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Health Risk Assessment of Heavy Metals in Soil Rhizosphere and Onion Bulbs Cultivated in Danbam Farmlands, North East, Nigeria

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Abstract: *This study was conducted to determine the levels of heavy metals (Cd, Cr, Mn and Pb) in soil rhizosphere and onion bulbs from four locations in Danbam area of Bauchi State Spectrophotometry method was employed for the determination of the concentrations of the metals. The concentrations of all the heavy metals were found to be in the range 4.06×10^{-8} to 1.91×10^{-1} mg/kg which are below the permissible level (0.02, 500 and 0.3 mg/kg for Cd, Mn and Pb respectively) set by FAO/WHO. The study also revealed that daily metal intake (DIM), hazard quotient (HQ) and hazard index (HI) were below unity and points to a nonexistence of potential public health. Calculated bioconcentration factors (BCF) suggested higher concentration of heavy metal ions in the soil than in the onion bulbs and did not portray any risk to public health.*

Keywords: *Assessment risk parameters, Heavy metals, Health risk, onion bulb, soil rhizosphere*

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1.0 Introduction

In our previous work we reported a comprehensive documentation on the level of distribution of some metals between the soil rhizosphere and onion bulbs cultivated in the same soil (Karu *et al*. 2021). Soil rhizosphere is the layer or region of the soil that is directly influenced by root secretions and associated soil microorganisms. The presence of some metals in the soil rhizosphere could be toxic to plants if the safe concentration limit is exceeded (ref). Soil contamination by metals (especially heavy metals) may arise from industrial, domestic or agricultural sources such as indiscriminate disposal of untreated industrial waste, application of fertilizers, insecticides or manures, mining and exploration activities (Bystricka *et al.*, 2015 and Smith, 2009). Commonly known and established toxic metal ions are those of heavy metals such as lead, cadmium, manganese, chromium, nickel, etc. Plants have the potentials to absorb these metals from the soil through foliar absorption process and can consequently lead to bioaccumulation up to a toxic level (ref). Therefore, when contaminated plant is consumed directly by man (or indirectly by eating animals that fed on these plants), the heavy metal ions are transferred to man and can subsequently impart toxic impact (Yusuf, 2007; Shabanda, 2015)

However, at moderate concentrations, some heavy metals such as manganese and chromium (Cr) display useful biochemical functions especially in the activation of enzymes. Manganese converts nitrogenous waste products into urea while chromium aids in the maintenance of the glucose level of the blood. Other metal ions that are not heavy metals have also been found to play significant roles in biological systems. For example, magnesium is useful in the formation and in the activity of chlorophyll pigment needed for photosynthesis (Farhat, *et al* 2016).

It has been pointed out by Bystricka *et al.*, (2015) that some vegetable species can bio-accumulate high levels of heavy metal ions that can lead to decrease in the quantity and value of some biological products without immediate manifestation of expected visible symptoms and damages

One of the ways Pb can be absorbed is through the roots of plants or through deposition on the leafy vegetables (such as onions) and can be transferred to higher organism through the food chain (Nas and Ali, 2018); Tan and Nguyem, 2010).

The contamination of the environment with heavy metals is usually of great concern especially that the food chain is affected and its importance cannot therefore be over emphasized. Danbam in Bauchi State Nigeria is endowed with agricultural products such as cotton, groundnut, millets, sorghum, onions and cowpeas. These products, together with livestock (like cows, sheep and goat) that are reared in large numbers are often transported to other parts of the state and the country (especially Southern parts of Nigeria) At present, there is no significant concentration of industries in the Danbam but other activities that can contribute towards the increase of heavy metal ions in the soil are prevalent. Consequently, the present study presents the health risk assessment of heavy metals in the soil rhizosphere and onion bulbs cultivated in Danbam village in Bauchi State, Nigeria. In evaluating the health risk of the selected heavy metals associated with the consumption of onions, certain assessment risk model parameters such as Hazard Quotient (HQ), Biocentration Factor (BCF), Hazard Index (HI) and Daily Intake of Metals (DIM), Hazard and Health Index (HI) shall be employed.

1.1 Bioconcentration factor (BCF) between soil rhizosphere and onion bulb

The Bioconcentration factor (BCF) can be expressed as the ratio of the concentration of a chemical species in the organism to its concentration in the surrounding environment. The transfer of trace elements from soil to edible parts of plant is best described by considering the bioconcentration factor. BCF is calculated as the ratio of the concentration of heavy metals in the vegetables to the corresponding concentration in the soil where the vegetables were obtained (equation 1)

$$BCF = \frac{C_{onion\ bulb}}{C_{soil\ rhizosphere}} \quad (1)$$

where; $C_{onion\ bulb}$ and $C_{soil\ rhizosphere}$ represent the heavy metal concentrations in the extracts of onion bulbs and in the soil's rhizosphere (on a dry weight basis) respectively. If the BCF is greater than unity, it indicates higher uptake of heavy metals by the onion bulb than in the soil rhizosphere but BCF below 1.0, is an index towards high heavy metal concentration in the soil rhizosphere in relation to the levels in the onion bulbs and therefore low uptake of heavy metal ions by the onion bulbs.

1.2 Daily intake of metals, hazard quotient and health index

In order to evaluate the potential health risks associated with long term ingestion of heavy metal contaminated onion bulbs, the average daily intake of metal (DIM), non-carcinogenic risks (hazard quotient, HQ) for individual heavy metals in all the samples, and hazard index (HI) were evaluated. The average daily intake of metal (DIM) can be expressed according to equation 2

$$DIM = \frac{C_{metal} \times C_{factor} \times C_{intake}}{B_{average\ weight}} \quad (2)$$

where, C_{metal}, C_{factor}, C_{intake} and B_{weight} represent the metal concentrations in the samples (ppm), conversion factor, the daily intake of the onion bulbs and the average body weight, respectively. Target hazard quotient (HQ) is a ratio of the determined dose of a contaminant to oral reference dose that is considered as detrimental. If the ratio is greater than or equal to 1, an exposed population is at risk.

$$HQ = \frac{DIM}{R_fD} \quad (3)$$

where DIM is average daily metal intake and R_fD is reference dose.

Hazard index (HI) is used to estimate the potential human health risk when more than one heavy metal is consumed. It is the sum of the hazard quotients for substances that affect the same target organ or organ system.

$$HI = \sum HQ\ (HQ_i + HQ_{ii} \ldots\ldots HQ_n) \quad (4)$$

2.0 Materials and Methods

The sampling sites, digestion and analysis of samples were as presented in our previous article (Karu *et al*., 2021).

2.1 Sampling sites

The study was selected within the catchment areas that cultivate onions in Kwadatala, Tingariye, Kaderi and Ganjiwa of Danbam Local Government Area of Bauchi State, Nigeria. Danbam is located within longitude 10. 71° and latitude 11.68° Four (4) different soil rhizospheres together with their onion bulbs were collected from four (4) farmlands and were labeled as presented in Table 1.

The samples were transported to the laboratory for acid digestion. The edible portions were dried to constant weight at room temperature. in at room temperature for four weeks and weighed occasionally until a constant weigh was attained. The dried samples were ground to fine powder using mortar and pestle and sieved to 2 mm before storage in polyethylene bags, Similarly, 10 g of the soil samples were also crushed to fine particles.

Table 1. Sample classification/labeling

Sample location	Soil sample	Onion sample
Kwadatala	S1	A1
Tingariye	S2	A2
Kaderi	S3	A3
Ganjiwa	S4	A4

2.2 Digestion and analysis

Digestion of the sample was carried out with concentrated 10 cm^3 HNO_3 and heated for 45 minutes to obtain a dark brown solution 10 cm^3 of aqua regia, (consisting of HNO_3: HCl in a ratio of 1:3) was added to the solution and heated for 10 minutes. The yellow-brown residue obtained was re-dissolved in 10 cm^3 of 1 M HNO_3 and heated until white yellow residue that was allowed to cool appeared. The residue transferred quantitatively to a 50 mL volumetric flask and made up to the mark with deionized water. The digested 50 cm^3 solution was transferred into an acid rinsed polyethylene sample container and labeled prior to further analysis. Spectrophotometric method was used for the determination of heavy metal concentration in the various digested samples as reported by Jeffery *et al.*, (1989).

3.0 Results and Discussion

The concentrations of metals in the soil rhizosphere and in the onion bulb were analyzed by spectrophotometric method and the results obtained are presented in Table 2.

Cadmium is highly toxic non-essential heavy metal and it does not have useful role in biological system because it is toxic at even low concentrations (Ambedkar *et al*., 2012). Cadmium poisoning in man could lead to anaemia, renal damage, bone disorder and cancer of the lungs (Suruchi, 2011; Edward *et al*., 2013). Table 2 reveals that the concentration of cadmium in all the eight samples ranged from 4.06×10^{-8} to 1.49×10^{-5} mg/kg. These result revealed that cadmium concentration in the eight samples were below the WHO / FAO limit of 0.02 mg/kg (WHO / FAO 2007).

Manganese is essential element required for various biochemical processes. The kidney and liver are the main storage organs for manganese in the body. Mn is essential for normal bone structure, reproduction and normal functioning of the central nervous system. Manganese deficiency may lead to reproductive failure in both male and female (Saraf and Samant, 2013). The Mn concentration in all the eight samples which ranged from 6.15×10^{-4} to 1.91×10^{-1} mg/kg were below the permissible limit of 500 mg/kg set by FAO/WHO, 2007.

Lead has toxic effects on organs that include kidneys, liver, lung and spleen that cause different biochemical defects. It exhibits neuropathology when adults are exposed occupationally or accidentally to excessive levels. There is a relationship between Pb in the human body and the increase of blood pressure of adults (Ametepey *et al.*, 2018). Pb concentration in the samples ranged from 5.20×10^{-3} to 1.70×10^{-3} mg/kg (Table 2). The present study revealed that lead concentrations in all the samples were below the WHO / FAO stipulated limit of 0.30 mg/kg (WHO / FAO 2007). However, chromium was not detected in all the samples analyzed.

Table 2. Heavy metal concentration (mg/kg) in soil rhizosphere and onion bulb obtained from four (4) different farms in Danbam LGA, Bauchi State

Sample	Cd	Mn	Pb	Cr
S1	1.27×10^{-8}	1.91×10^{-1}	2.30×10^{-3}	ND
S2	7.00×10^{-7}	6.15×10^{-4}	2.70×10^{-3}	ND
S3	4.05×10^{-8}	2.11×10^{-1}	1.80×10^{-3}	ND
S4	2.22×10^{-7}	5.20×10^{-3}	2.80×10^{-3}	ND
A1	4.06×10^{-8}	1.22×10^{-3}	1.70×10^{-3}	ND
A2	1.49×10^{-5}	1.22×10^{-3}	5.20×10^{-3}	ND
A3	1.02×10^{-6}	2.75×10^{-3}	2.10×10^{-3}	ND
A4	7.96×10^{-7}	1.00×10^{-3}	5.10×10^{-3}	ND

****ND = not detected**

3.1 Health risk assessment

Bioconcentration factor of metals between soil rhizosphere and onion bulb

Table 3 presents the values of BCF for Cd, Mn and Pb from soil rhizosphere to the edible onion bulbs collected from the four study sites. As the key components of human exposure, BCF is significant and essential reflects a high accumulation of the uptake metal ion by the onion bulbs from the soil rhizosphere From the results obtained, all the four onion bulb samples were found to have BCF greater than 1 for Cd. Samples A2 and A2 to A4 had BCF values greater than 1 for Mn and Pb. This suggests higher uptake of heavy metals by the onion bulb compared to the concentration in the soil rhizosphere. The BCF values for Mn were found to be less than 1 in samples A1 and A3, which indicate high concentration of heavy metal ion in the soil rhizosphere compared to onion bulbs and hence low uptake of heavy metals by the onion bulbs.

Table 3. Bioconcentration factor (BCF) of metals between soil rhizosphere and onion bulbs

	BCF	
Cd	**Mn**	**Pb**
3.20	0.01	0.74
21.30	1.98	1.93
25.20	0.01	1.17
3.59	0.19	1.82

The exposure of toxic metals to humans occurs can occur through several pathways including inhalation, food-chain, and dermal contact. The DIM, HQ and HI of Cd, Mn and Pb were calculated for adults in all the samples in order to evaluate the potential human health risk arising from the ingestion of onion bulbs.

The DIM and HQs values were found to be less than 1 for all samples (Table 4). Hence, there is no need for concern regarding the continuous consumption of the onion bulbs in terms of potential health risk. When HQ exceeds 1, there will be concern for potential health effect (Huang *et al*. 2008).

Hazard index (HI) values of the studies heavy metals were below 1 (ranging from 8.75×10^{-4} to 1.07×10^{-2} mg/kg), indicating acceptable level of non-carcinogenic adverse health effect. The estimated low HI values for all the heavy metals in the soil rhizosphere and in the onion bulbs pose no health risk to the consumer.

Table 4. Daily metal intake (DIM, mg/kg), non-carcinogenic risk (hazard quotient, HQ) and overall toxic risk (hazard index, HI) of soil rhizosphere and onion bulb obtained from four (4) farms in Danbam LGA, Bauchi State

	DIM			HQ			**HI**
Sample	Mn	Pb	Cd	Mn	Pb	Cd	
S1	1.4×10^{-4}	1.7×10^{-6}	9.5×10^{-12}	1.0×10^{-2}	4.9×10^{-4}	1.9×10^{-8}	1.1×10^{-2}
S2	4.6×10^{-7}	2.0×10^{-6}	5.2×10^{-10}	3.3×10^{-5}	5.8×10^{-4}	1.1×10^{-6}	6.1×10^{-4}
S3	1.6×10^{-4}	1.3×10^{-6}	3.0×10^{-11}	1.1×10^{-2}	3.8×10^{-4}	6.1×10^{-8}	1.2×10^{-2}
S4	3.9×10^{-6}	2.1×10^{-6}	1.7×10^{-10}	2.8×10^{-4}	5.9×10^{-4}	3.3×10^{-7}	8.8×10^{-4}
A1	9.1×10^{-7}	1.3×10^{-6}	3.0×10^{-11}	6.5×10^{-5}	3.6×10^{-4}	6.1×10^{-8}	4.3×10^{-4}
A2	9.1×10^{-7}	3.9×10^{-6}	1.1×10^{-8}	6.5×10^{-5}	1.1×10^{-3}	2.2×10^{-5}	1.2×10^{-3}
A3	2.1×10^{-6}	1.6×10^{-6}	7.6×10^{-10}	1.5×10^{-4}	4.5×10^{-4}	1.5×10^{-6}	5.9×10^{-4}
A4	7.5×10^{-7}	3.8×10^{-6}	5.9×10^{-10}	5.3×10^{-5}	1.1×10^{-3}	1.2×10^{-6}	1.1×10^{-3}

4.0 Conclusion

The present study was performed to assess heavy metal levels (Cr, Mn, Pb and Cd) in soil rhizosphere and onion bulbs and their associated health risks in Danbam, Bauchi State. The results confirmed that the concentrations of heavy metal ions in all the eight samples are below the permissible limit of WHO / FAO. The the average daily metal intake (DMI), hazard quotient (HQ) and hazard index (HI) were ~~all~~ below 1 and therefore the consumption of the onion bulbs from Danbam may not cause any health risks to humans. Calculated bioconcentration factors suggest high heavy metal concentration in rhizosphere soil in relation to the levels in onion bulbs.

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Conflict of Interest

The authors declared no conflict of interest

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