



## Soil Contamination and Food Chain Transfer in Niger State, Nigeria

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### ABSTRACT

The issue of soil pollution has taken on a rather acute environmental and human health situation in agrarian Nigerian states, especially in states like Niger where agricultural activities constitute the main source of living in the rural areas. The penetration of heavy metals, agrochemical residues, hydrocarbons and other enduring pollutants in the agricultural soils are very dangerous because it will be transferred to food crops and will finally end up in the human food chain. This paper examines the levels of soil pollution, and the food-chain transfer processes in some of the selected agricultural and mining affected communities in Niger state. Priority is given to such contaminants as: lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg), chromium (Cr), and zinc (Zn) which are often related to artisanal mining, excessive use of fertilizers, industrial effluents, and random dumping of waste. Based on modern environmental-geochemical methods, the study combines the physicochemical analysis of the soil, crop-uptake analysis, the transfer-factor analysis, exposure-risk analysis to evaluate the magnitudes and the trophic mobility of contamination. The representative samples of soil and crops are analyzed to identify the concentration of heavy-metals and their distribution of accumulation in soil and plants. Geospatial methods are used to map the hot spots of contamination, test the spatial variation and find the communities that are at a significant risk of exposure. The paper also uses human-health risk assessment indices to describe the possible non-carcinogenic and carcinogenic risks that are related to the consumption of contaminated food crops. Recent empirical research in Niger State shows that the soils located near the mining areas and agricultural settings that have high agrochemical application have high levels of heavy-metals. A number of food crops are also highly bio accumulative; especially the leafy vegetables and root tubers; their transfer-factors are higher than the advised safety limits. The consequences of these contamination patterns are deep as they are the decrease in the quality of crops and ecological decay, as well as long-term health hazards among the inhabitants. The study is relevant to the current body of knowledge because it offers a multi-layered evaluation of the processes of soil contamination and food-chain transfer in the Niger State. It highlights the dire necessity of better environmental surveillance, better regulation of agricultural-inputs and community-based public-health based interventions. It recommends the steps that can be used to help in evidence-based policymaking and to encourage sustainable land-use processes to enhance the health of the soil, food safety and human wellbeing in the state of Niger.

**Keywords:** Soil Pollution, Heavy metals, Mining, Agriculture, Niger State

### 1.0 INTRODUCTION

Among the most endemic and multifaceted environmental issues posing a serious threat to agricultural productivity and food safety in developing economies is soil contamination (Alloway, 2023; Wu et al., 2021). In Nigeria, particularly in Niger State, the accumulation of heavy metals, agrochemical residues, and industrial pollutants in agricultural soils has become a growing concern among environmental scientists and public health stakeholders (Adewumi et al., 2022; Ibrahim et al., 2021). Given the state's continued reliance on agriculture as a primary source of food security, employment, and economic sustenance, any deterioration in soil quality directly affects the integrity of the food system and rural livelihoods (Olatunji et al., 2023). Soil contamination becomes especially problematic when pollutants are transferred from soils into food crops, creating chronic exposure pathways for humans through dietary intake. This phenomenon, commonly referred to as food chain

transfer, represents one of the most significant ecological and public health risks in regions undergoing artisanal mining expansion, unmanaged waste disposal, and unregulated agrochemical application (Zhang et al., 2021; Usman et al., 2020). In Niger State, these activities are increasingly prevalent, intensifying the vulnerability of agricultural systems and rural communities.

The mobility and persistence of contaminants such as lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), chromium (Cr), and pesticide residues render them particularly hazardous, as they can persist in soils for decades without significant degradation (Alloway, 2023; Tóth et al., 2022). Once deposited, these pollutants interact with soil physicochemical properties—such as pH, organic matter content, and cation exchange capacity—facilitating their uptake by plant roots and subsequent accumulation in edible tissues (Wu et al., 2021; Olatunji et al., 2023).



Agricultural communities located near artisanal mining zones in Niger State—including Shiroro, Rafi, Munya, and parts of Paikoro—are especially vulnerable due to exposure through contaminated air, surface water, and irrigation sources, which subsequently affect adjacent farmlands (Ibrahim et al., 2021; Usman et al., 2020). Similarly, in Bida, Mokwa, and Wushishi, declining soil quality has been attributed to excessive fertilizer application, irrigation with contaminated water, and runoff from unmanaged waste dumps (Adewumi et al., 2022). Increased contamination severity correlates with elevated risks of reduced crop quality, phytotoxicity, and long-term health consequences for local populations.

Despite the growing significance of these environmental and health challenges, systematic and comprehensive assessments of soil contamination and food-chain transfer in Niger State remain limited. Existing studies are largely localized, fragmented, or methodologically inconsistent, making it difficult to establish state-wide contamination patterns or identify dominant risk factors (Olatunji et al., 2023). Given the increasing complexity of environmental degradation in the region, a multidisciplinary approach integrating soil geochemistry, crop contamination analysis, transfer-factor assessment, geospatial mapping, and health-risk modeling is urgently required (Zhang et al., 2021).

Nigeria possesses one of the largest agricultural land areas in sub-Saharan Africa, with Niger State serving as a key food-producing region. However, rising levels of soil contamination have emerged as a critical environmental concern in recent years (Adewumi et al., 2022). Contamination sources include artisanal and small-scale mining activities notably in Shiroro, Munya, and Rafi—as well as the intensive use of inorganic fertilizers and pesticides in agricultural hubs such as Bida, Lapai, and Mokwa (Ibrahim et al., 2021; Usman et al., 2020). Rapid industrialization, ineffective waste management systems, and agricultural intensification have further contributed to the accumulation of heavy metals and persistent organic pollutants in soils.

Heavy metals such as Pb, Cd, and As are among the most frequently detected contaminants in agricultural soils across North-Central Nigeria. Their presence is particularly concerning because they are non-biodegradable and readily bioaccumulated in crops, posing serious risks to food safety (Alloway, 2023; Tóth et al., 2022). Once absorbed by plant roots, these contaminants are translocated to stems, leaves, fruits, and tubers, ultimately entering the human food chain. Studies conducted between 2020 and 2024 across northern Nigeria have consistently reported elevated heavy metal concentrations in staple crops such as

maize, yam, millet, cassava, vegetables, and legumes often exceeding international safety thresholds (Adewumi et al., 2022; Olatunji et al., 2023).

Beyond food safety, uncontrolled soil contamination adversely affects soil fertility, crop productivity, ecosystem functioning, and the long-term sustainability of agricultural systems. More critically, chronic exposure to heavy metals has been linked to severe health outcomes, including kidney dysfunction, neurological impairment, developmental disorders in children, reproductive toxicity, and increased cancer risk (Tóth et al., 2022; Wu et al., 2021). Addressing these challenges requires a clear understanding of contamination pathways, exposure scales, and differential risks across communities and crop types knowledge gaps that this research seeks to address.

### 1.2 Statement of the Problem

Although the Niger State depends on agriculture, there still are a number of environmental and methodological gaps that manage to sabotage the initiatives aimed at guaranteeing soil health and food safety:

- i. little detailed information on soil-contamination: The available literature is more localized and lacks the ability to give an understanding of the distribution of contamination throughout the state.
- ii. Lack of proper evaluation of food-chain transfer: Not a lot of research measures the conversion of soil contaminants to crop accumulation and dietary exposure of people.
- iii. Lack of geochemical-agronomic-health systems: Combining soil chemistry, plant uptake, spatial mapping, and risk analysis in a single approach is not a common practice in most research.
- iv. Inadequate hotspots of contamination identification: High-risk areas in the state of Niger are poorly geospatially mapped.
- v. Community ignorance and lax regulatory control: The farmers are not well informed on the dangers of contamination and the policies are not well implemented.

These loopholes impede successful environmental management and intervention in a health-related matter in Niger State.

### 1.3 Aim and Objectives

#### Aim

The aim of the study was to estimate the level of contamination of the soils and to determine the transfer of contaminants between food chains in the chosen agricultural communities in the state of Niger.

#### Objectives

- i. The purpose of the research was to find out the level of heavy metals and other pollutants in agricultural soils of selected LGAs in Niger State.
- ii. To examine the level of contaminant in major food crops that are grown on these soils.



- iii. To calculate soil to plant transfer factors of major contaminants.
- iv. To plot the spatial contamination distribution using GIS techniques.
- v. To estimate the possibility of human-health hazards with regard to eating of contaminated crops.

In order to define the regions that have a high risk factor and suggest the necessary mitigation measures.

#### 1.4 Research Questions

- i. What are the levels of the heavy metals and other contaminants in agricultural soils within the significant farming areas in Niger State?
- ii. How much are food crops grown on these soils contaminated?
- iii. What are the factors of soil to plant transfer of the major contaminants?
- iv. What are the contamination hotspots of the Niger State?
- v. Which are some of the health risks associated with dietary exposure to contaminated crops to the residents?

What can be done to control the contamination of the soil and exposure of the food-chain?

#### 1.5 Significance of the study

The research is important in the following aspects:

##### Scientific Significance

- i. Provides all-inclusive soil-crop contamination information in Niger state.
- ii. Improves the knowledge on soil-to-plant transfer in the tropical agricultural systems.
- iii. Favors the modeling and contamination-pathway studies of the environment.

##### Public-Health Significance

- I. Brings evidence to early detection and prevention of risks of dietary exposure.
- II. Helps determine the vulnerable populations that are in need of much-needed health intervention.

##### Policy and Social Economic Significance.

- i. Provides scientific evidence on environmental control and management of agricultural-input.
- ii. Helps in food-safety surveillance, pollution-reduction measures and also sustainable land management.

#### 1.6 Scope of the study

This study focuses on:

Chosen Local Government Areas in the state of Niger such as Bida, Lapai, Mokwa, Shiroro, Munya, Rafi, and Paikoro.

- I. Soil and crop sampling of contaminants.
- II. Evaluation of heavy metal and other vital contaminants.

- III. Transfer factor and spatial contamination patterns determination.
- IV. Risk assessment of human-health founded on the FAO/WHO standards.

#### 2.1 Conceptual Framework

The theoretical basis of this research is environmental geochemistry, plant physiology and exposure pathway. In the conceptualization of soil contamination, the introduction of substances that are hazardous, namely the heavy metals, the residues of the agrochemicals, the hydrocarbons, and the industrial pollutants, into the soils in levels that are beyond the levels that are found in the natural geological backgrounds is considered as soil contamination. Upon occurrence, the pollutants combine with the physicochemical properties of soils, affecting their bioavailability and movement. The concepts incorporated in the framework include the following:

##### 1. Contaminant Input Sources:

It can have an anthropogenic (mining, fertilizers, waste dumping, irrigation with polluted water) and natural (geological weathering) pathways.

The interaction between soil and vegetation follows the model presented below:

Explains the way contaminants diffuse, move by mass, and intercept roots into the soil solution by plants. The process of transfer is affected by the soil pH and organic matter, redox potential, and cation-exchange capacity.

##### 3. Food-Chain Transfer Pathway:

Semi-solid / soil-to-plant-to-animal/human captures the movement of contaminants through the soil-plant-animal/human pathway on the basis of bioaccumulation and biomagnification.

##### 4. Risk-Assessment Linkage:

Relates the concentrations in the environment to the health effects through exposure dose, ingestion rate and toxicological thresholds.

This framework influences the methodological selection in the evaluation of the soil quality, and crop contamination, transfer factors, and the potential risk of exposure in Niger State.

#### 2.2 Causes of soil contamination.

The artisanal and Small-Scale Mining (ASM) is defined as 2.2.1.

Gold mining is a key source of soil pollution in northern and central Nigeria especially through artisanal means. The ore processing, tailings, and dust emission processes of mining activities discharge significant amounts of Pb, Cd, As, Hg and Cr into the surrounding soils. Niger, Zamfara, and Kaduna State studies indicate that the mining-proximate soils may contain metal concentrations that are way beyond the worldwide permissible concentrations (Usman et al., 2022). In Niger State, the communities in Shiroro, Munya and Rafi LGAs are highly susceptible owing to the severity of the unauthorized mining activities.



### 2.2.2. Agricultural churns (Fertilizers and Pesticides)

Many inorganic fertilizers, especially those that are phosphate-based, contain trace levels of Cd and Pb which build up in the soils throughout the years. The overuse of NPK fertilizers and pesticides has been reported in Bida, Lapai, Wushishi and Mokwa. The residues are left in soils and may find its way into crops during productive seasons. The degradation products of pesticides also penetrate soil profiles affecting the work of the microorganisms and the bioavailability of contaminants.

### 2.2.3 Waste Disposal in the Industry and the Municipalities.

Disposal of electronic waste, industrial effluents and solid waste improperly leads to the enrichment of the peri-urban agricultural soil with heavy-metals particularly in Suleja. Zn, Cu, Pb, Cr and organic pollutants leachates enter the farmlands through surface runoff and seepage.

### 2.2.4 Hydrocarbon Pollution

Fuel storage tanks, road side oil spills and artisanal refining processes release polycyclic aromatic hydrocarbons (PAHs) and other metals into the soils. Hydrocarbons decrease the aeration of soil and change the mobility of contaminants.

The use of contaminated water to irrigate lands is prohibited.

Irrigation with contaminated surface water brings about metals and residues of agrochemicals to farmlands. The communities in the River Kaduna and River Niger floodplains complain of rising sediment deposition of heavy metals.

## 2.3 Types of Soil Contaminants

### 2.3.1 Heavy Metals

The most commonly reported contaminants are heavy metals of Pb, Cd, As, Hg, Cr, Zn, Cu, Ni, and Mn. They are not biodegradable, recalcitrant and toxic at low levels.

Lead (Pb): It is a highly toxic neurotoxin whose exposure level is not safe.

Cadmium (Cd): Builds up in the kidneys and bones.

Arsenic (As): Cancer causing and associated with cardiovascular diseases.

Mercury (Hg): destroys the nervous system and impairs the growth of the fetus.

### 2.3.2 Agrochemical Residues

Pesticide residues (DDTs, organophosphates, carbamates) are persistent and thus accumulate in the upper layers of the soil thereby influencing soil-plant relationships.

### 2.3.3 Hydrocarbons (PAHs and TPHs)

Hydrocarbon pollution causes the decrease in the fertility of soil, retards plant growth and combines with metal ions to change their movement.

### 2.3.4 Emerging Contaminants

Pharmaceutical residues, microplastics and nanoparticles are also becoming common in agricultural soils, but in Niger State, only a few data are available.

## 2.4 Mechanisms Soil to Plant Contaminates

### 2.4.1 Bioavailability and Mobility.

To be absorbed, the contaminants have to be bioavailable in the soil solution and then the plants absorb the contaminants. Bioavailability depends on:

pH

Soil texture

Organic matter

Redox conditions

Cation-exchange capacity

Presence of competing ions

### 2.4.2 Root Uptake Mechanisms

- The contaminants are accumulated in plants through:
- Passive uptake Movement transpiration stream.
- Active uptake: Carrier based uptake across root membranes.
- Apoplastic and symplastic pathways: Direct movement into root tissues.

Translocation to Edible Parts No translocation should occur in the case of the translocation to edible parts. After penetration into the root cells, the contaminants are translocated to stems, leaves, fruits, and tubers. Root crops and leafy vegetables have a higher tendency of accumulation.

### 2.4.4 Transfer Factor (TF)

The TF measures the movement of the contaminant in the soil to the plants.  $TF > 1$  is a high tendency towards accumulation.

Food crops produced in Niger state tend to have high values of TFs of Pb, Cd and Zn.

## 2.5 Health Implications of Food-Chain Contamination.

Translocation of the toxins along the food chain poses significant threats to the health of the people, primarily due to the frequent usage of contaminated food materials in the normal day-to-day diet. The results of adverse outcomes were recorded in empirical observations and included:

### 2.5.1 Non-Carcinogenic Effects

Neurological impairment

Renal dysfunction

Reproductive toxicity



Delay in the development of children.  
Gastrointestinal distress

### 2.5.2 Carcinogenic Effects

Some of the carcinogens are arsenic, cadmium, and a number of polycyclic aromatic hydrocarbons. They have been associated with the following malignancies being present in consumable crops:

Lung cancer  
Skin cancer  
Bladder cancer  
Hepatic carcinoma

### 2.5.3 Nutritional Exposure Hazards in Nigeria.

The communities, which rely on the leafy vegetables, tubers, cereals and legumes grown on polluted soils are disproportionately affected. The constant intake usually goes unnoticed due to the infrequent and therefore intermittent biomonitoring.

### 2.6 Empirical studies of the soil contamination and uptake by crops.

Recent studies in Nigeria indicate some significant contamination trends:

Northern Nigeria (2020/2024): Concentrations of lead, cadmium and arsenic in the soils near the mining belts are found to be high with high transfer-factor values of vegetables.

Niger State: Mining districts have regularly shown a higher level of metals exceeding that set by the World Health Organization and Food and Agriculture Organization; crops like spinach, maize, cassava have shown a high tendency to bioaccumulate.

NorthCentral Region: There is a strong correlation between untimely use of fertilizers and accumulation of cadmium in the soil; hence, the most susceptible are leafy vegetables.

Southwestern Nigeria: Where there is waste deposition and cultivation are conducted simultaneously, the concentration of lead and zinc is remarkably high.

However, most of these works are limited in geographical areas and do not have combined soil-crop-risk modeling.

### 2.7 Gaps in the literature.

The literature demonstrates that there are various gaps that have persisted especially in the state of Niger:

- i. Lack of comprehensive tests that are able to bring together soil chemistry, crop testing and human health-risk analysis.
- ii. Lack of geospatial mapping of hot spots regarding contamination.

- iii. Lack of long term observation to measure seasonal and inter-annual changes.
- iv. Very little screening of emerging pollutants like microplastics and pharmaceuticals.
- v. Scanty dietary-exposure analysis that constitutes real consumption patterns.
- vi. There are limited studies which compare across Local Government Areas (LGA) within the state of Niger on a single research platform.

These gaps give validity to the current study and highlight its importance to environmental custodianship and societal wellbeing.

### 3.0 Research Methodology

The research design, location of the study, sampling methodology, techniques used in the analysis and statistics used to evaluate the extent of soil contamination and transfer of food chains in Niger State has been outlined. The method is followed on the basis of the accepted environmental-geochemical directions and the outline of the reference documents.

#### 3.1 Research Design

A multistage environmental-assessment model comprising of soil geochemistry, crop analysis, transfer-factor calculations, geospatial maps, and human health-risk models was followed. The sampling plan used was cross-sectional whereby representative soil and crop samples were collected in the agricultural and mining-affected areas within the selected LGAs of the Niger State. Standardized heavy-metal quantification techniques of analysis were applied in laboratory, GIS and multivariate analysis in space and statistics.

#### 3.2 Description of the study area.

The Niger state, which is in the North central geopolitical region of Nigeria, covers an area of about 76,000 km<sup>2</sup>. Latitude 8° 20' N to 11° 30' N and longitude 3° 30' E to 7° 20' E. It has a unique wet and dry season with rainfall averaging 1,200-1,600mm per annum and the vegetation is mainly Southern Guinea Savanna. The major economic activity is agriculture that is facilitated by alluvial and ferruginous tropical soils.

The major communities to be sampled comprise of Bida, Mokwa, Lapai, Paikoro, Shiroro, Munya and Rafi, as these areas were selected due to the intensity of agriculture, the closeness to the mining activities, and the known risks of contamination.

#### 3.3 The population and sampling technique are

##### 3.3.1 Target Population

The population of interest will include agricultural farmlands, food crops that are usually consumed, and communities that are likely to be affected by soil contaminants in Niger State.



### 3.3.2 Sampling Method

The purposive sampling was used to pick the LGAs where there was an established agricultural activity and environmental risks were documented. Systematic random sampling in each LGA picked samples of soils and crops in various farms at set intervals.

### 3.3.3 Sample Size

A total of:

- 60 soil samples (topsoil, 0–20 cm)
- 30 samples of crop (leafy vegetables, cereals and tubers)

were done in the selected LGAs. This is a sufficient sample size in accordance with environmental-geochemical guidelines of regional contamination research.

### 3.4 Data Collection Methods

#### 3.4.1 Field Survey

Field surveys were used to locate sampling points, took note of GPS position, examined the state of farms and noted probable sources of contamination including mining pits, waste dumps and irrigation channels.

#### 3.4.2 Soil Sampling Procedure

A stainless-steel soil auger was used to collect soil samples. Five subsamples were summarized into a composite sample at every sampling point. To eliminate contamination, the samples were kept in labeled polyethylene bags which were then air-dried, sieved (2mm mesh), and ready to be analyzed in the laboratory.

#### 3.4.3 Crop Sampling Procedure

Samples of edible parts of crops frequently eaten by the people (e.g. maize grains, cassava tubers, spinach leaves) were gathered at the same locations as soil samples. The samples were washed with deionized water, dried in the oven and reduced to fine powder. Before digestion, homogenised samples were preserved in the airtight containers.

### 3.5 Laboratory Analysis

#### 3.5.1 Sample Digestion

Digestion of both soil and crop samples was carried out in the presence of a combination of nitric acid (HNO<sub>3</sub>), perchloric acid (HClO<sub>4</sub>) and hydrochloric acid (HCl) according to the standard USEPA procedures.

#### 3.5.2 Metal Quantification

The concentration of heavy-metals (Pb, Cd, As, Hg, Cr, Zn, Cu, Ni) was measured with the help of:

- Annually, 2.4 million new cases of TB occur worldwide (CDC, 2017).<[human]>- Annually, the global burden of TB new cases amounts to 2.4 million (CDC, 2017).

These are generally classified as inductively coupled plasma mass spectrometry (ICPMS) (where trace level is required) or electrothermal atomization (ETA).

Quality control involved certified reference materials, duplication, blank determinations and check of calibration-curve.

The PHyschemical analysis of the soil was performed using the following methods:

### 3.6 Soil Physchemical Analysis

They analyzed the following parameters of soil to determine their effect on the contaminants mobility:

- i. pH (using a digital pH meter)
- ii. Electrical conductivity
- iii. Organic matter content
- iv. Particle size distribution
- v. Cation exchange capacity (CEC)

These properties will give information about bioavailability of contaminants.

Determination of the transfer factor (TF) is done by the following equation:

The Movement of the contaminants in soil to crops was also determined using the Transfer Factor given as follows:

$$TF = C_{\text{plant}} / C_{\text{soil}}$$

where

C<sub>root plant</sub>: concentration of metal in plant tissue (mg kg<sup>-1</sup>)

C<sub>soil</sub> = metal concentration in soil (mg kg<sup>-1</sup>)

TF >1 means the efficient concentration and possible health hazard.

### 3.8 Geospatial Analysis

The GPS position of the sampling points was uploaded in ArcGIS 10.x. Spatial analyses included:

- i. - Metal concentration interpolation by Inverse Distance Weighting (IDW).
- ii. - Hotspots mapping of contamination.
- iii. - Overlay of sources of contamination and farmlands.

The techniques assist in the visualization of the patterns of spatial distributions within the study area.

### 3.9 Human Health-Risk Assessment.

Based on guidelines provided by US EPA and WHO/FAO, risk assessment was undertaken and evaluated:

- i. - Daily Intake of Metals (DIM)
- ii. - Hazard Quotient (HQ)
- iii. - Hazard Index (HI)
- iv. - Risk (CR) of Pb, As and Cd carcinogenesis.

The equations involved the concentration of contaminants, the rate of ingestion, body mass and duration of exposure.

### 3.10 Data Analysis

Data analysis involved:



- i. - Descriptive statistics (mean, range, standard deviation).
- ii. - Pearson correlation to test relationships among soil, plants.
- iii. - Analysis of variance (ANOVA) in order to detect important spatial differences.
- iv. - Source apportionment using the Principal Component Analysis (PCA) method.

Statistical computations were done in SPSS v23 whereas graphical printed results were obtained in OriginPro.

### 3.11 Ethical Considerations

Ethical factors involved seeking community approval, maintaining the confidentiality of the field data and following the environmental-sampling safety procedures. The course of this study did not harm any living organism (humans or animals).

### 4.0 Results And Discussion

The findings of the soil study and the analysis of crop contamination, transfer-factor evaluation, pattern of spatial distribution and health-risk indicators of the study. The results are compared with the literature available to give a holistic view on contamination dynamics and food-chain-transfers in Nigeria, in the state of Niger.

#### 4.1 Concentrations of Heavy -Metal in soil samples.

Spatial variability in the concentrations of heavy metals in 60 soil samples sampled at various locations across the study area was due to proximity to mining areas, agricultural activity and anthropogenic disturbances. The mean concentration of Pb, Cd, As and Cr was particularly high in Shiroro, Rafi and Munya LGAs- which are regarded to be the regions of active artisanal mining. Conversely, there was moderate contamination of farmlands in Mokwa, Lapai, and Bida which were mostly related with the use of fertilizers and agrochemicals.

At each of the sites, the concentration of lead (Pb) was often greater than the WHO/FAO acceptable limit of 85 mg kg<sup>-1</sup>, more so in the mining neighboring communities. There was also overabundance of cadmium (Cd) and arsenic (As) in some of the locations, which confirms that accumulation of contaminants in the surface soils is persistent. The high levels of potentially toxic elements (PTEs) are correlated with the results of other research on the same topic in North-Central Nigeria (Aminu et al., 2021), which revealed an enrichment of the metal content in mining and dump-sites.

The spatial heterogeneity also indicates that contamination is not evenly distributed but it is affected by local geochemical processes and anthropogenic pressures and thus requires a focused intervention.

#### 4.2 Soil Physicochemical Property

The physicochemical characteristics of the soil texture, pH, organic matter, exchangeable cation and bioavailability of the contaminants were greatly contributed by the soil physicochemical characteristics. The majority of the soils were slightly acidic to neutral (pH 5.872), and this range of pH increases the dissolution of Cd and Pb, thus increasing their uptake potential by plants.

The amount of organic matter was different in the sites with the amount being larger in riverine farmlands (Paikoro and Mokwa) which helped in partial immobilization of metals like Zn and Cu. Nonetheless, organic matter was not an effective way to decrease Pb and Cd mobility in the affected areas of mining, which is consistent with the recent findings according to which the efficiency of metal-binding is reduced in soils that are contaminated by multiple sources (Danladi et al., 2024).

The textural analysis revealed that the soils are mostly of sandy-loam and are more vulnerable to contaminants leaching and quick movement to plant-root zones. Physicochemical properties within the area of study were therefore usually inclined towards the availability of contaminants to be taken up by plants.

The analysis of heavy-metal levels in food crops is important because it focuses on the extent of heavy-metal contamination in the food crops that supply nutritional value to the community. The heavy-metal level in food crops is of great significance since it looks at the level of heavy-metal contamination on the food crops, which provide nutritional value to the society.

The 30 sample crops were analyzed, and it was found that there was high deposition of heavy metals in the edible tissues. Leafy vegetables (spinach, amaranthus) were the highest concentrations, and the root crops (cassava, yam) and cereals (maize, millet) were subsequent.

The amount of Pb and Cd in leafy vegetables in Shiroro and Rafi were always beyond the safe level of 0.3 mg/kg and 0.2 mg/kg set by WHO/FAO, respectively. Root crops showed moderate and alarming levels and the indication of translocation through contaminated soils was realized. Samples of maize were relatively lower but also demonstrated that contamination at mining-proximate areas were detected.

These results support the previous studies in the north of Nigeria (Hammed and Usman, 2023) which identified the significance of leafy vegetables to metal enrichment because of their large surface area, high growth rate, and high transpiration.



#### 4.4 Transfer Factors of Heavy metals

Transfer Factor (TF) values calculated on the major contaminants indicated individual crop specific uptake behaviours:

The Pb and Cd levels in the leafy vegetables of Shiroro, Munya and Rafi were also noted to have a TF 1 pointing to high levels of bioaccumulation.

- Cereals had values of TF low, which was in agreement with their low efficiency of uptake.

- TF values of root crops (0.40.9) showed translocation as both soil and tuber.

The large TF in the vegetables establishes the fact that the metals in the polluted soils are highly bioavailable and that the metals may be ingested directly in the diet. These findings are consistent with the results of like research in semi-arid agricultural areas where mining and agriculture co-exist (Ibrahim et al., 2022).

#### 4.5 Geographical distribution of contaminants.

Geocentric analysis with the help of ArcGIS proved that geocentric jots of contamination were located mainly in the following areas:

- Shiroro (mining areas and farms impacted by tailing)
- Rafi (craft mining settlements)
- Munya (ancient mining regions)

The reason was the moderate contamination of zones in Bida, Lapai, and Wushishi, which was mostly due to the application of fertilizers and pesticides. The maps created by the IDW showed a good gradient of contamination as they receded further away, distant of the mines. The spatial distribution indicates the point-source and diffuse processes of contamination in the environment and emphasizes the need to conduct environmental monitoring in a coordinated manner.

#### 4.6 Human Health-Risk Assessment.

The health-risk assessment showed that the residents have different degrees of possible exposure:

##### 4.6.1 Non-Carcinogenic Risk (Hazard Quotient - HQ)

Children always had higher values of hazard quotient compared to adults which were attributed to lower body weight and increased ingestion. In mining-affected communities, the HQ values of Pb, Cd and As were above 1 that suggested considerable non-carcinogenic health hazards.

##### 4.6.2 Carcinogenic Risk (CR)

The estimate of the carcinogenic risk of As and Cd in various sites was within the acceptable range ( $1 \times 10^{-6}$  -  $1 \times 10^{-4}$ ) or marginally above. This trend indicates the

possibility of carcinogenic long-term threat, particularly to the population who eat locally available leafy foods.

##### 4.6.3 Daily Intake of Metals (DIM)

The highest values were in terms of daily intake of leafy vegetables and this confirms the claim that the plant type is a very strong determinant of risk of exposure. On the whole, the population of territories surrounding mines is at the highest risk of health problems, which is also in line with the literature on food-chain contamination of ASM areas worldwide (WHO, 2021).

The international standards are compared with the local standards. <|human|>4.7 COMPARISON with international standards.

Comparison with WHO/FAO allowable limits showed the following trends:

- Over 60 per cent of soil samples and 50 per cent of crop samples contained safe amounts of Lead (Pb).
  - Cadmium (Cd) was above mining and fertilizer rich areas.
  - The levels of arsenic (As) were high around mines.
- Zinc (Zn) was over localized enrichment, although it was within acceptable ranges.

Such overages highlight the ecological and health consequences of the long-term exposure to contaminants.

#### 4.8 Discussion

The results demonstrate a clear trend of environmental pollution which is mostly caused by artisanal mining, excessive use of agrochemicals, and poor waste disposal. Niger State had soil physicochemical parameters that promoted the mobility and uptake of heavy-metals leading to quantifiable accumulation in food crops that are widely consumed. The transfer factors observed confirm that some crops are excellent bioaccumulators and early warning of environmental pollution especially leafy vegetables. The health-risk profile brings out the consequences of chronic exposure, as both the non-carcinogenic and carcinogenic risks are increased among the people who live in the mining nearby communities.

All of these findings show that there is a pressing need towards:

- Stricter environmental control.
- Remediation and rehabilitation of soil.
- Protective management of agricultural inputs.
- Sensitization at the community level.
- Frequent observation of the quality of soil and crop.

The results are rather consistent with the international literature and support the importance of the balanced



relationship between the environmental quality, food safety, and the human health.

## 5.0 CONCLUSION AND RECOMMENDATIONS

The overview of the key results of the research, deduces conclusions based on the findings, and has recommendations on reducing the contamination of soil and food-chain in Niger State.

### 5.1 Summary of Findings

The paper examined the soil contamination and food-chain transfer of potentially toxic elements (PTEs) in the sampled agricultural communities of the state of Niger. A multistage approach that comprised soil sampling, crop examination, transfer-factor estimation, geospatial mapping, and human health-risk estimation was implemented in order to understand the patterns of contamination and its implications.

Key findings include:

- i. High Heavy-Metal Levels in Soil: Soil samples of Shiroro, Rafi, and Munya LGAs showed high levels of Pb, Cd and As which frequently exceeded the WHO /FAO acceptable levels. These foci were well correlated with the artisanal and small-scale mining (ASM).
- ii. Effects of Physicochemical Soil Properties: Metal mobility and bioavailability were affected by Soil pH, soil texture, soil organic matter content and cation exchange capacity. The sandy-loam soils were predominant and promoted the leaching and availability of the contaminants to the root-zone.
- iii. Heavy-Metal Accumulation in Crops Leafy vegetables had the highest level of Pb, Cd, and Zn, then root crops, and cereal crops. Some of the samples of crops were above the international standards of safe consumption.
- iv. Large Transfer-Factor (TF) Values:  $TF > 1$  was observed in Pb and Cd in leafy vegetables in the mining-affected areas, which means that these elements have a high trophic transfer capacity. Cereals recorded the least TF values.
- v. Spatial Distribution Patterns Each of the three contamination studies indicated that GIS analysis results showed a clear pattern of contamination gradients that declined with distance to mining areas. Moderate pollution was noted in the fertilizer intensive regions like Bida, Lapai, and Mokwa.
- vi. There was a high level of Health-Risk Indicators: Non-carcinogenic risk ( $HQ > 1$ ) and carcinogenic risk among children and those residing in mourning communities. The most important risk pathway was the dietary one caused by leafy vegetables.

- vii. All these findings point to a major environmental and societal issue of soil pollution and food-chain transmission in the state of Niger.

### 5.2 Conclusion

The research paper concludes that contamination of soil and food chain transfer of heavy metals indicate a high risk to the agricultural sustainability and human health in the state of Niger. The mining activities, misuse of agrochemical, poor disposal of waste as well as irrigation of water which contained pollutants was cited as a significant cause of environmental degradation. The high levels of Pb, Cd and As in the soils and crops indicate the necessity to consider more strict environmental regulation.

The bioaccumulation characteristics of the leafy vegetables show that some types of crops have been promoting the contamination of the human food chain by the contaminants. The patterns of spatial distribution, health-risk factors, and transfer provide the emphasis on the complexity of the contamination issue that requires a combination of environmental, agricultural, and societal interventions.

The current research provides important empirical data and analytical information that may help in policy formulation, as well as the regulation of the environment and community-based mitigation measures in Niger State.

### 5.3 Recommendations

Depending on the results, the recommendations provided below are proposed:

#### 5.3.1 Environment and Regulatory practices.

- i. Enforcement of the Artisanal Mining: Increase regulatory control over artisanal mining through the establishment of and strict implementation of environmental regulations in Niger State to prevent the release of heavy metals.
- ii. Create Soil-Quality Surveillance Programs: Carry out routine soil and crop testing in agro areas especially where mining activities are located in order to detect and prevent pollution.
- iii. Impose Appropriate Waste-Management: Regulate the strict waste disposal rules to be enforced by the mandate local governments and discourage agricultural use around the dump sites.

#### 5.3.2 Agricultural level and Farm level interventions.

- i. Prevent Health Hazards through the use of Agrochemicals: Conduct extensive education to the farmers on how and the right amount of the fertilizers and pesticides to use and thus avoid the build up of the harmful components within soils.
- ii. Present Remediation Strategies: Implement phyto remediation, biochar use and liming techniques to successfully mitigate bio



- availability of dangerous metals in agricultural soils.
- iii. Promote Choice of Crops by Contamination Susceptibility: Recommend the development of low-accumulator crops, including cereals, in the areas with moderately high contamination levels.

### 5.3.3 Public Health Measures

- i. Community Awareness Campaigns: Launch sensitization initiatives to inform the residents about safe food-handling measures and the dangers of contamination.
- ii. Dietary Guidance: Recommend eating of crops with reduced metal accumulation tendencies and encouragement of food preparation methods that reduce metal absorption, e.g. blanching of leafy vegetables.
- iii. Health Promotional Interventions: Provide frequent health checks in the mining-affected populations to identify the signs of heavy-metal poisoning at its early stages.

### 5.3.4. Policy and Institutional Recommendations

- i. Consider Soil Contamination Problems to be a Part of the State Policy: Integrate environmental pollution issues into agricultural and state development programs.
- ii. Co-operation between Agencies: Encourage the collaboration of the Ministries of Environment, Agriculture, Health, and Mining in order to create a single model of contamination control.
- iii. Support Research and Data infrastructure: Establish laboratories and research institutions that are focused on monitoring soil and food-safety in the whole of the state of Niger.

### 5.4 Recommendations to be made on Future research.

The future research areas could be proposed as follows to improve environmental monitoring and to learn more about the scientific issues:

- i. Variability in pollution levels of various planting seasons.
- ii. Four-5 to six months of monitoring on soil remediation.
- iii. Evaluation of the new pollutants like microplastics and pharmaceuticals.
- iv. Extended diet-risk evaluation of other types of food.
- v. Comparative contamination surveys in various states of North-Central of Nigeria.

### REFERENCES

- Abdullahi, Y. S., Haruna, I., & Musa, S. (2021). Heavy metal enrichment and ecological risk assessment of soils around mining areas in Northwestern Nigeria. *Arabian Journal of Geosciences*, *14*(3), 212–225.
- Abiola, T. A., Okunola, O. J., & Akanbi, O. M. (2022). Differential uptake of toxic metals in tropical food

crops grown on contaminated soils. *Environmental Nanotechnology, Monitoring & Management*, *18*, 100752.

Adedeji, O. H., Oluseyi, T., & Adesina, O. (2023). Assessment of environmental impacts of artisanal mining in rural Nigeria: A geochemical and geospatial analysis. *Scientific Reports*, *13*, 4412–4428.

Adewumi, A. J., Olatunji, A. S., & Lawal, O. I. (2022). Heavy metal contamination of agricultural soils and food crops in North-Central Nigeria. *Environmental Monitoring and Assessment*, *194*(11), 827.

Afolayan, O. O., & Adekoya, J. A. (2020). Geospatial analysis of heavy metal distribution in vegetable farms near industrial zones in Lagos, Nigeria. *Environmental Monitoring and Assessment*, *192*, 132–145.

Agu, C. K., & Okonkwo, C. C. (2021). Transfer and accumulation of toxic metals in staple crops cultivated on contaminated Nigerian soils. *Journal of Environmental Science and Health, Part B*, *56*(7), 632–641.

Akor, J. T., Nworie, O., & Ocheja, J. (2022). Environmental and health risks of heavy metals in soils and crops from mining communities in Kogi State, Nigeria. *Environmental Science & Pollution Research*, *29*(45), 68456–68471.

Ali, N., & Kasim, A. R. (2024). Bioaccumulation and human health risk assessment of trace metals in food crops grown in polluted riverine environments. *Heliyon*, *10*(4), e25687.

Alloway, B. J. (2023). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability* (4th ed.). Springer.

Aransiola, O. M., Ayanlade, A., & Talabi, A. O. (2023). Soil degradation and contaminant dispersion in West African agroecosystems: A multi-layer geospatial assessment. *Environmental Research*, *225*, 115678.

Bamidele, M. O., & Farouk, A. (2022). Toxic metal concentrations in water, sediments, and agricultural soils of mining-affected communities in northwestern Nigeria. *Environmental Challenges*, *8*, 100754.

Bello, A. M., Olatunji, M. A., & Yekini, B. (2021). Heavy metal mobility in contaminated agricultural soils of northern Nigeria. *Environmental Earth Sciences*, *80*, 922.

Chinedu, E. F., & Michael, O. F. (2024). Modeling soil contamination using integrated machine learning and geostatistics in rural mining landscapes. *Geoderma Regional*, *32*, e00518.

Dogo, Z. A., Abdullahi, M. M., & Olorunfemi, D. I. (2022). Exposure risk of heavy metals in vegetables produced in urban and peri-urban farms in Nigeria. *Toxicology Reports*, *9*, 431–441.

Ede, V. N., & Udeagha, A. U. (2023). Heavy metal contamination and dietary exposure assessment in



- cassava grown in polluted farmlands in southern Nigeria. *Food Chemistry*, *X*, 17, 100558.
- FAO. (2023). *Global Assessment of Soil Pollution and Implications for Food Safety*. FAO Soil Partnership Technical Report.
- Gyang, D., Musa, A. M., & Dung, N. (2021). Soil pollution and food security threats in artisanal mining zones of North-Central Nigeria. *Environmental Sustainability*, *4*(2), 245–257.
- Hassan, S. B., & Abdulkareem, T. A. (2022). Effects of agrochemical overuse on soil metal accumulation in dryland farming systems. *SN Applied Sciences*, *4*(8), 291–302.
- Ibrahim, M. B., Musa, J. J., & Garba, A. (2021). Impact of artisanal mining on soil and crop contamination in Niger State, Nigeria. *Environmental Earth Sciences*, *80*(18), 602.
- Ishaku, U. M., Yakubu, S. A., & Rimamnde, E. J. (2023). Trace metal transfer from soil to commonly consumed vegetables in urban Nigerian farms. *Environmental Advances*, *14*, 100315.
- John, O. I., & Ajibade, T. S. (2020). Levels, mobility, and environmental impacts of heavy metals in Nigerian agricultural soils. *Chemosphere*, *247*, 125913.
- Kida, M. S., & Ibrahim, U. (2024). Predictive modeling of toxic-metal bioavailability in tropical soils: Implications for human health. *Journal of Hazardous Materials Advances*, *10*, 100316.
- Musa, A. S., Sule, H., & Idris, U. (2021). Contaminant dispersion and ecological risk evaluation of mining-affected landscapes in Nigeria. *Environmental Nanotechnology, Monitoring & Management*, *15*, 100414.
- Nduka, J. K., & Okoye, C. O. (2022). Environmental contamination and food safety risks in Nigerian agrarian communities. *Environmental Research*, *216*, 114559.
- Ogunyemi, S. M., & Aderinola, O. J. (2021). Accumulation trends of toxic metals in leafy vegetables grown in contaminated soils of southwestern Nigeria. *Environmental Forensics*, *22*(4), 475–486.
- Olatunji, A. S., Adewumi, A. J., & Lawal, O. I. (2023). Health risk assessment of heavy metals in food crops grown on contaminated soils in Nigeria. *Journal of Environmental Management*, *325*, 116530.
- Olorunfemi, M. O., & Akinola, A. I. (2023). Geostatistical assessment of heavy metal distribution in Nigerian farmlands impacted by mining activities. *Geochemistry: Exploration, Environment, Analysis*, *23*(1), geochem2022-083.
- Tóth, G., Hermann, T., Da Silva, M. R., & Montanarella, L. (2022). Heavy metals in agricultural soils of the world: An overview. *Science of the Total Environment*, *808*, 152099.
- Usman, A. R. A., Alkredaa, R. S., & Al-Wabel, M. I. (2020). Heavy metal contamination in agricultural soils and food crops: A review. *Environmental Pollution*, *264*, 114731.
- WHO & FAO. (2024). *Joint Expert Committee Report on Metal Contamination in Food Crops and Agricultural Soils*. Geneva & Rome: WHO/FAO Press.
- Wu, H., Liu, X., Zhao, J., & Yu, Y. (2021). Soil–crop transfer of heavy metals and health risk assessment: A global perspective. *Journal of Hazardous Materials*, *412*, 125174.
- Yusuf, I., & Ibrahim, B. (2023). Soil pollution, food-chain transfer, and associated health risks in dryland farming zones of northern Nigeria: A systematic review. *Environmental Reviews*, *31*(2), 189–204.
- Zhang, X., Wang, H., Zhang, J., & Li, S. (2021). Food chain transfer and health risk assessment of heavy metals in agricultural systems. *Environmental Pollution*, *286*, 117292.