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Assessment of Heavy Metal Contamination of Irrigated Vegetables Grown along the Kubanni Irrigation Site in Zaria, Nigeria

[1]Jabir Abdulkadir, Abdullahi Jibrin[2], Mukhtar Ibrahim[3] and Jabir Haruna Abdulkareem[4]

[1]Department of Basic Science, College of Agriculture and Animal Science, Division of Agricultural Science, Ahmadu Bello University, Zaria [2&3]Department of Geography and Environmental Management, Ahmadu Bello University, Zaria [4]Department of Soil Science, Institute for Agricultural Research, Faculty of Agriculture, Ahmadu Bello University, Zaria, Kaduna, Nigeria.
Corresponding Author: *jabir3671@gmail.com*

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Abstract

The presence of heavy metals in vegetables is a serious health issue to consumers. This study focuses on the analysis and quantification of heavy metals in vegetables, soils and irrigation water within the Kubanni irrigation site in Zaria, Nigeria. Field surveys were conducted to collect samples of vegetables, soils and irrigation water through random sampling across the study area and analyze them for heavy metal contamination. A total of 175 samples of vegetables, soils and water samples were obtained from 25 farmlands. The selected vegetables include spinach, cabbage, lettuce, onion and tomatoes. The metals analyzed include Cr, Fe, Pb and Cd. Atomic absorption spectroscopy was used to measure the levels of heavy metals in the samples. Results showed that all vegetables contained detectable levels of heavy metals beyond WHO permissible limits, with Tomatoes having the highest concentration of Cr (105.9 mg/kg), Fe was highest in lettuce (1382.4 mg/kg); Spinach recorded highest concentration of Pb (169.1 mg/kg) while lettuce had the highest Cd level (16.7 mg/kg). ANOVA result shows significant difference between heavy metal contents in vegetables and those of soils and irrigation water within the study area. Correlation coefficient analysis revealed that metals like Cr, Fe and Pb found in vegetables are positively related with metals in soils (0.284, 0.185, 0.453) and also with irrigation water (0.588,0.052, 0.301) while Cd is negatively correlated in both soil (-0.290) and water (-0.120). The study recommends good farming practices to ensure safety of vegetables with the Kubanni irrigation site.

Introduction

Rapid growth of urban population in Nigeria is associated with a rise in food demand including vegetables which are an essential part of our daily diet (Igwe et al., 2017). Urbanization increases the need for food, water, and land which forces farmers to rely on untreated water from adjacent rivers or streams to irrigate crops. Organic manure, municipal trash, and pesticides used during cultivation of vegetables are possible contamination sources (Traore et al., 2022). Given how it affects human health, food safety continues to be a top public priority. One of the major causes of death in the majority of developing nations in Africa, particularly in the West African sub-region, is the growth of food-related diseases (Anna et al., 2019). One of the key factors contributing to the rapid spread of foodborne illness in most parts of the world is the environment's lack of hygienic conditions (Amani and Aljahani, 2020). The majority of foods we consume contain one or more pollutants that could prove hazardous to our well-being. When food is exposed to with specific environmental toxins, contamination may develop (Gaddafi et al., 2020). It's possible for contaminants to exist in the soil or irrigation water. They can also be added to the soil by spreading organic manure made from garbage and animal waste (Getaneh, Mohammed and Siraj, 2018).

Fresh vegetables have a higher nutritional value than those that have been cooked or even partially cooked. They might, however, contain some pollutants notably heavy metals. Arsenic (As), Chromium (Cr), Aluminium (Al), Lead (Pb), Cadmium (Cd), and Iron (Fe) are a few examples of heavy metal pollutants that may be present in vegetables. Over the past few decades, the development of modern technology and human civilization has resulted in an increase in a variety of anthropogenic activities, including mining, the use of agrochemicals like pesticides and fertilizers, waste produced by the pharmaceutical industry, vehicle emissions, and many others. It is well known that these actions considerably contribute to the release of a certain amount of heavy metals into the environment (Bayissa and Gebeyehu, 2021). Considering the adverse effects that heavy metals have on both human and animal health, it is crucial to monitor their presence in soil, irrigation water, and produce (vegetables). Heavy metals like cadmium, chromium, iron and lead can harm human organs like the kidney, liver, and lungs if taken in large amounts (Binod, 2008).

The Kubanni River is one of the three main sources of surface water in Zaria. Others include Saye and Galma Rivers. The Kubanni is a seasonally flowing River, the dominant economic function of the River is irrigation, other uses include source of water for the Ahmadu Bello University and sand mining which was later banned by relevant authority in an effort to control erosion and further widening of the River valley. Varieties of crops are cultivated from irrigation to meet local nutritional needs within the study area. Examples of crops cultivated include spinach, cabbage, lettuce, carrot, etc. Most of the people engaging in the irrigation farming are small scale farmers. Apart from cash crops, food crops such as rice and maize are cultivated along the Kubanni River valley. Local markets such as Dan-Magaji and Kasuwan Mata are being served with agricultural commodities cultivated within the Kubanni irrigation site. Considering the volume of waste that is channeled into the River and used to irrigate crops alongside with organic solids (manure) as well as agro-chemicals used during cultivation, pollutants from various sources within the Kubanni irrigation site might seriously impair vegetables that are cultivated there.

Materials and Methods

The study area

The Kubanni Drainage Basin is located between Latitudes 11° 2' 0'' and 11° 12'0'' North and Longitude 7° 34' 0'' and 7° 48' 0'' East (See Figure 1). It covered a total area of about 21 km² (Abolude et al., 2012; Abdulkadir, 2022). According to Koppen's classification, Zaria is located in the tropical wet and dry climate zone designated as the Aw type. The wet season and the dry season are the two distinct seasons. The average annual rainfall is 1100 mm, with an intensity of 80 mm per hour. Convectional rainfall makes up the majority of the rainfall (Mangaji et al., 2020). The average temperature is high throughout the year with about 22 degrees Celsius in January which increases to 28 degrees Celsius in April, shortly before the start of the rainy season. The region's climate is conducive to irrigation farming, which enables farmers to grow a wide range of crops, including cabbage, lettuce, spinach, peppers, tomatoes, and carrots.

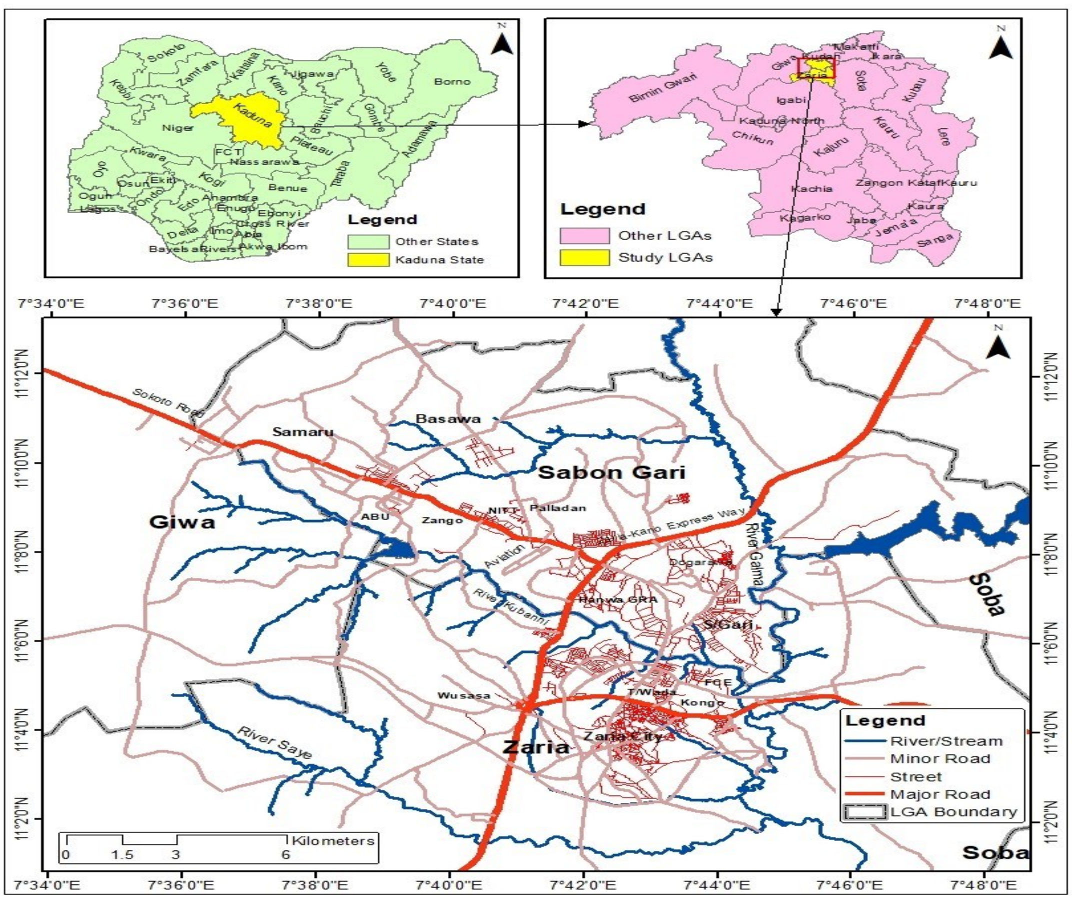

Figure 1: Zaria and its Environ Showing the Study Area

Source: Adapted from the administrative map of Kaduna state.

Sampling of soil, Irrigation Water and Vegetables

A total of 25 farmlands were selected as sampling stations. This is because there are differences in the kinds of crops that can be grown depending on the region. A farmer's experience or knowledge of the crop, the market, and their financial standing all play a role in the decision about the kind of vegetable to be cultivated. As a result, locations within the study region where the chosen crops are grown have been identified as 25 clusters in total.

Composite sample of soil were obtained using Randomized Complete Block Design (RCBD) method as used by Abdulkareem (2012). The lands were demarcated into uniform portion, 10 samples were randomly collected using soil Auger at 20cm depth. This is because vegetables have shallow root systems which do not exceed the 20cm depth. All the 10 samples were mixed in one bucket thoroughly, spread to a clean sheet. Surface litter, roots, pebbles and gravels were removed from the sample. The sample were divided into four, one portion was collected in a plastic bag. The bags were properly labeled with information such as location, crop type, and date. The samples were air dried (soil and vegetables samples only), crushed with mortar and pestle, sieved and packed into a clean plastic bag before they were taken to Mult-User laboratory at the Ahmadu Bello University Zaria for digestion and analysis using AAS machine.

For collection of vegetable samples, a random sampling method was used. Farmlands were partitioned into several units. Ten units were randomly selected for sampling. 1 sample was collected from each unit to make a total of 10 samples from each farmland. Because there are 5 varieties of vegetables selected for analysis in this study, a total of 250 vegetable samples were collected and homogenized to obtain 25 composite samples based on convenient sampling method. The choice for convenient sampling technique is based on the location and availability of resources for the study. The reason for selecting five vegetables is because they are the most commonly consumed vegetables within the study area. They include spinach, lettuce, tomatoes, onion and cabbage.

Irrigation water was collected closer to each of the selected irrigation farm. Because there are 25 farmlands under study, 25 water samples were purposively collected for analysis. The water samples were obtained at 5cm below water surface because that is the level where irrigation water is drawn from the river as used by Yakubu et al., (2017).

Laboratory Analysis

Laboratory analysis for determination of heavy metal concentration in irrigation water, soil and vegetable were conducted using Atomic Absorption Spectrophotometer (AAS). The metals analyzed include chromium (Cr), iron (Fe), lead (Pb) and cadmium (Cd). The metals were selected based on their health effects on consumers of contaminated vegetables.

Data Analysis

In this study, both descriptive and inferential statistics were used. Tables and charts from Microsoft excel were used to analyze some of the data while ANOVA and Peason's Correlation coefficient was conducted using SPSS software version 20.0.

Results and Discussion

Heavy Metal Pollutants in Vegetables

The levels of heavy metals in vegetables across the study area are contained in Figure 2, 3, 4 and 5.

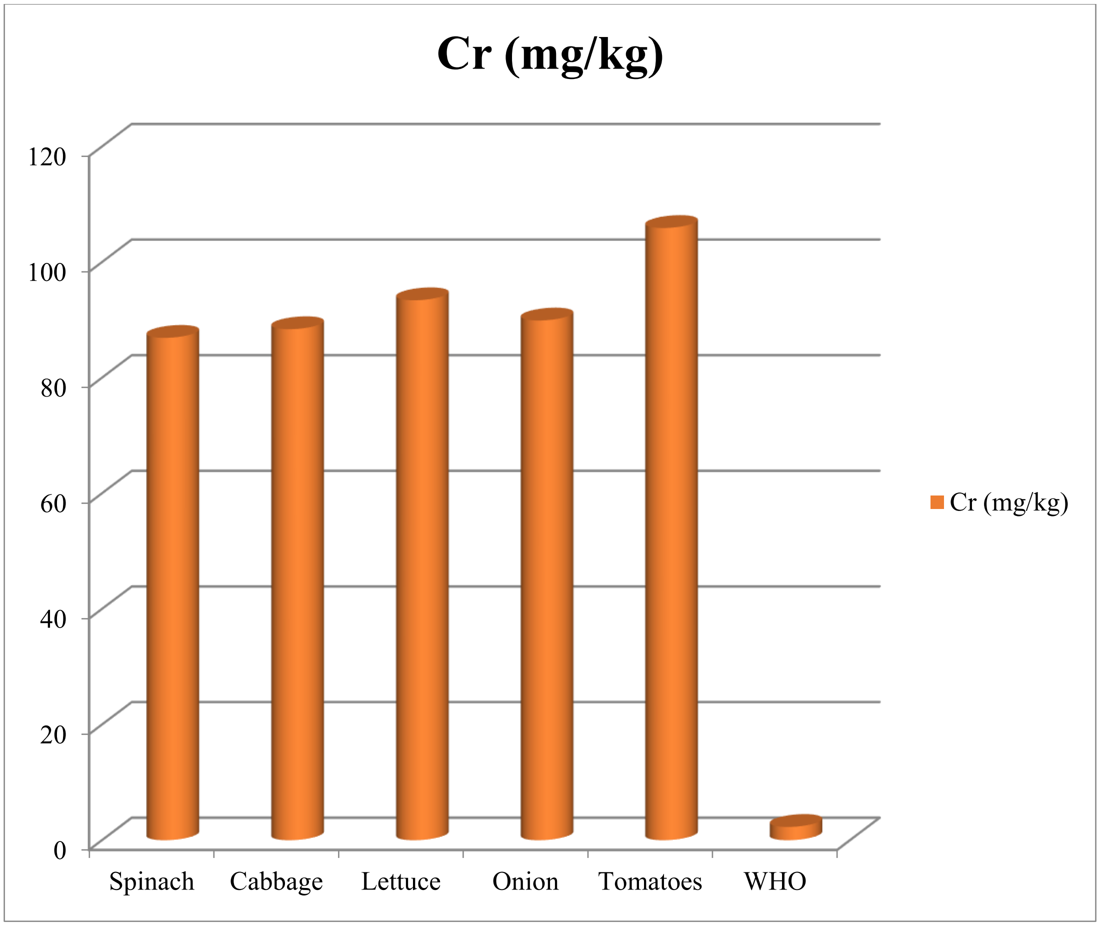

Figure 2: Chromium levels in Vegetables

As shown in Figure 2, all vegetables within the study area were found to be polluted with Cr. Spinach, cabbage, lettuce, onion and Tomatoes recorded a mean value of 86.9, 88.4, 93.4, 89.9, and 105.9 mg/kg respectively. Tomatoes had the highest Cr level (105.9 mg/kg) than all the selected vegetables while spinach is the least polluted with Cr. This means that tomatoes have more potential risk of causing health challenges related to high Cr contents in the study area than all other vegetables. The level of pollution with Cr in vegetables is in this order: Tomatoes > lettuce > onion > cabbage > spinach. Pollution level of Cr within Kubanni is far beyond the level observed by Faiz et al., (2021) who studied contamination of vegetables with Cr in Egypt stated that Cr is estimated at about 3.566 mg/kg in most vegetables. However, Xu et al., (2023) in their study of chromium contamination from vegetables in northern China observed that spinach recorded highest concentration of Cr (139.76 mg/kg) while lettuce had 18.23 mg/kg and cabbage with 9.63 mg/kg. According to Onakpa, Njan and Kalu (2018), spray of agro-chemicals especially fungicides and pesticides (see plate I) are major contributors of Cr to crops. The associated health effects of Cr include carcinogenic, hepatic, gastrointestinal, respiratory, skin, and cardiovascular effects. High Cr consumption causes respiratory diseases like airway irritation and obstruction, lungs and nasal cancer. Cr is also believed to cause kidney damage and as well as severe liver effect.

Plate I: A farmer spraying insecticide on Spinach

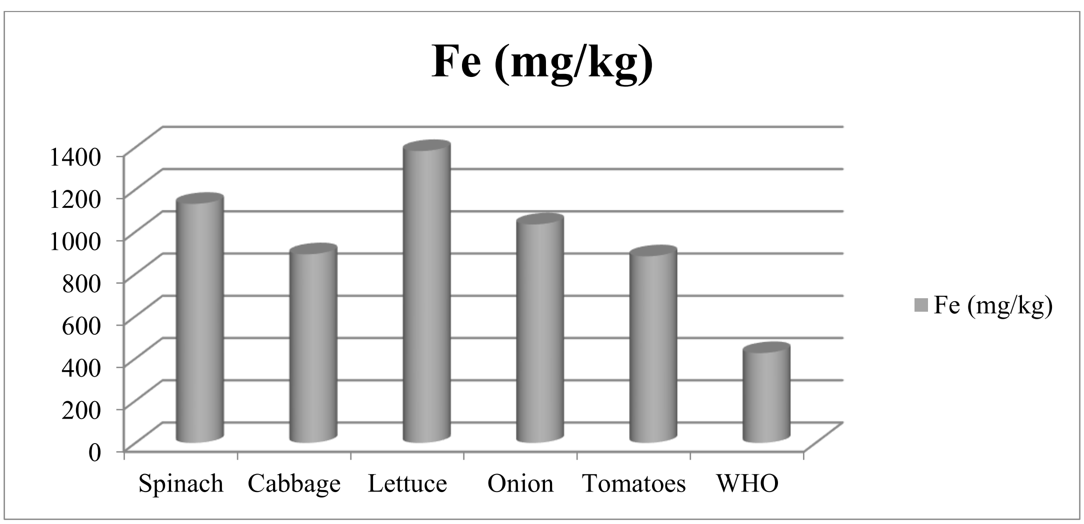

Figure 3: Iron levels in Vegetables

Figure 3 revealed that all vegetable samples across the study area were polluted with iron. Spinach, cabbage, lettuce, onion and Tomatoes recorded 1132.2, 893.3, 1382.4, 1034.8, and 883.8 mg/kg respectively. Highest concentration of Fe is observed in lettuce while tomatoes had the lowest. The order of pollution with Fe is lettuce > spinach >onion > cabbage > Tomatoes. Fe level in all the vegetable samples is above WHO limits of 425.5 mg/kg. Samuel and Sani, (2019) also reported higher levels of iron in vegetables cultivated along the Galma River in Zaria. Iron (Fe) is very useful to human and animal life, but excess amount may cause serious health effect. Examples of health challenges include Iron overload which results to damages to human organs like the heart, pancreas and liver. Excess iron is associated with health challenges such as colon cancer, neurological issues, such as cognitive impairment, Parkinson's disease, and Alzheimer's disease. Other harmful effects of Fe include nausea, vomiting, stomach pain and occasional diarrhea.

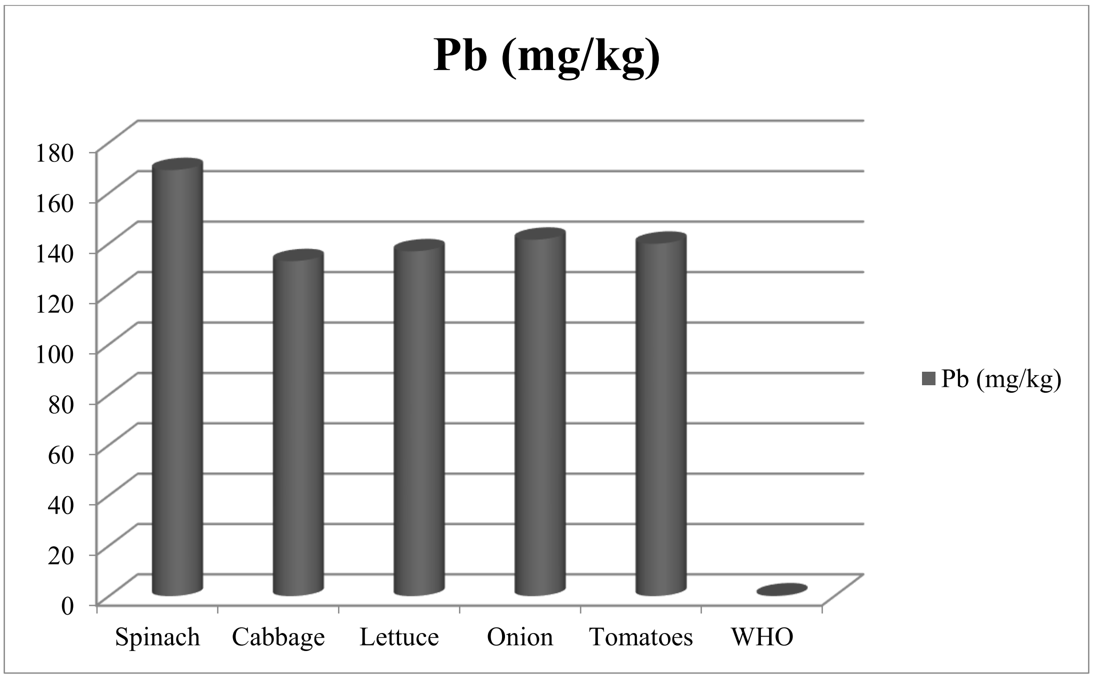

Figure 4: Lead concentration in Vegetables

As observed in Figure 4, all the selected vegetables were polluted with Pb in the study area. Spinach, cabbage, lettuce, onion and Tomatoes were found to contain high level of Pb with a mean concentration of 169.1, 133.0, 136.9, 141.5 and 139.9 mg/kg respectively. Spinach recorded highest pollution level with Pb while cabbage was the least polluted vegetable. The order of pollution by Pb is spinach >onion > Tomatoes > lettuce >cabbage. This means that Pb is absorbed most by spinach while tomatoes possess the lowest ability to absorb Pb among the selected vegetables within the study area. This is far more than what was observed by Lawal, Agbo and Usman, (2017) who reported a mean concentration of 8.35 mg/kg of Pb in vegetables within the Kubanni irrigation area. The level of Pb in all vegetables is beyond WHO/FAO limits of 0.3 mg/kg. High level of Pb in vegetables could be due to high absorption ability of the selected vegetables within the study area. The sources of Pb could be from old batteries and plastic material in dumpsites which are used as manure in the farm (see plate II). Lead (Pb) exposure can have a wide range of effects on a child's development and behavior, many of which are permanent. Some of the health effects of lead pollution include effects on the immune system, kidney function, nervous system, behavioral problems and many more.

Plate II: Heaps of organic manure from municipal dumpsites at Tudun-Jukun area.

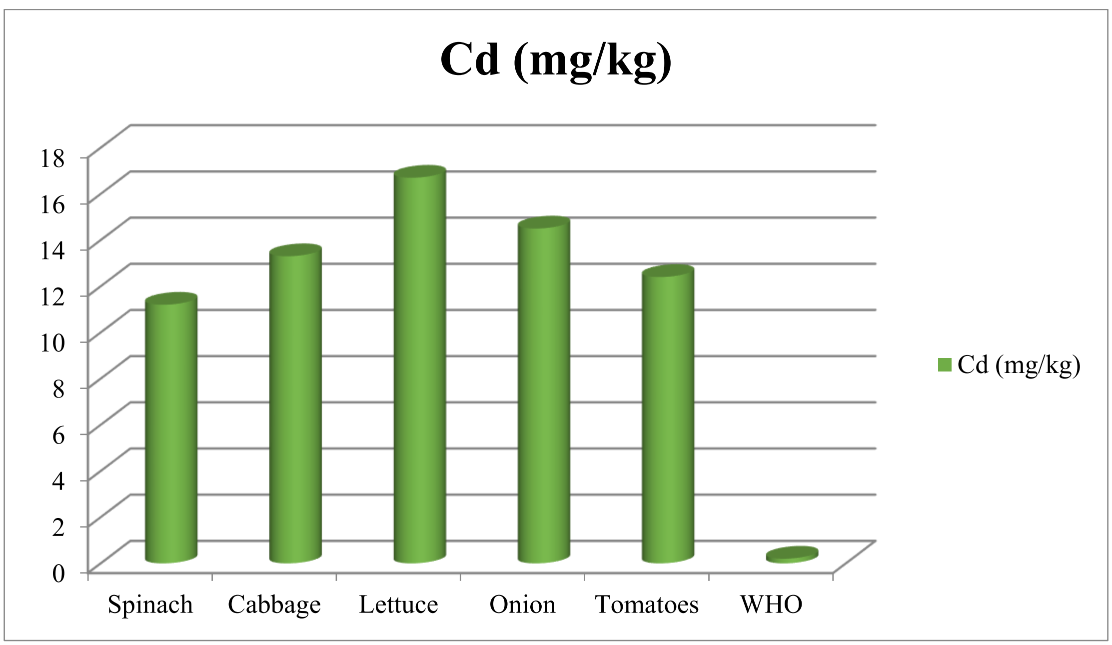

Figure 5: Cadmium levels in Vegetables

Figure 5 shows that all the selected vegetables within the Kubanni irrigation site were found to be polluted with Cd. Spinach, cabbage, lettuce, onion and tomatoes recorded a mean Cd level of 11.2, 13.3, 16.7, 14.5, and 12.4 mg/kg respectively. The order of pollution with Cd is lettuce >onion >cabbage> Tomatoes> spinach. Cd level in vegetables exceeds that of Yebpella et al., (2011) who observed a mean value 1.53 mg/kg of Cd in vegetables within the Kubanni irrigation area. Also, the level of Cd in vegetables within the Kubanni irrigation site is higher than what was observed by Faiz et al., (2021) in his study of vegetables contamination with Cr in Egypt recorded a mean concentration of 1.557 mg/kg in some selected vegetables. The raise in Cd pollution from vegetables may not be unconnected to higher level of pollutants generated from surrounding settlements within the study region. According to Kumar et al. (2019), burning of plastic materials used as manure (see plate II & III) as well as fertilizer application can add Cd contents in the soil which can be absorbed by plants. Consumption of higher cadmium level is associated with health challenges such as bronchitis, pulmonary edema and pneumonitis. It is also believed to cause kidney disease and failure. Cadmium is classified as a human carcinogen, meaning it can cause cancer. Other health challenges associated with high Cd intake include gastrointestinal problems like nausea, vomiting, abdominal cramps, and diarrhea.

Plate III: Dumpsites used as manure in an onion farm in Hayin Malam

Sources of Metal Pollutants

Table 1 compares the mean concentration of heavy metals in soil and irrigation water with WHO standards.

Table 1: Heavy Metals in Soils and water

Metals	Soil (mg/kg)	WHO Limit	Water (mg/L)	WHO Limit
Cr	443.8 ± 296.2	100	0.288 ± 0.324	0.1
Fe	5747.9 ± 1628.4	5000	0.102 ± 0.163	5
Pb	313.9 ± 188.2	2000	0.473 ± 0.377	5.00
Cd	24.3 ± 7.1	3.00	0.03 ± 0.02	0.01

Source: Field Survey, 2024

From Table 1, soil recorded a mean concentration of 443.8 mg/kg for Cr against the WHO limits of 100 mg/kg while irrigation water recorded a mean concentration of 0.288 mg/L above the WHO/FAO limit of 0.1 mg/kg. The presence of higher amount of Cr in both soil and irrigation water is an indication that they are the main sources of Cr in vegetables within the Kubanni irrigation area. Cr values observed in irrigation water from this study is slightly above the one observed by Ahmodu (2016) who reported a mean level of 0.1618 mg/L also from the Kubanni irrigation area. Cr in soil within the study area is also above the values reported by Mohammed and Folorunsho, (2015) who observed a highest mean value of 2.80 mg/kg of Cr in soils within the Makera drain in Kaduna, Nigeria. The reason for a higher Cr level in the study area could be due to increased demand for vegetables as well as increased used of agro-chemicals within the study area.

Fe content in soil is 5747.9 mg/kg slightly above the WHO limits of 5000 mg/kg. This concurs with the findings of Mohammed and Folorunsho, (2015) who reported higher levels of iron in soil within the Makera drain in Kaduna, Nigeria. However, the mean concentration of Fe in irrigation water is 0.102 mg/kg below the WHO limits of 5.0 mg/kg. Iron content in irrigation water is similar with the findings of Butu and Bichi, (2013) who observed a low Fe contents below WHO from River Galma in Zaria, Kaduna Nigeria.

The level of Pb in soil (313.9) and water (0.473) is below the WHO limits of 2000 mg/kg and 5.0 mg/kg. There is a remarkable difference between the findings of this study and that of Lawal, Agbo and Usman, (2017) who observed 7.22 mg/kg in soil and 0.46 mg/kg in water from the Kubanni irrigation area. The observed difference could be due to increased use of organic manure that contains heavy metal pollutants and also liquid waste that are channeled into the Kubanni River which are utilized for irrigation within the study area.

Cd in soil recorded a mean concentration of 24.3 mg/kg above the WHO limit of 3.0 mg/kg while irrigation water had 0.03 mg/L against the 0.02 mg/L WHO limit. High levels of Cd in soil and irrigation water is an indication that the sources of Cd in vegetables could be from soils and water within the study area.

Comparing Metal contents in Soils and Vegetables

Table 2: ANOVA Result for Metals in Soils and Vegetables

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	7.84E+08	124	6319612	3.295753	1.4E-23	1.24081
Columns	4.44E+09	6	7.4E+08	385.9908	1.4E-224	2.110748
Error	1.43E+09	744	1917502			
Total	6.65E+09	874				

Source: Field Survey, 2024, P=0.05

In Table 2, F critical value is < F calculated value, this means that there is a significant difference between heavy metal contents in soils and that of vegetables within the study area.

Table 3: ANOVA Result for Metals in Water and Vegetables

Source of Variation	SS	Df	MS	F	P-value	F crit
Rows	8448785	124	68135.36	1.031172	0.398558	1.24081
Columns	1.18E+08	6	19621464	296.9546	1.2E-193	2.110748
Error	49160277	744	66075.64			
Total	1.75E+08	874				

Source: Field Survey, 2024, P=0.05

From Table 3, F critical value (1.24081) is greater than F calculated value (1.031172). Hence, there is significant difference in metal content from vegetables and that of irrigation water.

Relationship between Metals in Vegetables and sources of contaminants

Table 3 and 4 shows result for Peason's correlation coefficient to assess the relationship between metals contaminants in soil and irrigation water and that of vegetables within the Kubanni irrigation site.

Table 4: Correlation between Metals in Vegetables and Soil

	Cr Veg	Cr soil	Fe Veg	Fe soil	Pb Veg	Pb soil	Cd Veg	Cd soil
Cr Veg	1							
Cr soil	0.283753	1						
Fe Veg	0.106674	0.032371	1					
Fe soil	0.382026	0.122913	0.184855	1				
Pb Veg	0.366138	0.248252	0.111103	0.271254	1			
Pb soil	0.464505	0.683305	0.045827	0.474208	0.453094	1		
Cd Veg	-0.24835	-0.2663	0.293043	0.04126	-0.24593	-0.28941	1	
Cd soil	0.464717	0.683712	0.04576	0.472522	0.452915	0.999995	-0.29022	1

Source: Field Survey, 2024, P=0.05, Veg= Vegetable

Table 4 shows correlation coefficient values between heavy metal in vegetables and soils within the study area. It revealed that a significant relationship exist between all metals in vegetables and that of soils. Cr, Fe and Pb show a positive correlation of 0.284, 0.185 and 0.453 while Cd is negatively correlated (-0.290). This means that heavy metal contents in vegetables are related with that of soil within the study area. It also shows relationship among different metals within the study area.

Table 5: Correlation between metals in vegetables and water

	Cr Veg	Cr water	Fe Veg	Fe water	Pb Veg	Pb water	Cd Veg	Cd water
Cr Veg	1							
Cr water	0.587989	1						
Fe Veg	0.106674	0.236061	1					
Fe water	-0.20426	-0.31912	0.052038	1				
Pb Veg	0.366138	0.573316	0.111103	-0.27325	1			
Pb water	0.429777	0.590768	0.22855	0.198656	0.301211	1		
Cd Veg	-0.24835	-0.06935	0.293043	0.172984	-0.24593	-0.05693	1	
Cd water	0.093888	-0.16324	0.109311	0.01927	-0.20098	0.195768	-0.12029	1

Source: Field Survey, 2024

Table 5 contains correlation coefficient result between metals in Vegetables and irrigation water. It also show a positive correlations between metals in vegetables like Cr (0.588), Fe (0.052) and Pb (0.301 while Cd is negatively correlated (-0.120).

Conclusion

In this study, the levels of heavy metals in vegetable were observed to be very high beyond the WHO recommended limits. All the metal pollutants in vegetables were related with metal pollutants in soils and irrigation water within the study area. The presence of heavy metals, such as chromium, lead, cadmium, and iron in large quantity from the selected vegetables poses potential health risks to consumers. The study highlights the importance of monitoring heavy metal levels in vegetables and the need for stricter regulations in agriculture to ensure food safety.

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