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ORIGINAL RESEARCH ARTICLE

Bio-Concentration Factors of Heavy Metals in the Leaf and Root System of Some Selected Vegetables along the Dilimi River in Jos North, Plateau State, Nigeria

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ABSTRACT
This research sought to evaluate the bio-concentration factors of specific heavy metals to facilitate the sustainable management and use of irrigation sites. Sixteen samples of lettuce and spinach were gathered, and each was divided into leaves and roots, placed into a different polythene bag and tagged with the plant's name, part, and stratum. The heavy metals that were analyzed included Lead (Pb), zinc (Zn), cadmium (Cd), chromium (Cr), iron (Fe), and Nickel (Ni). The analysis was done using Atomic Absorption Spectroscopy (AAS). The findings showed that all the metals Cr, Fe, Pb, Ni, Zn, and Cd were within the WHO recommended permissible limit in soils, despite the vegetables having higher Fe concentrations than the recommended limit of 20.00 ppm. The results also showed that the roots and leaves of spinach and lettuce vegetables primarily categorized the heavy metals as having moderate Bio-Concentration Factor (BCF) values, which ranged between 0.1 and 1.0. The results also revealed hyper-accumulation of Ni (1.723) and Cr (1.249) in the leaves of lettuce and spinach. The results also indicate a weak relationship between plants and the heavy metals in the soil. The strongest association ($r = -0.512$) was found between Ni in the soil and Fe in the vegetables. Farmers along the river should be made aware of the detrimental consequences of their actions.

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soil contamination, metal uptake, lettuce and spinach, bio-accumulation, and sustainable irrigation

INTRODUCTION
Vegetables are the greatest source of vitamins and a vital component of any country's economy. They are, therefore, ingested because they support health. However, they also include other harmful compounds (pollutants) and the nutrients they offer. Heavy metals are a notable example of such pollutants (Tchounwou *et al.*, 2012). Keepax *et al.* (2011) state that heavy metals are metals with densities greater than 5 to 6 g/cm3 and may be harmful at larger concentrations. Lead, mercury, arsenic, cadmium, chromium, copper, Nickel, and Zinc are among the most prevalent heavy metals contaminating the environment (Tchounwou *et al.*, 2012).

In many underdeveloped nations, such as Nigeria, wastewater is frequently utilized to irrigate fruits and vegetables due to a lack of clean water resources. Most African nations that struggle with water scarcity frequently use unconventional sources, such as contaminated water from industrial and domestic runoffs (Al-Ansari *et al.*, 2013). Crop irrigation with uncontrolled wastewater causes some potentially hazardous metals to build up in the soil and has a negative impact on plant growth (Muhammad *et al.*, 2019).

Given that they provide humans with vitamins, minerals, carbohydrates, dietary fibres, and vital amino acids, vegetables are regarded as a necessary part of human nutrition. Nevertheless, they belong to a food group that maximally contributes to ingesting heavy metals, nitrate, and other anions (Okunlola, 2019). Vegetable contamination by heavy metals has drawn a lot of attention lately because vegetables can bioaccumulate heavy metals due to their relatively high dietary content (Oluwatosin *et al.*, 2010; Mawari *et al.*, 2022), which puts human health at risk. As human activities increase, especially with modern technology, pollution and contamination of the human food chain have become inevitable (Marshall, 2003).

According to Okunlola (2019), a number of widely used herbicides in horticulture and agriculture had significant metal concentrations. In light of food nutrition,

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agricultural yield technologies, and health impacts, it is critical to determine the metal content of vegetables (Makinde *et al.*, 2010). To make sure that the amounts of these metals in the food satisfy the set international standards, testing and analysis are required because of the food products' persistent character, cumulative behaviour, and potential for toxicity from consuming leafy vegetables and fruits (Okunlola and Abdul-Azeez, 2018).

Vegetables are consumed enormously by humans all over the world. Consumption of contaminated fruits and vegetables is the most likely route of heavy metal exposure. Hence, it is important to quantify heavy metal concentration in frequently consumed fruits and vegetables (Tchounwou *et al.*, 2012). They are consumed in both cooked and raw forms, thus vegetables containing toxic metals can cause detrimental effects on human health (Ahmad *et al.*, 2021).

Thus, this research aims to evaluate the bio-concentration factors of toxic metals in soil and certain plants (lettuce and spinach) along the Dilimi River. Most of the locals in studied locations are unaware of the direct or indirect effects that the rate at which vegetables absorb heavy metals has had on them. This might have led to several issues that the residents of the study region and nearby areas might not have been aware of. The investigation aimed to ascertain the degree of selected heavy metal (Zn, CR, Pb, Ni, Fe, and Pb) bioaccumulation in a vegetable tissue, specifically spinach and lettuce, along the Dilimi River in the state of Jos North LGA Plateau.

MATERIALS AND METHODS

Study Area

The Jos Plateau is a highland region of the north-central Nigerian highlands (Mailoushi *et al.*, 2015). The research geographical area is located between latitudes 9°51' N and 10°3' N and longitudes 8°48' E and 8°67' E (Figure. 1). Most of the Jos Plateau's perimeter is bounded by escarpments that range in height from 300 to 600 meters. It covers an area of roughly 8600 km³, approximately 1,200 m. It climbs above 1400 m to the south of Barkin Ladi and the east of Jos (Dung-Gwom *et al.*, 2009). The Plateau's climate is very different from the plains around it. The Inter-Tropical Convergence Zone's (ITCZ) seasonal movement determines three distinct seasons: a warm season (March and April), a rainy season (May to September), and a harmattan wind that generates the coldest weather (December to February) with temperatures between 18°C and 22°C (Wuyep and Daloeng, 2020). A dusty and dry north-easterly airflow

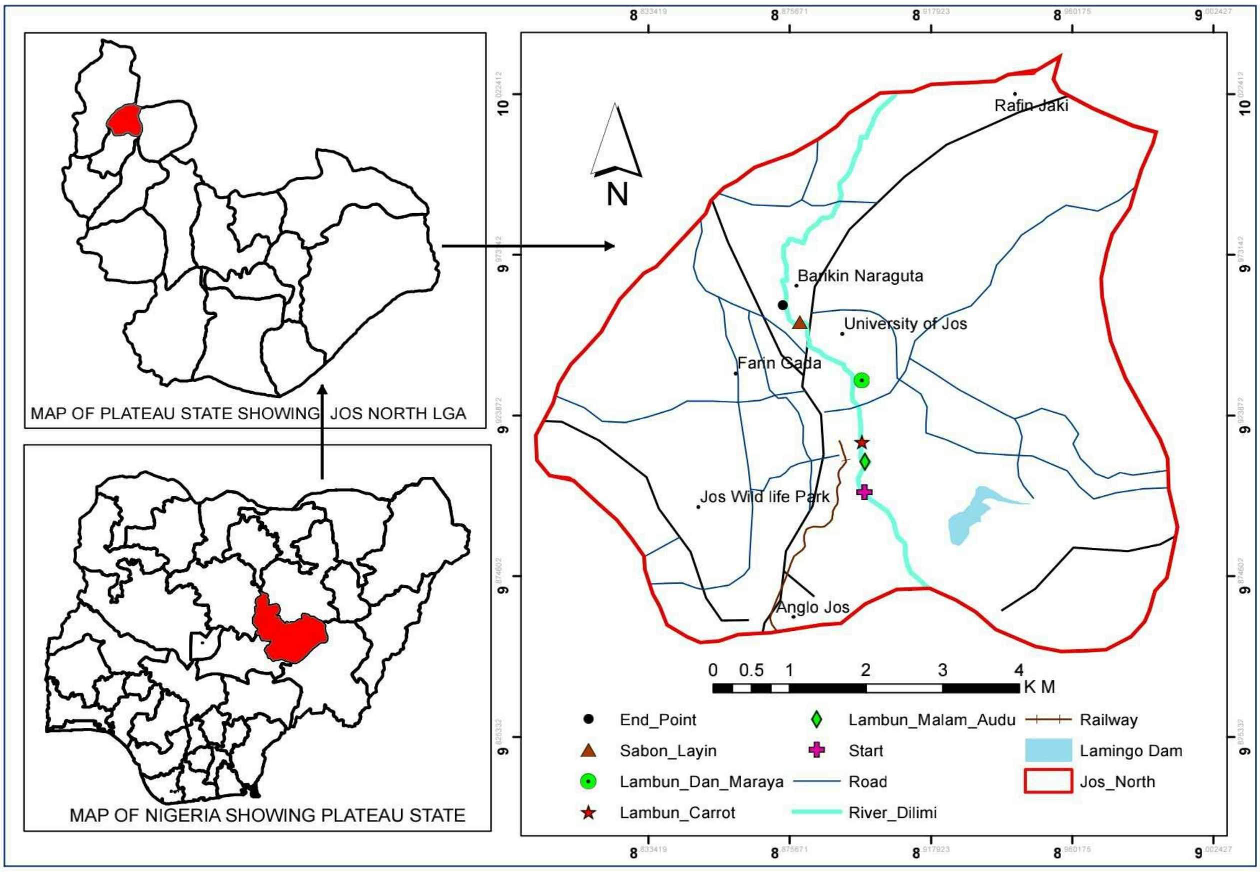

Figure 1: Study area showing the sampling points. Source: Cartography, Geography Dept BUK (June 2022)

that provides clear skies and cool or cold nighttime temperatures of 15.5°C to 18.5°C defines the cool months (Philemon and Yakmut, 2018). erratic daytime temperatures, little precipitation, and dust clouds (Harmattan). The north-easterly airflow diminishes as the ITCZ approaches from the south, causing temperature and humidity to rise. As a result, the rainy season begins, marked by a slight decrease in temperature and humidity (Wuyep and Daloeng, 2020).

Materials used

Materials like a hoe, marker, paraffin mark, hand glove, polyether bag, scissors, masking tape, and hand-held GPS were employed in this study. A portable GPS device was used to determine the geographic coordinates of every sampling site.

Method of Sample Collection

Since the research aims to evaluate the bio-concentration factors of particular heavy metals from particular plants along the Dilimi River, an experimental research approach was chosen in two stages. This research adapts stratified and basic random sampling techniques.

The irrigable fadama site was initially divided into four strata: Lanbun Malam Audu, Lanbun Carrot, Lanbun Dan Maraya, and Lanbun Sabon Layi. Each layer was appropriately designated. During the second stage, random samples of soils and vegetables were taken from each of the four layers. To obtain 16 soil samples, four (4) samples were taken from each of the four strata (4 x 4 = 16). The study used 48 samples (32 + 16 = 48) of the soil and vegetable samples since 32 and 16 soil samples were used in the investigation.

Sample Preparations and Treatment

To remove any suspended particles, the collected samples were divided and cleansed using distilled water after being cleaned with tap water. Every leaf sample had its calyx and pedicel cut off and put to the corresponding shoot. Using a plastic knife, the sample was divided into smaller pieces. The required quality assurance precautions were followed to avoid contaminating the sample. Unwanted elements were taken out of the soil. To prevent contamination, soil samples were allowed to air dry in a sterile room before being pulverized and put in polyethylene bags for examination after passing through a 600 µm screen. The samples were placed in various crucibles and burned for two hours at 650 °Cin a furnace.

0.5 g of each plant sample's ash was measured and put into a beaker severally. Each was treated for ten minutes at 100^{0}C on a hot plate to eliminate carbonates and oxidizable elements. 1 ml of concentrated HNO_3 and 3 ml of concentrated HCl were added. After adding deionized water to the solutions up to 30 ml, a Whitman filter paper (#41 Whatman filter paper) was used to filter them. The heavy metals' presence in the filtrate was then examined.

Digestion of Soil Samples and Laboratory Analysis

To destroy any oxidizable elements and carbonates, 3 ml of concentrated HCl and 1 ml of concentrated HNO3 were added to 0.4 g of soil samples, which were weighed individually from each irrigable area into a beaker. The beakers were heated on a hot plate for ten minutes at 100°C. After adding deionized water to the solutions up to the 30 ml mark, the student-grade Whitman filter paper was used to filter them. Heavy metal content in the filtrate was examined. To eliminate any background metal concentration throughout the system, blank samples of reagents were examined.

The amount of the target heavy metals in the filtrates was inhaled inside the Atomic Absorption Spectroscopy (AAS) excitation zone, where a flame discharge caused them to dissolve, evaporate, and atomize. The analytical and non-analytical light wavelengths that the monochromator separated the hollow cathode lamp emitted. The metal under analysis determined the performance of the hollow cathode lamp. Light-sensitive detectors were used to quantify the amount of light absorbed, and a computer was used to measure the detector's reaction and convert it to concentration.

Method of Analyzing Data

The data was analyzed using the Statistical Package for the Social Sciences (SPSS), edition 16. The means and standard deviations of the heavy metal concentrations for each sample were computed using a Microsoft Excel 2010 spreadsheet. The standard deviation of the mean, or mean ± SDM, was employed to demonstrate the heavy metal concentrations. Additionally, the outcome was compared to the World Health Organization (WHO) and Food and Agricultural Organization (FAO) standards (Table 1). Using SPSS version 16, analysis of Variance (ANOVA) was also applied to the heavy metal concentration values, with values for $p < 0.05$ being regarded as statistically different. To find meaningful variations between the means, the Least Significant Difference (LSD) was employed.

RESULTS AND DISCUSSION

Concentrations of Heavy Metals in Vegetables and Soil

According to the investigation, spinach plants had an average concentration of Cr ranging from 0.17±0.02 to 0.22±0.02 ppm, which was substantially lower than the

40-ppm allowed threshold for animal feed (FAO, 1998) but still below the 0.2 ppm crucial level for fodder crops (McDowell, 1997). According to a Pakistani study (Amin *et al.*, 2013), the amounts of Cd, Cr, and Pb in spinach grown in soil irrigated with wastewater were 0.26, 53.02, and 40.10 ppm, respectively. Our investigation's findings were substantially lower than these figures.

When contrasting the Fe and Cr amounts in spinach samples with those reported by Kfle *et al.* (2020) in plants from similar environments, the quantities of Ni, Pb, and Cd are lower. Comparing spinach with sewage water irrigated grass (ryegrass) and ryegrass, Aganga *et al.* (2005) found that the amounts of Cd are similar, Pb and Fe are higher, and Ni and Zn are lower in spinach.

Bio-concentration Factors of Selected Heavy Metals

The heavy metal bio-concentration factor in spinach plants is as follows: Cr (1.121ppm) > Cd (0.657ppm) > Ni (0.548ppm) > Zn (0.352ppm) > Pb (0.159ppm) > Fe (0.06ppm). But Ni had the largest bio-concentration factor in the lettuce plant (1.04 ppm), followed by Cd, Zn, Pb, Cr, and Fe (Figure 2).

While the roots of the spinach plant had greater bio-concentration factors for Cd (0.741ppm) and Pb (0.248ppm), the leaves of the plant had higher bio-concentration factors for Cr (1.249ppm), Fe (0.073ppm), Ni (0.743ppm), and Zn (0.476ppm). The sequence of heavy metal bio-concentration factors in the leaves of lettuce plants is Ni > Cd > Zn > Cr > Pb > Fe. The sequence of heavy metal bio-concentration factors in spinach leaves is Cr > Cd > Ni > Zn > Pb > Fe (Table 2).

Table 1: Concentrations of Heavy Metals in Vegetables and Soil with FAO/WHO Standards

Plant Name	Sample	Cd	Cr	Fe	Pb	Ni	Zn
Spinach	Soil	0.01±0.01	0.17±0.02	220.06 ±87.44	3.06 ±2.26	0.15±0.06	3.56 ±1.61
	Root	0.01±0.01	0.17±0.02	25.98 ±5.06	0.76 ±0.36	0.05±0.03	1.70 ±0.81
	Leaf	0.01±0.00	0.22±0.02	20.59 ±5.86	0.21 ±1.15	0.11±0.05	0.81 ±0.42
Lettuce	Soil	0.01±0.01	0.22±0.06	163.74 ±31.34	3.79 ±2.08	0.11±0.09	2.58 ±0.95
	Root	0.01±0.01	0.08±0.07	29.74 ±4.94	0.13 ±0.07	0.18±0.26	2.44 ±1.93
	Leaf	0.01±0.01	0.09±0.04	21.66 ±4.05	0.09 ±0.31	0.04±0.02	0.99 ±0.38
FAO/ WHO (ppm)	Soil	3.0	100	1500	85	35	100
	Plant	0.30	1 .5	20	10	1.5	50

Values are mean ± standard deviation.

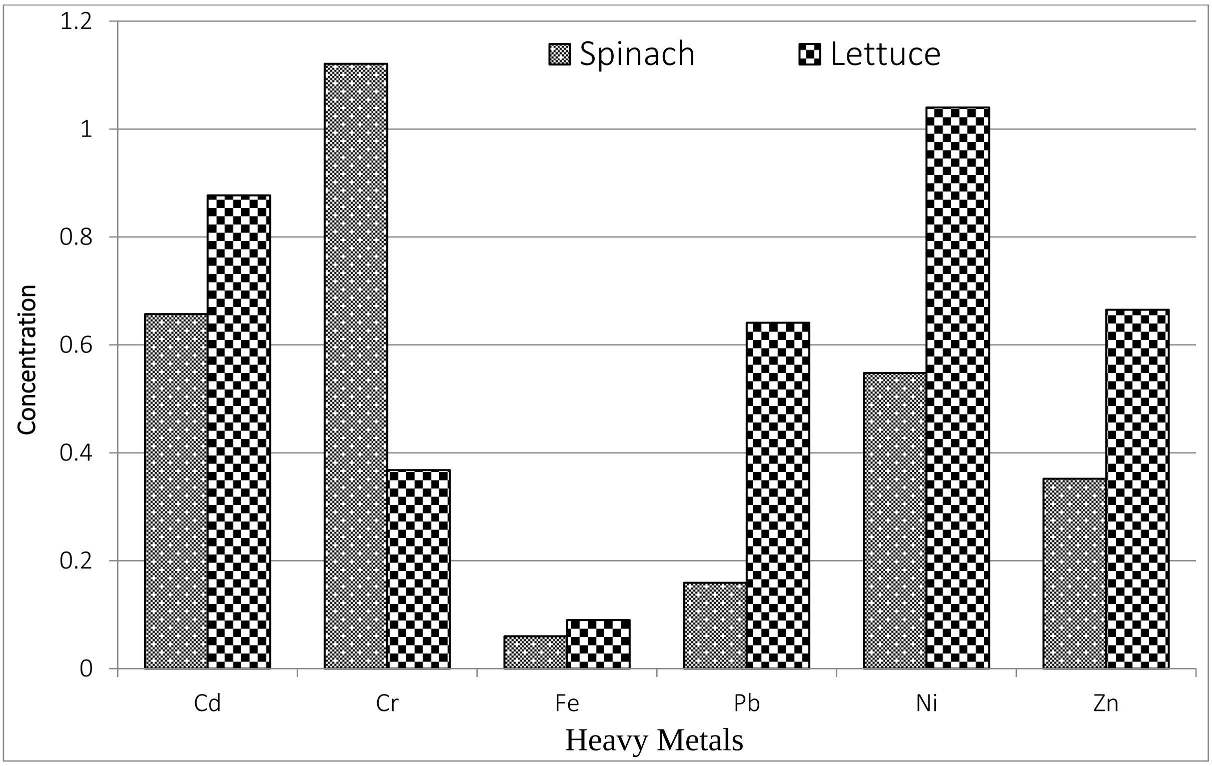

Figure 2: Heavy metals' mean bio-concentration factor (BCF) values.

Table 2: Heavy metals' mean bio-concentration factor (BCF)

Plant	Part	Cd	Cr	Fe	Pb	Ni	Zn
Spinach	Root	0.741	0.993	0.048	0.248	0.354	0.228
	Leaf	0.573	1.249	0.073	0.070	0.743	0.476
Lettuce	Root	0.768	0.339	0.035	0.306	0.358	0.385
	Leaf	0.985	0.398	0.145	0.024	1.723	0.945

Table 2 displays the average BCF values of the spinach plant's metal concentrations in relation to the soil. In the spinach leaves, Cr had the highest BCF value at 1.249 ppm, followed by Ni (0.743 ppm), Cd (0.573 ppm), and Zn (0.476 ppm). In the spinach roots, Cr had the highest BCF value at 0.993 ppm, followed by Cd (0.741 ppm), Ni (0.354 ppm), Pb (0.248 ppm), and Zn (0.228 ppm). Spinach absorbed the metals from the soil at a moderate rate; the BCF values of the other metals vary from 0.048 ppm to 0.073 ppm.

The results also revealed an excess of Ni (1.723 ppm) and Cr (1.249 ppm) in the leaves of lettuce and spinach plants. According to Netty *et al.* (2013), BCF values indicate low accumulator plants between 0.01 and 0.1, no accumulator plants are indicated by BCF values less than 0.01, and hyperaccumulator plants are indicated by BCF values between 1 and 10.

The BCF findings indicated no relationship was found directly between the metal concentrations in the soil and the concentrations in the lettuce and spinach plants. Compared to soil Cr concentration, spinach root's BCF value for Cr is somewhat lower than that of spinach leaf, suggesting that spinach root has a lesser capacity to absorb Cr. Consequently, compared to spinach leaves, the concentration of Cr in spinach roots is lower (Table 2). This suggests that vegetables have a moderate capacity to draw heavy metals out of the soil. In a related investigation, Njoh (2019) found that Cd had a high transfer potential while analyzing heavy metals in agricultural and vegetable soil samples from Gemikonagi and Dipkarpaz (North Cyprus). The low BCF values of Fe in the leaves and roots of lettuce and spinach plants may be due to an elevated quantity of metals in the soil or reduced translocation starting from the root and working up to the shoot (Aganga *et al.*, 2005).

Soil-vegetable transfer coefficients (%) of heavy metals

The outcome displays the heavy metal transfer coefficients (%) among soil and vegetables (Table 3). The soil-plant transfer coefficient is critical in determining human exposure to heavy metals through the food chain because it illustrates the movement of pollutants from soil to plants (Gupta *et al.*, 2013; Tasrina *et al.*, 2015). The results show that both vegetables' transfer coefficients for Cd, Cr, Fe, Pb, Ni, and Zn were high. Spinach leaf exhibited the highest Ni (5.42) and Cr (5.27) transfer coefficients, whereas spinach root had the highest for Cd (7.30,0 Fe (7.26), Pb (6.98), Cr (4.86), and Zn (4.65). The transfer coefficients for Cd (8.53), Cr (5.75), Fe (4.50), Zn (4,46), Pb (2.40), and Ni (2.28) were greater for the lettuce root. Conversely, the greatest Cd (6.77) and Ni (5.81) transfer coefficients were found in lettuce leaves.

The results also show that Cd has better transferability and that the spinach plant's root has a larger capacity for absorption than the spinach leaf. Additionally, the metal's chemical form, amounts in the soil, plant uptake capacity, and rate of plant species growth all affect the transfer coefficient (Tinker, 1981). The results show a direct correlation between the soil-plant transfer coefficients and detected heavy metal concentrations. Since Cd and Zn are naturally occurring heavy metals in soil, their increased mobility and lesser retention relative to other cations may account for their greatest coefficient values (Zurera *et al.*, 1987; Alam *et al.*, 2003). The increased contamination from wastewater irrigation, agrochemicals, solid waste combustion, solid waste disposal and sludge applications, and vehicle exhaust could cause elevated quantities of these heavy metals (Intawongse and Dean, 2006).

Table 3: Soil-vegetable transfer coefficients (%) of heavy metal

Plant	Part	Cd	Cr	Fe	Pb	Ni	Zn
Spinach	Root	7.30	4.86	7.26	6.98	4.26	4.65
	Leaf	4.13	5.27	4.81	4.84	5.42	2.79
Lettuce	Root	8.53	5.75	4.50	2.40	2.28	4.46
	Leaf	6.77	3.88	3.46	0.55	5.81	3.48

Heavy Metal Relationships in Soil and Vegetable Samples

The findings of the Pearson correlation study are displayed in Table 4. There were numerous metals with substantial correlations (coefficients >0.6) considering the concentration of heavy metals in the spinach sample. There was a substantial correlation found between Fe concentrations and Zinc ($r = 0.831$; $P < 0.01$), Lead ($r = 0.742$; $P < 0.01$), and Nickel ($r = 0.536$; $P < 0.01$), for example. Robust associations imply a shared origin, and these metal kinds might be representative of lithogenic soil parent minerals (Facchinelli *et al.*, 2001; Ali *et al.*, 2016).

Nevertheless, no association was seen between Cd, Cr, and other elements in the spinach samples. This could imply that the presence of Cd and Cr metals in spinach was more likely the result of unrelated, diverse sources, perhaps even human activity. However, the metals in the lettuce samples showed strong connections. There were significant associations found between Cr and Fe ($r = 0.693$; $P < 0.01$), Pb ($r = 0.624$; $P < 0.01$), Zn ($r = 0.485$; $P < 0.05$), and Cd and Pb ($r = 0.543$; $P < 0.01$). Furthermore, Fe and Zn ($r = 0.727$; $P < 0.01$) and Pb ($r = 0.783$; $P < 0.01$) showed a strong association. This implies that related sources, including anthropogenic sources, were more likely to have impacted the amounts of heavy metals in the lettuce samples.

Table 5 displays the heavy metal element Pearson's correlation matrix for soil samples and plants under study. The distribution of the statistics shows that most heavy metals have positive relationships with one another, with positive values predominating. The concentrations of other heavy metals will rise in tandem with an increase in one, and vice versa (Su and Liu, 2014). The stronger the link between two heavy metals, the higher the value. The strongest link was found between Ni (soil) and Fe (plant) ($r = -0.512$), then between Fe (soil) and Cr (plant) ($r = -0.479$), and between the soil's Cr and the plant's Cd ($r = -0.459$).

Table 4: Heavy metal correlation analysis in lettuce and spinach plants

Plant		Cd	Cr	Fe	Pb	Ni	Zn
Spinach	Cd	1.000					
	Cr	-0.249	1.000				
	Fe	0.084	-0.234	1.000			
	Pb	0.055	-0.082	**0.742****	1.000		
	Ni	0.245	0.336	**0.536****	**0.635****	1.000	
	Zn	-0.005	0.043	**0.831****	**0.785****	**0.640****	1.000
Lettuce	Cd	1.000					
	Cr	0.394	1.000				
	Fe	0.400	**0.693****	1.000			
	Pb	**0.543****	**0.624****	**0.783****	1.000		
	Ni	-0.027	0.120	0.268	0.288	1.000	
	Zn	0.340	**0.485***	**0.727****	**0.842****	0.356	1.000

**The correlation is significant at the two-tailed 0.01 level. *The correlation is significant at the two-tailed 0.05 level.

Table 5: Correlation analysis between soil and vegetable-heavy metals

Heavy Metals in Plant	Heavy Metals in Soil					
	Cd	Cr	Fe	Pb	Ni	Zn
Cd	0.215	**-0.459**	0.115	0.162	0.344	0.032
Cr	-0.230	0.324	**-0.479**	0.024	-0.191	-0.341
Fe	-0.056	0.224	-0.041	0.185	**-0.512***	0.206
Pb	0.165	0.135	-0.115	0.362	-0.141	0.194
Ni	0.115	0.212	-0.182	0.206	0.144	-0.085
Zn	0.165	0.376	-0.103	0.324	-0.203	0.094

**At the 2-tailed 0.01 level, the correlation is significant. *At the 0.05 level (2-tailed), the correlation is significant.

CONCLUSION

The study's conclusions indicate that except for iron (Fe) in the vegetable, the amounts of Ni, Cr, Fe, Pb, Zn, and Cd in both soil and vegetables are within the WHO/FAO's permitted limits. According to the bio-concentration factor value, there is a greater potential for Cr and Ni to be transferred from the soil to the vegetable leaves. The study found a weak relationship ($P > 0.05$) between heavy metals in vegetables and soil. The highest concentration of heavy metals was found in the soil samples, then in the roots and leaves of the selected plants. Elemental concentrations varied between the soil and the plants as well. Based on this study, regularly monitoring soil heavy metal levels is advised to avoid an excessive buildup in the food chain and consequent hazards to human health. Therefore, to reduce health risks, this study recommends that administrators, public health experts, and environmentalists increase public knowledge regarding the need to refrain from consuming vegetables cultivated in contaminated soils. Further study is also recommended on risk to human health through identifying the actualized Health risk/attribution/connecting exposure to actual disease conditions in the population.

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