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Evaluation of Heavy Metal Contamination in Soils and Vegetable Crops from Agbara Industrial Zone, Ogun State, Nigeria

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Abstract

Heavy metal contamination of agricultural soils can affect the quality of crops grown in industrial areas. This study evaluated the concentrations of cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn) in agricultural soils and vegetables from the Agbara Industrial Zone, Ogun State, Nigeria. A cross-sectional field-based design was used, and samples were collected from selected vegetable farms. The study analysed a total number of forty-five (45) samples, comprising farm soil and three vegetable types: spinach (*Spinacia oleracea*), tomato (*Solanum lycopersicum*), and okra (*Abelmoschus esculentus*). Samples were prepared by acid digestion, using USEPA Method 3050B for soil and wet acid digestion for vegetable samples, and the metals were determined using atomic absorption spectrophotometry. Pearson correlation analysis was used to examine relationships among the analysed metals, with significance tested at the 0.05 and 0.01 levels. The results showed that soil generally had higher concentrations of Fe, Zn, Cu, Cd, Pb, and Cr than the vegetables, while Ni was higher in spinach than in soil. Spinach recorded the highest concentrations of Cd (0.752 mg/kg), Ni (3.651 mg/kg), and Pb (0.526 mg/kg). Cd exceeded the reference value of 0.10 mg/kg in all vegetables, while Pb exceeded 0.30 mg/kg in tomato and spinach. Several strong positive correlations were observed among the metals. The findings provide baseline information on heavy metal concentrations in agricultural soils and vegetables within the study area.

Introduction

Heavy metal contamination of agricultural soils is an important environmental problem because these pollutants can remain in the soil for long periods and may enter food crops grown for human consumption. This problem is of particular concern in areas where agricultural activities take place close to industrial and urban centres. Heavy metals such as cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), iron (Fe), and manganese (Mn) can enter agricultural soils through industrial emissions, wastewater, traffic activities, poorly managed waste, and some agricultural inputs. Once present in the soil, these metals may persist and affect soil quality, crop growth, food safety, and human health (Mai et al., 2024; Yao et al., 2024).

Some heavy metals, such as iron, copper, and zinc, are essential for normal biological functions when present at appropriate levels. However, excessive exposure can be harmful. Other metals, including lead and cadmium, have no known beneficial biological role and may pose serious health concerns when they accumulate in food and are consumed over time. Exposure to high levels of heavy metals has been associated with effects on the nervous system, kidneys, bones, blood, and other body systems (Briffa et al., 2020; Eruola et al., 2025). The presence of these metals in agricultural soils is therefore not only an environmental concern but also a food safety and public health issue.

Agricultural soils located close to industrial areas are particularly vulnerable to contamination. Industrial activities may release metal-containing dust, fumes, wastewater, and other wastes into the surrounding environment. In addition, untreated or poorly treated wastewater may be used for irrigation, while municipal waste, sewage sludge, manure, pesticides, and roadside activities can introduce additional contaminants into agricultural land (FAO & UNEP, 2021; Traoré et al., 2022). Over time, repeated exposure to these sources can increase the concentration of heavy metals in the soil. The metals may then be taken up by crops through their roots or deposited directly on plant surfaces.

Vegetables are of particular concern because they form an important part of the daily diet in Nigeria. The increasing population of urban areas has increased the demand for locally produced vegetables, including vegetables cultivated close to industrial and residential areas. In some locations, farmers depend on nearby streams, rivers, drainage channels, or other water sources for irrigation. Where such water is contaminated, it can contribute to the movement of heavy metals into agricultural soils and crops (Taiwo et al., 2021; Traoré et al., 2022). The consumption of contaminated vegetables may therefore provide an important pathway for human exposure to heavy metals.

The ability of vegetables to accumulate heavy metals differs between crop species and depends on several factors, including soil characteristics, the concentration and availability of metals in the soil, irrigation practices, and the physiological characteristics of the plant. Leafy vegetables may be particularly vulnerable because of their large leaf surfaces and their ability to take up metals through their roots. Previous studies have reported higher concentrations of some heavy metals in leafy vegetables than in fruit vegetables grown under contaminated conditions (Gelaye & Musie, 2023; Manwani et al., 2023; Onaji et al., 2024). It is therefore important to assess both the concentration of metals in agricultural soils and their levels in the edible portions of crops grown on those soils.

In Nigeria, heavy metal contamination of agricultural environments has been reported in areas affected by industrial activities, urban development, mining, waste disposal, and contaminated irrigation water. Studies from different parts of the country have identified heavy metals in soils, irrigation water, vegetables, fish, and other environmental media (Hussaini et al., 2021; Oloruntoba et al., 2024; Suleiman & Ibrahim, 2025). Research in southwestern Nigeria has also shown that industrialisation and urban growth can contribute to environmental pollution and increase the potential for human exposure to contaminants through locally produced food (Akinnifesi et al., 2021; Akinsola et al., 2022; Taiwo et al., 2021).

Although previous studies have examined heavy metal contamination in Nigerian agricultural soils and vegetables, there is still limited site-specific information on the relationship between contamination of farmland soils and the vegetables cultivated within the Agbara Industrial Zone of Ogun State. Existing studies have reported contamination in different industrial and urban areas of Nigeria, but findings from one location cannot necessarily be applied to another because industrial activities, soil characteristics, farming practices, irrigation sources, and waste management practices differ from place to place. In addition, some previous studies have focused mainly on the concentration of metals in either environmental media or food crops, with less attention given to comparing metal concentrations in soils and different vegetable species within the same agricultural setting.

There is therefore a need for current information on the levels of selected heavy metals in agricultural soils and commonly cultivated vegetables in the Agbara Industrial Zone. Information on the relationship between the metals is also useful because similar patterns of occurrence may provide an indication of possible common sources or pathways of contamination. Addressing this gap will provide evidence that can support environmental monitoring, agricultural management, food safety measures, and pollution control within the study area.

The aim of this study was to evaluate the levels of selected heavy metals in agricultural soils and vegetable crops cultivated within the Agbara Industrial Zone, Ogun State, Nigeria, and assess their implications for environmental and food safety.

The specific objectives of the study were to determine the concentrations of Cd, Cr, Cu, Fe, Ni, Pb, and Zn in agricultural soils within the Agbara Industrial Zone; determine the concentrations of the selected heavy metals in spinach (*Spinacia oleracea*), tomato (*Solanum lycopersicum*), and okra (*Abelmoschus esculentus*) cultivated within the study area; compare the concentrations of heavy metals detected in the vegetables with the applicable WHO/FAO food safety guideline values; and assess the relationships among the selected heavy metals using Pearson correlation analysis to provide an indication of possible common contamination pathways.

The study therefore provides baseline information on heavy metal contamination in agricultural soils and vegetables within the Agbara Industrial Zone and highlights the need for appropriate environmental monitoring and management of agricultural activities in industrial areas.

Materials and Methods

Study Area

The study was carried out in the Agbara Industrial Zone, located in Ado-Odo/Ota Local Government Area of Ogun State, southwestern Nigeria. Agbara is an important industrial and agricultural area situated along the Lagos–Badagry Expressway, approximately 31 km west of Lagos. The industrial area is located close to the Owo River and has developed rapidly because of the presence of manufacturing and other industrial activities. The centre of Agbara Industrial Area is approximately at latitude **6°31′00″ N and longitude 3°06′00″ E**, with an elevation of about 37 m above sea level (Ojekunle et al., 2018; Nigerian Meteorological Agency [NiMet], 2024).

The area has a mixture of industrial establishments, residential settlements, roads, open spaces, and agricultural land. The closeness of farmlands to industrial activities makes the area suitable for assessing the possible occurrence of heavy metals in agricultural soils and food crops. Previous environmental studies in Agbara have reported pollution associated with industrial activities and have identified several sampling locations within and around the industrial estate (Ojekunle et al., 2018).

Research Design

This study adopted **a cross-sectional field-based environmental assessment research design** involving the collection and laboratory analysis of agricultural soil and vegetable samples from selected vegetable farms located within the industrial zone. Because they provide reliable baseline information for evaluating contamination status, identifying pollution sources, and determining the extent of contaminant transfer within environmental media (Li et al., 2024; Oloruntoba et al., 2024).

During the field visit, accessible vegetable farms within the study area were identified and selected for sampling. The selected farms provided the locations from which the soil and vegetable samples were obtained. At each selected farm, soil samples were collected from the agricultural soil where the vegetables were growing. Vegetable samples were collected from the same locations as the soil samples. Collecting the two types of samples from corresponding locations made it possible to compare the concentration of heavy metals in the soil with the concentration found in the vegetables grown on that soil. The sampling locations were therefore treated as individual sampling points within the industrial zone. Each location was identified and recorded during field sampling, and the samples were properly labelled to maintain a clear connection between the farm, soil sample and vegetable sample.

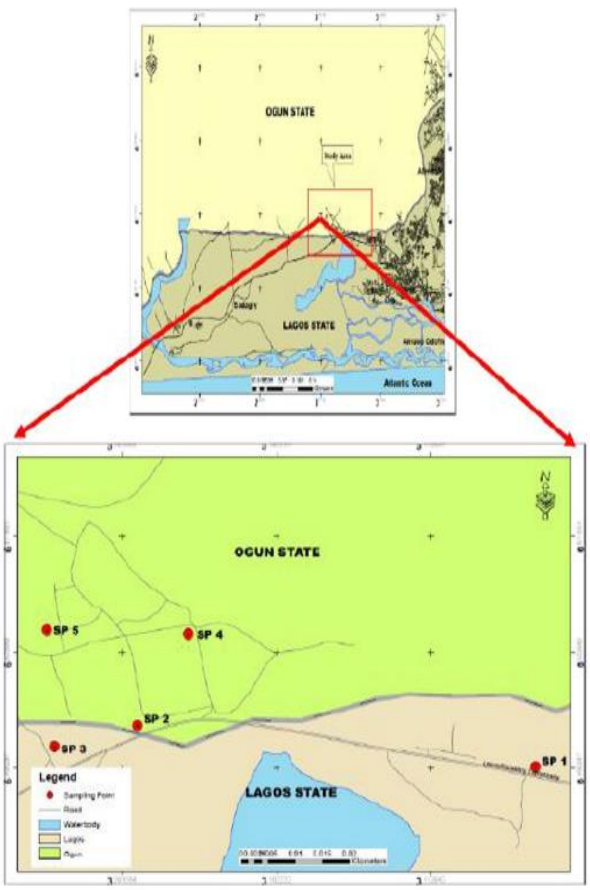

Figure 1: Ogun State Map, Showing the Area Map of Agbara Industrial Zone

Source: Ojekunle et al. (2018)

Sample Collection

Soil

A total of five (5) sampling sites were selected for the study. At each sampling site, soil samples were collected from the vegetable-growing area. Three (3) replicate soil samples were collected from each site, giving a total of fifty (15) soil samples for laboratory analysis. The replicate samples were collected separately to reduce the effect of differences in soil conditions within the same farm and to provide a more reliable estimate of heavy metal concentrations.

At each selected farm, the top layer of soil was taken from where plant roots grow, between 0 and 20 cm deep. This part of the soil is where most vegetables take in water and nutrients. It is also where heavy metals build up because of activities (ISO, 2017; FAO, 2023). A tool made of steel was used to collect the soil so that it would not get polluted by other metals. Soon as the soil was taken it was put in special boxes that keep it cool. This helped stop it from getting dirty. Kept it the same as when it was taken. In the laboratory the soil was left to dry in room conditions for a few days. Then it was broken up with a tool made of porcelain. After that it was passed through a sieve that is made of steel and has holes that are 2 mm wide. This removed pieces so that the soil could be tested for its physical and chemical properties and, for heavy metals.

Vegetable

Vegetable samples corresponding to each soil sampling point were collected simultaneously to facilitate evaluation of heavy metal transfer from soils to edible crops. The sampled vegetables included spinach (*Spinacia oleracea*), tomato (*Solanum lycopersicum*), and okra (*Abelmoschus esculentus*), which locally cultivated vegetables. At each sampling site, two (2) replicate samples of each vegetable were collected, giving ten (10) samples per vegetable and thirty (30) overall total vegetable samples for the study.

In the laboratory, vegetable samples were first rinsed gently with running tap water to remove adhering soil particles and dust, followed by repeated washing with deionised water to eliminate any remaining surface contaminants. The washed samples were blotted dry with clean laboratory tissue paper and separated into edible portions where necessary. Samples were then placed in an oven. Dried at a temperature between

65 and 70 ^{O}C until they reached a constant weight. This step was done to stop any growth and to make sure the heavy metal measurements were accurate. The dried samples were turned into a powder using a stainless-steel machine in the laboratory. The powder was mixed well. Then passed through a sieve that had holes of 0.5 mm. After that the samples were kept in sealed plastic containers. They waited there until they were ready for acid digestion and testing with instruments. Every time after taking a sample the tools were washed with water that had no minerals in it. The people working wore gloves that were only used once and then thrown away. All the samples were treated carefully marked clearly and written about properly. This was done following the rules that are accepted over the world for taking environmental samples (ISO, 2018; USEPA, 2023).

Preparation of Soil and Vegetable Samples

Soil

The samples were spread separately on clean surfaces and allowed to air-dry at room temperature for several days. Any visible stones, plant materials, roots and other unwanted materials were removed carefully by hand. After drying, the soil samples were gently crushed using a clean porcelain mortar and pestle to break up large lumps. Each sample was then passed through a clean 2-mm stainless-steel sieve to obtain a uniform soil sample for analysis. The prepared soil was mixed thoroughly and transferred into clean, labelled containers before digestion.

Vegetable

In the laboratory, each sample was first rinsed gently with running tap water to remove soil, dust and other materials attached to the surface. The samples were then washed repeatedly with deionised water to remove remaining surface contaminants. This washing procedure was applied carefully to all samples to ensure that the samples were treated in the same way. After washing, the samples were blotted dry using clean laboratory tissue paper. Where necessary, the edible portions were separated from other plant parts. The samples were then placed separately in the oven and dried at 65 to 70 °C until a constant weight was obtained. Drying to constant weight helped to ensure that differences in moisture content did not affect the comparison of heavy metal concentrations between samples.

The dried vegetable samples were ground into a fine powder using a clean stainless-steel grinder. The powder from each sample was mixed thoroughly and passed through a **0.5-mm sieve** to obtain a more uniform material for digestion. Each prepared sample was transferred into a clean, sealed and properly labelled plastic container and stored until acid digestion and heavy metal analysis.

Digestion

Soil digestion was done using the United States Environmental Protection Agency (USEPA) Method 3050B, an acid digestion method that is often used to find trace metals in soils and sediments. The method was described in USEPA (1996). A mix of nitric acid (HNO_3), hydrochloric acid (HCl) and hydrogen peroxide (H_2O_2) was put into each sample. The digestion happened on a plate that had a set temperature. The process continued until the sample was completely broken down and the liquid became clear. After the liquid cooled to temperature the digest was passed through Whatman No. 42 Filter paper into 50 mL flasks that had been cleaned with acid. The flasks were filled to the top with water that had no ions. The solutions that were made were put into labelled bottles made of plastic. Kept at 4 ^{o}C until they were tested with instruments.

Wet acid digestion was performed using concentrated HNO_3 and perchloric acid ($HClO_4$) in accordance with the procedures recommended by the Association of Official Analytical Chemists (Latimer, 2023) for plant tissue analysis. The digestion mixture was heated gradually until complete oxidation of the organic matter was achieved and a colourless solution was obtained. After cooling, the digest was filtered through Whatman No. 42 filter paper into 50 mL volumetric flasks and diluted to the calibration mark using deionised water. Digested samples were preserved in acid-washed polyethylene bottles pending instrumental determination.

Quality control

Reagent blanks, duplicates samples and Certified reference material (CRM), incorporated into the batch for analysis were used to check for contamination, precision and bias respectively. These procedures were followed in line with the general environmental sampling and quality-control principles reported in ISO (2018) and USEPA (2023).

Determination of the Concentration of Heavy Metals

The concentrations of metals (Cd, Cr, Cu, Fe, Ni, Pb, and Zn) was determined using atomic absorption spectrophotometer AAS (Agilent 240FS AA model, Agilent Lab, USA).

Before the samples were analysed, the AAS was calibrated for each metal using appropriate standard solutions prepared from certified metal stock solutions. A series of working standards covering the expected concentration range of each metal was prepared. The blank solution was first used to set the instrument to zero, after which the standards were analysed to produce a calibration curve for each metal. The sample solutions were then analysed under the same conditions, and the metal concentrations were obtained from the corresponding calibration curves.

The calibration of the instrument was checked regularly during the analysis to make sure that the readings remained stable. Where necessary, the instrument was recalibrated before continuing with the sample analysis. Results were recorded in mg/kg after taking the sample dilution factor into account.

The detection limits used for the analysis were 0.002 mg/kg for Cd, 0.003 mg/kg for Cr, 0.002 mg/kg for Cu, 0.005 mg/kg for Fe, 0.005 mg/kg for Ni, 0.010 mg/kg for Pb, and 0.001 mg/kg for Zn. These detection limits were used to determine the lowest concentration of each metal that could be reliably detected by the instrument.

Statistical Analysis

The study used Statistical Package for the Social Sciences (SPSS) 29, 2022 (Pallant, 2020) software to compare the relationship between heavy metals using Pearson correlation. And 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 (Field, 2024).

Results and Discussions

Results

The results in Table 1 shows clear differences in the concentrations of the metals among the soil and vegetable samples. Iron had the highest concentration in the farm soil, with a mean value of 3,125.012 ± 0.15 mg/kg. Among the vegetables, Fe was highest in okra (144.752 ± 0.01 mg/kg) and lowest in tomato (36.156 ± 0.05 mg/kg). The concentration of Zn ranged from **31.430 ± 0.01** mg/kg in okra to 42.150 ± 0.06 mg/kg in tomato, while the soil recorded 69.563 ± 15.11 mg/kg. Overall, the measured soil concentrations were higher than the concentrations found in the edible vegetable samples for Fe, Zn, Cu, Cd, Pb and Cr. Nickel was the exception, because its concentration in spinach (3.651 ± 0.12 mg/kg) was slightly higher than the value measured in the farm soil (3.010 ± 0.98 mg/kg).

In Table 2 the result shows that the measured Cd concentrations in all three vegetables were above the reported WHO/FAO maximum permissible limits of 0.10 mg/kg. Okra recorded 0.235 ± 0.08 mg/kg, tomato recorded 0.245 ± 0.35 mg/kg, and spinach recorded the highest value of 0.752 ± 0.011 mg/kg. Pb was also above the reported WHO/FAO maximum permissible limits of 0.30 mg/kg in tomato and spinach. Tomato recorded 0.361 ± 0.13 mg/kg, while spinach recorded 0.526 ± 0.08 mg/kg. The Pb concentration in okra, 0.073 ± 0.01 mg/kg, was below the WHO/FAO maximum permissible limits. The highest measured Fe concentration in a vegetable was 144.752 ± 0.01 mg/kg in okra, compared with the WHO/FAO maximum permissible limits of 426 mg/kg. The highest Zn concentration was 42.150 ± 0.06 mg/kg in tomato, compared with 100 mg/kg, while the highest Cu concentration was 44.751 ± 0.11 mg/kg in okra, compared with 73 mg/kg. The highest Ni concentration was 3.651 ± 0.12 mg/kg in spinach, compared with 10 mg/kg. And also, all measured

Cr concentrations were also below the WHO/FAO maximum permissible limits.

The correlation result in Table 3 shows strong positive relationships among several of the metals. The strongest relationships were between Cd and Pb ($r = 0.997$, $p < 0.01$), Fe and Cd ($r = 0.996$, $p < 0.01$), Fe and Pb ($r = 0.992$, $p < 0.01$), and Fe and Cr ($r = 0.985$, $p < 0.01$). Other strong relationships included Fe and Cu ($r = 0.943$, $p < 0.01$), Cu and Cr ($r = 0.970$, $p < 0.01$), Cd and Cr ($r = 0.969$, $p < 0.01$), and Pb and Cr ($r = 0.959$, $p < 0.01$). Zn also showed significant positive relationships with Cd ($r = 0.890$, $p < 0.01$), Pb ($r = 0.911$, $p < 0.01$) and Cr ($r = 0.799$, $p < 0.05$). However, the relationship between Zn and Cu ($r = 0.704$) was not marked as statistically significant. Similarly, Zn and Ni ($r = 0.512$) did not show a statistically significant relationship. Ni generally showed weaker relationships with the other metals. Its correlations ranged from $r = 0.351$ with Cr to $r = 0.544$ with Cd. Overall, none of these relationships was marked as statistically significant.

Table 1: Mean Values of Heavy Metals Concentrations in Some Vegetables and Soil from Agbara Industrial Area

Metals (mg/kg)	Vegetable/Soil			
	A. esculentus	*S. lycopersicum*	*S. oleracea*	Farm Soil
Fe	144.752 ±0.01	36.156 ±0.05	117.451 ±0.23	3125.012 ±0.15
Zn Zn	31.430 ±0.01	42.15 ±0.06	39.231 ±2.03	69.563 ±15.11
Cu	44.751 ±0.11	23.850 ±0.06	29.120 ±0.15	79.090 ±0.08
Cd	0.235 ±0.08	0.245 ±0.35	0.752 ±0.011	5.913 ±0.15
Ni	0.120 ±0.03	0.098 ±0.01	3.651 ±0.12	3.010 ±0.98
Pb	0.073 ±0.01	0.361 ±0.13	0.526 ±0.08	3.737 ±0.14
Cr	0.332 ±0.04	0.285 ±0.23	0.245 ±0.12	0.650 ±0.04

Table 2: Mean Concentrations of Heavy Metals in Vegetables and Farm Soils from Agbara Industrial Area Compared with WHO/FAO (2011) Safety Limits

Samples /	Metals (mg/kg)						
Standard	Fe	Zn	Cu	Cd	Ni	Pb	Cr
A. esculentus	144.8 *±0.01*	*31.4 ±0.01*	*44.8 ±0.11*	*0.24 ±0.08*	*0.12 ±0.03*	*0.07 ±0.01*	0.32 *±0.04*
S. lycopersicum	36.2 *±0.05*	*42.2 ±0.06*	*23.9 ±0.06*	*0.25 ±0.35*	*0.10 ±0.01*	*0.36 ±0.13*	0.29 *±0.23*
S. oleracea	117.5 *±0.23*	*39.2 ±2.03*	*29.1 ±0.15*	*0.75 ±0.01*	*3.65 ±0.12*	*0.53 ±0.08*	0.25 *±0.12*
Farm Soil	3125 *±0.15*	69.6 *±15.11*	*79.1 ±0.08*	5.91 *±0.15*	3.01 *±0.98*	3.74 *±0.14*	0.65 *±0.04*
WHO/FAO (2011)	426	100	73	0.1	10	0.3	1.36

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

Samples	Fe	Zn	Cu	Cd	Ni	Pb	Cr
Fe	1	0.875**	0.943**	0.996**	0.474	0.992**	0.985**
Zn		1	0.704	0.890**	0.512	0.911**	0.799*
Cu			1	0.923**	0.351	0.897**	0.970**
Cd				1	0.544	0.997**	0.969**
Ni					1	0.537	0.353
Pb						1	0.959**
Cr							1

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

Discussions

Table 1 showed the average amount of heavy metals like Cd, Cr, Cu, Fe, Ni, Pb and Zn in the soil used for farming and in the vegetables, people eat around the Agbara Industrial Area in Ogun State, Nigeria. The results show that the soil has a lot more of these metals specifically Cd, Cr, Cu, Pb and Zn than the parts of the vegetables that people eat. This means that the soil is where these heavy metals are mostly found when they are released into the environment. This is similar to what other people found out in Nigeria. Oloruntoba et al. (2024) found out that the soil around industries in the southwest part of Nigeria had a lot more heavy metals, than the crops that were grown in that soil. This happens because the soil can keep these metals for a time by holding onto them with the help of clay and other organic materials. Similar observations were reported by Suleiman and Ibrahim (2025) in Kano State, where agricultural soils located near industrial activities contained markedly higher concentrations of toxic metals than vegetables cultivated on the same farms. And is also consistent with the established understanding that soils serve as long-term sinks for metallic pollutants because heavy metals are non-biodegradable and can persist in the soil for many years after their release from anthropogenic sources (Manwani et al., 2023).

The high amount of Cd and Pb in *S. Oleracea* (spinach), which is also known as spinach is very worrying. This is because leafy vegetables like spinach are really good at absorbing metals. The big surfaces of the leaves catch a lot of the stuff that is in the air. The roots of these plants are also very good at soaking up metals from the soil. Some people like Onaji et al. (2024) found out that the leafy vegetables they bought in Zaria had bad metals in them than some fruit vegetables. This means that people who eat these vegetables are at a higher risk of getting sick. It has been seen times that leafy vegetables, like spinach have more heavy metals in them than fruit vegetables. This is true even when they are grown in the kind of environment. Gelaye and Musie (2023) said that leafy vegetables often have heavy metals in them than fruit vegetables.

Table 2 showed the comparison of the measured mean value concentrations with the WHO/FAO guideline values. It showed that Cd concentrations in all analysed vegetables exceeded the recommended permissible limit of 0.1 mg/kg. Pb concentrations in *S. oleracea* and *S. lycopersicum* (tomato) also exceeded the recommended limit of 0.3 mg/kg. These findings are comparable with those reported by Suleiman and Ibrahim (2025). They also observed Cd concentrations above the WHO/ permissible limit in spinach, they also observed same for Pb concentrations in spinach and carrot. These vegetables were cultivated within the Sharada Industrial Zone in Kano State. Their study concluded that industrial emissions and contaminated irrigation practices were the contributors to heavy metal accumulation. The heavy metal accumulation happened in vegetables grown close, to facilities.

Conversely, although Cr, Cu, Ni, Fe, and Zn were detected in all vegetable samples, their concentrations remained below the WHO/FAO maximum permissible limits. This finding agrees with the studies by Ibrahim *et al*. (2024) and Guerrieri *et al*. (2024), who reported that while several essential trace metals were present in crops cultivated near industrial environments, many remained within internationally accepted food safety limits despite evidence of soil contamination. The relatively lower concentrations of these metals in edible tissues may be attributed to limited bioavailability in soil, selective uptake by plant roots, metal immobilisation through soil adsorption processes, and physiological mechanisms that regulate the movement of metals from roots to edible plant parts.

The Pearson correlation analysis in Table 3 further supports the existence of common contamination pathways within the study area. Strong positive correlations were observed among Cd, Pb, Cr, Cu, Fe, and Zn, whereas Ni exhibited comparatively weak relationships with the other metals. These strong correlations suggest that the majority of the analysed metals originated from similar anthropogenic sources and were transported through related environmental pathways before accumulating in agricultural soils and vegetables.

In environmental pollution studies, significant positive correlations among heavy metals are commonly interpreted as evidence of common emission sources or similar geochemical behaviour (Rehman et al., 2023). Conversely, weak or negative correlations may indicate different pollution sources, geochemical processes, or transport mechanisms (Zhao et al., 2024).

The findings also underscore the need for continuous monitoring of agricultural soils and vegetables cultivated around industrial estates. Environmental regulatory agencies such as the National Environmental Standards and Regulations Enforcement Agency (NESREA) and relevant state environmental protection authorities should strengthen surveillance programmes to ensure that vegetables entering local markets meet established food safety standards. Regular monitoring would facilitate the early detection of contamination trends and support timely intervention before heavy metal concentrations reach levels that pose unacceptable risks to human health. In addition to regulatory measures, farmers cultivating vegetables near industrial zones should be encouraged to adopt sustainable agricultural practices that minimise heavy metal uptake. Such practices may include periodic soil testing, careful selection of crop species with lower metal accumulation potential, application of organic amendments that reduce metal bioavailability, and avoidance of irrigation with untreated industrial wastewater. Public education programmes are also essential to increase awareness among farmers, consumers, and local communities regarding the health risks associated with heavy metal contamination and the importance of safe agricultural practices.

Conclusion

This study evaluated the concentrations of selected heavy metals in agricultural soils and vegetable crops cultivated within the Agbara Industrial Zone, Ogun State, Nigeria. The results showed that the soil contained higher concentrations of Fe, Zn, Cu, Cd, Pb and Cr than the vegetable samples, while Ni was higher in spinach than in the soil sample. Among the vegetables analysed, spinach generally recorded higher concentrations of Cd, Ni and Pb, while tomato recorded the highest Zn concentration and okra recorded the highest Cu and Cr concentrations. Comparison with the guideline values used in this study showed that Cd concentrations in okra, tomato and spinach were above the WHO/FAO recommended limit of 0.10 mg/kg. Pb concentrations in tomato and spinach were also above the WHO/FAO recommended limit of 0.30 mg/kg. The Pearson correlation analysis showed several strong positive relationships among the metals, particularly between Cd and Pb, Fe and Cd, Fe and Pb, and Pb and Cr. These relationships indicate that some of the metals tended to vary together in the samples. However, the correlation results alone cannot confirm that the metals came from the same source. Overall, the findings show that Cd and Pb require particular attention in the vegetable samples examined, especially because their measured concentrations exceeded the reference values used for comparison. However, the study did not directly determine the sources of the metals or measure human exposure. Therefore, the findings should be interpreted as evidence of heavy metal contamination in the sampled agricultural environment rather than as direct evidence of health effects. Further studies involving soil properties, irrigation water, background or control sites, and metal transfer from soil to crops would provide a better understanding of the factors contributing to the observed contamination.

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Conflict of Interest

There is no conflict of interest regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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