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Concentrations and health risk assessment of selected heavy metals in drinking water sources, food, and soils of Lapai (Northcentral Nigeria)

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Abstract:
Background: *Many countries enacted policies and regulations limiting lead (Pb) and Cadmium (Cd) levels in foods and drinks. However, African countries, including Nigeria, have generally been slow in adopting policies and regulations concerning heavy metals pollution. This paper aims to estimate the level of selected heavy metals in vegetables, staple food, and drinking water in Lapai, Northcentral of Nigeria. To this end, forty-one (41) common drinking water samples from different sources, eighteen (18) food grains samples, and Ten (10) vegetable samples commonly grown around 2 rivers were involved in the investigation.*
Materials and Methods: *Atomic Absorption Spectrophotometry was used for heavy metals quantification.*
Results: *The mean concentrations of Pb and Cd detected in drinking water ranges from 0.1-1.0 and 0.04-1.07 mg/L respectively which exceeded the permissible limits (0.02 and 0.01). The mean concentration of Pb and Cd in the edible part of the grains and vegetables ranges from 1.05-5.86 and 0.13-1.06 mg/kg respectively. 80 and 90% of the samples were observed to be within the safe limits for Pb and Cd (5.0 and 1.0) respectively. The mean Cu concentration in all samples was within safe limits. Transfer Factor of vegetables showed that leafy vegetables e.g., spinach have high bio-absorptivity.*
Conclusion: *Estimated daily intakes (EDI) of heavy metals by the consumption of analyzed vegetables were found to be well below the permissible levels. Although, a complete EDI of all other dietary and non-dietary exposure sources of heavy metals is required. These results indicate the potential risk of Pb and Cd toxicity from drinking water from these communities.*

Key Words: *Heavy metals; Food; Water; Toxicity; Estimated Daily intake.*

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I. Introduction

The Nigerian economy is primarily agriculture-based, but rapid and chaotic urbanization with a resultant small-scale industrial activity is contributing to elevated levels of pollutants in the urban milieu of the country. These unregulated industrial activities have resulted in the generation of different types of pollutants, an enormous number of wastes, and environmental hazards. The transfer of these pollutants through drainage and surface runoff from their sites of contamination to water can potentially affect both aquatic and terrestrial life [1].

Amongst the environmental pollutants, of major concern, is the pollution by heavy metals. Environmental pollution by heavy metals (HMs) (Mercury, Lead, Arsenic, etc..) is a worldwide public health problem, characterized by high blood lead levels among people living in polluted areas [2]. HMs such as mercury (Hg), arsenic (As) cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn) continually pose a significant risk on human and environmental health. Though, some HMs such as Cu, Fe, Mn, Zn, and Cr are essential for life, while others like Hg, Cd, Pb, and As, are unfortunately toxic to humans and the environment [3]. Pollution due to anthropogenic activities (mining, smelting, exhaust from automobiles, or wastes of different kinds) is the main source of HMs and to a lesser extent, from geogenic sources. The consequence of the former and later sources in the environment is the possibility that food and drinking water could also contain them. Therefore, food and drinks are the primary sources of chronic exposure to low levels of As, Pb, and Cd for non-occupationally exposed individuals. Trace's amount of the aforementioned HMs in the biosphere may results in serious alterations to all the living organism and may also lead their bio-transfer in the food chain which if consumed above permissible limits can be deleterious to human health. Inhalation and ingestion are the two primary routes of human exposure to these elements [4].

Over the years, evidential research on the adverse impact of HMs on humans has been explicated and reported in many scientific kinds of literature more specifically in the developing world [5]. The exposure and risk assessments of HMs on different population groups and their resultant health risks posed by these elements were studied intensively [6–12]. Of important concern, is the HMs lead due to its deleterious health effect on the biological system. Exposure to high Pb concentration has been reported as the cause of a condition in which a person's immune system attacks its cells (autoimmunity). Adversely, autoimmunity leads to joint diseases, an ailment of the kidneys, circulatory and nervous system diseases [13]. Therefore, dysfunction or hypertension in adults and delays in children's physical and mental development including decreased intelligence quotient are attributed to prolonged exposure to lead [14]. At higher concentrations, Pb can cause irreversible brain damage, observable in children, mostly under the age of six [10].

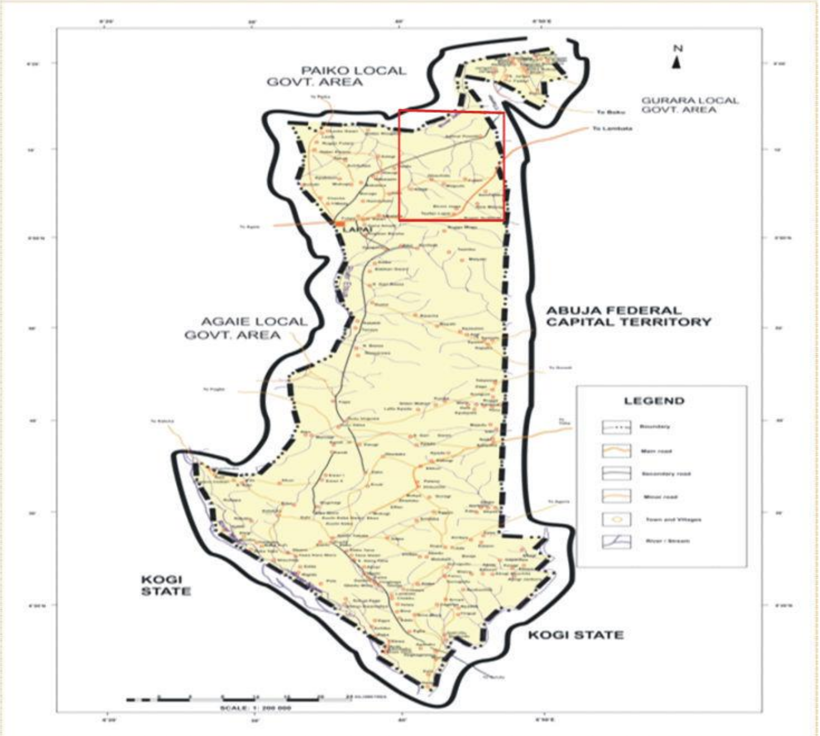
The biochemical importance of water, vegetables, and staple food (Grains) in the human system can never be over-emphasized in this literature. Water is indispensable to life, as it serves as the main medium through which all biochemical processes, biomolecules assume a shape with the aid of water, and they also participate in biochemical reactions. While the energy of the body, proteins, fats, vitamins, minerals, and enzymes comes from the most imperative food sources such as vegetables and staple foods. Therefore, it is very imperative to devoid these important driven precursor molecules of life processes from geogenic pollutants of HMs (Pb, and Cd, etc.) origin. Explicating these sources will reduce the burden of the adverse health effect of HM (Pb) on humans. Literature had previously reported that drinking water sources were contaminated by HMs through effluents from metal workshops, smelters, tanneries, chemical, and pharmaceutical industries. Thereby resulting in considerable alteration to the overall well-being of living things exposed to such water sources [1,5,15]. It is, therefore, discernible that streams and rivers where these geogenic pollutants debilitate into, serve the villages and towns along with them. Consequently, possible transmission of HMs may exist from contaminated soil to the plants grown on the polluted soil, and consequently to the animals that consume such plants. The maximum contaminant levels (MCL) vary with the type of source. According to WHO, the MCL recommended for HMs (Pb, Cd and Cu) in food, drinking water and soil are (5.0, 0.2, and 40 mg/kg,), (0.01, 0.003 and 2.0 mg/L) and (13, 3 and 50 mg/kg) respectively [16–19].

Information on HMs (Pb, Cd, and Cu) in drinking water, vegetables, and grains are lacking in Lapai North central Nigeria. This research is aimed at addressing this food safety concern. Therefore, this study was conducted in this part of Nigeria to assess these heavy metals originating from the locality.

II. Materials and Methods

Analytical grade chemicals purchased from Merck chemicals (Germany) were employed throughout the study. All glassware and plastic container used were washed with a detergent solution followed by 20 % nitric acid and then raised with topwater and distilled water. Other chemicals and reagents used were of analytical grade and used as received from Sigma Aldrich UK. All working solutions are prepared freshly.

Study area and Sampling Collection:



Lapai is the headquarter of the Lapai Local Government Area in Niger State, Nigeria, adjoining the federal capital territory. It's located on the Latitude: 9° 02' 60.00" N and Longitude: 6° 33' 59.99" E, in the western part of the area. It covers an area of 3,051 km² and a population of 110,127 as of the 2006 census.

Samples Digestion Procedures:

Samples were digested to prevent analytical interference by the removal of organic impurities. The water samples were digested with concentrated Nitric acid. Briefly, 20 mL of nitric acid (50 %) was added to 50 mL of sampling water in a 250 mL conical flask, and then heated on a 100ºC water bath to 10 mL of the mixed solution. After cooling, it was then filtered in a plastic pet bottle and made up to 20 mL with distilled water, and then stored in the refrigerator. Also, about 0.2g of the predigested food (grains and vegetables) samples were weighed in separate test tubes then, 5ml of digestion mixture (a mixture of perchloric acid, nitric acid, and sulfuric acid) was added to each test tube. The resultant mixture was then heated for 12 hours in a hot fume chamber. The digests were then mixed with distilled water and filtered, the filtrate was allowed to cool and further diluted with distilled water to 100 mL in a volumetric flask. The diluted filtrates were then transferred into a plastic pet bottle.

Analytical Procedure:

Heavy Metals in food grains, vegetables, soil, and water samples were analyzed by Flame Atomic Absorption Spectrophotometry (Spectroscopy Max Plus, Molecular Device Inc. Sunnyvale, CA, USA).

Transfer Factor (TF) in Vegetables:

The TF (%) of heavy metal is defined as the percentage transfer of metal contents from the growing substrate (soil) to the vegetables. Transfer factor was calculated after the following mathematics equation:

$$TF\% = \frac{Cp \times 100}{Cs} \qquad \textit{Equation 1}$$

Where TF % is the level of metal concentration, Cp is a metal concentration in the plant and Cs is the metal content in the substrate (soil).

Estimated daily intake (EDI):

The estimated daily intake (EDI) of heavy metals (Cu, Pb, and Cd) depended on both the heavy metal concentration in vegetables and the amount of consumption of the vegetable. This was estimated as:

$$EDI = \frac{Cm \times Wf}{Bf} \qquad \text{Equation 2}$$

Cm is the heavy metal concentration in vegetables (mg/kg), Rattan et al., (2005). Wf defines the average weight of vegetables consumed per person per day in Northern Nigeria, which according to the report was around 312g/person/day; a value far below the recommended value of 400g [21]. While Bw defines the bodyweight of an average child and adult of Nigeria was estimated to be 33kg and 68 kg respectively [20,22,23].

Data Analysis:

Analyses of metal ions in all the samples were carried out in AAS. Statistical analysis was done using GraphPad Prism version 9.0.0 software.

III. Results and Discussion

The potential pathways of community exposure to HMs contents in selected drinking water, grains, and vegetables collected in Lapai town of north-central Nigeria were investigated. To this end, forty-one (41) common drinking water samples from different sources (Sachet water, bore-hole water, and river water), 18 food grains samples, and 10 vegetable samples commonly cultivated in 2 rivers (Rafindam and Tsowa) were involved in the investigation. The observed concentrations of Pb, Cd, and Cu in the drinking water, grains, and vegetables were compared with the Maximum Contaminant Level (MCL) as established by the world Health regulatory bodies to assess the levels of food contamination.

The concentration of Pb, Cd, and Cu in the different water samples were investigated, the result is presented in figure 1.

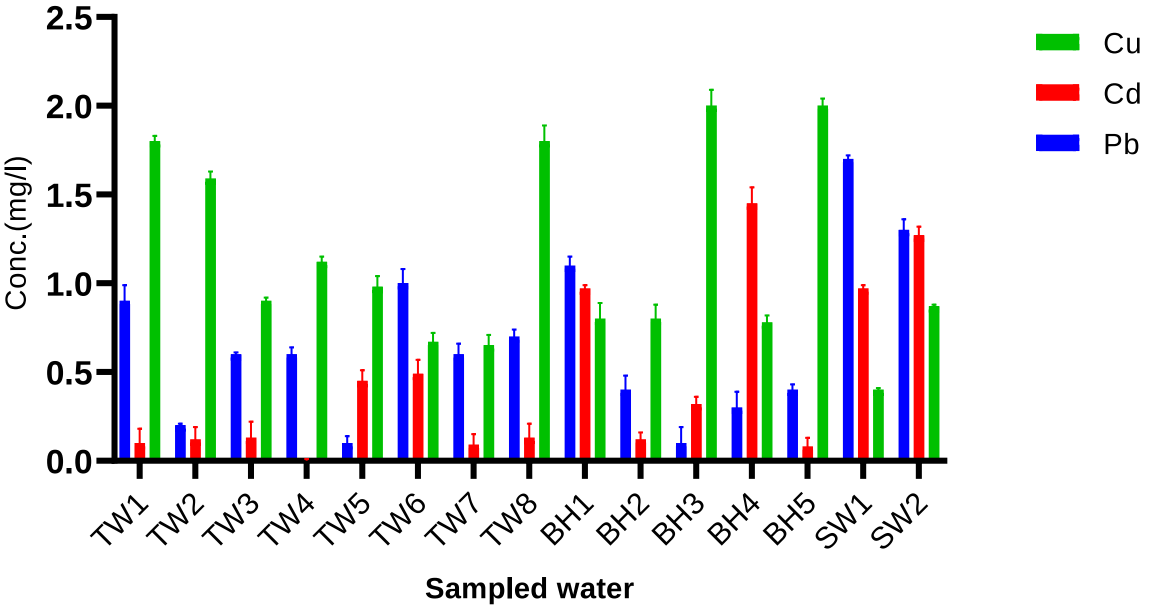


Figure 1: Mean heavy metals concentration in sampled drinking water in Lapai community
[1] (TW =Table water, BH= Borehole, SW= Stream water
TW1= AHK, TW2 = AH Soje, TW3 = A.A Soje, TW4 = S.U Soje, TW5 = Jantabo, TW6= Ndakitabu, TW7= Somaji, TW8= STwata. BH1= Afuwali, BH2 = Afu Tanko ilimi, BH3= Afu Liman, BH4 = Fed. Lowcast, BH5= Water board. SW1= Rafin dam, SW2= Tsowa river).

Mean Cu concentrations were found to be higher in all the sampled water compared to the Cd and Pb. There are also variations between the mean concentration of metals (Cd and Pb) in the sampled water. TW1-8 are samples from popular drinking sachet water (pure water as it's called) sold for consumption. The Pb levels in these samples range from 0.1-1 mg/l, with the highest concentration observed in TW6 (1.0 mg/l). The concentration of Pb exceeded the maximum limit (0.01 mg/l) in all the samples. The level of Pb in BH1-5 (Borehole) water, collected from different areas of the community also showed that 4 out of the samples were above the maximum limits. The least concentration is observed in BH3 (0.1) and the highest concentration in BH1 (1.1). Sample SW1-2 (stream water) were all found to contain a high concentration of Pb. These are streams that are also used for irrigation purposes in the town. It was also observed that Cd concentration in all the samples ranges from 0.04 in TW4 to 1.07 in SW2. These values far exceeded the maximum limits set by the world health organization and Nigerian standard (0.003 mg/L) for Cd in drinking water [17–19]. These findings lay credence to other similar findings in Nigeria and other countries that drinking water is found to contain heavy metals Pb and Cd [17–19,24,25]. Studies had revealed that the concentration of Pb, Cd, and other heavy metals in drinking water is dependent on the closeness of the water to sources like industrial activities: metal melting and coal refining and oil-fired power stations, electroplating plants, rate of development of the area, the topography of the land, climatic conditions and solid waste disposals [18]. Environmental exposure to Pb and Cd has detrimental health implications as they are carcinogenic and have been largely reported to impair the function of vital organs (kidney and liver), destroy testicular tissue and red blood cells [1,17].

The mean HMs concentration in selected grains and edible portions of vegetables cultivated in Lapai town were analyzed and the results are indicated in figure 1. The mean value of Pb in food grain was observed (1.05 mg/kg) in wheat, with an observed maximum concentration (2.24 mg/kg) in rice. Further, the mean value of Pb in vegetables was also observed to contain a minimal concentration (3.09) in Jute mallow while the maximal concentration (5.86) where observed in Cayenne pepper. Comparatively, the Pb level in both the food grains and the vegetables were observed to be within the safe limit, set for heavy metal (Pb) (5.0) by the World Health Organization (WHO)/Food and Agricultural Organization (FAO). The only exception was observed in Jute Mallow, which has a level of 5.86 mg/kg. Pb is a potential carcinogen and is associated with the etiology of several diseases, such as cardiovascular, blood, kidney, nervous system as well as bone diseases [1]. However, in contrast to our findings, the following studies reported Pb levels that are above the safe limits in food [1,8,9,26].

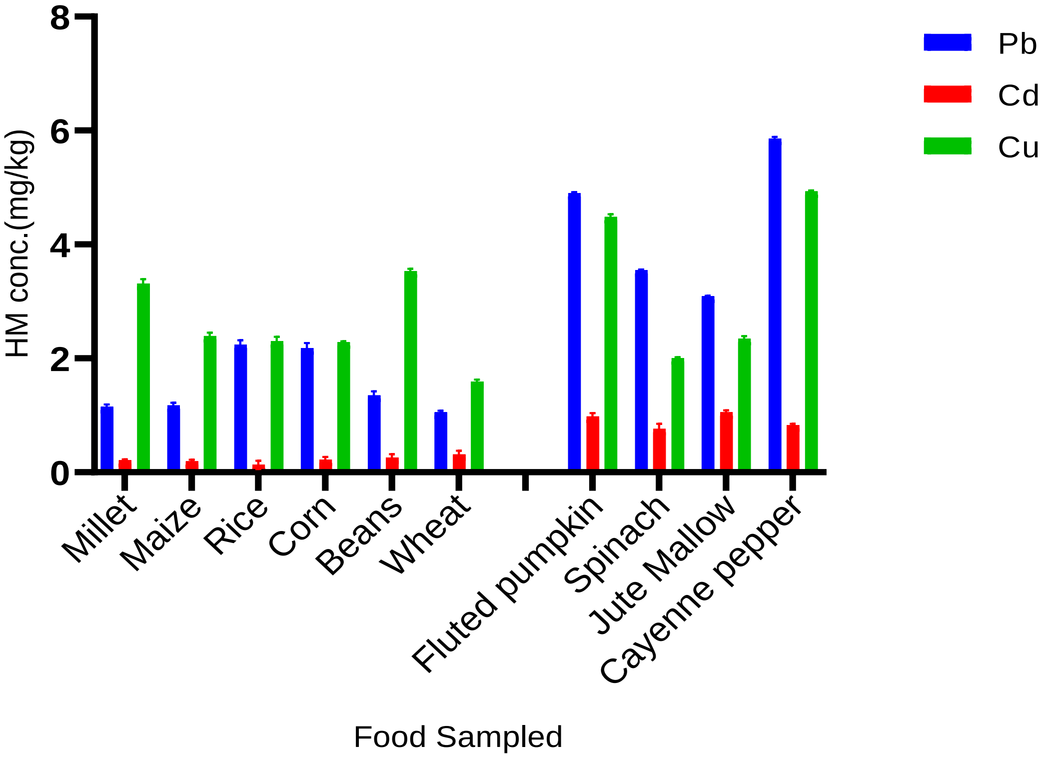


Figure 2: Heavy metals concentration in grains and vegetables marketed in the Lapai community. HM (Heavy Metals)

The mean level of Cd in food grain was observed (0.13 mg/kg) in rice, with an observed maximum level (0.36 mg/kg) in wheat. Further, the mean value of Cd in vegetables was also observed to contain a minimal concentration (0.78) in Spinach while the maximal concentration (1.06) where observed in Jute mallow. Cadmium is a potential carcinogen that may impair the functions of vital organs such as the kidney and liver, therefore its level above the safe limit in food is not without a consequence. The mean concentration of Cd in the edible part of the grain and vegetables were observed to be above the safe limit (0.20), except for rice and maize. This result was similar to that reported by Aksoy & Demi, (2006), which indicated concentration of Cd ranging from 0.24 to 0.97 mg/kg, and Chabukdhara et al., (2015) with a maximum level in spinach. But a result from the analysis of vegetables irrigated with different treatment water in Pakistan soil showed a Cd level range of 0.01-0.17 mg/kg which is within the safe limit [5].

The result of the analysis also showed that the level of Cu is between 1.59 mg/kg in wheat grains and 5.93 mg/kg in cayenne pepper. The values were observed to be within the safe limits set for Cu (40.0) in food. Copper is an important essential element in a biological system. Its function as a cofactor in biocatalyst, required for body pigmentation and also in maintaining a functional nervous system, etc. [28]. Copper at higher concentrations can be deleterious to the biological system because it is known to cause toxicity effects, and also acute exposure to Cu (200 mg/kg) can lead to death [11]. A similar study conducted in Lagos; Nigeria indicated the concentrations of Cu in all the tested samples (Fruits and Vegetables) to be varied between 0.002 and 0.07 mg/kg [28]. While, Sharma et al., (2016) and Ismail et al., (2014) reported a higher Cu concentration of 80.33 and 102.7 mg/kg respectively, in spinach samples cultivated in irrigation sites. The concentration of metals across the various grains and vegetable samples showed some particular traits; higher concentrations were observed in all the vegetables when compared with the grains irrespective of the metal under consideration. This was suspected to be mainly because the vegetables were cultivated with irrigation water from Rafindam and Tsowa rivers.

The result of the analysis of heavy metals (Pb, Cd, and Cu) in the soil samples obtained from the two irrigation sites is indicated in Table 3. The results were compared to the maximum contaminant levels of the metals as indicated by the world health regulatory agencies.

Table 1: Heavy Metal Concentrations in soil samples from the two vegetable irrigation sites (mg/kg)

	Pb	**Cd**	**Cu**
Rafindam	22.2	3.08	21.6
Tsowa River	23.4	2.51	24.2
MCL	13	3	50

This showed that the Pb values obtained from the treatment sites were far above the permissible MCL (13 mg/kg). The Cd level in Rafindam was also above the permissible limit (3) while the Cu levels were within the MCL values (50). The primary risk factors of metal exposure were contaminant transfer by soil to plants tissue. Therefore, the observed elevation of heavy metals in vegetables might be influenced by their relative concentration in the growth medium (soil) and the type of vegetable. This is in line with suggestions that spinach and radish pod could serve as excellent agents for phytoremediation, due to their larger surface area, which influences their rate of heavy metal absorption [5].

The percentage mean concentration of the heavy metals transferred from the soil to the vegetables was also investigated. It describes the movement of HMs from soil to vegetables (plants). Transfer factor determination is an imperative risk component that defines the extent of human exposure to these contaminants.

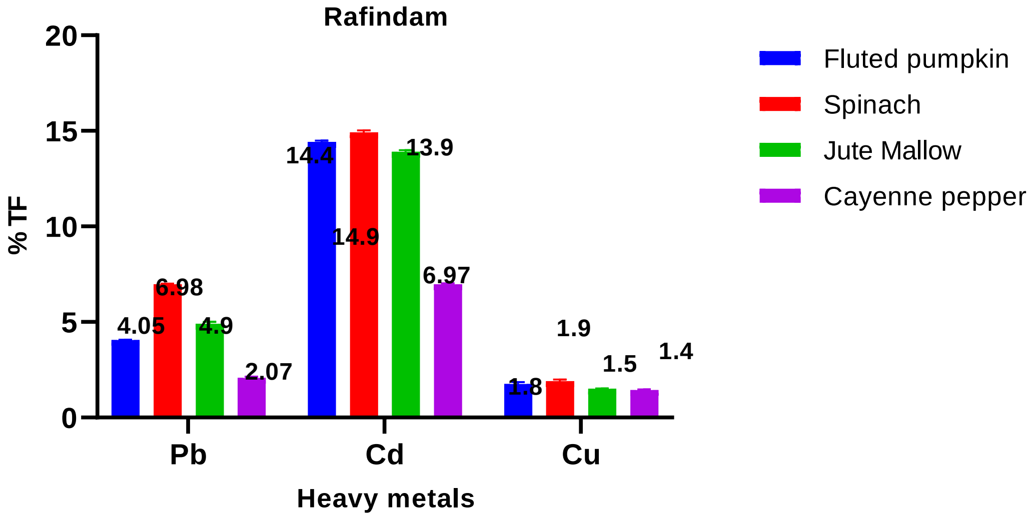


Figure 3: Transfer Factor (%) of heavy metals in Rafindam-irrigated grown vegetables

The finding in figure 3 indicated that all the four vegetables irrigated by Rafindam water had high Cd %TF values followed by Pb and Cu with the least. Among the vegetables, spinach showed the highest transfer factor of Cd (14.9), Pb (6.98), and Cu (1.9). This was followed closely by fluted pumpkin and jute mallow with the factors Cd (14.4, 13.9), Pb (5.05, 4.9), and Cu (1.8, 1.5) respectively. While cayenne pepper showed the lowest TF values of heavy metals. From these findings, it can be deduced that the transfer factor of the three metals in Rafindam irrigated water is in the following order: Cd>Pb>Cu. while spinach showed the highest absorptivity followed by fluted pumpkin and Jute mallow. This is in line with suggestions that spinach and radish pod could serve as excellent agents for phytoremediation, due to their larger surface area, which influences their rate of heavy metal absorption. This is consistent with another finding that showed Cd has a higher factor with the following order Cd>Cu>As>Pb [8].

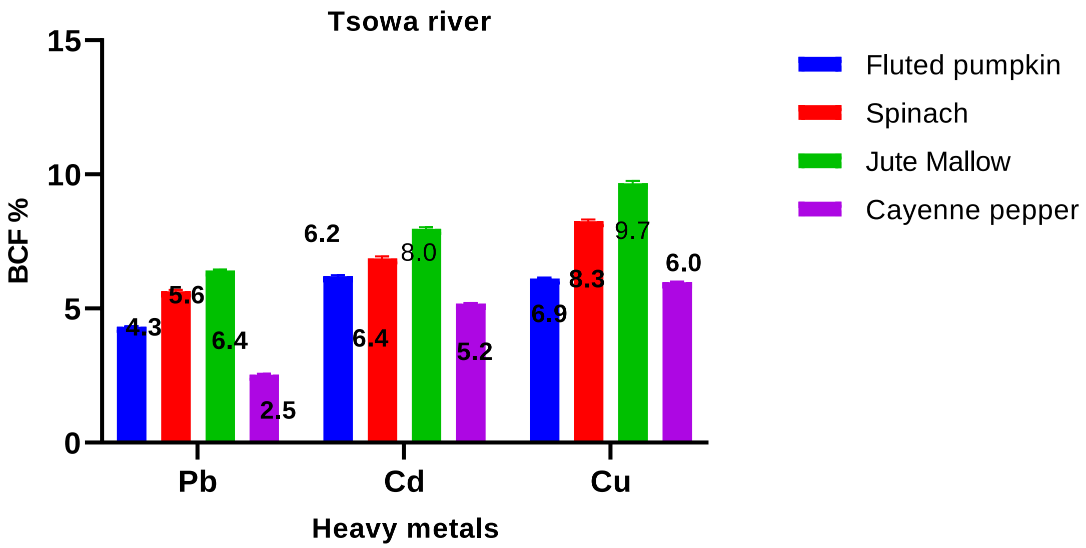


Figure 4: Transfer Factor (%) of heavy metals in Tsowa river-irrigated-grown Vegetables

The finding in figure 4 indicated that all the four vegetables grown by river Tsowa-irrigated water had high Cu TF values followed by Cd and Pb with the least. Among the vegetables, Jute mallow showed the highest transfer factor of Cu (9.7 %), Cd (8.0 %), and Pb (6.4 %). This was followed closely by spinach and fluted pumpkin with factor Cu (8.3, 6.9), Cd (6.4, 6.2), and Pb (5.6, 4.3) respectively. Similarly, Cayenne pepper showed the lowest TF values of heavy metals. This finding is in contrast with our finding on heavy metals transferability. Nevertheless, worthy of note is the TF of the vegetables as reported, leafy vegetables have high heavy metals uptake than fruit vegetables such as potatoes [5,8,11].

The estimated daily intake (EDI) of contaminants (heavy metals) was also investigated to evaluate the associated health risk. Of the key environmental routes of exposure such as contaminated soil, food, groundwater, and dust in the environment, etc., the most significant one after water is food. Table 2 indicated the result obtained from the evaluation EDI of Pb, Cd, Cu in consumed vegetables irrigated with Rafindam and River Tsowa water.

Table 2: Estimated daily intake of heavy metals in consumed vegetables irrigated Rafindam and Tsowa water (mg/day)

Sampling site	Vegetables	Pb	Cd	Cu
Rafindam	Fluted Pumpkin	0.004	0.001	0.006
	Spinach	0.007	0.001	0.002
	Jute Mallow	0.005	0.001	0.001
	Cayenne pepper	0.002	0.001	0.001
Tsowa River	Fluted pumpkin	0.005	0.001	0.007
	Spinach	0.006	0.001	0.009
	Jute Mallow	0.004	0.001	0.011
	Cayenne pepper	0.002	0.001	0.009

The result showed the EDI value for Cd and Cu were all within the permissible MCL of 0.001 and 0.5 mg/day respectively in both consumed vegetables from the irrigation site under study. The EDI value for Pb was above the MCL in Spinach consumed in both Rafindam (0.007 mg/day) and Tsowa irrigated (0.006) vegetables. Similarly, the value for Jute Mallow (0.005 mg/day) and Fluted pumpkin (0.005) Rafindam and Tsowa irrigated water. However, EDI values of consumption of Cayenne pepper (grown on any water type), Fluted pumpkin from Rafindam, and Jute mallow from Tsowa river were all found well within the permissible MCL of Pb (0.004 mg/day).

IV. Conclusion

This study reports the results of an assessment of heavy metals (lead cadmium, and copper) in drinking water sources, food (grains, vegetables), and soil. The drinking water sources are contaminated with heavy metals in multiple folds and thus, do not meet the international safety standard. The concentrations of heavy metal in food samples were largely within permissible MCL as indicated by world health regulatory bodies. The mean concentrations of heavy metals in soil and their uptake by plants pose no significant effects though there is variation in the TF rate between vegetables. The findings on the estimated daily intake of heavy metals in foods showed that all vegetables grown with Rafindam and Tsowa irrigated waters are within the safe limits. Therefore, this study suggests that regular scrutiny of the heavy metals present in food (vegetables and grains) drinking water, and soil is required to avoid extreme accrual in the food chain and thus elude human health risks.

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