https://chemclassjournal.com/
ChemClass Journal Vol. 9 Issue 2 (2025); 571-583
e-ISSN:3092-8214 p-ISSN:3092-8206
DOI: https://doi.org/10.33003/chemclas-2025-0902/180

Assessment of the Bioaccumulation of Heavy Metals in Soil and Selected Vegetables in Barkin Ladi and Riyom Areas of Plateau State, Nigeria

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Abstract

The intake of heavy metals through contaminated food crops has raised concerns about potential carcinogenic and non-carcinogenic health impacts on humans. This study assessed levels of heavy metals in vegetables (lettuce, green beans, carrots, eggplant, cabbage, and spinach) and soil obtained from Barkin Ladi and Riyom Areas of Plateau State, along with their bioaccumulation. A total of six vegetables and six soil samples were taken from farms in each of these areas, prepared and digested using aqua regia, and the supernatant was analyzed using AAS for heavy metals (Pb, Zn, Cr, Co, Cd, Mn, and Cu). The concentration of these metals in vegetables in Barkin Ladi ranged from Pb (0.0019 – 0.0165), Zn (0.0783 – 2.7462), Cr (0.0814 – 0.2994), Co (0.0027 – 0.1165), Cd (0.0012 – 0.0170), Mn (0.0280 – 1.1132), and Cu (0.1851 – 1.4199) in mg/kg respectively, while in Riyom the values varied from Pb (0.0013 – 0.0145), Zn (0.0763 – 2.7432), Cr (0.0804 – 0.2944), Co (0.0017 – 0.1135), Cd (0.0010 – 0.0150), Mn (0.0230 – 1.1102), and Cu (0.1751 – 1.2199) in mg/kg correspondingly. The average concentration of heavy metals Pb, Zn, Cr, Co, Cd, Mn, and Cu in soil from Barkin Ladi and Riyom were 0.0138, 0.2495, 0.0722, 0.4646, 0.0577, 3.4897, 0.9007 and 0.0124, 0.2465, 0.0690, 0.4523, 0.0555, 3.4755, 0.8973 mg/kg respectively. The bioaccumulation factor for Pb in both study areas is less than 1.00 except for eggplant, which has values of 2.895 and 3.919 in Barkin Ladi and Riyom respectively, raising concern. The accumulation of Pb can be harmful to human health due to long-term consumption of eggplant in these areas. Other metals with bioaccumulation values greater than 1.00 are not significantly toxic to humans. However, constant monitoring of these metals in vegetables within these areas is recommended to prevent accumulation from long-term consumption, which could have negative impacts on human health.

Keywords: Accumulation, health, heavy metal, Permissible, toxicity, vegetable.

Introduction

Contamination of vegetables by heavy metals is the most serious environmental problem and has significant implications for human health. Such contamination comes from sources such as atmospheric deposition, waste disposal, fertilizer application, and wastewater in agricultural land [1]. Heavy metals are usually characterized by their toxicity and complexity of chemical behaviour [2]. Heavy metals are not biodegradable and can accumulate in living organisms. Although trace quantities of certain heavy metals are essential for animal and plant growth, they are of considerable environmental concern due to their toxicity and cumulative behaviour [3]. These heavy metals may pose risks and hazards to humans and the ecosystem through direct ingestion or contaminated soil, the food chain (soil-plants-human or soil-animal-human), reduction in land usability for agricultural production causing food insecurity, and land tenure problems [4, 5].

In most countries around the world, despite evidence of the toxicity of these metals, avoidable contamination is on the rise. Nigeria is not an exception to this, as soil has been accumulated by most heavy metals in the environment, resulting in a serious decrease in infection to crops, animals, and human beings [6]. This has prompted auditing and monitoring of metals in the environment (soil, water, and food) to become essential aspects of pollution studies.

Vegetable plants form the major component of most African dishes, providing the nutritional needs of consumers such as minerals, vitamins, protein, and other nutritional requirements. Contamination of vegetables with heavy metals may be due to irrigation with contaminated water and metal-based pesticides, industrial emissions, transportation of the harvested products, storage, and at the point of sales [6]. These heavy metals, in turn, enter the human body through the consumption of food crops, including vegetables contaminated with these metals, water, and inhalation of dust [7].

According to Adeel *et al*. [8], prolonged consumption of contaminated foodstuffs with these metals may lead to unceasing accumulation in the liver and kidney of humans, resulting in the disturbance of biochemical processes such as liver, kidney, cardiovascular, nervous, and bone disorders.

Several studies have been conducted by different researchers on bioaccumulation in various vegetables from different areas, primarily irrigated lands [9, 10]. This work, however focuses on a broader range of vegetables from farmlands within these areas.

Therefore, this study aimed to assess the bioaccumulation of heavy metals in soil and selected vegetables in Barkin Ladi and Riyom Areas of Plateau State, Nigeria.

Materials and Methods

Samples Collection: The samples were collected in Riyom and Barkin Ladi Areas of Plateau State, Nigeria. For Barkin, samples were collected in Gwol and Kassa villages, and these vegetables include Lettuce, Green bean, Carrot, Eggplant, Cabbage, and Spinach. Each of these samples was taken in different locations coded as A, B, C, D, E, F, by directly uprooting the vegetable into pre-washed polythene bags. Grap sampling technique was carried out at the different spots in triplicate, each triplicate samples was used to form a composite sample for a particular sample site; while the soil samples were also collected using a plastic spoon in the same position where the vegetables were taken, into different pre-washed polythene bags.

In Riyom, the samples were collected in Hwol-Riyom, Chol, and Dachindo villages into pre-washed transparent polythene bags, and the soil samples were also taken from the same spot as the vegetables into cleaned polythene bags within the depth of 5-10 cm, using a plastic spoon to scrape the soil from the top. Grap sampling was adopted to obtain the samples at the different spots coded as A, B, C, D, E, F, samples collected from a spot in triplicate were used to form a composite sample for a particular sample site). All of these were sealed and transported to the laboratory for further treatment.

Sample Treatment

In the laboratory, the vegetables were washed with tap water and then rinsed with distilled water. The water was allowed to drip out, then the vegetables were each chopped up with a stainless-steel knife into smaller pieces (100 g) and air-dried for 72 hours in the laboratory, after which they were ground using a mortar and pestle.

The soil samples were also air-dried for 72 hours, all debris removed, and sieved with a 2μm sieve size. Both the ground vegetable samples and soil samples were bottled separately and preserved for further analysis.

The ground vegetable samples were digested by measuring 1.00 g of each powdered sample into a digested flask and adding 10 cm^3 of concentrated Hydrochloric acid (HCl) and Nitric acid (HNO_3) in the ratio of 1:3 respectively. This was heated to 70°C for 40 minutes and later increased to 120°C. The digestion was completed when the solution became transparent/clear and white fumes appeared. This was diluted with 20 cm^3 of distilled water and boiled in a water bath for 15 minutes, then finally allowed to cool and transferred to a 100 cm^3 volumetric flask and made up to the mark with distilled water, filtered through NO.42 Whatman filter paper into screw-capped sample bottles, and made ready for AAS analysis [11].

For the soil samples, 2.0 g of each of the sieved samples was digested with aqua regia as described by Alexander and Ubandoma [11], and the filtrate was used for heavy metal analysis, using AAS.

Determination of Bioaccumulation Factor (BAF)

The bioaccumulation factor (BAF), also known as the transfer factor, is the ratio of heavy metals present in the vegetables to that found in the soil [12].

$$BAF = \frac{Cvegetable}{Csoil} \text{ -------------------------- (1)}$$

Where BAF is the bioaccumulation factor, Cvegetables is the heavy metals concentration in the vegetables, and Csoil is the heavy metals concentration in the soil, respectively.

Results and Discussion

The mean concentration of heavy metals in vegetables in Barkin Ladi and Riyom areas is presented in Tables 1 and 2, with their corresponding soil concentrations in Tables 2 and 4, and bioaccumulation factors in Tables 5 and 6.

Table 1: Concentration of heavy metals in various vegetables in Barkin Ladi, Plateau State

Sample	**Pb**	**Zn**	**Cr**	**Co**	**Cd**	**Mn**	**Cu**
Lettuce	0.0019± 0.0006	0.2744± 0.0060	0.1107± 0.0067	0.0027± 0.0004	0.0012± 0.0006	0.0280± 0.0040	0.1851± 0.0279
Green beans	0.0030± 0.0010	2.7462± 0.0668	0.2944± 0.0172	0.1165± 0.0017	0.0027± 0.0014	1.1132± 0.0110	0.3781± 0.0062
Green beans leaves	0.0129± 0.0118	0.1365± 0.0061	0.1390± 0.0196	0.0373± 0.0012	0.0043± 0.0020	0.2620± 0.0050	0.9856± 0.3980
Carrots	0.0064± 0.0035	2.3556± 0.0482	0.2104± 0.0088	0.0282± 0.0036	0.0026± 0.0013	0.2980± 0.0040	1.4199± 0.5460
Egg plant	0.0165± 0.0069	2.6527± 0.0101	0.1867± 0.0133	0.0609± 0.0007	0.0070± 0.0001	0.5430±0.0 040	1.1667± 0.1405
Cabbage	0.0076± 0.0037	0.0783± 0.0219	0.1011± 0.0088	0.0099± 0.0009	0.0170± 0.0043	0.1000± 0.0050	1.1154± 0.2164
Spinach	0.0064± 0.0057	1.0546± 0.3848	0.0814± 0.0292	0.0209± 0.0005	0.0095± 0.0024	0.2060± 0.0020	0.5921± 0.0250

Table 2: Concentration of heavy metals in the soil sample where the vegetables were taken in Barkin Ladi, Plateau State

Sample	Pb	Zn	Cr	Co	Cd	Mn	Cu
A	0.0163± 0.0049	0.0268 ± 0.0034	0.0398 ± 0.0208	0.4164 ± 0.2180	0.0516 ± 0.0158	3.0480 ± 0.0180	0.6412 ± 0.4971
B	0.0211± 0.0129	0.0009 ± 0.0002	0.0299 ± 0.0223	0.3018±0 .0180	0.0542 ± 0.0052	2.4480 ± 0.0100	0.1732 ± 0.0348
C	0.0090± 0.0030	1.4097 ± 0.0103	0.0531 ± 0.0381	1.0980±0 .0162	0.0563 ± 0.0011	7.5250 ± 0.0660	0.1773 ± 0.0657
D	0.0057± 0.0028	0.0168 ± 0.0056	0.1721 ± 0.0028	0.3759±0 .0088	0.0590 ± 0.0008	3.1050 ± 0.0050	1.0768 ± 0.4853
E	0.0092± 0.0087	0.0195 ± 0.0033	0.0755 ± 0.0202	0.3171±0 .0041	0.0617 ± 0.0004	2.5810 ± 0.0670	1.6637 ± 0.8671
F	0.0212± 0.0016	0.0232 ± 0.0008	0.0627 ± 0.0078	0.2784±0 .0004	0.0634 ± 0.0012	2.2310 ± 0.0090	1.6717 ± 1.2001

Table 3: Concentration of heavy metals in various vegetables in Riyom, Plateau State

Sample	Pb	Zn	Cr	Co	Cd	Mn	Cu
Lettuce	0.0013 ± 0.0002	0.2454 ± 0.0050	0.1102 ± 0.0062	0.0017± 0.0003	0.0010 ± 0.0004	0.0230 ± 0.0050	0.1751 ± 0.0278
Green beans	0.0020 ± 0.0010	2.7432 ± 0.0662	0.2944 ± 0.0170	0.1135± 0.0016	0.0017 ± 0.0015	1.1102 ± 0.0110	0.3751 ± 0.0062
Green beans Leaves	0.0109 ± 0.0118	0.1325 ± 0.0061	0.1360 ± 0.0196	0.0343± 0.0012	0.0023 ± 0.0010	0.2420 ± 0.0050	0.9656 ± 0.3980
Carrots	0.0054 ± 0.0035	2.3356 ± 0.0482	0.2004 ± 0.0088	0.0272± 0.0036	0.0024 ± 0.0013	0.2780 ± 0.0040	1.2199 ± 0.5460
Egg plant	0.0145 ± 0.0069	2.6517 ± 0.0101	0.1667 ± 0.0133	0.0409± 0.0007	0.0050 ± 0.0001	0.5030 ± 0.0040	1.1467 ± 0.1405
Cabbage	0.0066± 0.0037	0.0763 ± 0.0219	0.1001 ± 0.0088	0.0069± 0.0009	0.0150 ± 0.0043	0.1000 ± 0.0050	1.1134 ± 0.2164
Spinach	0.0044± 0.0057	1.0526 ± 0.3848	0.0804 ± 0.0292	0.0109± 0.0005	0.0065 ± 0.0024	0.2040 ± 0.0020	0.5901 ± 0.0250

Table 4: Concentration of heavy metals in soil samples from Riyom, Plateau State

Sample	Pb	Zn	Cr	Co	Cd	Mn	Cu
A	0.0123±0.0049	0.0248 ± 0.0034	0.0348 ± 0.0208	0.4064 ± 0.2180	0.0506 ± 0.0158	3.0460 ± 0.0180	0.6402 ± 0.4971
B	0.0201±0.0129	0.0009 ± 0.0002	0.0249 ± 0.0223	0.3008 ± 0.0180	0.0502 ± 0.0052	2.4460 ± 0.0100	0.1702 ± 0.0348
C	0.0090±0.0030	1.4047 ± 0.0103	0.0501 ± 0.0381	1.0970 ± 0.0162	0.0543 ± 0.0011	7.5050 ± 0.0660	0.1673 ± 0.0657
D	0.0037±0.0028	0.0138 ± 0.0056	0.1701 ± 0.0028	0.3739 ± 0.0088	0.0570 ± 0.0008	3.1040 ± 0.0050	1.0748 ± 0.4853
E	0.0090±0.0087	0.0135 ± 0.0033	0.0735 ± 0.0202	0.3071 ± 0.0041	0.0607 ± 0.0004	2.5410 ± 0.0670	1.6607 ± 0.8671
F	0.0202±0.0016	0.0212 ± 0.0008	0.0607 ± 0.0078	0.2284 ± 0.0004	0.0604 ± 0.0012	2.2110 ± 0.0090	1.6707 ± 1.2001

Table 5: Bioaccumulation factor from B/Ladi

Sample	Pb	Zn	Cr	Co	Cd	Mn	Cu
A	0.117	10.238	2.781	0.006	0.023	0.009	0.289
B	0.142	3051.333	9.846	0.386	0.050	0.455	2.183
C	0.611	151.667	4.649	0.124	0.079	0.107	5.691
D	0.711	1.670	3.962	0.026	0.046	0.040	8.003
E	2.895	157.899	1.085	0.162	0.119	0.175	1.083
F	0.826	4.015	1.339	0.031	0.276	0.039	0.670
G	0.301	45.456	1.298	0.075	0.150	0.092	0.354

Among the metals studied (Pb, Zn, Cr, Co, Cd, Mn, and Cu) in the six selected vegetables (Lettuce, Green beans, Carrots, Eggplant, Cabbage, and Spinach), Lead (Pb) has the highest concentration of 0.0165 mg/kg in Eggplant and the least in Lettuce 0.0019 in Barkin Ladi Area. This corresponds to 0.0145 mg/kg and 0.0012 mg/kg in Riyom Area, respectively, as presented in Tables 1 and 3.

Table 6: Bioaccumulation Factor from Riyom

Sample	**Pb**	**Zn**	**Cr**	**Co**	**Cd**	**Mn**	**Cu**
A	0.105	9.900	3.167	0.004	0.020	0.008	0.274
B	0.100	3048.000	11.823	0.377	0.034	0.454	2.204
C	0.542	147.222	5.462	0.114	0.046	0.100	5.673
D	0.600	1.663	4.000	0.025	0.044	0.037	7.292
E	3.919	192.152	0.980	0.109	0.088	0.162	1.067
F	0.733	5.652	1.362	0.022	0.247	0.039	0.670
G	0.218	49.651	1.325	0.048	0.108	0.092	0.353

The higher concentration of Pb in Barkin Ladi compared with Riyom may be attributed to mining activities, which are more prominent in the Barkin Ladi axis. Both concentrations of Pb in vegetables in the two study areas are lower than the guideline limit of 0.3 mg/kg set by the World Health Organization [13].

The bioaccumulation factors presented in Tables 5 and 6 reported the values of 2.895 and 3.919 for Eggplant in the two study areas, which means consumption of this over a long period can possibly impact the health of the consumers in these areas. This work is in agreement with earlier work by [14, 15, 16] who also reported the value of Pb in vegetables to be lower than the WHO limit. However, other researchers reported higher values than the findings of this work, which can be attributed to human activities due to higher usage of pesticides and herbicides and the use of polluted water for the irrigation of these vegetables in farms.

Among all the heavy metals results obtained, Zn has the highest concentration in these vegetables, with a concentration of 2.7462 mg/kg in green beans and the least concentration of 0.0783 mg/kg in Cabbage in Barkin Ladi, as presented in Tables 1 and 2. These values are 2.7432 mg/kg and 0.0763 mg/kg in Riyom, as indicated in Table 3 accordingly. These values and all other concentrations of Zn in the studied vegetables were lower than the permissible limit of 40 mg/kg set by the World Health Organization [17].

Nevertheless, long-term bioaccumulation of Zn over time could lead to higher levels that may result in human risk. Zn in this study showed a higher concentration than other metals, which could possibly be attributed to the use of agrochemicals such as pesticides and Zn-contaminated irrigation water. Earlier work reported Zn content in agricultural herbicides and insecticides and subsequently found Zn in vegetables fumigated with pesticides [18, ,19,20, 21].

The difference in Zn concentration within the study areas can be attributed to human practices and the selection of pesticides used. Meanwhile, other work reported higher values for Zn in vegetables in different parts of the world [22, 23] and these differences in values were attributed to human practices. The bioaccumulation factor of Zn is very high in this study, presented in Tables 5 and 6, showing all the vegetables bioaccumulate Zn. Although Zn is one of the essential minerals that plays a crucial role in body functions such as immune system boost, development of immune cells, promote tissue repair, and regeneration.

The concentration of Cr recorded the highest value in Green beans 0.2944 mg/kg and the least in Spinach with a concentration of 0.0814 mg/kg, as indicated in Tables 1 and 3. The counterpart in Riyom recorded the same precedents with the concentration 0.2944 mg/kg and 0.0804 as indicated in Table 3, respectively. All the values obtained for all the vegetables were lower than the permissible value of 2.30 mg/kg set by the World Health Organization [24], indicating that all the vegetables examined were not contaminated with Cr. Previous work in Northern Nigeria reported higher values for Cr than the one obtained in this study. For instance, [25] reported the concentration of Cr to be 1.5 mg/kg for D. Carota, 66.10 mg/kg was reported for Carrots [25,] and [23], reported 1.922 mg/kg for Cr in Cabbage. This difference is a result of the use of agrochemicals and contaminated water for irrigation during the process of growing these vegetables. Excess uptake of Cr in humans has been linked with ulcers, pulmonary cancer [26]. The bioaccumulation factors for the study areas have values greater than 1.0, with the exception of Eggplant in Riyom, as presented in Tables 5 and 6. These calls for caution to avoid future health challenges.

The concentration of Co in the vegetables sampled in Barkin Ladi is in the order of Green beans 0.1165, Eggplant 0.0609, Green beans leaves 0.0373, Carrots 0.0282, Spinach 0.0209, Cabbage 0.0096, and Lettuce 0.0027 mg/kg, as indicated in Table 1, while that of Riyom study area has the concentration of Green beans 0.1135, Eggplant 0.0409, Green beans leaves 0.0343, Carrots 0.0272, Spinach 0.0109, Cabbage 0.0069, and Lettuce 0.0017 mg/kg, as presented in Table 3, respectively.

Furthermore, the concentration of Cd in both study areas in all the vegetables is lower than the 0.02 mg/kg permissible limits of the World Health Organization. Cabbage has the highest concentration of 0.0170 mg/kg, and Lettuce has the least with a concentration of 0.0012 mg/kg in Barkin Ladi, while other vegetables like Carrots have 0.0026, Green beans 0.0027, Eggplant 0.0070, and Spinach 0.0095, as presented in Table 1, respectively. While in the Riyom study area, Cabbage has the concentration of 0.0150, Lettuce 0.0010, Green beans 0.0017, Green beans leaves 0.0023, Carrot 0.0024, Eggplant 0.0150, and Spinach 0.0065 mg/kg, as recorded in Table 3, accordingly. The values obtained in this study were lower and agreed compared with earlier reports, while others disagreed with values reported in some parts of Africa and Asia known for indiscriminate use of pesticides. For example, [14] in eastern Nigeria reported the value of Cd in vegetables to be 0.011 mg/kg, which is less than the permissible limit as reported in this study, while [15] reported 1.33 mg/kg in Cabbage in Kumasi, Ghana, while [23] in Portugal reported 0.27 mg/kg in Cabbage.

Another study in Nigeria reported the value of Cd to be 7.67, 4.68, and 6.14 mg/kg in vegetables fumigated with metal-based pesticides [27, 28, 29]. Generally, Cd has relatively high mobility, which can easily be absorbed by the plant, as seen in Tables 5 and 6. This explains their presence in all the sampled vegetables in both study areas. Human exposure to Cd could lead to accumulation in human organs like nerves, lungs, kidney, and skeletal system, resulting in cancer and other health risks for humans [30, 31].

The concentration of manganese in Barkin Ladi study area shows higher concentration in Green beans with a value of 1.1132 mg/kg and least in Lettuce with a concentration of 0.00280 mg/kg. Others are Green beans leaves 0.2620, Carrot 0.2980, Eggplant 0.5430, Cabbage 0.1000, and Spinach 0.2060 mg/kg, as presented in Table 1. This followed the order Green beans > Eggplant > Carrots > Green beans leaves > Spinach > Cabbage > Lettuce. The study area of Riyom followed the same trends as that of Barkin Ladi, as reported in Table 3. All the values obtained for manganese in all the vegetables are lower than the permissible limit set by the World Health Organization 5.0 mg/kg, as reported by [32]. A careful observation of the results obtained from the soil of these study areas, presented in Tables 2 and 4, shows that these vegetables actually absorbed this trace metal from the soil. Manganese is one of the essential nutrients that plays a crucial role in various body functions such as enzyme function, bone health, wound healing, antioxidant properties, and metabolic processes.

The concentration of Cu in Barki Ladi study area varies for each of these vegetables sampled from Lettuce with a concentration of 0.1851 to 1.4199 mg/kg in Carrots. Other vegetables have a concentration of Green beans 0.3781, Green beans leaves 0.9856, Eggplant 1.1667, Cabbage 1.1154, and Spinach 0.5921 mg/kg, respectively, while the Riyom study area is also recorded in Lettuce 0.1751, Green beans 0.3751, Green beans leaves 0.9656, Carrots 1.2199, Eggplant 1.1467, Cabbage 1.1134, and Spinach 0.5901, as presented in Tables 1 and 3, respectively.

Observation of these results shows that the vegetables from Barkin Ladi study area have higher concentrations of these metals than those of the Riyom study area, and this is as a result of more mining activities and impacts of human practices in Barkin Ladi than Riyom. When considering the results of the soil in the two study areas, the results demonstrate the same trends because the Barkin Ladi area has more concentration of human activities than Riyom due to mining, industrial activities, and population density. Cu plays several essential functions in the human body such as connecting tissue, immune system support, neurological function, and antioxidant properties.

The results of bioaccumulation factors presented in Tables 5 and 6 show Pb, Co, Cd, and Mn all have values of less than 1.0, except Pb in Eggplant with the value of 3.919, meaning that these vegetables are not accumulators of these metals except Eggplant, which can be said to accumulate Pb. The bioaccumulation factor of Zn in both study areas is much higher than 1.0, indicating these vegetables are accumulators of Zn. Cr has a value of greater than 1.0, except for Eggplant, which is less than 1.0 with the value of 0.980, indicating Eggplant is not an accumulator of Cr. Cu also shows a bioaccumulation factor of greater than 1.0, except for Spinach, Cabbage, and Lettuces with values less than 1.0 in both study areas, hence these vegetables are not accumulators of Cu.

Conclusion

The contamination of heavy metals in vegetables cannot be underestimated as these foodstuffs are essential components of the human diet, and their contamination is one of the most crucial aspects of food hazards. In this study, the results revealed the concentrations of these metals (Pb, Zn, Cr, Co, Cd, Mn, and Cu) in the sampled vegetables (Lettuce, Green beans, Carrots, Eggplant, Cabbage, and Spinach) are generally below the permissible limit set by the World Health Organization. Most of these vegetables are not accumulators of these metals because their bioaccumulation factor (BAF) is less than 1.0 (BAF <1), except Eggplant that has the BAF > 1 (2.895 and 3.919) for Pb in Barkin Ladi and Riyom study areas.

In a similar trend in both study areas, all the vegetables sampled show to be accumulators of Zn (BAF > 1), while Cabbage and Spinach are found to be accumulators of Cr (BAF > 1), and Green beans, Carrots, and Eggplant were also found to be accumulators of Cu in both study areas (BAF > 1). The study recommends regular monitoring of these heavy metals in these vegetables in the study areas to avoid health risks as a result of accumulation over a long-term period.

Acknowledgements

The authors are grateful to the staff of the postgraduate laboratory of the Department of Chemistry, University of Jos, for their contribution in making available the reagents and equipment used for this work and my undergraduate students for support in the sampling of the soil and vegetables in Barkin Ladi and Riyom study areas despite the security challenges.

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