY17380004 to assay the concentrations of some selected heavy metals in a flooded rice farm in Hadejia LGA of Jigawa State, Nigeria. The aim is to gain insight into the dispersion of heavy metals in flooded farms as a consequence of climate change. The ratios of the concentrations of *Zn*, *Cd*, *Fe*, *Cu*, *Ni*, *As*, *Pb*, *Mn,* and *Cr* in the control area to that of the study area were found to be 3:7, 12:9, 3:4, 3:5, 3:4, 12:3, 6:7, 2:5 and 4:5 respectively. The results highlight the positive influence of flooding on the concentrations of all the elements except *Cd* and *As,* which demonstrated a reduction trend. Also, the concentrations of *As* in the study and control locations were found to be 17.75 ± 7.12 higher than the maximum permissible limit in the soil as recommended by WHO, signifying that Arsenic content is high in Hadejia soil.

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INTRODUCTION

The climate in Nigeria, like every other part of the world, has been changing more appreciably, with evidence manifesting in recent years (Echendu, 2020; Umar & Gray, 2023; Mfon et al., 2022). Observations such as rise in temperatures, increase in precipitation or rainfall and flooding, rise in the sea level, desert encroachment at the savanna region, frequent extreme weather conditions, and the loss of biodiversity, among others, as highlighted in (Haider, 2019; Haddad et al., 2024; Abubakar, 2020; Mfon et al., 2022; Agbonkhese et al., 2024). Among other effects of climate change, flooding has demonstrated the highest level of impact in Nigeria, including socio-economic, Psycho-social, health, and environmental impacts and, above all, loss of human lives (Agbonkhese et al., 2024; Mfon et al., 2022; Nkwunonwo, 2016; Umar & Gray, 2023). More than twenty-five states in Nigeria (more than 2/3 of the entire states) are impacted by flooding annually and the situation has aggravated in recent years (Mfon et al., 2022). Floods have caused much damage in the affected states in Nigeria, ranging from the destruction of homes, bridges, roads, farmlands, and crops, critical public infrastructure, and contamination of land, water bodies, and public drinking water sources (Nnodim & Ezekiel, 2020; Agbonkhese et al., 2024; Bamidele & Badiora, 2019; Echendu, 2020). Because of the severe nature of the flooding events that have been recorded recently, the landmass covered by the flood waters stretches beyond the coastal areas to the hinterland, thereby resulting in the huge destruction of many farms located upland in addition to those at the lowland regions (Visser et al., 2012). This huge impact of flooding on farmlands has further exacerbated the challenge of hunger and food insecurity that Nigeria is grappling with. Furthermore, the surviving farm crops around the flooded areas are potentially vulnerable to contamination from various contaminants transported and deposited on the surface soil by flooding, which in turn could be leached to the sub-surface soil as the flood waters recede and also result in the contamination of groundwater aquifers (Alzain, 2023; LA et al., 2024; Ouyang et al., 2020).

Research has shown that soil pollution is highly influenced by flooding above other natural means of spreading contaminants in the environment (Punia, 2021; Wang et al., 2019; Wijngaard et al., 2017; Alzain, 2023). For example, in a review study conducted by Punia (2021), the role of climatic conditions such as temperature, wind, and precipitation in the spread of heavy metals was assessed with emphasis in an area with extensive mining activities.

Correspondence: John Simon. Department of Physics, National Open University of Nigeria. Plot 91, Cadastral Zone, Nnamdi Azikiwe Express Way, Jabi, Abuja, Nigeria. ✉ sjkahugu@yahoo.com.

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The major sources of the heavy metal contaminants were reported to be the tailings, overburden rocks and abandoned mine pits. The climatic conditions such as temperature, especially in arid or semi-arid areas, catalyses some chemical reactions that produce granular efflorescence salts at the surface of the tailings and blown by strong wind and dispersed in the environment, while in the tropical and mostly wet areas, the tailings and overburden rocks are spread mainly by leaching. In a similar study conducted by Mfon et al. (2022), the impact of flooding on soil contamination was highlighted, and the study emphasized the effects of flooding, such as the submerging of farmlands, and human habitation, distribution of heavy metal-rich contaminants from different sources to the farms, where transfer into crops occurs in various degrees. Institutionalization of countermeasures was recommended by Mfon et al. (2022) to coup the relevant stakeholders should prioritize the level of destruction and contamination occasioned by perennial flooding in Nigeria.

In addition to the fact that heavy metals are common constituents of mine tailings and overburden rocks, garbage from dumpsites, herbicides and pesticides residues, industrial sewages and effluents *et cetera* are other potential sources of heavy metals amongst contaminants that are spread by flood (Agbonkhese et al., 2024; Adetunji & Oyeleye, 2018; Nnodim & Ezekiel, 2020). This has made flooding one of the significant natural phenomena that spread heavy metal contaminants in the environment, especially in water and soil (Alzain, 2023; Punia, 2021; Haddad et al., 2024). Research has shown that the distribution of heavy metals to the environment by wind is extremely negligible in comparison with flooding, especially in a tropical region like Nigeria (Punia, 2021; Qiao et al., 2019). The present study, therefore, focuses on the spread of heavy metals in an area affected by perennial flooding. It compares it with a selected control area subject to similar routes of heavy metal dispersion, except that it is free from flooding. This allows the results obtained to be attributed solely to flooding rather than to other means of dispersal.

Hitherto, the Northwestern part of Nigeria has been highlighted as the greatest region that has recorded the highest number of flooding occurrences in the past decade (Umar & Gray, 2023; Nkwunonwo, 2016). The Northwestern states are known for extensive agricultural activities including farming and rearing of livestock. More than 60% of cereal crops in Nigeria are from the country's Northwest region, and states like Jigawa have a reputation for rice, guinea corn, and millet production (Asadu, 2015; Sambo & Sule, 2024). Unfortunately, Jigawa state is also reported to be the second most affected state in terms of flooding after Niger state in Northwest Nigeria (Umar & Gray, 2023). The incidence of flooding has become a regular occurrence in places like the Hadejia local government area of the Jigawa state, where more than 40% of the arable land of the local government area is submerged by flood waters during the period from July to September when the region experiences a heavy downpour (Muhammad et al., 2024; Nasidi et al., 2023). Hadejia, being the major rice-producing area of the state, has lost so many hectares of rice farms to flooding, as seen in the juxtaposed images in Plate 1. Farmers have to develop adaptive measures to lessen their economic losses annually by planting early ripening rice varieties that would be due for harvest before the onset of heavy downpours that lead to heavy flooding and by dry season farming in areas that were submerged by flood in the rainy season (Muhammad et al., 2024).

Plate 1: A Snapshot of Flooded Rice Farms in Tsarawa Village of Hedejia LGA, Jigawa State.

One striking observation that led to the choice of this area for an investigation of heavy metal spread is the perennial nature of flood in this region and the ever-increasing artisanal mining of solid minerals in other local government areas of the neighboring states, rice milling industries in the state and the potential enrichment of the flooded farmlands with contaminants known to be heavy metals carriers such as; tailings, overburden rocks, industrial effluents, pesticides herbicides *et cetera.*

Prior to this time, heavy metals presence in soil, water, and food crops has been investigated in this area (Muhammad, 2024; Garba et al., 2016; Danladi et al., 2025). The assessment conducted by Muhammad (2024) on heavy metals concentration in soil samples collected from Hadejia and Gashua towns revealed that heavy metals such as Cadmium (Cd), Lead (Pb), and Arsenic (As) were found to have concentrations that exceeded the recommended permissible limits by the World's Health Organization (WHO) for both samples. The study recommended an analysis of heavy metal concentrations in farmlands and farm produce in the study area to ascertain the level of heavy metal pollution. The trace metals levels were assayed for groundwater in Hadejia by Garba et al. (2016); the levels of Manganese (Mn), Chromium (Cr), and Lead (Pb) in the groundwater samples were slightly higher than the maximum permissible limit of Nigerian Standard for Drinking Water Quality, which highlights the need to nib the reason for such elevated levels of concentrations. In another study conducted by Danladi et al. (2025), concentration levels of heavy metals in Okra, Spinach, and Tomato grown in Gudincin Town, Hadejia LGA assayed. The results of this investigation revealed that the concentration of heavy metals, such as Zn, Cu, Cr, Cd, and Pb, were within permiscible limits recommended by WHO and are unlikely to result in any health concerns by consumption of the vegetables.

In spite of this research, there's no reported investigation of the spread of heavy metals in the perenially flooded farmlands in Hadejia to the best of our knowledge, thereby emphasizing the need for extensive studies such as this to reveal the impact of the flood on the contamination level of the surface soil in the flooded farmlands and provide some advisory measures to key stakeholders to ensure that public health is safeguarded. This study, therefore, aims to investigate the degree of impact of flooding occasioned by climate change on the spread of heavy metals in flooded farmlands at Hadejia LGA of Jigawa State and to establish whether or not the perennial flooding incidents have potentially elevated the concentrations of heavy metals in the constantly affected areas.

MATERIALS AND METHODS

Description of the Study Area

The area of this study is the Hadejia community in Hadejia LGA of Jigawa state, Nigeria. The location of the lie between latitudes $12.4506\,N$ and $12.270\,N$, and longitudes $10.0404\,E$ and $10.226\,E$ ($\text{Garba, et al., 2016}$). Hedejia LGA shared boundaries with Kirikasamma LGA from the East, Mallam Madori LGA from the North, and Auyo Local Government from the West (Tudunwada & Abbas, 2022). It is known for its vast arable land and massive production of Agricultural products such as Rice, Millet, Guinea Corn, Groundnuts, and Vegetables (Muhammad et al., 2024). Hadejia is also popular due to the presence of river Hadejia, a major Nigerian river that eventually empties in Lake Chad, and it is extensively used to sustain dry season irrigation farming and fishing in some parts of Kano and Jigawa states (Gana et al., 2018). It is reported by Imam & Babuga (2021) that Hadejia experiences an extended dry season and a brief wet season, typically from June to September. Throughout the year, climatic conditions fluctuate significantly, with an overall temperature slightly warmer. The average annual temperature is approximately 25°C, while the monthly temperature range averaging from 21°C in the coldest month to 31°C in the hottest.

Typically, between the months of December and February, the Harmattan, influenced by the North-East Trade wind originating from the Sahara desert, prevails, and daily temperatures can drop to around 17°C (Imam & Babuga, 2021). The annual rainfall varies between $600\,mm$ and $762\,mm$, accounting for considerable fluctuations in yearly rainfall, sometimes leading to prolonged and severe droughts and subequently heavy downpours (Kaugama & Ahmed, 2014). Overall, the climate of the region is primarily shaped by two major air masses: the Equatorial Maritime (South-West Trade Winds) and the Tropical Continental (North-East Trade Winds), the former which originate from the Gulf of Guinea, bring rainfall while the latter winds transport dry, cold, and dusty air from the Sahara Desert during the dry season (Imam & Babuga, 2021). The vegetation in Hadejia is the Sudan Savannah type, characterized by vast grasslands with sparse and clustered trees, majorly Neem trees (Ahmed, 2023).

Materials

The materials used to conduct this research were:

i. The sample collection tools such as plastic hand shovel, polythene bag, hand gloves, boots, sample collection bottles, indelible ink, masking tape, Global Positioning System (GPS), pen and exercise book
ii. Sample digestion and analysis tools such as standard solutions of nitric acid, perchloride, sulphuric acid, and distilled water, beakers, digital weighing balance, sieve, mortar and pestle, basins, fume cupboard, hot plate, filter papers steerer, MP-AES setup
iii. Data analysis tools such as personal computer, Mircosoft Excel version 2016, IBM SPSS Statistical package version 27.0, Python data analytical tool implemented with Jupyter Notebook

Sample Collection and Preparation

A submerged rice farm was randomly selected from the vast farmlands that were submerged around Tsarawa Village, a suburb of Hadejia's main town located approximately 10 km from the local government headquarters. Soil samples were also randomly collected at the dried portions of the farmland where the flood water has receded, as presented in Figure 1. The surface layer of the soil was collected at a depth of 3-5 cm with the aid of a plastic hand shovel. The plastic hand shovel was used for this sample collection exercise to minimize contamination due to heavy metals associated with the steel type. A total of 25 samples were collected into plastic sample bottles and labeled with unique sample identification (ID) codes using indelible ink and masking tape. The same sample IDs were recorded in an exercise book, and the coordinates of the sampling points were also taken using the GPS device and recorded against each sampling location in the exercise book. As the control, the same collection procedure was used in collecting three replicate samples from a farm upland, at about 8 km from the flooded farmlands. The sample bottles were all collected into a polythene bag and safely transported to the laboratory, where they were air-dried, smashed into fine granules, and sieved by passing through a 15 mm mesh to obtain a clean powder; the same was transferred to clean and well-labeled sample bottles for digestion.

Sample Digestion and Analysis

To facilitate sample digestion, 1 g of each sample was precisely measured using a digital balance and transferred into a clean, empty beaker. A mixture of 10 mL of nitric acid, 2 mL of 60% perchloric acid, and 5 mL of concentrated sulfuric acid was then added to the beaker. The sample was thoroughly mixed using a glass rod before being heated on a hot plate within a fume cupboard for approximately 1 hour. The digestion process continued until the sample reached complete dryness at 100°C. After cooling to room temperature, the digested sample was filtered into a 60 mL standard sample bottle and diluted to the marked level with distilled water. The resulting filtrate was stored in an airtight glass container for subsequent heavy metal analysis.

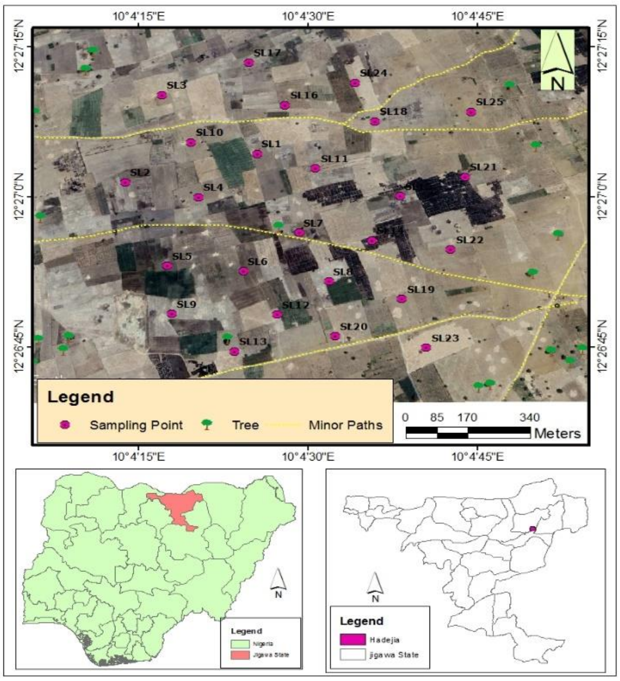

Figure 1: Location Map showing the Study Area and the Sample Collection Points

The Agilent/MP-AES model MY17380004 situated at the Central Research Laboratory of the Bayero University Kano, Kano State, Nigeria, was used to analyze the digested samples, and the analytical signal obtained from the analysis of each sample was evaluated using Agilent MP Expert software 1.6.0.9255. The settings of the machine operating parameters used for the study are presented in Table 1, while the settings per element are presented in Table 2.

Table 1: MP-AES Operating Settings

Parameter	Setting
Pump speed (rpm)	15
Sample introduction	Manual
Sample uptake time (s)	15
Stabilization time (s)	5
Read time (s)	3
Number of replicates	3
Background correction	Automatic

Calibration was performed using different concentrations of standard solutions, and the linear regression analysis for each heavy metal was carried out by plotting the measured intensity and the corresponding concentration. For each heavy metal, good linearity between intensity and concentration was observed over the measured range $(R^2 \geq 0.99)$, indicating the fidelity of the analytical method and, hence, the confidence level of the data obtained.

Table 2: Machine Settings per Element and Calibration Parameters

Element	AW (nm)	C F	NF (L/min)	Min. Conc. (ppm)	Max. Conc. (ppm)	C E (%)
Zn	Zn (213.857)	RW	0.45	0.0	5.5	15
Cu	Cu (324.754)	RW	0.7	0.0	5.5	15
Cd	Cd (228.802)	RW	0.5	0.0	5.5	15
Cr	Cr (425.433)	RW	0.9	0.0	5.5	5
Pb	Pb (405.781)	LW	0.75	0.0	5.5	5
As	As (193.695)	LW	0.75	0.0	5.5	15
Mn	Mn (403.076)	LW	0.9	0.0	5.5	5
Fe	Fe (371.993)	LW	0.65	0.0	5.5	5
Ni	Ni (352.454)	LW	0.7	0.0	5.5	5

*Key: *AW= Analyte Wavelength, CF= Calibration Fit, NF= Nebulizer Flow, CE= Calibration Error, RW= Rational Weighted, LW= Linear Weighted*

RESULTS AND DISCUSSION

Concentrations of Heavy Metals in the Study and Control Area

The data obtained from the analysis with the MP-AES machine was organized using an Excel sheet v2016 and subsequently subjected to descriptive statistics using the Statistical Package for the Social Sciences (SPSS). Table 3 presents the results obtained, the mean concentrations of *Zn*, *Cd*, *Fe*, *Cu*, *Ni*, *As*, *Pb*, *Mn,* and *Cr,* respectively, for the study location samples and the control. From the results presented in Table 3, ratios of the concentrations of *Zn*, *Cd*, *Fe*, *Cu*, *Ni*, *As*, *Pb*, *Mn,* and *Cr* in the control area to that of the study area were found to be 3:7, 12:9, 3:4, 3:5, 3:4, 12:3, 6:7, 2:5 and 4:5 respectively. These ratios indicate that the influence of flooding on the dispersion of *Zn*, *Fe*, *Cu*, *Ni*, *Pb*, *Mn,* and *Cr,* respectively, was positive and negative for *Cd* and *As*. This implies that *Zn*, *Fe*, *Cu*, *Ni*, *Pb*, *Mn,* and *Cr* are being enriched by the perennial flooding in the area while *Cd* and *As* are depleted since their concentrations were higher in the control than in the study area as depicted in Figure 2. This observation can be attributed to the acidic nature of the soils in Hadejia LGA, as reported by (Muhammad, 2024). It has been shown that both cadmium and arsenic compounds tend to be more soluble in acidic conditions and at temperatures above25^{0}C (Afzal et al., 2024; Su et al., 2025; Rajendran et al., 2024), which is the case in Hadejia, as described in section 2.0 of this article.

Comparison with WHO's Limits

A comparison of the mean concentrations of the heavy metals in the study and control locations with the WHO's recommended Maximum Allowable Limits (MAL) of their concentrations in soil, to understand the likelihood of heavy metals pollution in the flooded farmlands. The comparison is well depicted in Figure 3. The comparison revealed that the mean concentrations of *Zn*, *Cd*, *Fe*, *Cu*, *Ni*, *Pb*, *Mn,* and *Cr* were below their respective WHO's 1996 MAL (Aurnab et al., 2024), except *As,* which was higher than its MAL in both samples, highlighting the relatively higher concentration of *As* in Hadejia soils, both flooded and unflooded.

Table 3: The Concentration of Heavy Metals in the Soil from a Flooded Rice Farm ($N = 25$)

Concentration (mg/kg)	Elements								
	Zn	Cd	Fe	Cu	Ni	As	Pb	Mn	Cr
Mean Concentration	2.67	0.09	674.19	1.18	1.18	17.75	0.67	16.04	0.85
Standard Deviation	1.09	0.04	264.65	0.24	0.64	7.12	0.09	2.58	0.18
Control Concentration	1.14	0.11	495.87	0.72	0.90	29.58	0.58	6.22	0.67
Standard Deviation	0.42	0.01	157.65	0.03	0.20	8.23	0.13	2.46	0.18
Ratio of Concentrations	3:7	12:9	3:4	3:5	3:4	12:3	6:7	2:5	4:5

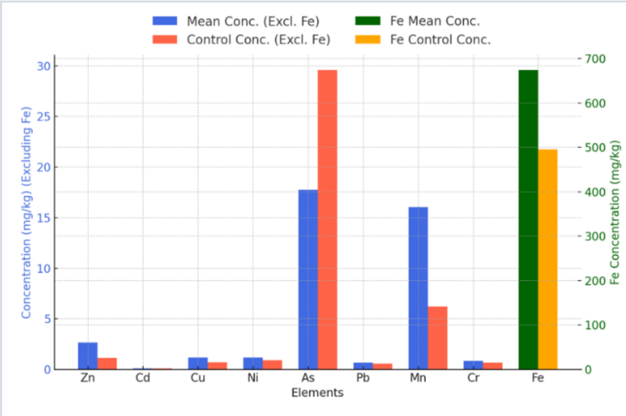

Figure 2: A Comparison of Heavy Metals Mean Concentrations in the Study and Control Locations

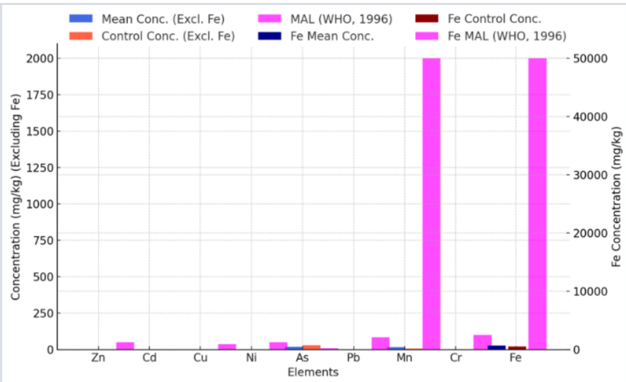

Figure 3: Triple Comparison of the Concentration of Heavy Metals in the Study and Control Locations and the WHO's Recommended MAL

Comparison with Similar Research

The mean concentrations obtained from this study were also compared with those similar investigations conducted in other places. The comparison is presented as a chart in Figure 4. From Figure 4, the concentration of all the heavy metals assayed was lower than those from other locations such as Iran, Bangladesh, and China (Rostami et al., 2021; Alam et al., 2020; Guo et al., 2019), except for *Fe,* which is higher in our study area than other locations. Intriguingly, the heavy metals concentrations from our assessment were well comparable to those obtained from a study conducted in Ebonyi state (Ugbede et al., 2021), and this could be attributed to the common geology in terms of the basement complex of Ebonyi and Jigawa state.

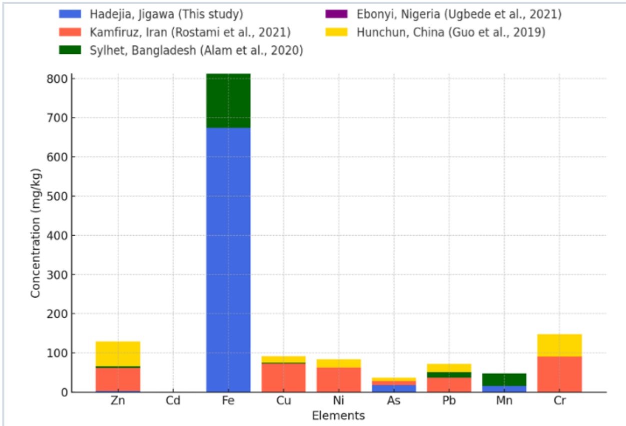

Figure 4: Comparison of Heavy Metal Concentration in this Study with Farmlands in other Locations

CONCLUSION

In this study, the dispersion of heavy metals influenced by flooding resulting from climate change was investigated to ascertain the impact of flooding on the soil enrichment of heavy metals in flooded rice farms of Hadejia LGA of Jigawa State, Nigeria. The study compared the concentrations of the heavy metals in the study and control locations. The ratios of the concentrations of *Zn*, *Cd*, *Fe*, *Cu*, *Ni*, *As*, *Pb*, *Mn,* and *Cr* in the control area to that of the study area were found to be 3:7, 12:9, 3:4, 3:5, 3:4, 12:3, 6:7, 2:5 and 4:5 respectively. This indicated that the dispersion of these elements is positively influenced by flooding except *Cd* and *As* which demonstrated a negative influence. It was noted that the decreasing concentrations of Cd and *As* in the flooded location could be attributed to the fact that the soil in Hadejia LGA is generally acidic, and both *Cd* and *As* compounds have high solubility in water under acidic conditions. The concentrations of *As*, 17.75 ± 7.12 and $29.58 \pm 8.23\ mg/kg$ in the study and control location, respectively, were also found to be greater than the maximum permissible limit in the soil as recommended by WHO, thereby highlighting how naturally rich hadejia soil is in Arsenic content. Based on the results obtained in this study, a comprehensive investigation should be conducted to reassess the arsenic content in the entire soil profile of Hadejia LGA, as well as in the crops grown in the area, for the purpose of safeguarding public health.

DECLARATION OF COMPETING INTEREST

The authors have no conflict of interest to declare with regard to the publication of this work. All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors."

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AUTHOR'S CREDIT

J. Simon: Conceptualization, Methodology, Fieldwork, and Initial draft; E.A. Ibanga: Supervision and Review; E.P. Inyang: Conceptualization, Methodology and Review; H.G. Kama: Conceptualization and Review; K.O. Momoh: Methodology and Initial Draft; S. Bello: Methodology, Fieldwork, Data analyses, and results interpretation; A.G. Yisa: Data analyses, results interpretation, and Review; and D.S. Balami: Visualization, Review, and editing.

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